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1914

PREFACE

THE first edition of this book was published in 1876, and in the preface to that edition the authors stated that :—

'This text-book, although adapted for the use of students generally, is written specially for those numerous operators and artisans who are employed in the actual transmission of telegrams and in the maintenance of telegraphs in England. Care has been taken to render it as far as possible independent of theory, and of little more than an elementary knowledge of mathematics The book is intended to serve as an introduction to the study of more advanced works upon the art and science of telegraphy. Its dimensions have necessarily confined the authors almost entirely to the consideration of English telegraphy, and compelled them to abandon the submarine cable branch of the subject. The systems described are those which have borne the test of continued experience, and are more or less in practical use at the present day. Hence it is that the problems of quadruplex, multiplex, and other novel systems of telegraphy have been omitted And as the class for whom the book is specially written are not as a rule engaged in the application of the laws of currents to testing and experimental purposes, the discussion of Ohm's laws, and the apparatus depending upon them, are not dealt with.'

The fourth edition, which appeared in 1884, was enlarged, chapters on Quadruplex, Repeaters, and on Telephones being added. In 1891 the ninth edition appeared, again enlarged and revised. The chapter on Special Telegraphy was replaced by three chapters on Duplex, Automatic, and Submarine Telegraphy respectively; other chapters were added on Multiplex Telegraphy, on Materials for Construction, on Instruments for Testing, and also various appendices. The fifteenth edition

appeared in 1899, again brought up to date, and somewhat enlarged, but with no new chapters. The last revision took place in 1905, when two additional chapters dealing with Telegraph Switching Systems and Wireless Telegraphy were added.

In 1913 it was realised that, though the demand for the book still continued, it was now somewhat out of date, and another revised edition was urgently required.

Unfortunately, Sir William Preece was approaching the end of his long life, and though he had personally supervised the work of revising this text-book in all previous editions, he felt that this new revision must pass to younger hands. With his full approval and encouragement, I took up this work in 1913 but he passed away before it was completed. During his long illness, my father took an immense interest in its progress, and almost his last act was to read through and correct the proof of the re-written chapter on Wireless Telegraphy—a subject which held his interest to the end.

I have endeavoured to adhere to the original aim of the authors to adapt the book for students, but the main difficulty which had to be faced was to deal with, briefly, the many new advances in the science and art of telegraphy and telephony, without at the same time producing an unwieldy volume, and one unsuitable for use as an elementary text-book.

I have to thank the Publishers most heartily for allowing this book, after nearly forty years' existence, to appear in a new and a slightly larger size, but notwithstanding this increase in dimensions, some of the contents had to be cut out, and I decided, though regretfully, to eliminate the chapter on Submarine Telegraphy. This is a most important subject, but a telegraph engineering student has to decide, before he commences his studies, whether he will take up land telegraphy or submarine telegraphy, as these are two practically independent branches of Telegraph Engineering. The engineer who is employed with land telegraphy gets no experience of submarine work beyond occasional submarine or subfluvial links in his lines, whilst the submarine telegraph engineer gets no experience with land telegraphy beyond the terminal land lines to his cables. It seemed better therefore to be content in this book to deal with river and coast cables only, and these are included in Chapter XV.

New chapters have been added on Secondary Batteries;

on the Baudot System ; and on Comparative Results Obtainable with Various High Speed Telegraph Systems. Every old chapter has also been subjected to severe revision, excepting only the first, which, though written by Sir William Preece in 1876 and slightly revised by him in 1884 and 1891, as the nomenclature of the different electrical units became standard, still remains the clearest and most concise statement of the essential electrical terms used in Telegraphy.[1]

The present edition cannot now claim to be a description of telegraphy as practised by the British Post Office. In 1876 this Department, though it led, and continues to lead, the world in the applications of electricity to telegraphy, was still to some extent in its infancy, and the most advanced methods then known were easily understood by the elementary student ; also, the position the Department held was only slightly superior to British Colonial Departments. But now the enormous traffic which the Department has to handle has forced it to drop almost entirely the more primitive systems and to instal only the latest and most advanced apparatus obtainable, whereas for most of the British Colonies which have sparse populations, and therefore light traffic, the earlier type of apparatus is still the most efficient. To describe in detail the intricacies of the advanced apparatus is not possible in a textbook for students, and I have attempted merely to describe, as clearly as I can, the simpler forms of telegraphy, and to make this book really useful to students and to young Colonial Engineers, leaving it to more advanced technical works to deal thoroughly with the British system. The chapter on Telephony is purely a brief introduction to a subject which requires a separate text-book for complete treatment. The same may be said regarding the chapter on Wireless Telegraphy. Thus whilst this new edition still remains an elementary text-book for students, and an introduction to advanced works on telegraphy, it is hoped that it will also prove to be of considerable service to all who are concerned with telegraphy in India, in the Colonies and in all other sparsely populated countries.

That is to say, this has been my aim, but if I have been in any way successful in carrying it out, the praise is really due to

[1] It is interesting to note that in 1876 the 'ohm' and the 'weber' are the only units mentioned, that the 'weber' gave way to the 'coulomb' in 1884, and that the 'volt' and 'ampère' are not mentioned until 1891.

Mr. R. W. Weightman, the late Chief Engineer to the Natal Government Telegraphs, whose great assistance in advising, in supplying information, and in correcting and revising the proofs has been invaluable, and to him my deepest thanks are due. I have also to express my sincere gratitude to the British Post Office Institution of Electrical Engineers for the loan of blocks and for much information which is embodied in the book; also to Messrs. Siemens Brothers & Company, Limited, to Mr. Crawter of the Chloride Battery Company, to Mr. Clifford Higgins of the Exchange Telegraph Company, to the Marconi Company, and to many others for blocks, drawings, and descriptions which have aided largely in making this book more complete.

W. LLEWELLYN PREECE.

March, 1914.

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TELEGRAPHY

CHAPTER I

ELECTRICAL TERMS

It is not intended that this book shall be a treatise on electricity. It is a Text-book of Telegraphy, dealing with the application of electricity to the conveyance of information to distant points beyond the reach of the ear and the eye. As, however, practical telegraphy is wholly dependent upon electricity, some acquaintance with the elementary principles of that science is essential on the part of the reader if he is to understand telegraphy; and these therefore will be incidentally introduced so as to render the explanations given as much as possible independent of previous knowledge. At the outset it is necessary that the student should have a clear understanding of the meaning of some of the technical terms commonly employed in connection with telegraphy, and accordingly these will be explained in the present chapter; but the question what electricity is, whether it be a fluid or a force, whether it be a form of matter or a form of energy, will not be discussed, the practical application not being dependent on theory.

Electricity is an agent pervading terrestrial and solar space, and is as universal in its effects as are heat and light. We are cognisant of its existence when we hear the roar of thunder and see the flash of lightning, but we do not know its particular form any more than we know that of sound or that of light. The sound of the thunder and the flash of the lightning affect the ear and the eye—we hear the sound and see the light—but we do not assume the existence either of sound or of light as distinct entities or things. We can speak of the quantity

of sound caused by the explosion of a cannon or by the blowing of a penny whistle; the quantity of light emitted by a glow lamp or by a rushlight; the quantity of heat required to melt a pailful of ice or to solder a metal joint, without implying by the term *quantity* a mass or volume of anything actually present. The term implies relative magnitude only. It is the answer to the question 'how much?' It implies the notion of more or less. When we speak of the magnitude of electricity present we speak of its *quantity*. When we read of a church spire destroyed, of trees riven to splinters, of wires fused, or of flocks killed, the damage done is due to the electricity passing, and the amount of that damage is referable to its magnitude or *quantity*. If we take a piece of sealing-wax, a glass rod, or an ebonite comb, and rub it against the coat sleeve, we find it has the property of attracting feathers, straws, and other light bodies. Electricity has been excited upon its surface, and the force of attraction is found to increase with the quantity of electricity present. Equally the force with which bodies are attracted towards each other is an indication of the quantity of electricity excited. So we may say that ELECTRIC QUANTITY *is the magnitude or amount of electricity present.*

We may therefore assume that the electricity on a body has a physical magnitude which, like all other physical magnitudes, is capable of measurement and of reference to some standard. Since quantity implies the notion of more or less, we must be able to answer the question 'more or less than what?' All physical magnitudes need a standard of reference or *unit* with which comparison and therefore calculation can be made. The notion of more or less is supplied by the number of these units which are present. If we wished to express in feet the distance between any two places, we might say 'let the distance between A and B be *f*,' or if we wished to express in gallons the volume of water in a tank, we might say 'let the capacity of the tank be *g*,' *f* and *g* respectively representing '*f*,' feet, and '*g*,' gallons; *f* and *g* standing for any number whatever, and the *foot* and *gallon* being the units or standards of reference taken or understood. So, too, if we wanted to find the quantity of electricity required to effect a certain purpose, we might commence by saying 'let the quantity of electricity be *q*,' by which we should mean an unknown number '*q*,' units of electricity and our investigation might bring it out 0·01 of a unit, or 3 units,

or 50 units, or any other number. The unit quantity of electricity in general use has been called a *coulomb*, from one of the great French philosophers. Thus we see that in the literal representation of a physical quantity we assume the existence of a standard or unit to which we give a name, as foot, gallon, coulomb, and we express its value numerically or represent it by the use of a letter.

Whenever electricity has been produced by any means, the bodies which exhibit evidence of its presence are said to be *electrified* or *charged with electricity*, and their condition is said to be one of *electrification*. For instance, a cloud which is capable of discharging itself with a flash of lightning is said to be electrified. A piece of sealing-wax rubbed with flannel or fur becomes electrified. A glass rod rubbed with silk is also electrified. In the two latter cases, although both substances have been electrified by friction, yet the character of the electrification in each case is different. The sealing-wax and glass seem to be imbued with exactly opposite qualities: for while two bodies, each electrified by contact with either the sealing-wax or the glass, repel each other, two bodies, one electrified by the glass and the other by the sealing-wax, will attract each other. By an arbitrary convention the electricity excited on glass has been called *positive*, while that excited on sealing-wax has been called *negative*. All electrified bodies are either positively or negatively electrified. A thundercloud, for instance, may at one time be positively and at another time negatively charged. When a cloud charged positively approaches a cloud equally charged negatively and discharge (lightning) takes place between them, complete neutrality, or zero, results. This justifies the use of the opposite terms.

Whenever we walk upstairs or ascend a hill we are conscious of having expended energy. We have, in fact, raised our bodies through a certain height against the influence of the force of gravity. We have done work upon our bodies; and whenever we make an effort against a force of any kind, through any distance, we do work. Thus a horse does work in drawing a load, heat does work in converting water into steam, and thereby driving trains and propelling vessels. Electricity does work when it moves substances against the force of gravity, or when it flows against resistance, and all electrical phenomena are illustrations of energy expended, and are measured by the work done in producing them.

An electrified body acquires a certain quality or condition by which it possesses this power of doing work. In the same way that a poker placed in the fire must acquire a high temperature before it burns the hand, or as water must acquire a high pressure before it bursts the pipe, so an electrified body must acquire a certain condition before it is capable of doing work. The property possessed by such a body, which is analogous to temperature and pressure, is called *potential.*

If it be desired to transfer heat from A to B (fig. 1), it is essential that the temperature at B be lower than at A; and if it be desired to cause a flow of liquid or gas between two such points, it is equally essential that there be a difference of pressure between them. So if we desire to transfer electricity from

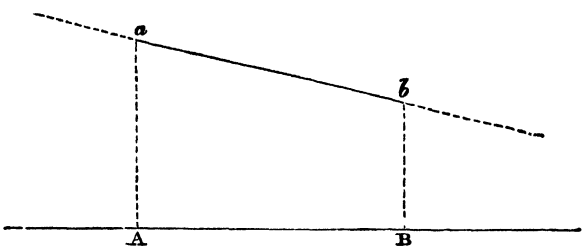


Fig. 1

A to B either along a conducting wire, such as that of a submarine cable, or through the air, it is imperative that the potential at B be less than at A.

Hence, POTENTIAL *implies that function of electricity which determines its motion from one point to another.*

And the *difference of potential* which determines the amount of this motion is called ELECTROMOTIVE FORCE. The unit of electromotive force is called a *volt.*

The transference of electricity, such as that from a charged cloud to the earth, from a piece of glass rubbed with silk to a piece of ebonite rubbed with flannel, or a signal from Europe to America, may take place in different *times*; the path between A and B offers obstruction to the passage of electricity; the medium through which it passes, whether composed of an air space or of any conducting material, is an obstacle to be overcome. Electricity in motion does work, it excites light, decomposes liquids into their constituent elements, generates

heat, produces magnetism, &c.; and the amount of work done in a given time with the same electromotive force depends on the resistance to be overcome: hence the term RESISTANCE implies *that quality of a conductor in virtue of which it limits the amount of work being done in a given time by a given electromotive force.*

The unit of resistance is called the *ohm,* from Ohm, the German physicist, who determined mathematically the laws that regulate the flow of electricity.[1] It is convenient for brevity's sake to use a symbol to represent the ohm as we use ° to represent degrees, and ′ minutes. The symbol in general use is ω, the Greek *omega.* Thus we say that the resistance of a wire between London and Birmingham is 1,200ω, and that of one of the Atlantic cables is 6,000ω.

Those bodies which offer very great resistance to the passage of electricity through them are called *insulators*; those which offer very little resistance are called *conductors.* The difference between a conductor and an insulator is one of degree only. Thus the resistance of a given volume or mass of metal is very small compared with that of an equal volume of glass, ebonite, or air. The former, therefore, is a conductor, the latter are insulators. The property of matter which determines its resistance is evidently molecular, for it varies with and is dependent upon the physical structure and condition of a body as well as upon its mass. For instance, water, when a liquid, is a conductor; when a solid, an insulator; while some substances are insulators when cold, and conductors when hot.

Under certain conditions conducting bodies have the power of accumulating and retaining a quantity of electricity, and the amount which they can thus retain is termed their CAPACITY. The unit of capacity is the *farad*; but as this is too great for ordinary use, a sub-unit known as the *microfarad,* which is one-millionth part of a farad, has been generally adopted.

The transference of electricity from one point to another is called a CURRENT. A current can flow only between two points *at different potentials separated from each other by a resisting medium.* To produce a continuous current these points must be maintained at different potentials. A current will flow from the higher to the lower potential so long as a difference of potential exists, but when the potentials are equalised it will cease.

[1] For Ohm's Law, *see* Appendix, Section A.

Hence we see that what is understood by the term CURRENT *is an apparent transference of electricity from one point to another to produce equalisation of potential.* One current differs from another only in its *strength*—or, in other words, in the quantity of electricity which is transferred by each in equal times. The unit of current is an *ampère*, but as this unit is too great for telegraph purposes, a sub-unit known as the *milliampère* is used by telegraph engineers. The milliampère is one-thousandth part of an ampère.

A current is always supposed to flow from the point of higher potential to that of lower potential. The former point is taken to be positive to the latter ; and, *vice versâ*, the lower is taken to be negative to the higher point. The terms positive and negative *currents* are frequently used, but they are misnomers. There is only one current flowing between A and B (fig. 1), and it varies in direction. It is quite correct to apply the term positive or negative to currents *with respect to a given point*, and by those terms to imply direction only, for while stationed at a given place currents may flow *from* or *towards* us ; but it is quite incorrect to speak of positive or negative currents without reference to a given point, for what is a positive current at one point is a negative current at another. The current is, however, supposed to flow from the body positively charged to that negatively charged. For the sake of convenience the potential of the earth is always assumed to be *zero* ; so that when we speak of the potential of a body, we really speak of the difference between its potential and that of the earth. This does not mean that the earth has *no* potential, for every thunderstorm and every telegraph line tells us that it has, and we shall have to speak of phenomena which show us that different portions of the earth's surface have different potentials at different times ; but generally, the tendency of all bodies electrically connected with the earth is to fall or to rise to its potential.

A current can only be *constant* when we have two points separated from each other by an invariable resistance, and *maintained* at the same difference of potential. The material conveying the electricity, whether it be earth, air, water, or matter in any form, separately or conjointly, is called a CIRCUIT, and *the circuit is the whole path along which the electricity is supposed to flow.*

These are the principal terms, independent of all hypotheses,

which are used in the science of electricity in its application to telegraphic purposes, and it is upon their clear comprehension that the ease or difficulty of the mastery of the technical details of telegraphy depends. The nature of electricity itself is not known, nor is it necessary to the telegraphist that it should be known to him. He is principally interested in its quantitative measurement and its application to practical purposes. Let him master its elementary principles, its general ideas, its properties and its conditions, and he can well afford to leave to physicists the discussion of its nature, and to mathematicians the determination of its laws.

CHAPTER II

BATTERIES

If two plates of different metals be immersed in acidulated or saline water, it is found that a difference of electrical potential is established between them. Let Zn (fig. 2) be a zinc plate and Pt a plate of platinum immersed in acidulated water, then as long as the two metals are kept apart, as shown, no action is observed to take place between them, but immediately they

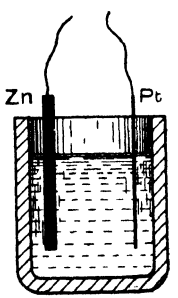


Fig. 2

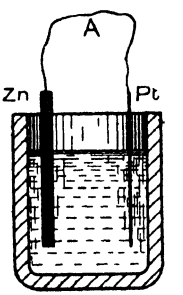


Fig. 3

are metallically connected together, either by being brought into actual contact at any point, or by means of a wire (A, fig. 3), and so long as they remain so connected, the zinc is eaten away and the acidulated water is decomposed into its constituent elements, one of which unites with the zinc to form a salt of that metal, while the other—namely, hydrogen—appears at the platinum plate in the form of bubbles, some of which adhere to the plate while others rise to the surface of the liquid.

The wire employed to connect the two plates outside the liquid also appears to become possessed of some very remarkable properties.

a. If it be wound round a piece of soft iron, it will render that iron for the time being magnetic, and almost immediately it is removed the iron will lose all trace of magnetism.

b. If it be placed in the immediate neighbourhood of a freely suspended magnetic needle, the needle will at once exhibit a tendency to place itself at right angles to it.

c. If the wire be broken and the ends immersed in water, the water will be decomposed ; oxygen collects at the end of the section proceeding from the platinum plate, and in this *nascent* state forms, as a rule, an oxide of the metal composing the wire. Hydrogen rises from the end of the section coming from the zinc plate.

The other manifestations of the energy which the wire possesses, viz. its generation of heat, its production of light, and its physiological effects, may be passed over, for they are not at present employed in practical telegraphy.

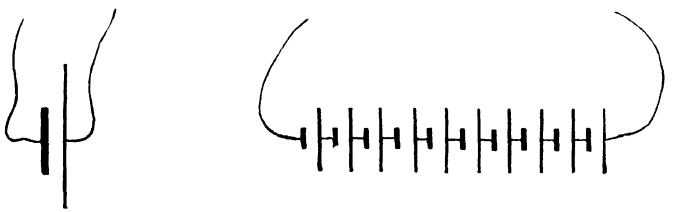


Fig. 4

To this combination of two different metals in acidulated water the name of a *cell* is given ; and a series of such cells, properly arranged, forms a *galvanic or voltaic primary battery.* It is convenient to represent a cell symbolically or conventionally by a thick and thin line of different lengths—the former representing the zinc and the latter the platinum plate, as in fig. 4. A battery is similarly represented by a combination of these, as shown in the same figure.

The action observed is said to be due to a current which is assumed to start from the chemically attacked zinc plate, to pass through the liquid to the platinum, and thence to return by means of the wire to its starting point. This term ' current ' (p. 5) is purely a convention of language, and must not be taken to imply in any way the actual transference of matter from one point to another. The word was introduced in the early days of electricity, when electricity was believed to be a fluid, and it has ever since been retained.

The energy which the wire possesses in virtue of this transference of electricity, or, as we may now call it, the *strength* of the current, varies with the metals which are employed in the cell, as well as with the solution in which they are placed. In water acidulated with sulphuric or nitric acid the maximum effect is obtained when the metals farthest apart in the following list are used: silver, copper, antimony, bismuth, nickel, iron, lead, tin, cadmium, zinc. In water acidulated with hydrochloric acid the above order is modified as follows: antimony, silver, nickel, bismuth, copper, iron, lead, tin, cadmium, zinc.

Various theories have been advanced to account for the determination of the difference of potential resulting in this peculiar action, but they all involve theoretical considerations beyond the scope of this work.

The zinc plate of a cell is named the positive plate or element, the platinum or copper the negative plate or element. These terms positive and negative convey no meaning of themselves; they are merely intended to denote the relative condition of the two elements. The result in the cell of the flow of current is this: the liquid itself is decomposed; the hydrogen (H) rising at the copper (Cu) plate leaves it untouched, and the oxygen (O) attacks the zinc (Zn) plate, and gradually eats it away by forming zinc oxide (ZnO). Assuming first that pure water (H_2O) is made use of, the action which takes place may be symbolically represented thus:

Before contact—

$$Zn, \overline{H_2O}, \overline{H_2O}, \overline{H_2O}, Cu.$$

After contact—

$$\overline{ZnO}, \overline{H_2O}, \overline{H_2O}, H_2Cu.$$

But zinc oxide (ZnO), which is non-conducting, is insoluble in water, and consequently if pure water were used the action would soon cease, because the zinc plate would be speedily covered with an insulating compound. Hence sulphuric acid (H_2SO_4) is added, which instead of zinc oxide deposits the soluble zinc sulphate ($ZnSO_4$), so that the zinc plate is left clear for further action. The addition of H_2SO_4 has also the effect of reducing the resistance offered by the water to the passage of the current. This action is symbolically represented thus:

Before contact—

$$Zn, \overline{H_2SO_4}, \overline{H_2SO_4}, \overline{H_2SO_4}, Cu.$$

After contact—

$$\overline{ZnSO_4}, \overline{H_2SO_4}, \overline{H_2SO_4}, H_2Cu.$$

Although the deposition of hydrogen upon the copper plate s quite harmless so far as the copper itself is concerned, yet . has a very deleterious effect upon the general working of he cell. The working is impeded, and the electromotive force ɔ. 4) is very sensibly diminished by it. To this obstructive ction the name of *galvanic polarisation* has been given. It s due to the fact that the free hydrogen accumulating upon he copper plate behaves with respect to it in a manner almost xactly similar to that of the zinc itself—that is to say, the ydrogen assumes a positive potential relative to the copper. 'he result is very nearly the same as if two plates of zinc were pposed to each other. If such were the case, no difference of otential could be determined, and consequently no current vould be obtained.

It will thus be seen how essentially necessary a matter it ecomes to prevent the accumulation of free hydrogen upon he negative plate.

In 1836 Daniell invented the battery which bears his name, n which he succeeded in completely eliminating polarisation. 'his battery appears under various modifications, but the prin- iple, which is as follows, is the same in all.

Zinc and copper are employed as the positive and negative lates respectively, but instead of being in the same liquid they re placed in different liquids, which are separated from each ther by a porous partition. The liquid surrounding the zinc s diluted sulphuric acid ; that surrounding the copper a solution f copper sulphate ($CuSO_4$). The part played by the latter is he distinguishing feature of the Daniell battery. The instant he two plates are connected with each other action commences ; he zinc plate is attacked, and a salt (zinc sulphate) of that netal is formed ; the hydrogen liberated at the copper plate educes the copper sulphate, expelling from it the metallic opper, which is thrown down in a perfectly pure state upon he copper plate of the cell. The hydrogen then, by combining vith the radicle SO_4, forms sulphuric acid (H_2SO_4), which, finding

its way through the porous partition into the zinc cell, maintains the solution there at a constant strength.

The consequence of this is that the positive plate is gradually eaten away, and the liquid surrounding it becomes a solution of the zinc sulphate; the copper sulphate is reduced, but the negative plate — the main point to be looked after—is kept perfectly clean and bright by the deposition upon it of pure metallic copper thrown down by the hydrogen from the solution of copper sulphate.

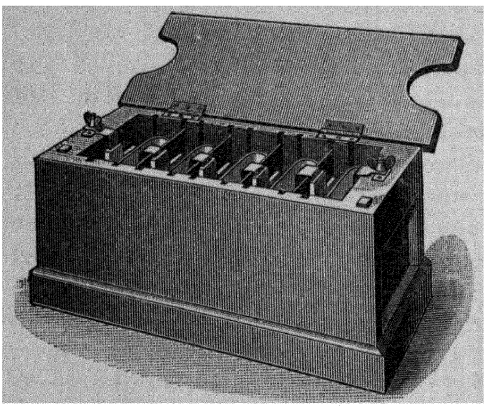


Fig. 5

The electromotive force of a Daniell cell is taken to be 1·079 volt.

One of the most convenient of the various forms of the Daniell battery, and that which has been much employed in the various telegraph systems, is the following:

A teak trough (teak is selected on account of its durability, and from the fact that it shows little tendency to warp) is divided into five spaces or cells, which are separated from each other by slate partitions (figs. 5 and 6). It is then coated throughout, including the slate partitions, with marine glue.[1] The object of this is to render the trough perfectly water-tight and prevent any leakage from one cell to another. On the adhesive surface thus formed a glass plate is fixed at the sides and bottom of each cell, as otherwise the materials of the battery would adhere

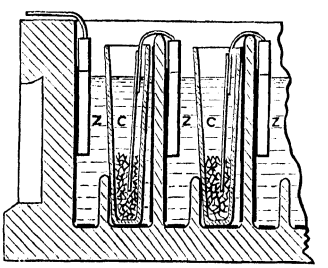


Fig. 6

[1] Marine glue, patented by Jeffrey in 1842, is formed by dissolving one pound of caoutchouc in four gallons of naphtha, and allowing this to stand for ten or twelve days. Two parts of shellac are then added to one part of this mixture, and the compound thus obtained is cooled on marble slabs.

to the cells. At the right of each cell is placed a porous earthenware pot, kept in position by a small ridge running parallel to the sides of the cell, and in which is inserted a thin copper plate four inches square. Opposite the porous pot in each cell is placed the zinc plate, four and a half inches wide and two and a half inches deep.

The porous pots are then filled to about one third of their height with crystals of copper sulphate, and pure water is poured in up to the level of the top of the zinc plate. A short time is allowed for this solution to force the air from and to saturate the porous earthenware, after which the zinc divisions are filled with pure water to within a quarter of an inch of the top of the zinc plates. The copper plate of one cell is connected with the zinc of the succeeding cell by a copper strap passing over the slate partition. The plates, in fact, are permanently connected with each other, and are issued in pairs. One end of a copper strap is fastened to the copper plate by means of a copper rivet, and the other end, after being well tinned for about $\frac{3}{4}$ inch so as to insure good metallic connection, is cast into the zinc plate.

The last copper and the last zinc are each connected to a brass binding screw or terminal, which become respectively the positive and negative poles of the battery.[1]

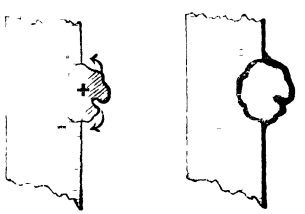
In setting up a Daniell battery there are various points to which special attention must be given, a disregard of any one of which will more or less mar its action.

a. The copper sulphate, which is manufactured by dissolving either pure copper or scales of cupric oxide in sulphuric acid, must be of the purest possible description. The foreign ingredient mainly to be found in it is iron, the presence of which may be ascertained by the following test: The copper sulphate, like all the copper salts, forms with excess of ammonia a deep blue solution, whilst the iron sulphate, under similar circumstances, is precipitated as a dirty-brown powder. If, therefore, to a solution of copper sulphate ammonia be added until this deep blue colour is obtained, the amount of iron present, provided there really is any, can be readily known. In good copper sulphate it should never exceed 0·55 per cent.

b. The metals, but more especially the zinc, should be as

[1] Note that the connection at the *negative plate* is the *positive pole* and that at the *positive plate* the *negative pole*.

pure as can possibly be obtained. This applies to the metals not only for a Daniell battery, but for every other species of battery as well. For, if any foreign ingredients make their appearance the action of the battery is seriously interfered with ; the effect is the same as though a number of small plates of different metals were opposed to each other. Local currents are generated, the plates are needlessly attacked, and the general condition of the battery is impaired. Let fig. 7 represent a portion of a zinc plate containing several particles of iron, tin, or lead, which are the usual impurities to be met with in it. The contact of either of these metals (say lead) with zinc causes the latter to have a positive potential relatively to the former, and if the impurity be on the surface of the plate, a liquid arc intervenes so that, all the required conditions being present, a current starts from the zinc to the lead through the liquid (fig. 7 A). Owing to the *local action* which is thus commenced, the zinc plate is eaten away to no purpose, the liquid is decomposed, and the hydrogen which is liberated partially polarises the zinc plate (p. 11). The consequence is that the resultant[1] current may be materially weakened, at the same time that the battery is proportionately injured.



A Fig. 7 B

c. The copper sulphate used must be in the form of crystals, and not a powder. In the latter state it dissolves slowly, and in time adheres so tenaciously to the cell that it can with difficulty be removed.

d. Care must be taken that the zinc plate does not touch the porous pot. Should it do so a local action commences at once, due to the fact that some of the copper sulphate makes its way through the porous partition into the zinc division, and may come in contact with the zinc plate. Now the compound radicle SO_4 (which together with Cu makes up copper sulphate) has a far greater affinity for zinc than for copper ; it consequently

[1] The term *resultant* implies the ultimate effect of a series of actions which may be similar or opposite in their character. There may be several causes present to determine currents in the same or different directions, and the *resultant current* is the final result or algebraic sum of the currents arising from all those causes.

leaves the latter, which is precipitated in a metallic state on the side of the porous partition or upon the zinc plate as a black spongy deposit.

Batteries such as those described, in which these precautions have been taken, will remain in constant action for some weeks without requiring any attention whatever. At the expiration of a month it becomes necessary to refresh them, and the following points must then be seen to :

a. The solution in the zinc cell should not be supersaturated with the zinc sulphate. The result of this would be the deposition of crystals on the zinc plate, the copper strap, and along the edges of the cell, whereby the liquid would be carried off by capillary action, and short-circuits formed between the cells. Should this occur, the crystals must be removed, a portion of the liquid drawn off, and the cell refilled with water. The solution is in the best possible state when it is semi-saturated with the zinc sulphate ; its conducting power is then at a maximum.

b. The zinc plate should be examined, and if there be any quantity of what at first sight appears to be black mud upon it, this should be scraped off and carefully laid aside. The ' black mud ' contains the purest copper, and its presence on the zinc plate is thus accounted for : Liquids differing in specific gravity and separated from each other either by gravity alone or by a porous diaphragm, possess the power of gradually diffusing into each other, and in time forming a mechanical mixture. As the specific gravities of a solution of the zinc sulphate and of a solution of the copper sulphate are different, they mingle with each other in course of time through the porous partition ; but no sooner does the copper sulphate enter the zinc cell than the radicle SO_4 leaves it and unites with the zinc, for which, as has been already observed, it has a more decided affinity. The copper of the copper sulphate is thus set free and deposited on the zinc plate. The action of the battery is thereby gradually weakened, until eventually, when the zinc plate is covered with copper, the current entirely ceases to flow. It is just, in effect, as if two plates of the same metal were employed, between which no difference of potential can of course be determined. The copper, on account of the finely divided state in which it is precipitated from its sulphate, speedily becomes oxidised and loses its bright metallic lustre.

c. The copper cell should be examined, and if the crystals of copper sulphate are nearly exhausted a fresh supply should be added, and water poured in to supply the place of that which may have been carried off by evaporation.

b. Special care should be taken that the connecting straps and the terminal binding screws are kept bright and clean.

The battery, at the end of two months, if it has been in constant use, and three months if it has been but moderately worked, should be thoroughly cleaned throughout

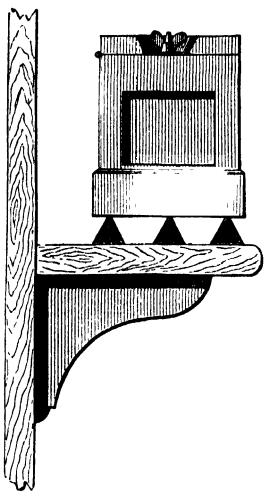


Fig. 8. ⅛th real size

It is essential that the battery should be placed in a dry position, free alike from the extremes of heat and cold, and be protected as far as possible against the accumulation of dust upon it. If it rests on damp ground it is worked unnecessarily and its force is consequently reduced, for the damp ground more or less short-circuits the battery. To prevent this the batteries are sometimes placed upon wooden racks, the boards of which should be of a triangular section, as shown in fig. 8.

The battery which of late years has obtained most favour is that invented by the late M. Leclanché, of the Eastern Railway of France, in 1866.

Zinc is employed in this cell as the positive element, and carbon as the negative element. One liquid only is used in this cell and a special material surrounds the negative element and acts as the depolariser. This depolarising agent is manganese dioxide (MnO_2), the pyrolusite of mineralogists. This mineral is to be found in Germany, France, Hungary, Brazil, Cornwall, Devon, &c., and is one of the main sources of supply of oxygen. For use in the battery it was formerly broken up into coarse grains and carefully sifted ; in this way all that existed in the form of a powder was got rid of. But it has been found during late years that whereas the granular form of this agent was the more preferable for cells required to discharge at very low rates, for most purposes the cells gave superior results if finely powdered manganese dioxide were used. The manganese

dioxide is mixed with an equal volume of carbon crushed to about the same state as the manganese itself. An earthenware porous pot, into which a plate of carbon has been placed centrally, is then entirely filled with this mixture and sealed up with bitumen. The zinc is usually in the shape of a circular rod, and the electrolyte is a solution of chloride of ammonium (NH_4Cl), the ordinary sal-ammoniac.

When a cell is connected to a closed circuit, the following action takes place: The zinc is attacked by the chlorine in the sal-ammoniac; chloride of zinc is formed, and dissolved in the liquid. The other constituent of the sal-ammoniac, namely, ammonium (NH_4), is immediately, on being set free, oxidised by the dioxide of manganese, and ammonia and water are thereby formed. So long as this simple action goes on unimpeded by any other, galvanic polarisation is prevented, and the strength of current obtained from this combination remains constant. The manganese dioxide is reduced to a lower oxide known as the sesquioxide (Mn_2O_3).

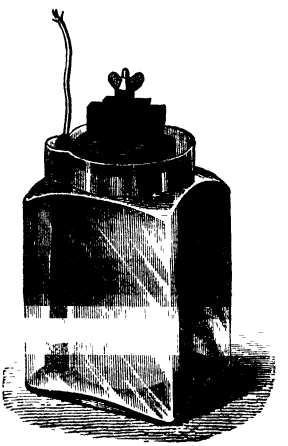


Fig. 9

This type of cell is obtainable in many various forms, the most common being that shown in fig. 9. Into a glass vessel containing a solution of sal-ammoniac a zinc rod is placed; the porous pot containing the carbon plate and the mixture of pounded carbon and dioxide of manganese is next inserted into it. This carbon plate is fitted with a binding screw, which is firmly fixed in the top of the plate for the purpose of connecting it with the wire proceeding from the neighbouring zinc.

Another form of this cell, introduced to avoid the use of a porous pot, is known as the 'agglomerate.' The depolariser instead of being in the form of powder, or granules, is mixed with gum lac resin and formed into slabs, a number of which embrace the carbon block and are held in place by rubber rings.

Three sizes of both these forms of cell are used, known as No. 1, No. 2 and No. 3—No. 1 being the largest, the container holding three pints of electrolyte.

A still larger form of the agglomerate cell than the No. 1 is in fairly general use. This is known as the six-block agglomerate. In this cell the carbon block is grooved to receive six cylindrical agglomerate rods, which are held firmly by a coarse canvas cloth wrapped round and kept in position by rubber rings. The zinc is of a shallow circular pattern and the container is usually an earthenware jar.

The latest pattern, and one from which comparatively heavy discharges for appreciable times can be obtained is known as the 'Sack' cell. In this type the porous pot is replaced by a canvas sack. This enables far larger cells to be manufactured, and the largest now obtainable holds about six pints of electrolyte and gives some 450 ampère hours with a discharge of 100 milli-ampères.

Table A gives the normal outputs of various types of these cells.

TABLE A

APPROXIMATE SIZES AND CAPACITIES OF LECLANCHÉ WET CELLS

Type.	Approximate capacity in ampère hours at steady discharge for 6 hours per day to 50% of initial voltage.				Outside measurements of jar.
	at 25 m/a.	at 50 m/a.	at 100 m/a.	at 200 m/a.	
Sack No. 00 .	650	560	475	375	13″ × 6″
Carsack No. 00 .	300	280	270	250	9″ × 6″
With canvas No. 1 .	200	180	160	120	7½″ × 4½″
With canvas No. 2 .	120	105	90	70	6¾″ × 4″
With canvas No. 3 .	80	60	50	35	6″ × 3½″
With porous pot No. 1 .	100	75	50	30	7″ × 4½″
With porous pot No. 2 .	50	40	30	15	6″ × 3½″
With porous pot No. 3 .	25	22	15	5	5″ × 3″
Agglomerate 6 block	80	70	60	50	7″ × 5½″

The introduction of the non-encrusting zincs has reduced the maintenance costs of these cells. This type of zinc is more brittle than the usual form but, owing to its shape and quality, it dissolves more regularly.

In setting up a Leclanché battery the following points must be carefully attended to:

a. A strong solution of sal-ammoniac should be used (not crystals with a supply of water, and not a saturated solution);

care should be taken that none be spilt on the edges of the cell or on the porous pot, as this is apt to give rise to capillary and subsequent chemical action. In the action of the battery double salts—oxychlorides of zinc and zinc ammonic chlorides—are formed. They are the result of a secondary action which makes its appearance after the battery has been kept steadily at work for a short time, and which seriously interferes with its constancy. So long as chlorine only is set free at the positive plate and ammonium liberated at the negative, so long is galvanic polarisation averted; but as soon as oxygen arises at the zinc, and hydrogen unconsumed accumulates on the carbon—which actually does occur after continued working—galvanic polarisation ensues, a counter-current is generated, and the resultant strength of current obtained from the battery is reduced. This galvanic polarisation, along with every trace of secondary action, speedily disappears if the battery be left to itself; and it is not observable at all if the battery is called into play only at intervals.

b. The porous pot should stand not more than two-thirds its height in the solution, as the latter tends to creep up the pot by capillary action, and when the water has evaporated, a crust of the salt is formed in the neck of the vessel which may short-circuit the cell.

c. The connecting wires from the carbons to the succeeding zincs must be carefully protected. This is done by covering them with paint, tar, gutta-percha, Chatterton's compound,[1] or any other substance of a similar nature. India-rubber has been found to answer the purpose as well as anything. The object of this is to prevent the free ammonia given off in the action of the battery from reaching the metallic wire; if the wire is exposed to the smallest extent, the ammonia attacks it and gradually eats it through. The result is that the circuit is broken, and the battery is for the time rendered perfectly useless.

With the ordinary type of these cells the top of the porous pot is covered with marine glue, or an asphalt composition. Care has to be taken, however, to leave a hole in the same so as to allow the air to escape when the pot is placed in the solution. The cells of a Leclanché battery are joined up in the usual

[1] Chatterton's compound is a mixture of resin, Stockholm tar, and gutta-percha, in the following proportions: 1 lb. of resin; 1 lb. of Stockholm tar; 3 lbs. of gutta-percha.

way to form a series. Fig. 10 shows how three of these cells are so connected.

A Leclanché battery thus set up will remain in good condition for a period varying according to the amount of work which it is called upon to do If it be required only for occasional use, such as the ringing of bells for either signalling or domestic purposes, or if it be employed upon a speaking circuit along which comparatively little traffic passes, it is really difficult to say how long the battery would last, provided the precaution be taken to add every now and then a little

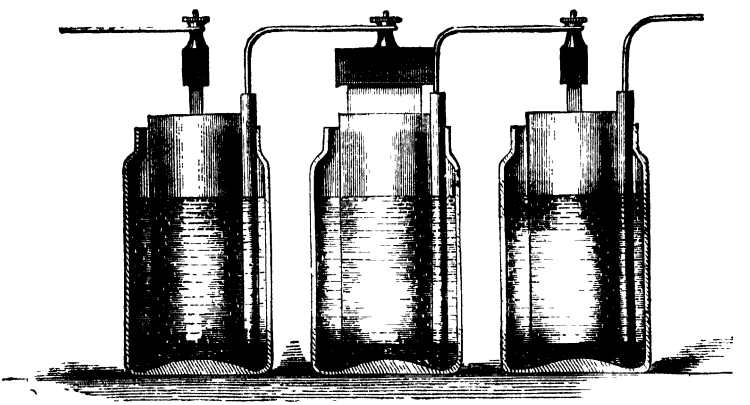


Fig. 10. ½th the real size

water to the liquid in the cells to compensate for evaporation, and if need be cleaning the zincs.

A Leclanché battery possesses the decided advantage over a Daniell in that there is no waste of materials when it is not actually at work, for the diffusion which takes place in the Daniell battery cannot exist with the single fluid in the Leclanché. A Leclanché cell for its output is appreciably cheaper than a Daniell cell, both in first cost and in maintenance.

The electromotive force of the Leclanché cell at its best may be 1·6 volt, but in practice it cannot be relied upon to give more than 1·4 volt.

A form of the Leclanché cell which is very largely used, more especially for portable purposes, is one known as the ' Dry ' cell. With this cell, a compressed block of the depolariser surrounds the central carbon block and, in place of using a fluid

electrolyte, this liquid is mixed with plaster of paris, or held in absorbent paper, which is wrapped round the block of carbon and manganese; the whole mass is then fitted into a zinc case which forms the negative pole and the cell is sealed with bitumen. These cells have the advantage of extreme portability, and in the best forms of dry cell this advantage may outweigh the disadvantages due to the higher internal resistance. One other important point is that after once being set up they require no further attention until renewal is necessary.

Table A1 gives approximate capacity of various sizes of one make of these cells.

TABLE A1

APPROXIMATE CAPACITY AND DIMENSIONS OF DRY CELLS

Dry cells.	Maximum Resistance Ohms.	Maximum Fall of E.M.F. after 10 min. application of shunt of 2 ohms.	Current in milliampères.	Output. Watthours.	Approximate measurements.
Obach W . .	0·5	15%	20	20	$5\frac{1}{2}'' \times 2''$
,, X . .	0·5	20%	10	10	$4\frac{1}{2}'' \times 1\frac{1}{2}''$
,, Y . .	0·5	10%	50	50	$7'' \times 2\frac{3}{4}''$
,, Z . .	0·25	5%	140	140	$8'' \times 4\frac{1}{2}''$
,, P . .	1·0	25%	10	12	$3\frac{3}{4}'' \times 2\frac{3}{4}''$

Fuller's mercury bichromate cell (fig. 11) is very extensively employed. The zinc rod, which is of the form shown, cast on a copper wire, is placed in a porous pot, with two ounces of mercury, by which the zinc is kept self-amalgamated.[1] A carbon plate and porous pot are then inserted in a quart-size earthenware jar, into which are placed four ounces of bichromate of potash. This outer jar is then filled up to within two inches of the top with water and four ounces of sulphuric acid; water

[1] Mercury possesses the power of combining with several of the other metals, and forming alloys, which are known as amalgams. Zinc may be amalgamated by being first cleaned with hydrochloric or sulphuric acid and then rubbed over with mercury. The ordinary liquid arc can then no longer intervene between the various impurities in the plate—a mercurial metallic arc takes its place. Consequently the conditions for a local current are destroyed, and no local action on the surface of the plate can take place; at the same time a perfectly homogeneous surface is presented for the general working of the battery.

and a quarter of an ounce of sulphuric acid being added in the porous pot.

The cell is ready for work as soon as it is charged, but its full strength is not attained for some hours. Some polarisation takes place in this as in most other batteries; its effect when working through low resistance is to vary the strength of the current, but when working through a high resistance the variation, even if it occurs, is not perceptible.

The electromotive force, which is the main consideration in all batteries, is equal to 2·14 volts per cell—about twice that of the Daniell cell. By varying the thickness of the porous pot and the strength of the solution, the internal resistance may be made to range from half an ohm up to four ohms, according to the work which the battery is called upon to perform.

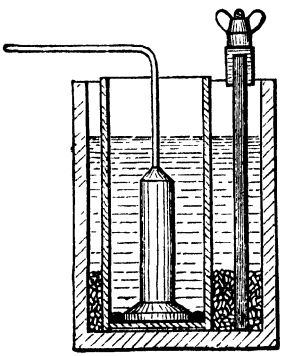


Fig. 11

The maintenance of this battery is inexpensive, and the labour required to keep the cells in good working order is not considerable. So long as the solution in the earthenware jar remains of a deep orange colour no attention is required; but when it assumes a bluish tint a portion should be withdrawn and a further supply of bichromate of potash, sulphuric acid, and water added; at the same time it may be necessary to withdraw a part of the solution from the porous cell, replacing it by water.

The zinc should remain bright and silvery in appearance when it is raised out of the solution. If it be dull or black it shows that there is not sufficient mercury. Care should be taken to use the full quantity—two ounces for a quart-size cell.

The Minotto is one of the earliest and now almost the only form of so-called ' gravity ' cells, and is largely used in India and Ceylon.

It consists of a round glazed earthenware jar, in the bottom of which is placed a circular copper disc with three holes perforated in it, as shown at C in fig. 12. Into these holes is slipped the conductor of an insulated copper wire, which has been stripped of its covering for a distance of about 2½ inches.

Fig. 14 shows an illustration of a Planté type positive, the surface of which it will be noticed is finely laminated vertically, the object being to increase as far as possible the area on which the active material, peroxide of lead, can be formed, and thus to secure the maximum capacity from a plate of a given area and weight. To increase the stability of the plate, it is intersected at regular intervals by horizontal ribs, which are not seen in the illustration, as they are in the core of the plate. Individual plates are connected to a stout lead cross bar provided with a suitable lug, to enable them to be connected to the adjacent cell, and are suspended from the sides of the glass container. The positive plates are cast in a mould at one operation.

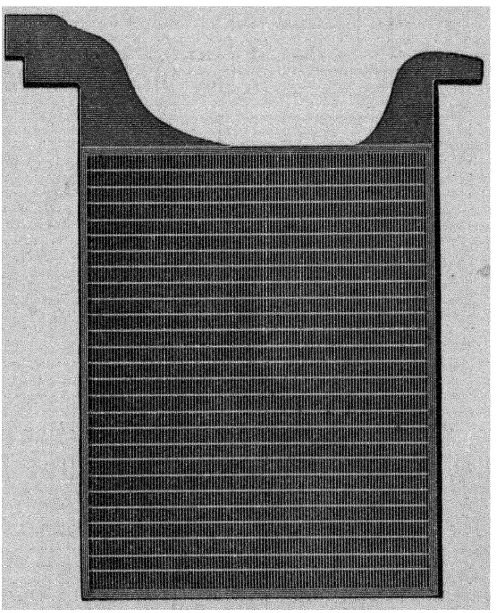


Fig. 14

Fig. 15 shows the grid or support of a Faure type positive plate, of which there are many different designs; but in this particular type, it will be noticed that the ribs on one side of the plate are 'staggered' or alternate with those on the other side, and they do not meet (bottom of fig. 15). There is therefore a clear space between the ribs from the top to the bottom of the plate, and the active material is thus in the form of long pencils embedded in the ribs. It is thus securely keyed in, and cannot drop out, which is one of the troubles to be avoided in the design of Faure type plates, and to get over which has been the aim of numberless inventions.

The top of fig. 15 indicates the appearance of a finished Faure positive plate, with the active material in place in the grid, and ready to be cast on to the cross bar as described above.

The negative plates used in conjunction with Faure type positive plates are usually pasted plates also, the grids or supports being sometimes similar to those used for the positive plates, but whereas the active material pasted into the positive plate is red lead, in the negative plates litharge (protoxide, PbO) is used.

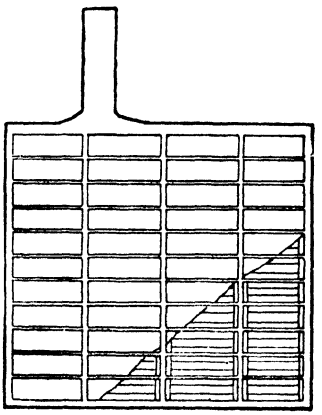


Fig. 15

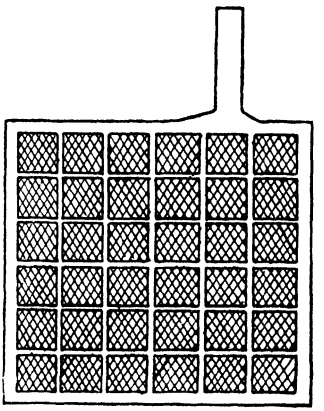


Fig. 16

The negative plates used in conjunction with Planté type positives are usually of the ' Box ' type (fig. 16). In this type of plate, the active material, instead of being pasted on to a grid, is arranged in a series of cages or boxes in a plate made in two halves, riveted together after the insertion of the active material. The outer surface of the plate consists of sheets of fine lead gauze.

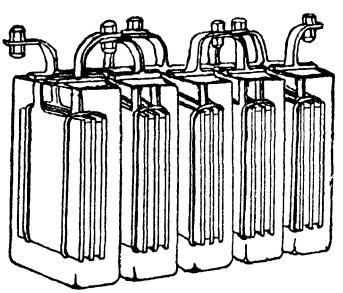


Fig. 17

The plates of whatever type are spaced apart at regular intervals by means of separators. Formerly either glass rods or ebonite forks were used for this purpose, but these have been discarded in favour of grooved wood separators, treated by a special process to remove from the wood all substances which might prove injurious to the plates. These wood separators in cells of a capacity suitable for telegraph work are kept in position by

a celluloid band passing right round all the plates (Fig. 17). The elements are thus rendered semi-solid, and as the wood separators entirely prevent any contact between plates of opposite polarity, the amount of attention required by the cells is reduced to a minimum. It will be noticed from Fig. 17 that the plates, instead of being suspended from the sides of the box, as is usual with larger cells, are hung from the cross-bars, which themselves rest on the sides of the box. The points of support are thus reduced to a minimum, which

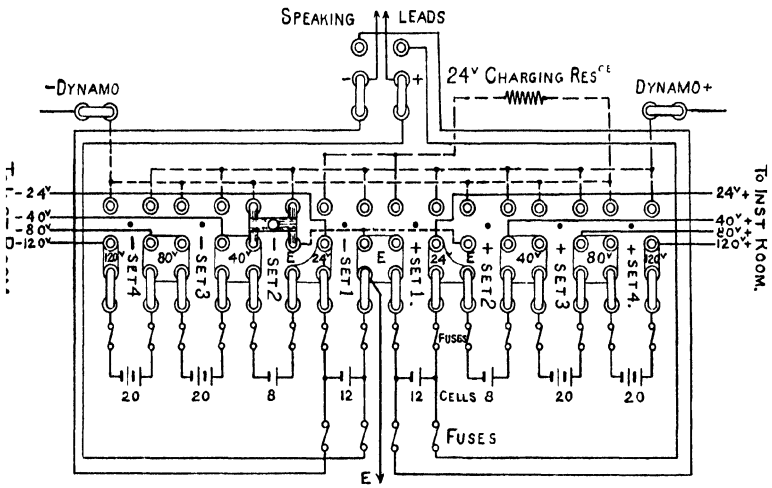


Fig. 18A

prevents syphoning of the acid from the boxes and maintains a high insulation.

The bolts for coupling the lugs of adjacent cells together are provided with lead-covered nuts, which prevent corrosion from the fumes rising from the sulphuric acid in the cells. The glass containing boxes can be placed on shelving, glass insulators being used on the underside of the boxes, or if it is desired to arrange the cells in 10-volt units, which is sometimes found convenient, five cells can be arranged in a wooden tray, supported at each corner by a glass insulator.

The great advantage obtained by employing accumulators in telegraph offices is that one set of cells can be used for many circuits; in fact even in large offices one set of cells is found ample for all the circuits. As however the voltage required by

a circuit is dependent on the length of that circuit and the type of apparatus used thereon, this set of accumulators must be arranged so that any particular voltage can be obtained therefrom. The usual practice now is to limit the voltages employed to four: 24 volts for local circuits and 40, 80 and 120 volts for long-distance lines. As, when working double current (see p. 89) two batteries are required, this means that for the complete equipment of a telegraph office, two sets of batteries are required each containing sixty cells, one to give the positive voltages and the other the negative.

In order to save the expense of duplicate sets of this size, the British Post Office has designed a simple system for charging the various groups of cells whilst still at work.

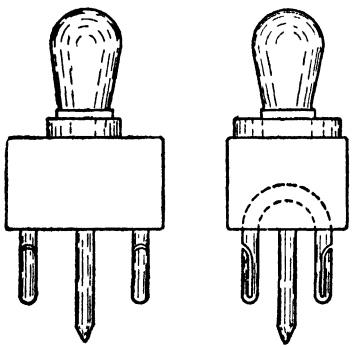


Fig. 18B

For this purpose a special cabinet is employed (fig. 18A). The two sets of cells are connected to sixteen sockets in the cabinet. From another row of sockets eight leads are taken to the instrument room, and a third set of sockets are connected to the charging dynamo.

This machine runs at the voltage sufficient for charging twenty cells. As each cell requires from 2·5 to 2·7 volts during charge, this dynamo gives a potential of 50–55 volts, but in order that the 12-cell group for local working can be charged as one set, a special resistance is inserted in that circuit. 'U' links are employed to couple together the various pairs of sockets for connecting the instrument leads to the batteries, and a special double 'U' link is used for connecting the charging dynamo to any one group of cells (fig. 18B) and arranged with a guide pin so that incorrect connections cannot be made. Fig. 18C gives the connections when charging various groups.

Should any group of these cells break down, or require disconnection for any purpose, the dynamo can be inserted in circuit to take its place.

The usual capacity of the cells used in telegraph offices is 45 ampère hours, but it is sometimes found desirable to use

70-ampère-hour capacity cells in the local circuit groups as these are more heavily worked. In some small offices 27 and even 18-ampère-hour cells are found sufficient.

It is necessary to insert resistances in all the instrument leads as a safeguard in the event of a line being short-circuited or earthed close at hand. Usually a 50-ohm resistance is inserted in the 24-volt leads, 80 ohms in the 40-volt leads, and on the higher voltages a 100-volt 16-c.p. incandescent lamp is used. All the leads from the battery and from the instruments should be equipped with fuses.

Instruments which may be worked as 'intermediate' sets require special arrangements.

A more expensive and elaborate switching and charging system is usually installed in the most important telegraph offices. This system includes two spare sets of twenty cells, the two batteries being each divided into four groups of twenty cells. These groups are connected to a rotary switch having four positions. With each position one group is connected to the charging dynamo, the other groups being in work. In every position also each group varies its place, and step by step each set of twenty cells is used in turn on the 40-, 80- and 120-volt circuit and finally charged.

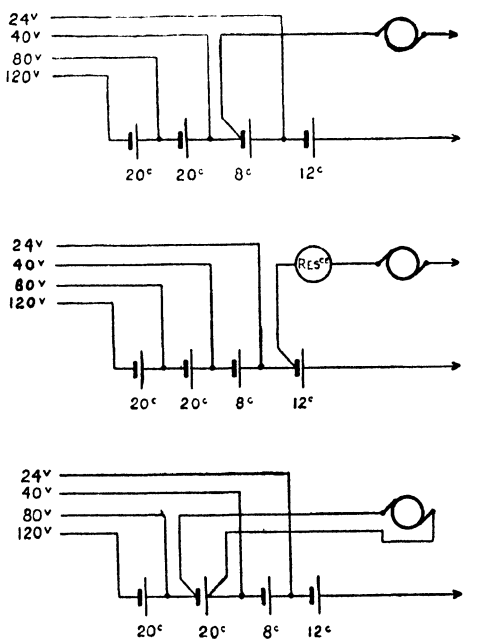


Fig. 18c

The use of these cells for telegraph and telephone purposes is being considerably extended, and when facilities exist for recharging them their introduction is a distinct advantage. The cost of the simpler B.P.O. system does not exceed £300, excluding the charging plant.

In Germany secondary cells for telegraph purposes are almost exclusively used in all except the smallest stations. The normal size of cell used—except in large offices—has a capacity of 15 ampère hours. In small offices, where no electrical plant exists suitable for charging, it is found economical to use primary cells to charge the accumulators. According to Dr. Strecker of Berlin, primary cells under ordinary working conditions on telegraph circuits deliver on the average only 0·002 to 0·005 ampère hour per day, whereas if the same are used to charge accumulators they will give some 0·05 ampère hour without requiring more attention.

Accumulators require careful attention in order that the best results may be obtained. The secret of their successful maintenance is proper treatment. The following points should be borne in mind:

1. Cells should never be allowed to stand idle when discharged.

2. Tests of voltage and of specific gravity should be taken daily and registered. The specific gravity will be found to tend to increase when the cell is charged. When such an increase is appreciable, pure distilled water should be added until the normal is obtained. Any variations from the normal conditions of a cell should be carefully inquired into. By careful observations a developing fault may be removed at an early stage.

3. Cells should never be discharged below 1·80 volt, and the specific gravity should never fall below 1·170 or rise above 1·250.

4. The normal colours of the plates are reddish brown or chocolate for the positives and bluish grey for the negatives, Any alteration from these colours indicates a fault. Sulphating, i.e. a whitish appearance on the surface of the plates, is due to under-charging or over-discharging and indicates bad treatment.

5. Any cell showing any tendency to failure should be removed and carefully examined and specially nursed until it recovers the normal condition.

6. Sediment should not be allowed to accumulate at the bottom of the cell until it touches the plates.

In situations where from any cause, such as distance from the manufacturer's works, it is not practicable to send the sulphuric acid for the electrolyte ready diluted for placing in the cells, it is shipped in a concentrated form. It is essential that

the water used for diluting it, or breaking it down as it is called, should be absolutely pure. To ensure this, distilled water should be used, both in the first instance and on any future occasion when it becomes necessary to compensate for evaporation, or for the spraying that occurs towards the end of charging. In the initial mixing process the water should be placed in the receptacle first and the acid then added carefully.

CHAPTER IV

SIGNALLING INSTRUMENTS

TELEGRAPHY is the art of conveying to distant points the first elements of language—either letters or numerals—by certain preconcerted signals or sounds; and the formation of these signals, by means of the action of currents of electricity upon permanent magnets, upon soft iron, and upon electrolytes, forms the next portion of our subject.

Telegraphic signals are either *visible* or *audible*.

Visible signals, again, are either *permanent* or *transient*; in other words, they are either *recording* or *non-recording*; and they differ from each other either in form or position.

Audible signals, on the other hand, are always *transient* or *non-recording*; they differ from each other either in tone or duration.

Hence we have different systems of telegraphy in which the signals are registered in different ways, and the currents do their work by different methods.

A.—THE NEEDLE SYSTEM

The needle is a visible system with transient or non-recording signals. It takes its name from the fact that the alphabet is formed by the vibration of a small pointer or *needle*, movable between two fixed stops. N S (fig. 19) is such a needle, movable in the plane of the paper about its centre C, the distance of its motion being restricted by the stops *a* and *b*. This needle is capable of receiving two distinct motions, the one to *a* and back, and the other to *b* and back. Its normal position is vertical. In the earliest needle system five of these movable pointers were employed; the number was afterwards reduced to two, and this was superseded by a needle system where only

one pointer is employed, and which therefore goes by the name of the Single-Needle System.

Since we have a motion to the right and a motion to the left as well, we can combine these two motions in any order or number we please, and so form a series of preconcerted signals which shall represent the alphabet. Thus, taking those letters which are most frequently used—viz. e and t—one motion

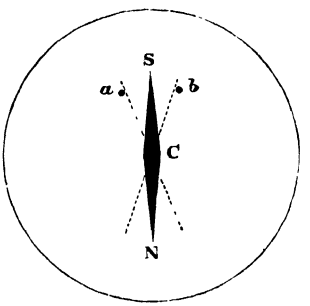


Fig. 19

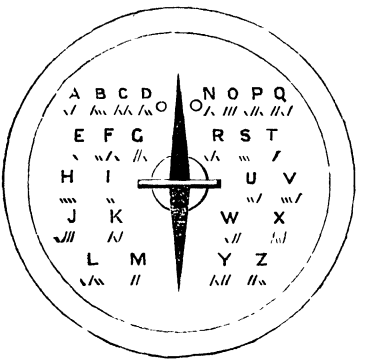


Fig. 20

to the left is the letter e, one motion to the right the letter t; and, taking those letters least used —viz. x and z—one motion to the right, two motions to the left, and one motion to the right represent x; two motions to the right and two to the left represent z. All the other letters are similarly formed of two, three, or four combinations; and thus, by a series of combinations,

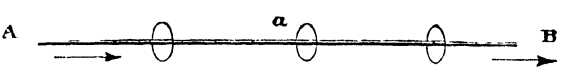


Fig. 21

not exceeding four movements of the needle, the whole of the alphabet can be formed. The manner in which the alphabet is made is shown by the above diagram (fig. 20), the little stroke \ representing a motion to the left and the longer stroke / a motion to the right.

The motions of the needle are produced by the mutual action of currents and magnets. Electricity and magnetism are so intimately related to each other that they may be considered to be only different phases of the same agency. Thus the motion of a magnet always produces electricity; the trans-

ference of electricity always produces magnetism. The neighbourhood of a current is, in virtue of this fact, a *magnetic field*—a term introduced by Faraday to denote the entire space through which a magnet diffuses its influence—and a magnet or a piece of soft iron placed there is influenced by the magnetism of that field.

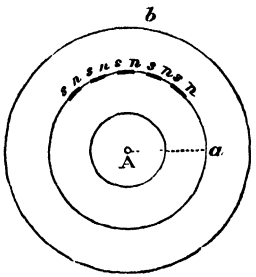


Fig. 22

Thus, if the wire A B (fig. 21) be traversed by a current in the direction shown by the arrow, it is surrounded along its whole length by a magnetic field. If a freely suspended magnet be placed in this field, it will itself move in a certain direction, which direction is dependent on the polarity of the field. If in fig. 22 the wire A were conceived to be surrounded by a ring of little magnets, all freely suspended by their centres at any distance A *a*, they would assume the positions shown in the figure, with all their N poles turned in one direction and all their S poles in the opposite direction. If their N poles were free, they would move in a circular path or orbit around the wire, in the direction shown. Hence we may conceive a wire conveying a current to be surrounded by a series of concentric tubes of magnetised matter, each formed by a series of concentric rings of magnetised molecules whose poles are all tangential, or at right angles to a radius of the ring. Such a series is shown in fig. 22. Thus, if a magnet be brought within the neighbourhood of the wire, it will be acted upon by the directive power of these

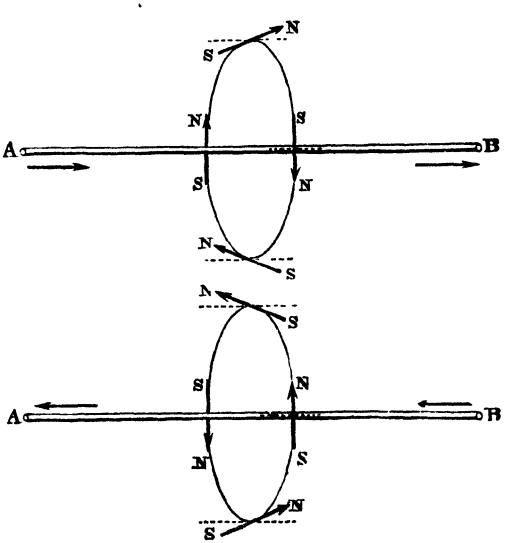


Fig. 23

imaginary magnetised molecules and tend to place itself at right angles to the wire, and always, under the same circumstances, in the direction shown by the molecules in fig. 22. We have conceived the current flowing in one direction; if it flow in the reverse direction, the polarity of the field will be reversed. Hence a current in one direction will cause a magnet suspended

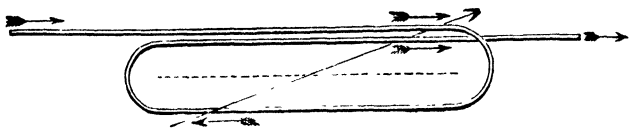


Fig. 24

above it to deflect to one side and a current in the opposite direction to the other side (fig. 23), and whenever the magnet is placed in the direction of the wire, it will always tend to form a tangent to a circle having that wire for a centre. There is no difficulty in remembering this direction of deflection. Taking the face of a watch and conceiving the current as going *from* you, the N poles will all be '*N*egatively rotated,' or moved to the right, like the hands of a watch (fig. 23). The energy of this action between a current and a magnet depends upon the strength of the current passing, upon the strength of the poles of the magnet, upon its shape and weight, and upon the distance between the magnet and the wire.

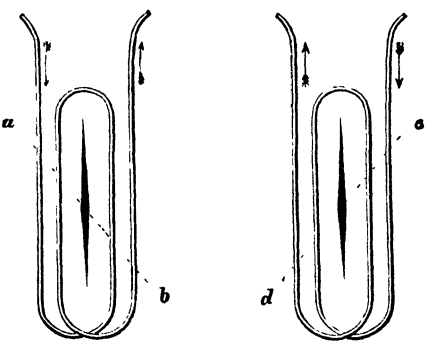


Fig. 25

The strength of the current acting upon the magnet can practically be multiplied at will. If the wire take a turn round the magnet, as shown in fig. 24, it will be evident, on a little consideration, that the directive action of the current as it passes above the magnet is the same as, and is added to, that of the current as it passes below; the effect of the current below the magnet is, in fact, duplicated by the additional turn. Hence the effect is triplicated in fig. 24. Thus, by multiplying the number of turns we multiply the effective action of the current

upon the magnet. In this way we have the means of rendering sensible the presence of the weakest possible current, and we can, by varying the direction of the current, vary its directive influence upon a magnet suspended along its length, so as to make it move either to *a b* or to *c d* (fig. 25).

The single-needle instrument is based upon these fundamental facts.

There are two forms of the single-needle instrument in

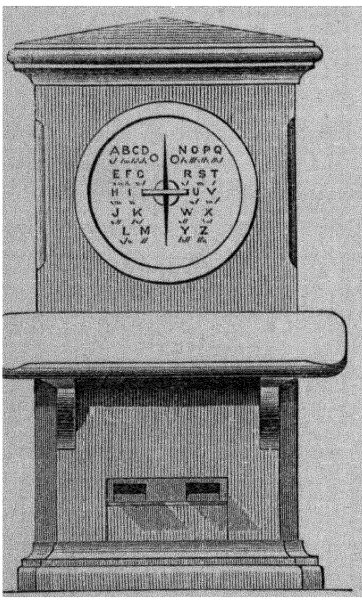


Fig. 26

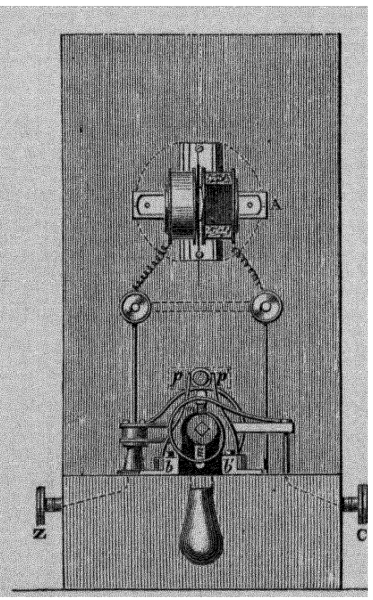


Fig. 27

½th real size.

general use, viz. the drop-handle and the pedal or tapper form. The essential principles of each are precisely the same ; the only difference between them lies in the mechanism of the manipulator or sending portion of the instrument.

Fig. 26 gives a view of a tapper form of instrument, and fig. 27 of a drop-handle single needle from which the case and dial have been removed. A (fig. 27) is the receiving portion of the apparatus. It consists of two ivory bobbins wound with fine silk-covered copper wire, and placed symmetrically with respect to a small magnetic needle free to move inside them (see p. 42 and figs. 31 and 32). Fixed upon the same axis as this small magnetic needle is an indicator moving over the outside of the dial (fig. 26). The motion of this indicator is limited by

two small ivory stops placed upon the dial, which is so constructed as to be capable of rotating upon its centre. The presence of earth currents,[1] by deflecting the indicator, would stop the working of the circuit if this provision were not made for rotating the dial. By this means the dial can be placed in such a position that the average earth-current deflection places the needle in position midway between the stop-pins.

If now a current of electricity pass through the coils, the magnetic needle and the indicator will be deflected. The direction of this deflection will depend upon the direction in which the current is passing. The two coils are wound quite distinct from

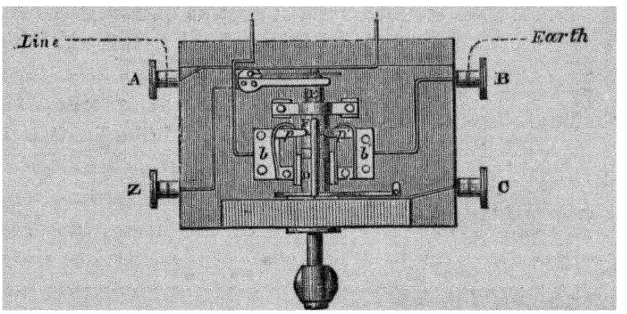


Fig. 28. ½th real size.

each other, but one end of each is soldered to the brass frame, and they thus act as if they formed one continuous coil. The advantage of this arrangement is that should the wire in either get broken or fused—as may happen by lightning—the instrument will still work, provided the wire be carried over to either of the screws. All, therefore, that is necessary to enable communications to be effected by this instrument, is an arrangement by means of which the magnetic needle can be deflected to right or left at will ; in other words, an arrangement by which the direction of the current passing through the coils can be reversed when desired. An investigation of the mechanism of the commutator, or sending portion of the instrument, will show how this is carried out (figs. 28 and 29).

[1] Different portions of the earth, from causes which are not yet known, are frequently at different potentials. When these portions at different potentials are connected together by wire, we have currents in the wire which are called *earth currents*. The currents vary in strength and duration during different periods of the day and year, and at certain seasons they acquire such magnitude as to be called 'electric storms.' They then interrupt the circuits to such an extent as to render working difficult and even impracticable.

The wire from the positive pole of the battery is attached to the terminal marked C, that from the negative to the terminal Z. The line-wire is led to A, and a wire from earth is connected to B. The arbor of the handle consists of two parts, D and F, formed of gun-metal, and separated by some insulating material: ebonite or, more frequently, boxwood is employed. To D a wire leading to terminal C is attached, to F a wire leading to terminal Z. p, p' are two steel springs, each of which is connected with separate brass bars, b and b' on the base of the instrument; by this means p is connected with terminal A through the coils, and p' is connected with terminal B by means of the other portion of brass-work b'. These two springs press against the 'bridge' shown at F, thus maintaining the continuity of the line. The section F of the arbor carries over it a metallic pin or projection m which when the arbor is at rest remains between the two springs p and p' without touching either; whilst D is similarly fitted beneath with a pin or projection m' which when the arbor is at rest remains between the two pieces of brass work b and b'.

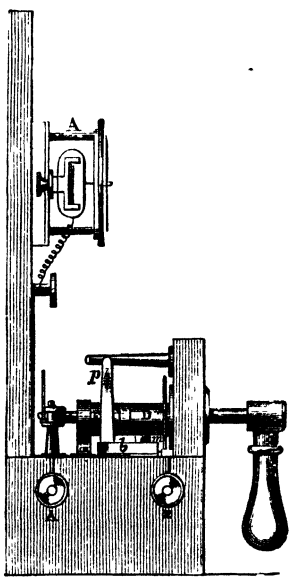


Fig. 29. ½th real size.

Let now the handle be moved to the left: the projection m' of the section D moves to the left, and pressing against the brass-work b—which along with the spring p is in connection with A—brings the positive pole of the battery on to the line-wire; at the same moment the projection m of section F is thrown to the right, and pressing against the spring p'—which with the brass-work b' is in connection with B—breaks its connection with the bridge and puts the negative pole to earth. In this way a positive current is sent along the line, through the receiving apparatus at the distant station, deflecting the needle there, and returning by means of the earth to B and thence to the negative pole of the battery.

Let the handle be next turned to the right. Everything is reversed: the projection *m'* is now thrown into contact with *b'*, and thereby puts the positive to earth; *m* is meanwhile pressed against spring *p*, and thus brings the negative to line. The current may now be regarded as passing along the earth through the coils at the receiving station, deflecting the needle in the opposite direction to what it previously did, and returning along the wire to A and thence to the negative pole of the battery. The single needle is essentially an English instrument; it was invented in England and is still employed on English railways to some extent.[1] Elsewhere the telephone has largely replaced it. The adjustment of the receiving portion of the apparatus is of the simplest possible character; in fact, when once at work no adjustment whatever is required. Any reasonable number can be joined up in circuit upon the same wire without fear of a complaint as to their working, unless it may be that of weak signals; and this can be readily obviated by the employment of additional battery power. The possibility of the small magnet inside the receiving coils being demagnetised, and even reversed in polarity by lightning was overcome by Varley, who introduced the needles which are maintained in an invariable magnetic condition by induction from large permanent magnets. Instead of the small permanent magnet, a soft iron needle

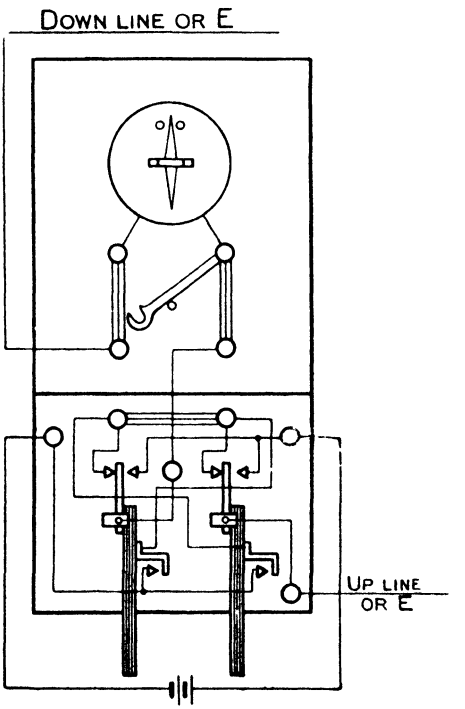


Fig. 30

[1] The principal advantage being that many can be connected on one line and all will work steadily without requiring any readjustments.

of the shape shown in fig. 31, *n s*, is employed. This owes its magnetism to the influence of two permanent bar magnets, N S and N′ S′, whose like poles are adjacent to each other, and which are fixed to a slip of soft iron let into the inner cheek of each bobbin. These bar magnets are very seldom demagnetised by lightning, except during storms of exceptional violence. They, however, like all permanent magnets, lose their magnetism after a time, and require remagnetisation.

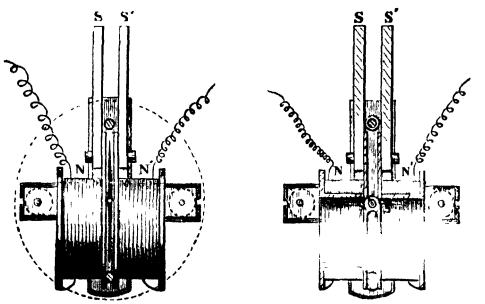


Fig 31

Another arrangement of induced needle (Spagnoletti's) is shown in fig 32. In this case the permanent magnets are of horseshoe form, one being placed above and the other below the axis of the needle.

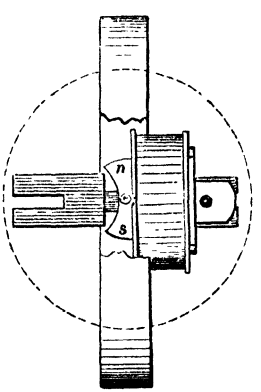
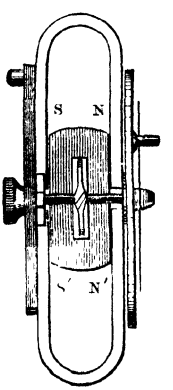


Fig. 32



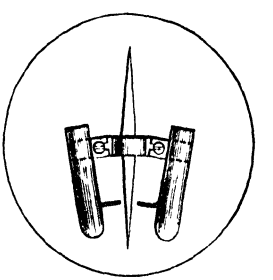


Fig. 33

The induced soft iron needle is in two sections, and of the form indicated; they are separated magnetically by being brazed together with a layer of spelter between them. The axle is of soft iron in two sections, the front part being extended to form the lower half of the needle, and the back part of it continued into the upper half. The like poles of the permanent magnets are adjacent, and thus the upper end of the central

needle is induced with S polarity, and the lower end with N polarity.

A simple but very important addition to the single-needle dial has been introduced in the form of *tin sounders*. One pattern of tin sounder is shown in fig. 33. It consists of a small tin plate cut and bent as shown, and so fitted that each time the needle is deflected it strikes either one or the other

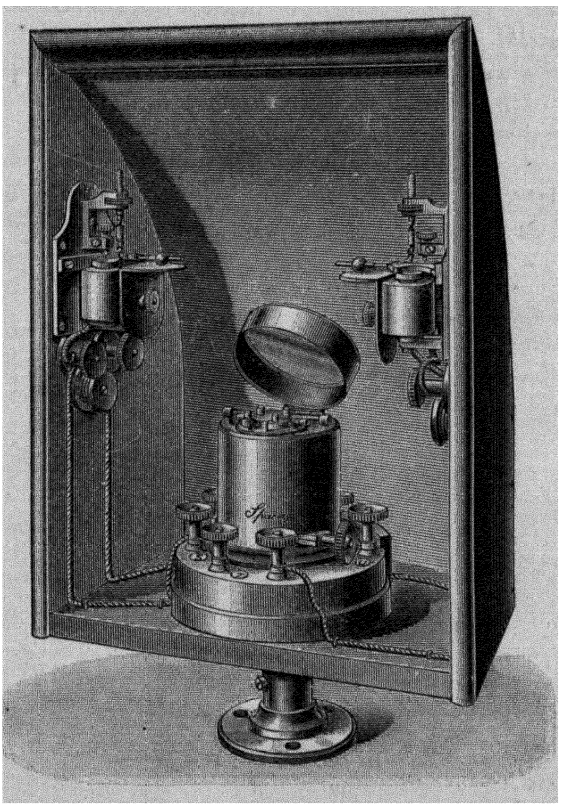


FIG. 34

of the two tin sounders. These sounders can be easily arranged to give sufficiently distinctive sounds for the two signals to be distinguished, and by this means the operator is enabled to read off the deflections by sound. Other metals have been tried, but commercial tin (that is, tinned sheet iron) seems to give distinctly the best result for this purpose. A later form provides for fixing the sounders independently of the bridge, which is preferable.

The Double-plate Sounder

In large offices where a greater volume of sound is required than that obtainable from the tin sounders a modification of the Bright's bell instrument, now obsolete, is sometimes employed. This is shown in fig. 34. It is called the Double-plate Sounder and consists of two sounders which are mounted, together with a relay, in a screen which is useful in concentrating and directing the sound. The relay used in this case is the Post Office Standard with neutral tongue (p. 53). The tongue is normally held, by means of a thin, flat spring, between two contact points, and is capable of being moved against one or the other according to the direction of the current through the coils, and so closing the local circuit of one or other of the sounders.

In a later form a galvanometer [1] is in the screen, and the relay is placed on the table, where it is more accessible for adjustment.

B.—The Acoustic System

The acoustic system is, like the needle, a transient or non-recording system, but differs from it, as its name implies, in the fact that the ear is made use of instead of the eye to interpret the signals sent. The main type of instrument employed in working this system is the *Sounder*.

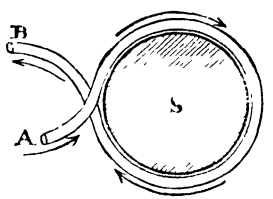


Fig. 35

This instrument is based upon the electro-magnetic effects of the current. Inasmuch as the neighbourhood of a current is a magnetic field, and filings of iron placed in that field acquire magnetic properties (p. 36) it follows that if we envelope a mass of iron filings—or even better, a piece of iron itself—with a ring of wire conveying a current, every filing or molecule of iron within this circle

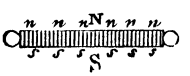


Fig 36

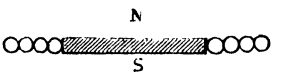


Fig. 37

will be similarly magnetised; that is, it will be so magnetised that similar poles lie in similar directions. Let A B (fig. 35) be such a wire, conveying a current in the direction

[1] For the purpose of indicating the presence of electric currents It is an instrument practically identical with the single-needle receiving coil.

shown, and S a flat disc of soft iron. Now inasmuch as every molecule constituting the soft iron disc lies in the magnetic field of that current, it will be polarised in the direction shown in fig 36 ; and as all these molecules have their polarities in the same direction, the resultant effect is as though there were one

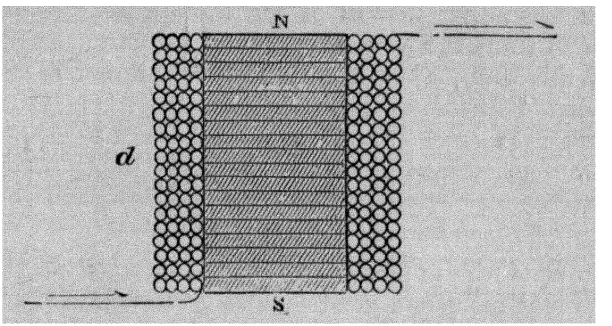


Fig. 38

magnet whose N pole was above and S pole was below the disc. Moreover, if instead of one ring of wire we were to surround the disc with several rings, the current flowing in the same direction in each ring, as shown by fig. 37, the effect would be magnified ;

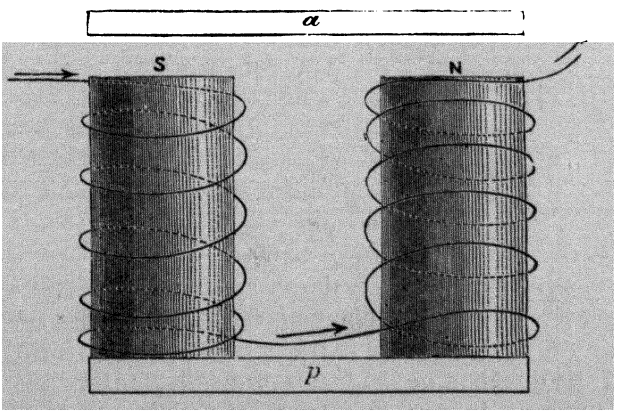


Fig. 39

and if we were to superpose several discs, as in fig. 38, thus surrounded with rings in all of which the current flowed in the same direction, the effect would be still further magnified, and we should have a powerful bar magnet, N S. Precisely this effect is produced by winding a helix of wire around an iron bar or core. By combining two such iron bars (fig. 39) by a cross

piece of soft iron *p*, and surrounding each bar with a coil of silk-covered wire, we construct an *electro-magnet* which is powerfully magnetised every time a current flows, and which therefore exerts attraction upon a bar of soft iron or *armature* (*a*) placed in front of it. The power which this electro-magnet exerts depends upon the strength of the current flowing, upon the number of turns the wire takes around the core, and upon the size of this core. Thus a very powerful current requires but

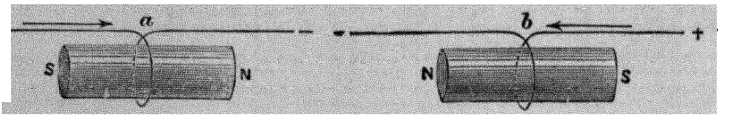


Fig. 40

a few turns of wire to produce a considerable effect, while a very weak current requires a great number of turns to produce any effect at all.[1]

The direction of the poles of the magnet is dependent upon the direction of the current and upon the direction in which the helix is wound. Electro-magnets are almost invariably wound

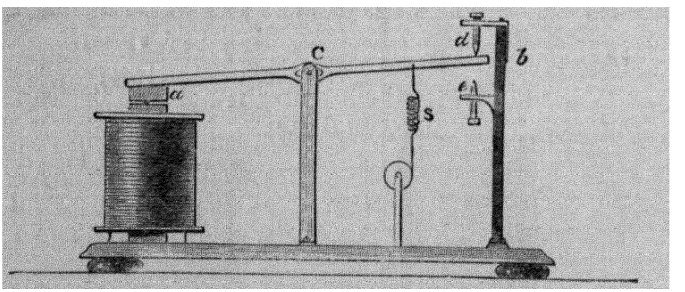


Fig. 41

with the right-handed helix, shown symbolically by fig. 40, and the polarity due to the different directions of the current is shown by *a* and *b*. Thus, if the current flows around the iron core in the direction of the hands of a watch whose face is held before the eyes, the N pole is away from us.

We can fix the electro-magnet at the end of a lever *a b* (fig. 41) pivotted at C, and limit its play by the two screws *d* and *e*. We can also maintain the lever in its normal position pressing against

[1] See Appendix, Section E, with regard to the Winding of Electro-magnets.

e by means of the antagonistic spring S, and then whenever a current of sufficient strength passes through the coil, whatever its direction may be, the attraction of the magnetised core will overcome the tension of the spring, and cause the end *b* of the lever to make a sharp blow against the adjusting piece *d*, and take up the position shown in the figure. When the current ceases, the attraction also instantly ceases, and the lever is pulled smartly back into its normal position against *e* by the action of the spring S. The blows made by the lever against *d* and *e* emit distinct and clear sounds, which are taken advantage of to convey to the ear the letters of the alphabet and other preconcerted signals. This is the principle of the Sounder

How can we convert the sound made by the contact of the lever against the two limiting stops into an alphabet? We have shown (p. 35) how two motions, a motion to the right and a motion to the left, of a vertical needle are applied to the communication of preconcerted signals through the eye; and we have seen that, by means for instance of tin sounders, we can do the same thing through the ear if we make one kind of sound to represent the motion to the left and another kind of sound to represent the motion to the right. This, however, requires the comparatively complicated two-lever mechanism of the commutator, as well as that the receiving instrument shall be polarised, and that there be three possible positions of the indicator. In the sounder we have still two sounds, but one—that against the stop *d*—is always produced when a current is sent, no matter in which direction; and the other is produced only on the cessation of the current. We are, therefore, obliged to obtain our two signals, not by the direction in which the current is sent, but by regulating the time during which it flows.

The lever striking *d* gives the commencement of the signal, and striking *e* the end of the signal. The *time elapsing between these two sounds* determines the kind of signal. Representing the one signal by a dot (.), and the other by a dash (—), we have the dot and dash alphabet of Morse.

It will be seen that in this alphabet we have introduced *duration* as an element of signalling. It is really duration of *silence* rather than duration of *sound*. The signals are formed of short or long intervals of silence between the sounds produced by the lever striking first *d* and then *e*, forming *dots* and *dashes*;

separated by *spaces*, which are the intervals between the two sounds made by the lever as it strikes *e* and *d* successively. There are three kinds of spaces: the space separating the elements of a letter, that separating the letters of a word, and that separating the words themselves. Thus sound reading and sending is a method by which time is divided into accurate multiples of some arbitrary standard or unit, viz. the dot.

1. A dash is equal to *three dots*.

2. The space between the elements of a letter is equal to *one dot*.

3. The space between the letters of a word is equal to *three dots*.

4. The space between two words is equal to *six dots*.

The basis of the alphabet therefore is the dot

. representing the letter..... e

and the dash

— representing the letter ..... t

Placing a dot before each of these elementary characters, we have

. . .. i
. — ..... a

Placing a dash before each elementary signal, we have

— . ..... n
— — ..... m

Now prefixing each of the above four signals with first a dot and then a dash, we have

. . . . s
. . — ..... u
. — . ..... r
. — — ..... w
— . . .. d
— . — ..... k
— — . ..... g
— — — ..... o

Pursuing the same system with these eight characters, we have

. . . .		h
. . . —		v
. . — .		f
. . — —	(German)	ü
. — . .		l
. — . —	(German)	ä
. — — .		p
. — — —		j
— . . .		b
— . . —		x
— . — .		c
— . — —		y
— — . .		z
— — . —		q
— — — .	(German)	ö
— — — —		ch

There is also the French accented è . . — . ., but with this exception no letter exceeds four signals.

A combination of five signals is employed to represent the numerals and cypher.

1	. — — — —
2	. . — — —
3	. . . — —
4	. . . . —
5	. . . . .
6	— . . . .
7	— — . . .
8	— — — . .
9	— — — — .
0	— — — — —

The stops and other signs of punctuation are made by a combination of six signals.

Period or full stop	. . . . .
Repetition or ?	. . — — . .
Horizontal stroke, or the divisional bar of a fraction	— — — — — —
Hyphen	— . . . . —
Apostrophe	. — — — — .
Note of exclamation !	— — — . . — —

There are many other signals in use, such as ... ... for the vertical stroke of a fraction, and some of those indicated above are rarely employed in England. *Ch*, for instance, has been abandoned because it is so much like '*to*.'

Fig 42 represents a simple sounder such as is generally employed in England. The sounder is in every respect the simplest of all the signalling apparatus in use, and simplicity in construction is a great consideration when technically unskilled operators are employed. The ends of the wire of the electro-magnet are connected to brass terminals fixed on the wooden base, and to these terminals the line and earth-wires are brought.

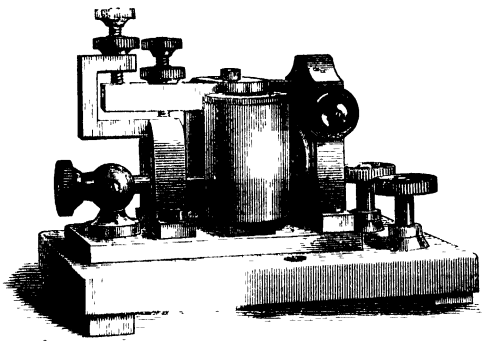


Fig. 42

One end of the antagonistic spiral spring is attached to a vertical arm projecting from the lever and the other to an adjusting screw (shown to the left in the figure), by means of which its tension may be increased or decreased at pleasure so as to compensate for the variation in the strength of the line current. The adjustable stop which passes through the lever strikes against the angular bridge-piece when the armature is attracted, and the other forms the banking stop for the lever in its position of rest.

The Key.—How are these currents of varying duration sent by the sending station? The apparatus for doing so, called a *key*, is much simpler than that required in the needle system, because no reversals are needed, currents in only one direction being required. The key (fig. 43) consists of a simple brass lever,

which is in connection with the line wire, and which is pivotted so as to be movable about its centre on a brass piece fixed upon a wooden base. It is maintained in its normal position by a spiral spring, causing the back of the lever to be held in contact with the back stop, which is in connection with earth through the receiving instrument, thus preserving the continuity of the line. One pole of the battery is placed in connection with the front contact piece, the other pole being put to earth. Thus whenever the key is depressed the lever is brought into contact with the front stop and the current flows to line. The moment the key is released the contact is broken and the current ceases. The duration of the current thus evidently depends

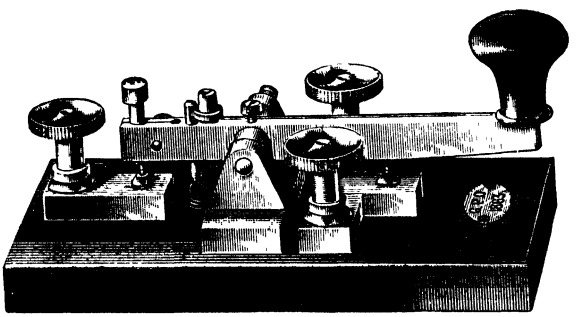


Fig. 43

upon the duration of this contact. These currents pass through the receiving instrument at the distant station and operate the sounder in the manner described at p. 47. Hence to send dots and dashes by this key it is only necessary to tap or move it as one would the key of a piano in order to produce crotchets and quavers.

Such is the sounder in its simplest form, though it is not always possible to work it in this simple form except for very short distances.

The Relay.—As the lines increase in length, and consequently in resistance, and the effects of imperfect insulation make themselves felt, the battery power would have to be increased beyond practicable limits in order to produce audible signals upon our sounders. Some method is then needed by which the inaudible weak line currents shall bring in fresh currents which will make

the signals audible. This is the function of the *relay*, by which a local battery is brought into play which works the receiving sounder in the same way as the line current would have done had it been of the requisite strength.

The relay is, in fact, nothing more nor less than a more delicate form of the electro-magnet and lever employed in the sounder previously described. It is wound with a finer and longer wire, and all its parts are more delicately constructed, so that a very weak current will cause the armature to move. However long a line may be, and however badly it may be insulated, if any currents at all can get through, so long can relays be constructed to move with those currents. The principle of operation is given by fig. 44. S is the electro-magnet of the ordinary sounder

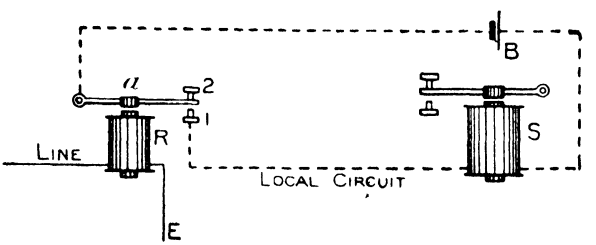


Fig 44

wound with thick wire, but requiring a stronger current to work it than can be sent from the distant station. R is the electro-magnet of the relay, wound with very fine wire and worked by the line current. B is a *local battery* whose positive pole is attached to one end of the coil of the sounder, and whose negative pole is connected with the lever of the relay. The other end of the coil of the sounder is connected with the lower contact 1 of the relay. When a line current passes through R it attracts the armature and brings the lever in contact with 1, so completing the *local circuit*. The local current therefore works the sounder, whose armature remains attracted just as long as does that of the relay, and thus every movement of the relay is repeated on the sounder.

There are many different forms of relay. Such a one as that just indicated is called a *non-polarised* relay. The forms of relay more largely used are called *polarised*, because their arma-

tures are maintained in a magnetised condition by permanent magnets. They differ principally from the non-polarised relay

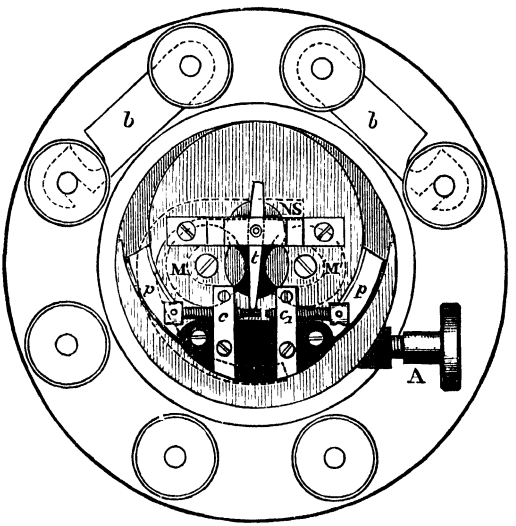


Fig. 45. ½ real size.

in that they are affected by the direction of the current, and under certain circumstances they are far more sensitive.

The British Post Office polarised relay consists of two electro-magnets M M′ (fig. 45) double wound on the differential principle and so connected that when a current is passed through their coils, their opposite poles are adjacent. M′ together with some other parts is omitted in fig. 46, in order to show the arrangement more clearly. Upon the axle *a* are fixed two soft iron tongues or armatures, *n*, *s*, which play between the soft iron pole-pieces of the electro-magnets, and are kept permanently magnetised by means of the magnet N S. Upon the same axle *a* is fixed the German silver tongue *t*, which therefore moves with the

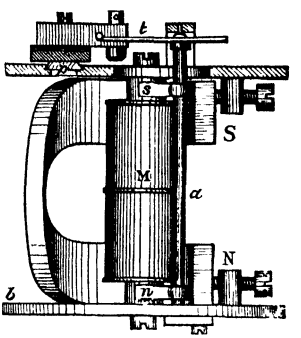


Fig. 46. ½ real size.

armatures n, s, and whose end makes contact with c or c_1 according to the direction of the current through the coils or to the 'bias' which is given to the tongue. The 'bias' is given by means of the screw A, by which the position of the contact points, which are fixed upon the movable piece p, is regulated. The screw A which is fixed on the base b (fig. 46) banks against the end of a lever pivotted at its centre, whose other end works in a slot in the curved piece p, which is concentric with a; when therefore A is screwed inwards, the contact points are moved to the right, and (the end of the lever being held against A by means of a spring) when A is unscrewed they are moved to the left. Almost any degree of sensitiveness or adjustment can by this means be obtained. The brass straps b b (fig. 45) are for the purpose of joining the coils of the relay in 'multiple' or 'series' at will. When the straps are as shown in fig. 45 the coils are joined in multiple; when required in series both straps are joined across the two back terminals. The electrical connections of the relay are shown in fig. 47.

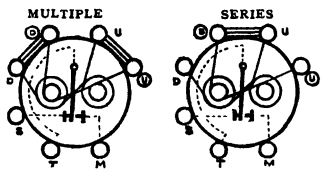


Fig. 47

Vyle Sounders

To a considerable extent the use of relays on single lines has been displaced by the use of the 'Vyle' direct reading polarised sounder. This instrument resembles in appearance the ordinary sounder. It has two coils which, for simplex working, can be connected externally in series or parallel. A permanent magnet is fixed underneath the instrument with its poles closely adjacent to, but not touching, the two cores of the electro-magnet, which are thus inductively magnetised (see fig. 48). The magnet is made sufficiently powerful to withstand any tendency to reversal produced by a current through the coil.

This simple addition to a sounder increases the sensitiveness considerably. The ordinary sounder requires 20–26 milliampères to give good signals; with this polarised sounder 10 milliampères give equally good results, and it will work when 3 milliampères

only are flowing. A further advantage is that the working current can be varied from 3 to 40 milliampères without calling for an adjustment of the armature. This obviates the necessity of adjustment screws. The distance between the armature and cores when the former is down should be 8 mils (0·2 mm.) and the distance between the lever and the upper limiting stop should then be 16 mils.

The differentially wound instrument has usually two coils of 500 ohms each, though for some circuits 1000-ohm coils are preferred. For simplex working only, the resistance may be 4500 ohms and the normal working current 6 milliampères.

The advantages of this polarised sounder are:

1. Its extreme sensibility.
2. Its great inductance[1] (some 62 henrys).
3. Its insensitiveness to fleeting currents owing to the mechanical inertia of the armature which is comparatively speaking somewhat heavy.

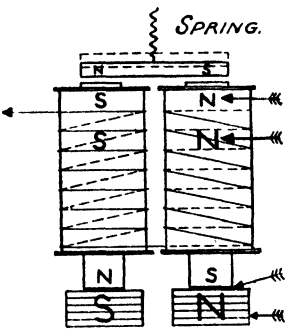


Fig 48

This principle of polarisation is also used for relaying sounders and other instruments.

The *vibrating sounder*, which has been extensively used of late years, especially for military purposes, was invented by the late Major Cardew, R.E., in 1881. Where other instruments fail from weak signals through faults of insulation on the lines, the vibrating sounder has proved eminently successful. It has been worked through sixteen miles of bare wire laid upon the ground in England, and through over twenty-three miles in Egypt, even when the conductor was in contact with stay wires and railway fences. It was used largely in the Egyptian and South African campaigns, as well as during the frontier expeditions in India, and on the badly-insulated jungle lines of that country, Ceylon, and West Africa. The instrument is illustrated diagrammatically in figs. 49 and 50, which show

[1] See page 150.

two rather different arrangements, either of which may be used. In the former an induction coil I is used; in the latter the coil is single wound for the sake of simplicity and cheapness. Both work well, but the latter is the more common.

The telephone T is the receiving instrument, and it has the advantage that it will emit notes of any pitch that are audible

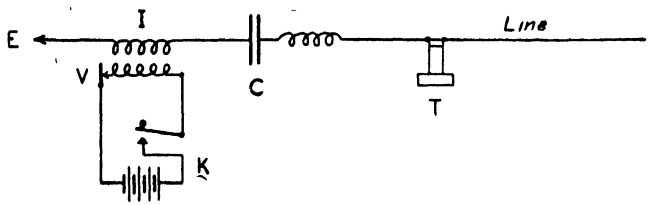


Fig. 49

by human ears without adjustment. A practised signaller is able to distingish the notes which emanate from different offices, and can eliminate one message from another when his

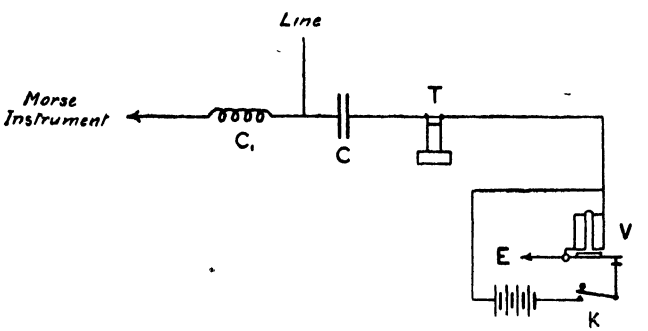


Fig. 50

instrument is affected by inductive disturbances. The coils of the transmitter V (often called a 'buzzer') are wound to a resistance of 20 ohms each. The spring armature vibrates, when a current is caused to pass, similarly to the hammer of an electric bell. The extra currents thus engendered have a derived circuit in the line and through the distant telephone. The battery consists usually of four Leclanché or dry cells put up

conveniently in a box with straps for portable purposes, and, with such a battery, it has been found possible to communicate over 300 miles of line.

With the aid of a 'separator,' consisting of a small condenser[1] C of $\frac{1}{3}$ microfarad capacity, and a coil C_1 with an iron core wound inductively to 200 ohms resistance, and joined to the line as shown in fig. 50, it is possible to work the vibrating sounder on an ordinary Morse circuit without interference. The condenser prevents the Morse signals from affecting the vibrator circuit, and the choking coil softens the clicks from the Morse instruments in the telephone, making it easier for the operator to read the notes from the distant 'buzzer.' It is not, of course, necessary to use the separator when the circuit is worked exclusively with the vibrating sounder.

In the instruments which have been described the signals are transient, and leave behind them no permanent record for reference. We have now to deal with recording instruments, in which the signals are permanent.

C.—The Morse System

The simplest and earliest of all is the 'Morse' recording instrument, so called from its inventor.

The Embosser.—The first form of Morse recorder was the Embosser, shown in fig. 51. The radical principle is exactly the same as that of the sounder, which has been already described. The recording arrangement is purely mechanical, and is as follows:

E E are the coils of the electro-magnet, *o* the armature. The latter is attached to a lever movable about an axis, and carrying at its further end a small steel style S. When the armature is attracted, so that that end of the lever is drawn down, this style is thrown upwards and pressed against a strip of paper *p*. This strip of paper is unwound from the roll above by being passed between two friction rollers W W′, which are set in motion by the action of clockwork. In the centre of the upper roller just over the style is a small groove, into which the paper is pressed so long as the armature is attracted. A mark is thus embossed on the upper surface of the paper, which will appear in the form of either a dot or a dash according to the time that the armature

[1] See page 107.

correspondingly held up against the paper strip and records a dot upon it; a dash in like manner is recorded if F be kept down for a longer time.

The paper which is employed is slightly coloured, and is in continuous rolls of slip three-eighths of an inch in width: the ink is a kind of printer's ink of good quality, diluted with olive oil.

This instrument has three distinct and separate adjustments:

1. Screws A and B, which regulate the play up and down of the armature F, and therefore of the inking disc I.

2. Screw C, which regulates the tension of the antagonistic spring S, tightening or slackening it as may be required.

3. Screw D, which regulates the position of the inking disc with respect to the paper and armature.

It is regulated for working thus:

a. The screw B is first adjusted, so that the disc I gently touches the paper without pressing it too hard when the end of the lever *f* banks against the stud 3.

If the disc presses the paper too hard, it makes thick and ndistinct signals; if it presses too lightly it causes the disc to jump and signals to split: thus — (t) may become . — (a), — . (n), or . . (i).

b. The electro-magnet is then raised by turning the screw D to the right, so that when the lever *f* rests upon the lower stud 3, the poles *just* clear the armature *without actually touching it.* A thin streak of light should be seen between the armature and the poles of the electro-magnet.

c. The screw A is next adjusted so that the lever *f* may be free to move though a space of about one-sixteenth of an inch. A and B together so regulate the play of the inking disc that while it just dips into the ink-well it also *gently* presses against the paper, so as to mark it clearly.

If, when a station is working, a continuous mark is made upon the paper, or signals run into each other, screw B should be raised. If marks should still run together when the coils are well clear of the armature, then the antagonistic spring must be tightened up.

As a rule, the screw C, is found sufficient to meet all requirements of adjustment; and when once A, B, and D have been fixed they rarely require alteration.

C, however, requires to be altered very frequently, and where

several stations exist in the same circuit a different adjustment is often required for each.

d. The ink-reservoir should never be too full, otherwise the apparatus is apt to become clogged with ink—a condition that indicates great carelessness.

e. The communication between the ink-reservoir and well frequently becomes choked with coagulated ink after disuse. This should be cleared with a piece of wire.

f. The ink-reservoir must be frequently cleaned out, and the ink never left in for any length of time.

g. When the day's work is over the paper should be taken from between the friction rollers, and the instrument should be allowed to run down, to prevent the weakening of the main-spring.

D.—The A B C System

This system, like the needle, is transient or non-recording, but it conveys its signals directly to the receiver by indicating with a pointer the letters of the alphabet arranged consecutively upon a dial. It is the simplest of all forms of telegraphic apparatus for reading messages, but its construction is complicated, and in consequence is being displaced by the more convenient telephone. The apparatus of this kind in use in England is Wheatstone's, but there are many other dial forms in use in other countries, such as Siemens', Breguet's, &c.

Wheatstone's A B C dispenses with the use of a battery, as the currents which are employed to move the indicator are produced by the application of magneto-electricity—one of Faraday's most brilliant discoveries—by which currents are produced through the relative movements of magnets and wires.

We have stated (p. 36) that when a current is flowing through a conductor, the neighbourhood of that conductor is converted into a magnetic field. The converse of this is also true, viz. that when a magnetic field is projected through or traverses, a conductor, or when a conductor traverses a magnetic field, that is to say, whenever the relative positions of the magnetic field and the conductor are altered, a current is produced. Thus to produce these effects motion is necessary, and their magnitude is dependent on the length of conductor in the field, the strength of the magnetic field, and the velocity of the conductor across it.

Let N S (fig. 54) be a powerful fixed bar magnet and C a movable hollow coil wound with a quantity of fine silk-covered wire, whose ends are attached to the coil of a galvanometer G. Let the coil C be rapidly moved over the pole N into the dotted position C′—a powerful momentary current will traverse the galvanometer. Let the coil be restored rapidly to its original position C—a current of equal strength, but in the reverse direction, will traverse the galvanometer. Now let the magnet be reversed, and the same movements be repeated, the same effects will be produced, but in the opposite direction. Again, let the coil be fixed and the magnet be movable. If the N pole of the magnet be inserted within the coil, a powerful current will

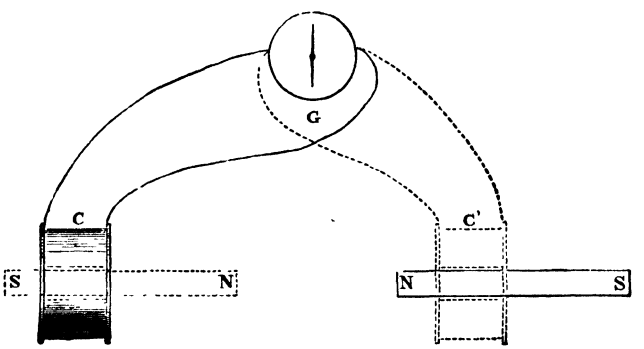


Fig. 54

traverse the galvanometer; and the same will occur, but in the reverse direction, when the magnet is removed. Reverse currents are generated when the poles are reversed. The currents produced by the motion of the coil over the N pole and towards the S pole, or by the insertion of the N pole into the coil, are in the same direction, as are also those produced by similar action between the S pole and the coil.

The actual direction in which the induced current will flow in each case is determined by a law first formulated by Lenz, and hence called *Lenz's Law*. It may be enunciated thus:

A current induced in a conductor by the relative movement of the conductor and a magnet, or of the conductor and another conductor in which a current is flowing, will flow in a direction the effect of which will be to oppose the originating motion.

For instance, in moving C to C′ (fig. 54), as C approaches

N the current induced will make the right-hand end of C of N polarity, so that the pole N and the approaching coil will tend to repel; but in moving from C′ to C the induced current would give a S polarity to the right-hand end of the coil.

If the magnet, instead of being a bar magnet, be of the

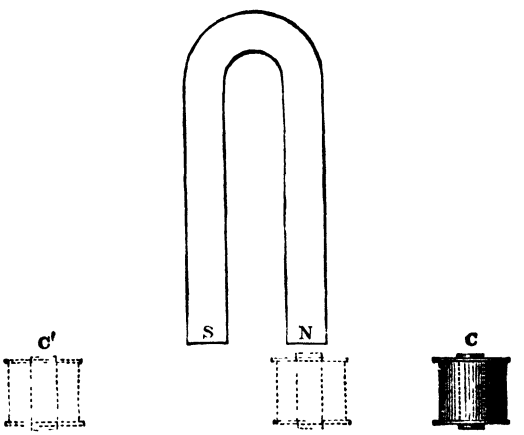


Fig. 55

ordinary horseshoe form, and if the coil instead of passing over the end of the magnet simply passes in front of its poles the same effects occur though in a somewhat diminished degree; but if the inside of the coil be filled with an iron core this loss is greatly compensated for, because the field is thereby strengthened. Let the coil be moved from C (fig. 55) to C′; as it approaches N a current is induced in one direction, as it leaves N a current is induced in the reverse direction; as it approaches S a current is induced in the same direction as the last, and as it leaves S a current is induced in the same direction as the first.

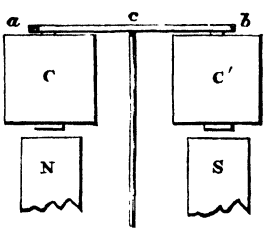


Fig. 56

Let us take two coils wound like an electro-magnet, the two cores connected by a piece of soft iron, *a b*, and arranged to rotate about their centre *c*, as shown in fig. 56; then, if the coils are made to take one quarter revolution, so that *a b* stands at right angles to N S, a current in a certain direction will be

induced in each; and if the coil-ends are properly connected to each other and to the line wires, the currents induced in each will strengthen one another, and a current of double strength will be obtained. If now the coils be rotated a further quarter revolution, the induced currents will be in the same direction as before (see last paragraph); so that a half revolution of the coils across the magnet will practically produce a single continuous current, strongest at its commencement and at its end. For the next half revolution a similar current but in the reverse direction will be induced; for, as already seen, the current obtained in receding is the reverse to that obtained in approaching, and in the same direction as that induced when approaching an opposite pole. Thus by every complete revolution of the coils two distinct currents are produced, one in each direction. It may be noticed that these currents are obtained without in any way disturbing the continuity of the circuit.

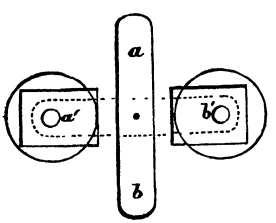


Fig. 57

Now instead of making the coils of wire and their iron cores (which are heavy) movable, let us fix the cores and coils to the poles of the permanent magnet, and simply cause the light piece of soft iron, *a b*, to revolve (fig. 57). This somewhat alters the conditions. The coils are now constantly under magnetic influence of the same polarity, but when the armature *a b* is across the pole pieces *a' b'* the strength of the magnetic field is concentrated upon it directly through the coils; if now the armature be moved to the position shown, then the magnetic field is disturbed and the lines of force are diffused, and this has the same effect upon the coils as if the magnet had been withdrawn, that is, it will induce a current (say a positive current) in them. Let *a b* be rotated another quarter revolution to take up the position *b' a'*; this restores the original condition of the magnetic field, and has the same effect upon the coils as causing the magnet to approach—this is, to induce in them a current in the reverse direction (say negative). Thus by this arrangement ***four*** currents, alternately positive and negative, are induced in the coils for each revolution of the armature.

The most effective portion of each induced current is just when the armature takes up its position across the cores or

leaves that position, so that the four currents due to one revolution are not produced at equal intervals; but by attaching to each pole of the permanent magnet two soft iron cores fitted with coils, as shown in plan by fig. 58 and in elevation by fig. 59,

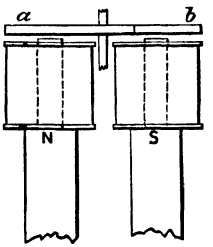


Fig. 58

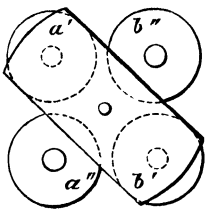


Fig. 59

the cross piece is approaching one core while it is leaving the other, and the irregularity is by this means eliminated.

We are now able to comprehend Wheatstone's magneto-

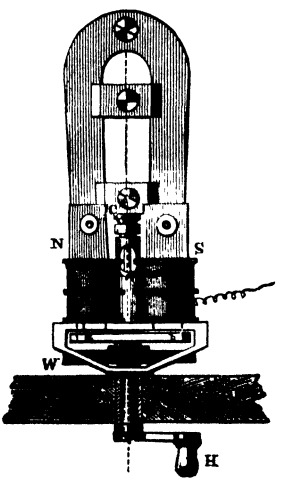


Fig. 60. Plan from below—$\frac{1}{4}$th real size.

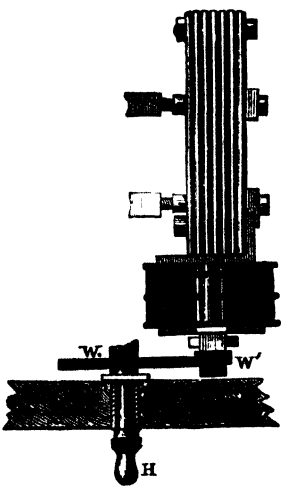


Fig. 61. Side elevation—$\frac{1}{4}$th real size

electric A B C apparatus. A plan and side elevation of the sending portion, called the *communicator*, are shown by figs. 60 and 61. It is mainly encased in a wooden box, which is not shown in either of these figures.

N S is a compound permanent horseshoe magnet, usually formed of seven simple magnets placed with their like poles

together. By means of this arrangement not only is greater magnetism obtained from the same mass of metal, but it is moreover longer retained. To each pole of the magnet two soft iron cores wound with insulated wire are fixed, as explained above. These are placed symmetrically with respect to an axis which carries a soft iron armature *a b*, whose breadth is rather more than the distance between two adjacent cores as shown in fig. 59, and which is made to revolve by means of the 'gearing' or driving wheels w w' turned by the handle H. Above this electrical mechanism is a dial, over which is a pointer *p* (fig. 62), the end of which traverses the circumference of the dial. This dial is divided into thirty equal spaces, upon which are marked the twenty-six letters of the alphabet, the three points of punctuation , ; . and a + known as the *zero* stop: inside these are placed, on each side, the numerals, with the cypher and a +. Opposite to each of the spaces is fixed a key similar to that shown by fig. 63, which can be depressed at will. These keys are placed outside an endless chain, held in position by being passed round a series of small pulleys (fig. 64), and so arranged that only one key can be depressed at a time. One effect of depressing a key is to press in the chain at that point as shown at c c; when another key is depressed the chain is straightened and the first key thereby thrown up into its normal position.

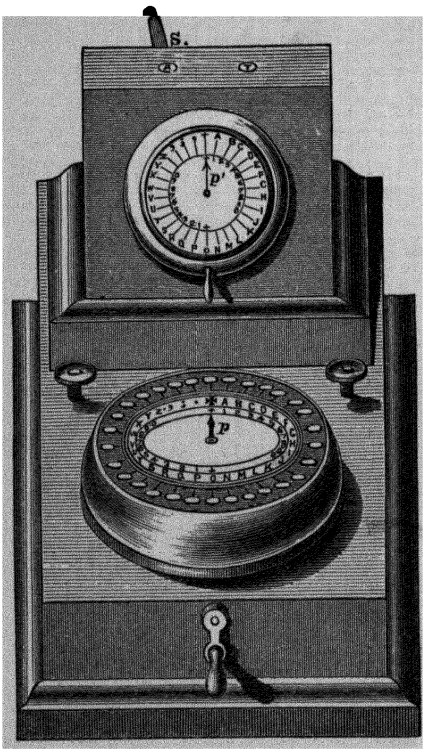


Fig. 62

If now the handle be turned and the armature sent through

one complete revolution in front of the four cores, four separate currents differing alternately in direction are generated. The motion is so adjusted that for each of these currents the pointer moves through one space, and thus for an entire revolution of the armature the pointer goes through four spaces, and four

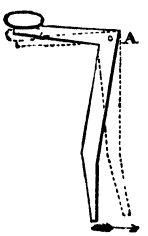


Fig. 63. ½ real size.

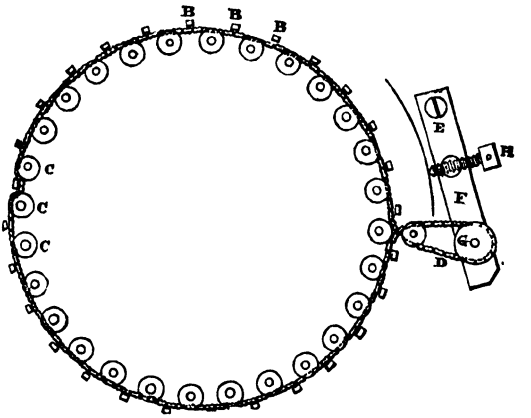


Fig. 64

distinct currents are sent in succession along the line to the distant station. When a key is depressed, the motion of the pointer is arrested on coming opposite to it ; and the currents, instead of going to line, are cut off. This is effected by means of a carrier arm fixed ' spring-tight ' on the axle, which revolves conjointly with the pointer, but which is thrown out of gear immediately the pointer is arrested by the depressed key ; it remains so until this key is raised by the depression of another, and, supposing the handle to be continuously turned, the pointer and carrier arm then resume their movement until again stopped when brought into contact with the latter key. The contact maker K is shown in fig. 65 : L is a spiral spring holding it against the stop M in its normal position of rest. As soon as the handle is turned and a key depressed to admit of the carrier arm revolving, K is drawn against N, which is in connection with the line and so held until the carrier arm is again stopped.

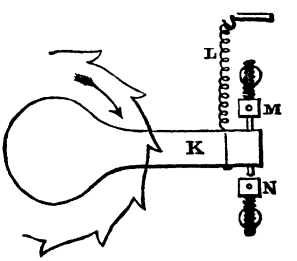


Fig. 65

It occasionally happens that the endless chain in the communicator, by means of which the motion of the keys is regulated, is either stretched to such an extent that more than one key can be depressed at the same time, or (by repair, for instance) it may be so shortened as to prevent even one key from being depressed. In the first case the chain requires to be tightened, and in the second to be slackened. Provision is

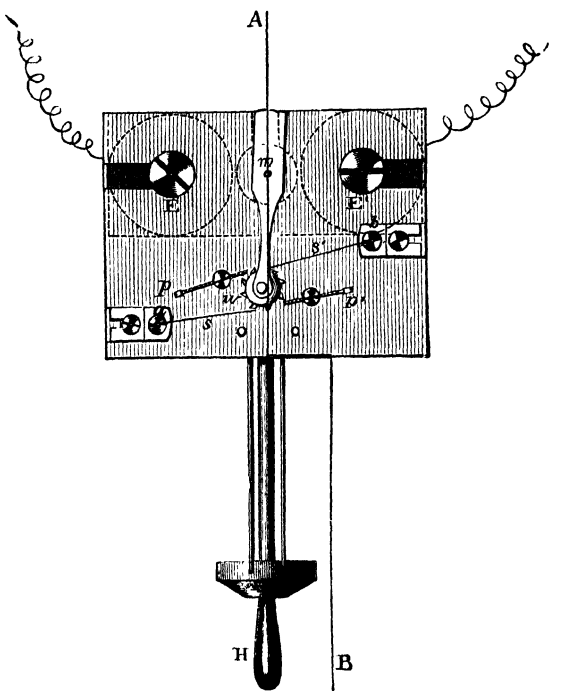


Fig. 66

made for effecting this by means of an arrangement which will be understood on reference to fig. 64.

The endless chain is passed around an additional pulley G, fixed upon a lever F, pivotted at E. In connection with this lever is an adjusting screw H. By screwing H in, the lever is drawn outwards, and, a greater portion of the chain being thus taken up in section D, there is less slack left. By unscrewing H, on the other hand, a portion of the chain is released and the length available for the action of the keys may be thereby increased to whatever extent is desired.

The Indicator.—The dial of the indicator is divided and marked in exactly the same manner as that of the transmitter. Movable upon an axis in its centre is a small pointer *p'* (fig. 62) which indicates whatever letters are sent. The motion of this pointer is regulated by a small escape-wheel *w* (fig. 66), which is propelled by the electro-magnetic arrangement shown in plan in fig. 66 and in section in fig. 67. E, E' are two separate electro-magnets, the cores not being joined across by a piece of soft iron as is ordinarily done. The coils are so connected up that the unlike poles of this pair of electro-magnets are adjacent, and between the coils, and lying parallel to the cores, are two small magnets *n s* and *n' s'* (fig. 67) fixed to an axis *m m'*. Upon this axis is fixed an arm which carries the ratchet or escape-wheel *w*, which thereby moves to and fro with it. The mutual attraction and repulsion between the cores when magnetised by the alternating currents that are sent and these magnets gives an oscillatory motion to the arm, which causes the escape-wheel to rotate in the following manner. The wheel has fifteen teeth cut on its circumference; its play is regulated by two small pallets *p*, *p'* (fig. 66), and two small steel pallet-springs *s s'*. Each motion to or fro of the magnets forces a tooth against one of the pallet-springs, which propels the escape-wheel forward through a distance equal to half a tooth, and causes the pointer on the dial to move through one space. A complete revolution, therefore, of the armature in the sender, which, as already remarked, generates four currents would carry the escape-wheel two teeth forward by four movements, and move the pointer through four spaces. H (figs. 66 and 67) is an adjusting handle which works the pointer on the dial in the same way as is done by the currents passing through the electro-magnet, so that the position of *p* and *p'* may be made to correspond.

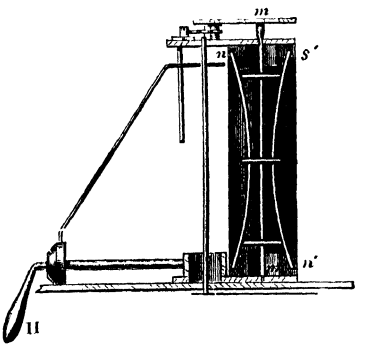


Fig. 67

When two stations are placed in communication with each

other, and the apparatus at each is perfectly adjusted, the pointer on the communicator at the sending station moves synchronously with that on the indicator at the receiving station. When at rest both should point to zero, and in these circumstances the zero key must be always kept depressed.

When there are only two stations in circuit Wheatstone's A B C is found to work very satisfactorily indeed. The addition of every intermediate station introduces an element of irregularity, and complicates to a great extent the adjustment of the apparatus. Four stations fitted with these instruments upon the same wire may be accepted as the limit of safety: only under quite exceptional circumstances should five be tried. As these instruments are invariably employed either upon circuits over which comparatively little work passe sor for private wires, an alarum bell is used in connection with them for the purpose of drawing attention when any communication is to be sent. This bell can be cut out of circuit by the movement of the switch, S, the top of which is shown in fig. 62. When this switch is at A the alarum and indicator are both in circuit, when turned to T the coils of the alarum are short-circuited, and the indicator only is in circuit.

The adjustment, more especially of the indicator, is a delicate matter, and requires a considerable amount of skill and training before it can be undertaken with safety. If the pointer in the indicator jumps, or moves on in advance of the letters sent, the currents are either too strong or the pointer is too lightly adjusted. Either the armature in the communicator should then be moved farther back from the cores, or the play of the escape-wheel in the indicator should be lessened by adjusting the small screws and springs. The screws p p' are provided with split heads in the usual way: the screws a and b (fig. 66) are for regulating the tension of the springs.

If on the other hand the indicator pointer lags behind and drops letters, the currents sent are too weak, or the springs are too stiffly adjusted. Either the armature should then be approached to the cores in the communicator, or the play of the ratchet-wheel in the receiver should be assisted by easing the studs and springs.

The main difficulties experienced with these instruments are due to atmospheric electricity. Lightning frequently deranges them to a great extent. Not only does it readily fuse the coils, on account of the wire with which they are wound

being necessarily so fine, but by demagnetising or even reversing the polarity of the small magnets in the indicator, it interferes with their action and renders a fresh adjustment or remagnetisation necessary. This latter danger has been overcome to a great extent in the form of indicator which is now issued by adopting the principle which was introduced into the coils for needle instruments (p. 41), that is to say, by employing induced instead of permanent magnets. Fig. 68 shows in plan

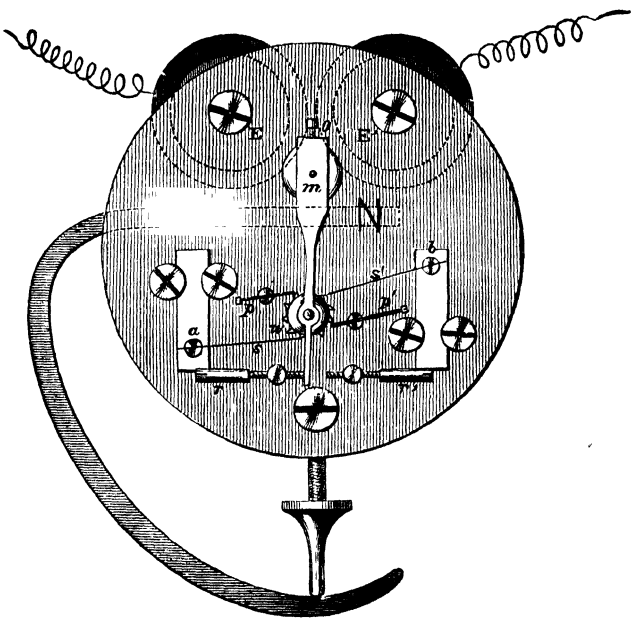


Fig. 68

the latest form of indicator. The escape-wheel and its adjustment are almost exactly the same as in the earlier issue: two additional screws *r* and *r'* are added by means of which the play of the arm can be better regulated. The compound magnet shown in fig. 67 is dispensed with, and in its place two soft iron armatures connected by a small axle pivotted at *m* are employed. The upper of these is indicated at O. These soft iron armatures are kept in a magnetised condition by means of the large bent horseshoe magnet N S partly shown in the figure: the S pole is at the lower end of the coils. The same beneficial results attend this arrangement as have been already referred to in connection with the single-needle instrument.

Occasionally, too, in the case of a heavy thunderstorm, the large permanent magnets in the sender have their magnetism

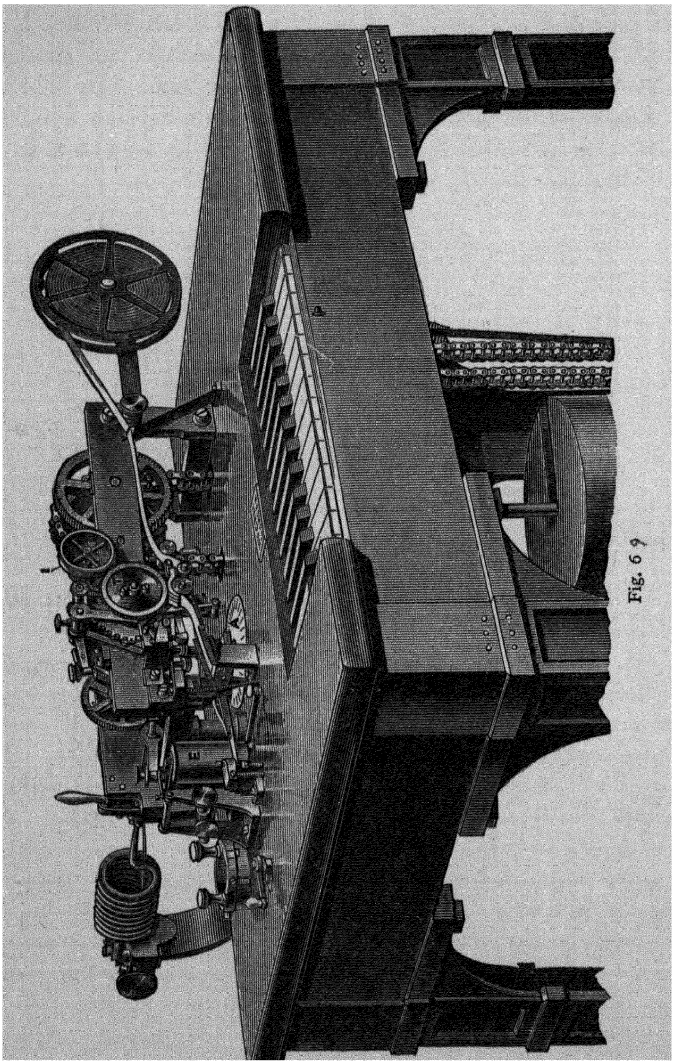


Fig. 69

reduced, so that the currents generated by them are too weak for the adjustment to which the apparatus has been set: indeed, instances have occurred, even in England, where the lightning has removed every trace of magnetism from these large magnets.

E.—Type-printing Instruments

These are instruments which record the messages sent in bold, clear Roman type. Many ingenious forms of apparatus have been devised and practically used for this purpose, especially in America, but only two have attained any considerable employment in ordinary telegraphy—namely, the Hughes and the Baudot; and the latter is now very largely displacing the former both on the Continent and in this country.

(1) *The Hughes Type-printer*

This instrument, shown by fig. 69, differs from all others of its class in being principally mechanical; only one current of short duration being employed to register each letter. The instruments at the sending and the receiving stations are identical in construction and movement. Their type-wheels (T, fig. 69), having the letters of the alphabet raised on their peripheries,



Fig. 70

and attendant apparatus are kept rotating synchronously and simultaneously. The sending apparatus is like a piano key-board, with the letters of the alphabet and any other signals needed engraved on the keys; when one of these keys is depressed a pin is raised on the plate marked A, which just catches a '*chariot*' rotating with the type-wheel, and thereby sends a current through the electro-magnet E to the distant station. This current causes the paper at both stations to be lifted at the same time into contact with the type-wheels. The wheels, having their circumferences coated with printing ink by means of the inking roller I, and rotating in unison, each print the letter corresponding to the pin raised at the sending station. The same movement causes the paper to be moved forward one space ready for the next signal. In this way, by touching each key required successively, words and sentences are spelt out and properly recorded at both stations simultaneously. Fig. 70 gives a sample of a short sentence so printed.

The mechanical construction of the apparatus is exceedingly

ingenious and perfect; but as it is in use only to a limited extent a full description of it does not fall within the scope of this work.

The electrical arrangement also is very simple, and very sensitive. The current which is sent does not *attract* an armature, but it temporarily weakens the polarity of a permanent magnet so as to cause it to *release* an armature which is then pulled away by the tension of a powerful antagonistic spring. The armature is restored to its normal position by the mechanical action of the instrument. This electrical arrangement is indicated by the following figure (fig. 71). N S is a powerful permanent magnet, having two soft iron pole pieces, to which two soft iron cores are permanently attached, surrounded with coils of wire which form part of the line wire: *a* is a movable soft iron armature and *s* an antagonistic spring. When this armature is placed upon the pole pieces, it is held there by the magnetism induced in the pole pieces by the permanent magnet N S, and it will bear a considerable tension of the spring *s* before it will be torn off; but if a current passes through the coils in such a direction as to induce in the cores a polarity the reverse of that induced by the magnet, the armature will be released and it will fly back with the full force of the tension of the spring. The instrument is thus actuated by exceedingly delicate currents but it records its signals with the full mechanical force of a trainwork driven by a heavy weight, the printing portion of which trainwork is brought into gear by the action of the spring *s* when the armature is released.

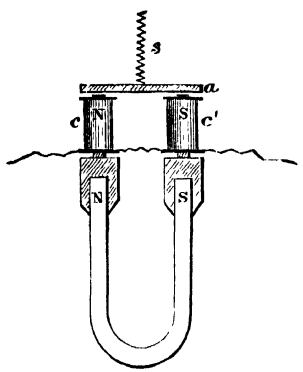


Fig. 71

Although the Hughes instrument was very extensively used in France and other continental countries its expense, which is very considerable both in initial cost and in working, has been the prime factor against its employment.

For a description of the *Baudot system* see Chapter X.

(2) *The Exchange Company's Type-printer*

There are some requirements for which the Hughes or Baudot would be quite unsuited. Thus the delivery of general and other news to many different points simultaneously by one operation, without reference to attention being given at those points, would be quite impracticable by the Hughes system. The general principle of the kind of instrument used for the transmission of news in this way will be clear from a consideration of the instrument used by the Exchange Telegraph Company of London.

The transmitting instrument consists essentially of a series of finger keys for determining the letter or sign that is to be recorded, as in the Hughes instrument. Two of these finger

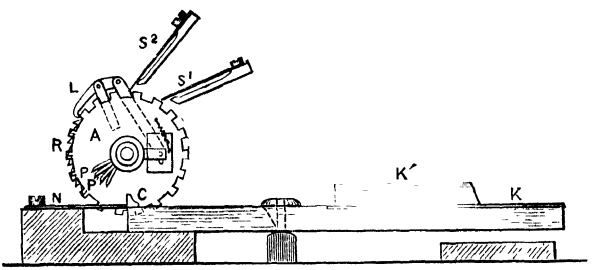


Fig. 72

keys, K, K′, are shown in fig. 72. The inner end of each key is beneath a small catch C, which, on being raised by the depression of the key, comes in contact with one of a series of pins, P, P′, upon a revolving barrel. These pins are arranged spirally around the barrel corresponding in number and position with the finger keys, and the barrel revolves continuously except when stopped by one of the pins coming against a catch on the depression of a key. Attached to the barrel by an ingenious friction arrangement is a contact-wheel A, with half the number of contact projections that there are letters and signs, and these projections come alternately beneath the two independent contact springs S^1 and S^2.

A ratchet-wheel R is driven continuously by an electric or other motor, and when running normally the pawl L, which is pivotted on a bracket attached to the hinder face of the contact-wheel A, engages with the ratchet-wheel R so that the pin-barrel and the contact-wheel are carried round by the motor. By the action of any of the pins P P′ stopping the barrel when a

key is depressed, the pawl is raised and the motor left to continue its revolution, although the barrel is stationary. On the release of the key the barrel again takes up the motion of the motor.

Such a transmitter as this may be used to work an almost unlimited number of recording instruments placed upon any number of lines. In connection with each line is a set of three

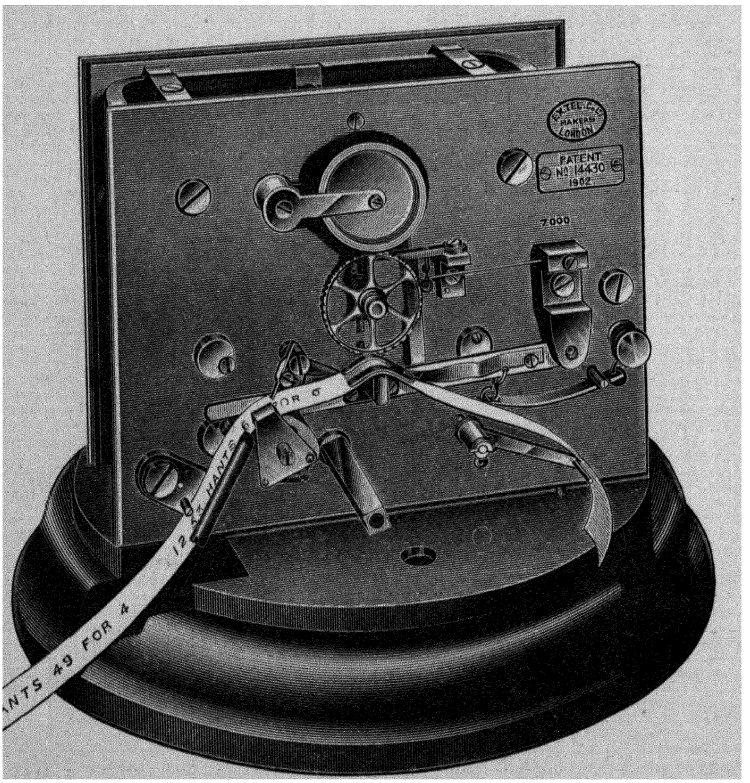


Fig. 73

relays, say R_1, R_2, and R_3. The tongue of R_3 is used to join up the line to the contacts of R_1 and R_2, the tongues of which are connected respectively to the positive and negative poles of two powerful batteries, the other poles being joined direct to earth. Relays R_1 and R_2 are actuated respectively on the completion of the circuit of a battery through s^1 and s^2 (fig 72), and R_3 may be considered to be kept closed so long as messages are being sent. Hence, as the pin-barrel and contact-wheel revolve powerful alternate currents are sent to each line.

This explains the general principle of working of the transmitting arrangement, but there are other electrical and mechanical details to which reference need not here be made. Switches are provided for joining up the batteries and for starting and stopping the motor. Provision is also made for preventing sparking at the contacts of the relays from the powerful currents that are required for working.

A general view of one form of recording instrument is given in fig. 73, and fig. 74 shows some of the electrical details.

The apparatus consists of a powerfully magnetised armature A, oscillating between the poles of two electro-magnets M_1 and M_2.

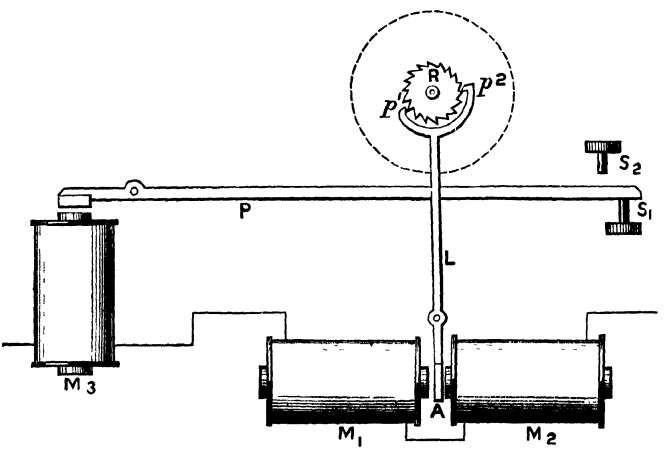


Fig. 74

A forked lever upon the armature axle carries pallets p_1, p_2, which are arranged to engage with the teeth of a ratchet-wheel R on the type-wheel axle in such a manner that when A is attracted towards M_1 the type-wheel is propelled by p_1, and when A is attracted towards M_2 the type wheel is propelled by p_2. These pallets are also so shaped that, when the armature is attracted either way, the type-wheel is held quite steady by their means. This is important in order to secure clear printing. The type-wheel shaft is connected to the train of clockwork supplying the motive power through the medium of a spring, which thus, both at starting and stopping, prevents the inertia of the train from interfering with the proper movements of the type-wheel.

M_3 is the printing electro-magnet, the armature of which is attached to the lever P, whose motion can be regulated by the

two stops S_1 and S_2. The paper slip upon which the record is made is carried by this lever, so that when M_3 attracts its armature the lever raises the paper into contact with the type-wheel (shown by a dotted circle), and the lowest letter or sign upon the wheel is recorded upon the paper. The commencement of the movement of the printing lever effects the forward movement of the paper slip by one space.

The printing and type-rotating magnets are in the same circuit, but the alternate currents from the transmitter which propel the type-wheel are too short in duration to overcome the inertia of the printing lever ; when, however, by the depression of a finger key, the contact-wheel is brought to rest for a short time, the current is prolonged, and, while the type-wheel is held firmly as described by one of the pallets p_1, p_2 the lever P effects the forward movement of the paper slip and then raises it against the type-wheel.

In a certain position of the type-wheel axle—which can be secured for every instrument in the several circuits by three complete revolutions of the transmitter contact-wheel—the type-wheel is locked until the printing lever is actuated. By this means the operator at the transmitter is enabled from time to time to set every recording instrument in his charge to zero, thus providing against any considerable loss of news in the event of any instrument happening to miss one or more of the alternate currents.

The speed of manipulation with a skilful operator reaches as much as forty words per minute.

The apparatus thus described is eminently suitable for the distribution of the specialised classes of news, but for the distribution of general news to clubs, hotels and similar institutions, and to private persons, it is desirable that the news should be printed on a broad band of paper in column form. For this purpose the Exchange Telegraph Company utilises the Higgins' Patent Column Printer, which is a descendant of the first patent and was the first column printing instrument brought into successful commercial use.

In a column printing instrument it will be seen that there must be accomplished over the one wire several functions, viz :

(i) To rotate the type-wheel and ink-roller, i.e. to set and ink the type.

(ii) To advance the printing platen, i.e. to effect the print.

(iii) To feed or traverse the type-carriage along the line.

(iv) To return the type-carriage to the commencement of the line in preparation for a fresh line.

(v) To feed the paper over the interlinear space in preparation for a fresh line.

The keynote of the design of the apparatus is simplicity, and it will readily be seen that since the apparatus must be relied upon to work without expert attention in a subscriber's office, this is a *sine qua non.*

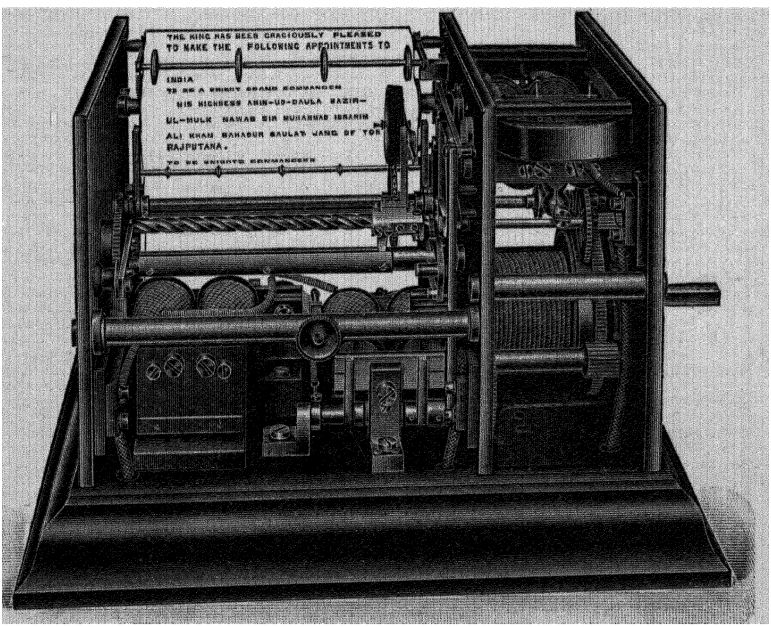


Fig. 75

Fig. 75 shows a view of the column printer. The type-wheel is mounted upon a nut which slides upon a square shaft rotated by alternating currents just as the simple type shaft of the tape printer is operated.

Upon the cessation of the alternating currents, the maintenance of an unidirectional current for a short period calls into operation the printing mechanism, which is responsive only to direct currents and not to the alternating currents which operate the type-setting magnet system.

At the same time a quick-motion screw, which is laid parallel

to the square shaft, is rotated and propels a nut longitudinally from left to right; to this nut there is attached the type-wheel which is thus traversed along the line in readiness for another print.

At the end of the line, upon pressing a key marked 'fresh line' on the transmitter the operator causes the release of a spring which has been wound by each successive printing impulse, and returns the type wheel to the beginning of the line; at the same time the paper is spaced forward by means of a ratchet wheel.

This instrument can be arranged to print 30,000 words without attention.

There are many different forms of recorders designed to suit the various classes of news; for instance, that employed for Stock Exchange quotations requires sixty characters, which are disposed upon two type-wheels carried on a common axis, from either of which a print may readily be made at the will of the operator.

The distributive printing telegraphs described were invented by Mr. F. Higgins, the company's chief engineer.

CHAPTER V

CIRCUITS

WE have defined the circuit (p. 6) to be the whole path along which the electricity is supposed to flow ; and we may consider two cases, (*a*) that in which a current is flowing, (*b*) that in which it is not flowing. If we erect a wire between A and B (fig. 76), the end at each place being connected with the earth, then the circuit consists of the whole path from A to B along the wire, and back again from B to A through the earth ; and this circuit may either have a current flowing through it, or it

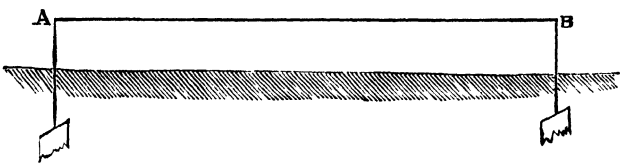


Fig. 76

may be free from all current. In the latter case the circuit is said to be *open*, in the former case to be *closed*.

These two conditions of the circuit are shown in figs. 77 and 78 respectively.

The earth is considered simply as a part of the circuit offering a certain resistance to the flow of electricity through it ; but, owing to its enormous dimensions this resistance is practically nothing. Hence the earth may be said to allow currents to flow through it in any direction and without any obstruction or interference when considered as a whole ; but in some sorts of dry and rocky formations and for limited distances it does offer resistance especially at the earth plate. This resistance can be measured and introduces peculiar disturbances which have to be eliminated or allowed for.

The battery which generates the current and the apparatus which renders it evident to the senses are essential and important parts of the circuit and their resistances are material in determining its working conditions.

Thus we see that whatever is in the path of the current —whether it be in the battery itself, in the apparatus, in the

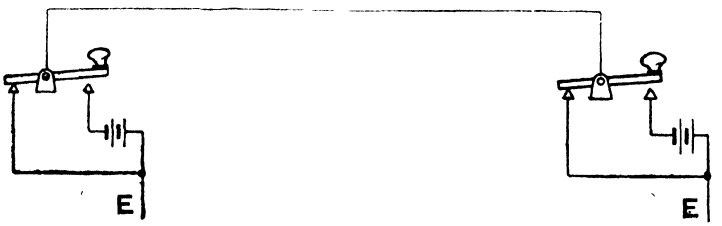


Fig. 77

line wire, or in the earth—whatever, in fact, offers any resistance to the passage of the electricity, is the *circuit*, and this circuit, for telegraphic purposes, may be either open or closed.

The needle instrument is invariably worked on the open-circuit system. The normal position of the needle when at

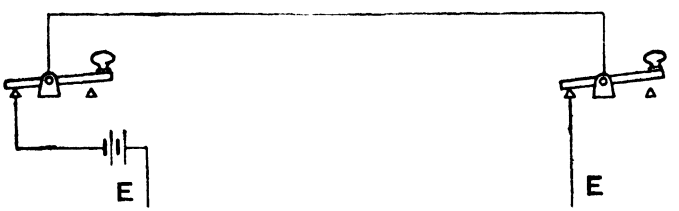


Fig. 78

rest being vertical implies the absence of current, and the motions to the right and left, due to the reversal of currents, imply some rearrangement of the circuit resulting in the flow of current in one direction or the other. K and K′ (fig. 79) are the commutators, B and B′ are the batteries, A and B are the coils and needles. When *r* of K is depressed the current flows from station A through the line to station B in one direction; when *l* is depressed the current flows in the reverse direction. The needle deflects in the direction of the current. Thus from A we can deflect the needle at B to the left by depressing *l*,

or to the right by depressing *r*; and similarly from B we can make the needle at A deflect in either direction at will.

The Morse or Sounder system is also in England usually worked on the open-circuit system, but it is worked with or

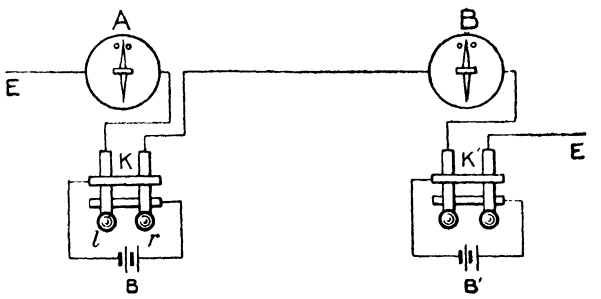


Fig. 79

without a relay. Open circuit working without a relay is called *direct working*. One form is shown in fig. 80. B, B′ are the batteries, and the instrument connections are so arranged that the

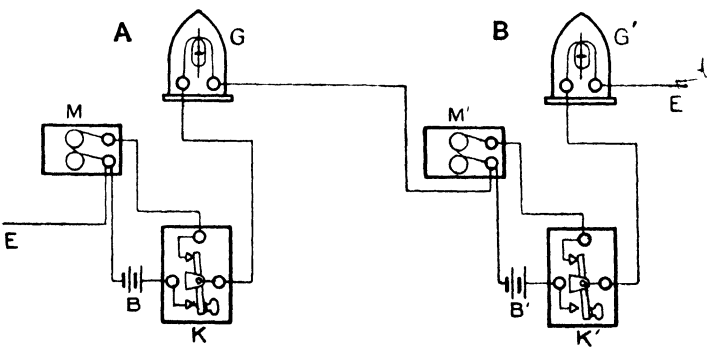


Fig. 80

current in the line always flows in the same direction, whichever station is sending. This is effected by reversing the line and earth connections at the down station. It is a conventional arrangement made for convenience, and not essential to the working of the apparatus. K is the key described on p. 50 which on depression at A permits the current to flow. G is a galvanometer which indicates the existence of the current, and M is the recorder

or sounder worked by the current received from the distant station. Now when station A wishes to communicate with station B, he depresses his key K, which brings the battery B into action, and sends a current which causes the needle of the galvanometer G, as well as that of G′ at B, to deflect, and works the recorder M′ at B, his own recorder not being affected. Thus the attention of B is attracted by the sound or motion of the recorder, or by the galvanometer, and A knows by his own galvanometer whether his current is going properly to line or not.

Direct working was used only for comparatively short lines, for if the length of line were considerable the electromotive force

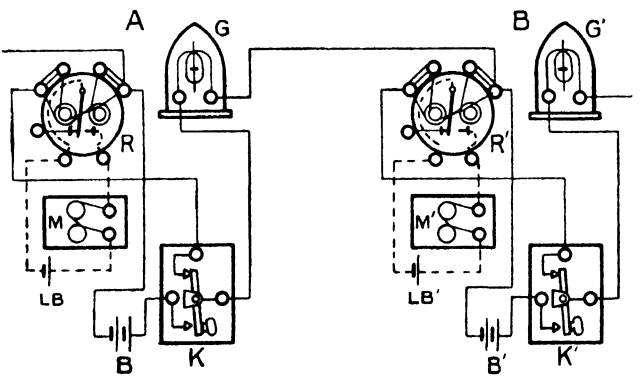


Fig. 81

required in order to obtain a current of sufficient strength to work an Ink-writer or a Sounder was so great that the cost of maintaining the battery became excessive. Where, therefore, the distance exceeded 20 miles, where the insulation of the wires was indifferent, and where abnormal resistance was introduced through the insertion into the circuit of intermediate stations, relays became necessary. The receiving instrument is then worked by *local currents*. M (fig. 81) is the recorder or sounder, L B a local battery, and R the relay which takes the place of the sounder in fig. 80; all the other connections are the same. When the key K at station A is depressed, a current flows from the battery B through K, G, R′, K′, G′, to earth and back to the battery at A. In flowing through R′ it moves the tongue of the relay, which completes the local circuit by which the local current flows from L B′ through M′, and records its signals.

Allusion has been made to the effect of the introduction of intermediate instruments. The introduction of such apparatus in no way affects the theoretical working of the circuit. If in either of the above two cases the earth wire at B, instead of being carried direct to earth, were attached to another line wire extending beyond it, it will be seen that the circuit would still remain whole and open, and that when any one station worked every other station would be affected. The theoretical connections at an intermediate station on a circuit working with local currents are shown in fig. 82. It is evident that while the apparatus is idle the continuity of the circuit is maintained

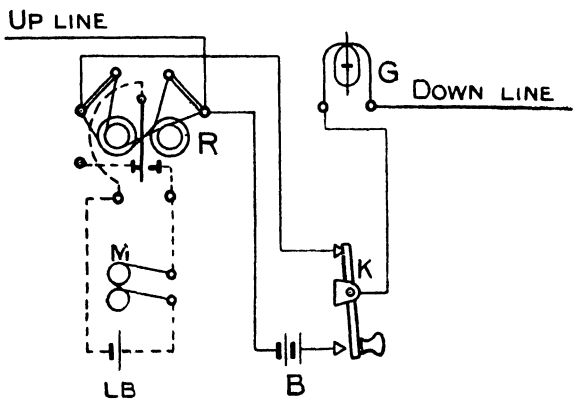


Fig. 82

through the key, and that when the key is depressed the currents flow through both the up and down line without affecting the sounder at the intermediate station itself, but operating those at the other stations. If simple sounder working be in use, it is only necessary to replace R by M alone, and remove LB.

The mode of connecting up a needle instrument intermediate is symbolically shown in fig. 83, where, for variety, drop-handle instruments are shown.

The closed-circuit system had never been a favourite in England; it had been frequently tried, but the experience of its use was sufficiently unfavourable to warrant its withdrawal. One important consideration was the increased cost arising from the greater consumption of materials, owing to the much longer time during which the current is passing. It is shown in its

simplest form in fig 84. M is the recorder or sounder, K the key, B the battery, as before; but there is a battery at only one station, and not at each station, as in open-circuit working. The key K has a movable handle or *switch*, as it is called, which

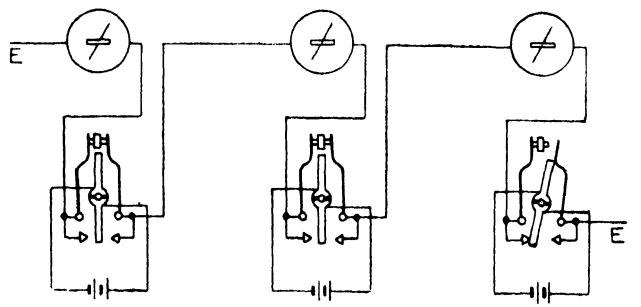


Fig. 83

normally is closed as shown in K at station B, and connects the battery to line, so that even when the circuit is idle the current is flowing. If A wishes to communicate with B this switch is pushed aside, the current ceases to flow, the circuit is

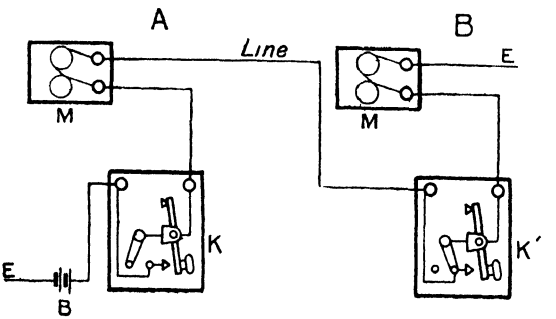


Fig. 84

open, and A works as in the open-circuit system, closing the switch when he has done working. If B wishes to communicate with A he also opens the switch; but when he depresses his key he does so simply to complete the circuit for A's battery, and therefore he works the circuit by means of that battery. A large number of intermediate stations can be inserted on such a circuit, and it is evident that if they all keep their switches closed the current flows throughout the whole circuit; and any

station, by opening his switch, can break in and operate every instrument upon the circuit by opening and closing the circuit of the one battery fixed at one of the terminal stations.

Closed-circuit working is very generally adopted in Australia and other colonies, as well as in America. It is also much used in Germany, where some circuits have as many as fourteen stations upon them. As, however, owing to leakage, the current from a battery at one end of a long circuit becomes gradually weaker according to the distance of the different stations, each station is sometimes provided with a part of the battery, which forms part of the circuit. This is shown in skeleton form in fig. 85.

There is another mode of working a closed circuit, which was originally introduced in America, has been used on the

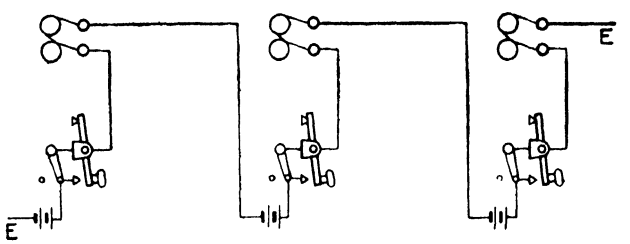


Fig. 85

Hanoverian lines, and is now applied to the State Railways of India. Instead of breaking the closed circuit by a switch, and converting it really into an open circuit with the key worked at any point, the instruments are caused to work by the interruption of the current. Relays are used which are held in their normal position of rest by the current, and which are caused to complete the local circuit by the interruption or cessation of the current. It is not much used.

There can be no doubt that where many intermediate stations are fixed on one wire worked on the Morse principle, the closed-circuit system offers considerable advantages over the open-circuit system ; for the inconveniences arising from the difficulty in maintaining the accurate adjustment of the apparatus, when receiving from different stations at different distances, owing to the variations in the current, are to a considerable extent avoided. The current at the same station is constant.

The introduction of the Vyle polarised sounder has modified

the practice of open-circuit working very considerably. This sounder being so much more sensitive than the ordinary sounder the electromotive force required for a definite length of line can be greatly reduced. The British Post Office now find it economical to use these instruments—direct working—over distances up to 400 miles, as, for instance, between London and Glasgow.

In addition to this, this form of sounder is employed on omnibus circuits with condensers and one central battery constituting practically a closed-circuit system, with the great advantage that current is only consumed when the line is operated.

The battery is situated at one of the terminal stations. A resistance known as the feed resistance (F, fig. 85A) is inserted

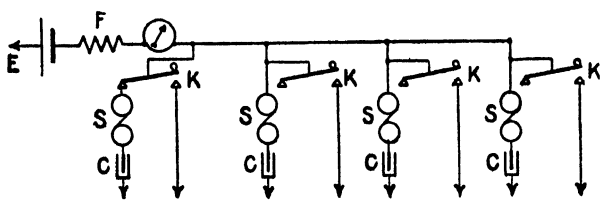


FIG. 85A

between the battery and the first set of apparatus. Each station is equipped with the usual galvanometer, a key (K), a sounder (S) and a condenser (C). The sounder and condenser are in series, the other terminal of the sounder being connected to the back stop or to the bridge of the key, the second terminal of the condenser to earth. The front stop of the key is also to earth. The stations are all in bridge, and the line is connected through the galvanometer to the bridge of the key. Thus normally the battery maintains a charge in the condensers. When any key is depressed, the condensers all discharge through the sounders, the line, and the depressed key to earth. When the key is raised, a charging current flows out from the battery through the sounders to the condensers.

According to the latest British Post Office practice, the feed resistance is 1000ω non-inductive, the condensers have 4 microfarad capacity, the sounders are 2000 ohms with a neutral adjustment, the negative pole of the battery is connected to line, and the voltage is kept as low as possible; 80 volts

is the most usual voltage, but 60, 40, or even 30 are often used. On a line of considerable length in which a comparatively high resistance conductor is used, it may be desirable to insert resistance in the local connections in each office so that the signals at all the stations may be practically of the same strength.

A drawback to the use of this form of circuit arises in small local stations where one set of apparatus only is necessary but where through lines are led in for testing purposes. When testing it is of great advantage to be able to insert this local set in a through line in order to communicate with the head testing office. But if the local set is for omnibus central battery circuit working, such an arrangement is impossible. Therefore a special set of apparatus with batteries would be required in the local station, and thus all the advantage of central battery working is lost.

When any length of gutta-percha covered wire, either in a submarine cable or in underground pipes; forms part of a circuit it tends to diminish the speed of working by accumulating upon the surface of the wire in virtue of its electrostatic capacity (p. 106), a portion of the current which otherwise would proceed to the distant station to record or register its marks. A similar effect, but on a smaller scale, occurs on overground wires. When, however, such lines are very long, the effect of this *electrostatic capacity*, as it is called, becomes evident. To overcome this distortion of the signals, more deliberate sending is necessary. The key must be held down longer to allow a dot to be made, for the short and smart dots made upon a short aerial line are entirely lost on an underground, a submarine, or a long overground circuit. This loss of speed is to a large extent remedied by *double-current* working. A second current, reverse in direction to the first current, and sent immediately after it, not only hastens the discharge or the clearance of the wire of the charge accumulated upon it, but it enables the relays to be worked in their most sensitive and, therefore, their most rapid position. This method of working is shown by fig. 86. G is the galvanometer, K the key, R the relay, S the sounder, and B the battery. The level *l* of the key consists of two brass pieces rigidly fixed together, but insulated from each other by a strip of ebonite. At the back of the key (as shown in fig. 113) each brass piece plays between two contact springs. The function

of the switch x shown at the lower part of the key is to connect the battery or the receiving instruments to line at will. In the diagram the switch is shown in the sending position, and it will be seen that the negative pole of the battery is joined to the down line and the positive pole to the up line. If the key be depressed, the back end makes contact with the upper springs and the battery connections are reversed. When, therefore, it is desired to send, the switch is placed in the position shown; and while the key is at rest the current sent out will pass through

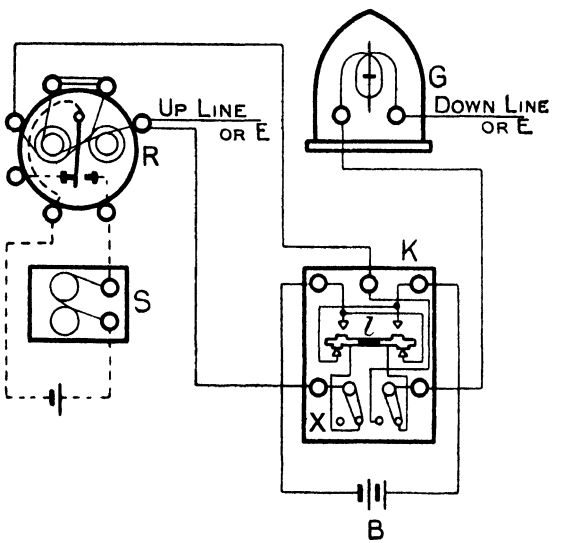


Fig. 86

the relay at the distant station and hold the tongue away from its contact point. Hence all antagonistic springs or other forces may be dispensed with, and the relay kept in the most sensitive condition for responding to any change in the current. When the key is depressed this current ceases, and a reverse current is sent to the line, which moves the tongue of the relay in the proper direction, and 'marks' are made.[1] Thus there is always a current flowing when the switch is turned for sending, and it is the reversal of this current which works the apparatus. It will be seen that when the switch is turned to receive, the line is joined through the key to the relay.

The double-current system of working not only expedites

[1] These currents are termed 'the marking' and 'the spacing' currents.

the rate of working on submarine, subterranean, and long overground circuits, but it frequently enables the working of the circuits to be continued in the face of considerable interferences and disturbances inherent to overground wires. It destroys in relays all the effects of residual magnetism ; it allows circuits to be worked with less powerful currents because the relay tongues may be adjusted to their most sensitive position, and consequently it enables them to be worked to much greater distances.

It is objected to this system of working that messages once commenced cannot be interrupted for corrections or inquiry, but general experience shows that the objection is only theoretical.

The difficulties of adjustment inherent to open-circuit working with single currents, owing to the variations in the strength of the currents received from different stations, are entirely overcome in double-current working: for whatever be the variations in the prime current the reversing current is equally and similarly affected, and thus the moving force and the antagonistic force vary together and are self-adjusting. Double-current working is generally adopted on ordinary Morse and Sounder circuits having intermediate stations upon them, or which exceed twenty-five miles in length.

We have seen that in the closed-circuit system one battery may be made to work all the stations on one circuit ; but there is another plan, by means of which it is possible with one battery to transmit on several circuits from one station, each circuit being independent of the others. This is known as the *universal battery* system. If several equal resistances be joined across the poles of a battery of comparatively low resistance, a current of equal strength will flow in each, and this current will be practically equal to the current which would flow through one of the resistances if it alone were in the circuit. This fact is the basis of the universal battery system. Several circuits (usually not more than five, unless secondary cells are used), whose resistances do not vary more than 25 per cent. between the highest and lowest, are grouped on one battery, one pole of which is connected to earth. If any circuit which is to be placed in a group is below the required resistance, then an equalising resistance coil is joined in the battery lead of that circuit.

It is necessary for satisfactory working that the resistance

of the battery shall be less than one-half of the joint resistance[1] of the several circuits worked from it.

It is clear that for this system the battery must not be worked double current as, if one circuit were sending a positive current and another were simultaneously sending a negative current, *both* poles of the battery would be to earth, that is, the battery would be short-circuited. For double-current working, therefore, two batteries with opposite poles to earth are required, and a single-current key provided with a switch is sufficient for sending. Fig. 102, p. 113, shows the actual connections of a double-current circuit on the universal battery system arranged for either simplex or duplex working. Similarly, single-needle circuits require a double battery, and the commutators also need slight alteration. Accumulators, owing to their low resistance and the ease with which they can be kept at a normal electromotive force, are peculiarly suitable for universal work. Almost any number of circuits can be supplied with current from one set of cells.

The electromotive force required to record the signals with the different forms of instrument used and on circuits of various lengths is a very important matter. It depends upon so many conditions of climate, country, size and age of wire, character of insulation, &c., that no definite rule can be laid down. The unit current is called the *ampère*, but for telegraph purposes we consider only the thousandth part of this, or the *milliampère*,[2] and the currents which are provided for the different instruments will be seen from the following table:

Needle	15 milliampères.
Vyle Sounder	10 ,,
Ink-writer	20 ,,
Sounder	35 ,,
Relays	15 ,,

Therefore the electromotive force must be regulated to give the strength of current indicated above. Now, one Daniell cell through one thousand ohms (1000ω) gives approximately one milliampère. For instance: a line 16 miles long, giving a resistance of 25ω per mile and having one intermediate station, is to be fitted with single-needle apparatus (resistance 200ω

[1] See Appendix, Section C. [2] See Appendix, Section B.

each), and worked by Daniell batteries ; how many cells will be required ? Here the total resistance in circuit is 1000ω, consequently the current given by 1 cell will be 1 milliampère ; but the instruments require 15 milliampères ; therefore, theoreti-

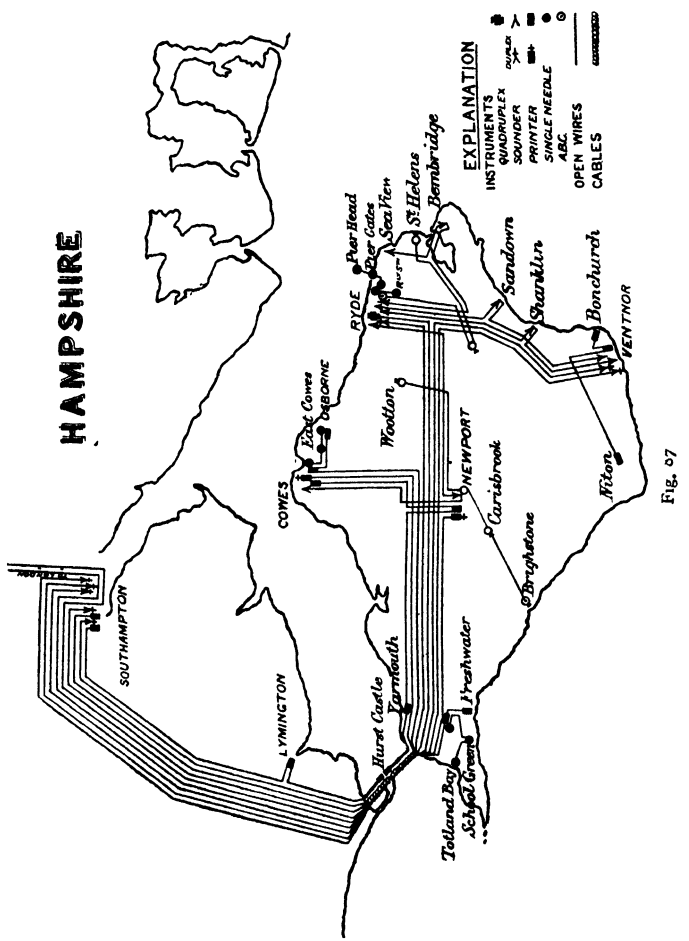


Fig. 07

cally, 15 cells will be required at each office. Twenty cells, however, would be fixed, to allow for leakage along the line in wet weather and for the internal resistance and the deterioration of the battery.

We can scarcely conclude this brief description of the mode of joining up instruments in circuit without referring to the

circuit arrangements required to serve a portion of the country. We will take the Isle of Wight. The diagram (fig. 87) shows how all the villages and towns used to be connected together, and with their great centres of communication, Southampton and London. It illustrates also the way in which the different instruments were employed. Thus little places like Brighstone, Carisbrook, St. Helens, which being mere sub-offices under larger head post-offices, Newport and Ryde, were amply served by the A B C. East Cowes, Totland Bay, School Green, communicated with their head offices by means of Needle circuits, because the amount of work did not justify the employment of a trained telegraphist. On the contrary, the traffic between Southampton and Osborne, Ventnor, Ryde, Newport, and Cowes, justified the employment of skilled operators, and they were served by Morse circuits; and the amount of business done at Ventnor and Ryde was such as to require communication with London as well as with Southampton. In some cases, as at Ryde, the business with London was such that only quadruplex (see Chapter VIII.) would meet it, and even this was sometimes insufficient, and additional facilities had to be afforded.

A direct wire, with only the terminal offices upon it, and fitted with Sounders, is the most perfect hand-worked telegraph arrangement we can devise. The insertion of intermediate stations at once reduces its efficiency, principally by blocking the wire with local messages. But even a direct wire must, where possible, be supplemented by a second means of communication in case of failure or accident. Thus Ryde has a sounder duplex circuit to Southampton which, in case of need, could be joined through to London. Telegraph circuits, even when of the simplest and most perfect character, are singularly liable to failure from causes which will be described; and occasionally periods of pressure arise from political, special, and local causes, such as elections, races, assizes, &c. It is imperative that a well-organised system shall be prepared for such emergencies.

CHAPTER VI

DUPLEX TELEGRAPHY

THE rapid increase in the business of telegraphy has called forth the exercise of the ingenuity of telegraph engineers to increase the capacity of a single wire for the transmission of messages. Duplex telegraphy is one way by which this has been effected. By this system messages can be sent on one line *in both directions at the same time*, thus practically doubling the carrying capacity of the wire, because station A can transmit a message to station B, while B is sending another message to A. Under ordinary circumstances, when A is working to B on the open-circuit principle (fig. 80) any interference on the part of B disconnects his receiving instrument and so prevents A's signals from being recorded. If now it can be arranged that the receiving instruments at both stations can be always in circuit, yet affected only by the currents sent from their own station when these currents interfere with the currents sent from the other station, then duplex telegraphy becomes possible. There are several modes of doing this, but we shall confine ourselves to a description of two methods which are in practical use, and which may be designated respectively the *Differential* and the *Bridge* methods of duplex working.

1. *The Differential Principle*

If two circuits of precisely equal resistance be open to a current, it will divide itself equally between the two, and the currents in each wire will be exactly equal. If, for instance, the wire **z** *l* **E** (fig. 88) offers the same resistance as the wire **z** *r* **E**, the current in *l* will have precisely the same strength as the current in *r*.

Now let the electro-magnet M (fig. 89) be similarly wound with two wires of equal length, one of which is in connection with *l*, and the other in connection with *r*. If the current through *l* traverse the electro-magnet in the *reverse* direction to that through *r*, and if the currents be equal, it is evident that the polarity induced by the one current must be exactly neutralised by that induced by the other current, for the effects are equal and opposite, and there will be no magnetism excited. Thus, as long as the two circuits are intact the currents which flow will not affect the electro-magnet; but if the currents in *r* be interrupted, those in *l* will excite the electro-magnet, and if those in *l* be interrupted, the currents in *r* will excite the electro-magnet.

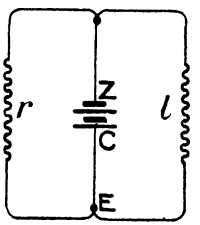


Fig. 88

Assume A and B (fig. 89) to be two stations connected together by the line wire *l*. Let M be an electro-magnet at A, wound as just described, and M′ a similar one at B; K a key,

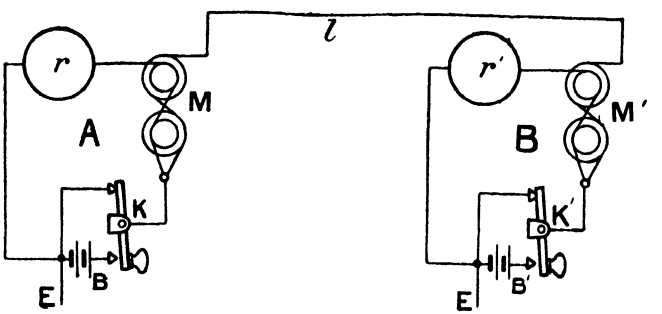


Fig. 89

and B a battery. Let *r* and *r′* represent resistance coils or *artificial lines*, each giving a resistance equal to the line circuit. Now let us in the first place assume A alone to be working to B; every time the key K at A is depressed a current is sent from A's battery. This current divides at M, the one half going through the coil in connection with *l* in M, through *l*, and at B, through the coil in connection with *l* in M′, through the key K′ at B to earth and thence back to the battery. This is called the *line current*. The other half, which is called the *compensation current*, passes around the electro-magnet M through the coil in connection with

r, through *r* and back to the battery. As these two currents are equal, their effect on M is *nil*, but the line current passing through one coil only of M′ operates it and causes signals to be given. Thus while A telegraphs to B its own instrument is not affected, but that at B is actuated. Similarly, when B alone is working to A its own instrument is not affected, but that at A is actuated. But when B is working to A at the same time that A is working to B, what happens? Every line current that leaves A at the same time that a line current leaves B is neutralised. The compensation current at A is now able to excite the electro-magnet, and the armature is moved *in precisely the same way as if* B's *currents were received.* In the same way B's line currents are neutralised, and its compensation currents move the armature of M′ in precisely the same way as if A's currents were received. Thus M and M′ continue to be worked by their respective stations, regardless of the fact that the line currents are being continually neutralised so that practically no current flows between A and B, and that they are operated sometimes by the line current and sometimes by the compensation current. Thus, while A sends messages to B, B can be sending messages to A upon the same wire and at the same time.

We assumed that the line current received at A from B was exactly equal to that proceeding from A to B, and that therefore they were exactly neutralised, but it is not so in practice, for owing to the effects of bad insulation the incoming line current is always weaker than the outgoing one. Hence the current received at A from B does not neutralise the whole of the current sent from A to B, but only a portion of it. It so weakens A's current to line that the compensation current preponderates over this resultant current, and the signals are registered by the preponderance. The *difference* in the strength of these two currents when both stations are working is very nearly equal to the strength of the current received at A when B alone works, so that the marks, whether made by the received line current or by the preponderating compensation current, are practically the same.

We have shown in the diagram that the same poles of the batteries are connected to line, and that therefore the line currents flow in opposite directions; but the same effects occur if the opposite poles are to line and the currents flow in the same direction. If the current from B flows in the same direction as that from A,

the effect when the two stations work simultaneously is not to weaken the resultant current but to strengthen it, and therefore to produce a preponderance of the current in coil *l* over that in coil *r* of relay M and consequently to register signals; but in this case the marks made at A when both stations are working simultaneously are not made by the preponderance of the compensation current over the line current, but by the excess of the resultant line current over the compensation current.

As shown in fig. 89, the keys K and K′ put the line to earth through the back contact, but there is an interval while the keys are being depressed when this connection is broken. In fact there are three positions which the key takes up during the operation of sending, viz., 1st, when resting upon the back contact; 2nd, when resting upon the front contact; 3rd, when disconnected from both contacts. The line circuit is not, however, in either case interrupted. The first and second cases are clear, but consider the third: take the key K (fig. 90) and depress it to the intermediate position; then the received current, when it arrives at the bridge of the key, instead of going to earth through the back contact stop, passes through the compensation coil of the electro-magnet and through the resistance R to earth. This continues the effect of the line current upon the electro-magnet; for though the resistance to the line current is twice as great and the current consequently reduced one-half, as it passes through *both* coils of the relay in the proper direction to actuate the armature, there is a double effect of a current of half strength, the influence of which is equal to the original current. In fact it is possible to dispense with the back contact altogether, but it introduces irregularities due to electro-magnetic inertia (p. 150), which tend to diminish accuracy and speed of working. For accurate duplex working the total resistance of the circuits should be disturbed as little as possible, so that even the portion of the circuit from the back contact of the key to the earth should be made equal in resistance to that of the battery by the insertion

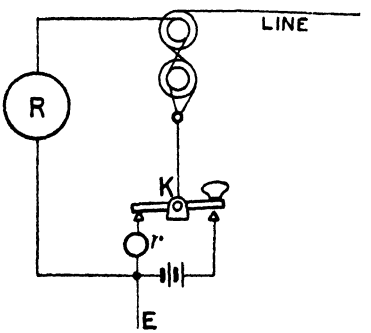


Fig. 90

of a resistance coil r; then the resistance is not altered whether the key is up or down. Theoretically the best form of key is one which does not break the back contact until the front contact is made.

This is the principle of the system which may be applied to any form of instrument, whether it be a direct ink-writer, a single needle, or a relay. As most circuits are worked with relays, we will illustrate such a system. This is done in simple form by fig. 91.

P is an ordinary polarised relay whose tongue moves between

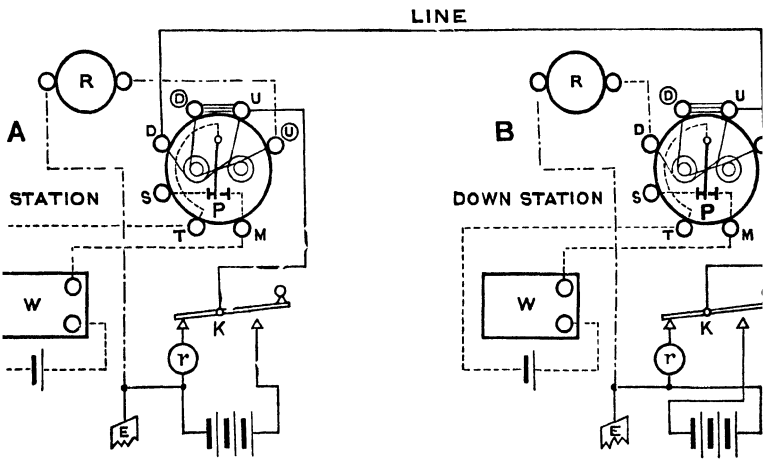


Fig. 91

the two points in connection with terminals S and M. Its normal position is against S. The line current moves it against M, and thus works the local circuit in which is placed the sounder or writer, W. Each bobbin of the electro-magnet is similarly wound with two wires of equal length and resistance, and the inner ends on one bobbin are then joined to the outer ends on the other, so that there are thus two circuits, each comprising one wire on both bobbins, and making an equal number of convolutions round the electro-magnet. The ends of the one wire are brought to the terminals D and U, and the ends of the other wire to the terminals (D) and (U). If now, while a current is traversing the circuit U to D in a direction to actuate the tongue, a second current of exactly equal strength is flowing

between (D) and (U) in the opposite direction, the effect on the tongue of the relay must be *nil*. The line wire at the Up Station is attached to terminal D, and the compensation wire to terminal (U). Terminals (D) and U are connected together by a brass strap and connected to the lever of the key K, which in its position of rest joins these two terminals to earth through the back contact. The other end of the line wire of course makes earth through the apparatus at the Down Station, which is similarly connected up, except that the line wire is attached to (U) and the compensation circuit to D.[1] The other extremity of the compensation circuit makes earth at E through the resistance coil R, which can be varied at will.

Now let the key at the Up Station be depressed ; a current flows and divides at (D) U, one portion passing through the coils of the relay from U to D and so out to the line, thence to earth at Down Station by way of the relay coil (U) (D), the key and the resistance coil *r*. This portion of the current tends to move the tongue of the Up Station relay against the stop M. The other portion passes through the compensation coil (D) (U) of the relay, through the resistance coils R, to earth at E, tending to hold the tongue of the relay against the stop S. If these two currents are of equal strength they will not influence the tongue of the relay, because they tend to move it with equal force in opposite directions. But if they be of unequal strength, then the tongue of the relay will be moved in the direction of the stronger current, and by a force equivalent to that of a current equal to the difference between the two currents. Let us at first insert in the adjustable resistance R, a resistance large compared with that of the line, then the current passing through the compensating circuit will be considerably less than that passing through the line circuit. Every time the key K is depressed the relay will work, and will cause signals to be made. By gradually decreasing the resistance in R the difference in strength between the two currents will be diminished, until at last a point is attained where their strength is equal, and where the tongue

[1] This reversal of the relay connections would not be necessary if the receiving instruments were not polarised. The connections might then be precisely alike at both stations, and the arrangement would work properly.

of the relay will be unaffected by the movement of the key. The artificial resistance R is now equal to that of the line circuit beyond terminal D.

The line currents which are received at the Up Station from the Down enter at terminal D, pass through the coil D U of the relay, and so to earth through the back contact of the key, moving the tongue against the stop M, and recording signals in the usual way. Now, it is evident that when A alone works to B, A's relay remains unaffected while B's relay records the signals sent from A. When, under similar circumstances B alone works to A, B's relay remains unaffected while A's relay records the signals sent by B. But when B works to A at the same time that A is working to B, the outgoing line current from each station is increased in strength by an amount equal to the strength of the incoming line current at each place; this, therefore, preponderates over the compensation current at each place to an extent precisely equal to the normal current received. Hence marks continue to be recorded with the same force and regularity when the stations work to each other simultaneously as when they work to each other separately and independently.

On p. 98 it was shown that in connection with the theoretical arrangement indicated by fig. 89 it is immaterial whether similar or opposite poles of the batteries at the two stations were to line; this, however, does not apply in the case of the receiving instruments which are *polarised*, as then one portion of the current—say that through the compensation circuit—tends to hold over the relay tongue to the 'spacing' or non-recording stop S, and therefore if the current from the other station reduced instead of augmenting the other current, no signal could be recorded; similarly, if it were the line circuit portion of the current which tended to hold the tongue to spacing, an increase of that current by the other station would not record signals. This consideration at once shows the possibility of duplex working on the double-current system; and in practice double-current duplex working is found to be so much superior to single current, that in England only the most unimportant duplexed circuits are worked single current.

There are certain irregularities in the working of such a system in actual practice which have to be provided against, due to variations in the resistance and in the electrostatic

capacity of the line. Telegraph wires, in fact, are in a constant state of change. If A and B be connected together by an aerial wire supported at intervals of about 80 yards upon earthenware insulators, then the current which arrives at B from A must necessarily be less than that which leaves A, because at each pole a small portion of the current escapes or leaks to earth. No earthenware support is an absolute insulator. Moisture is deposited upon its surface. The amount of this moisture continually varies, and the resistance of the insulator to the leakage of the current varies with it. Hence the difference between the current leaving A and that arriving at B is constantly varying, and the effect upon the current leaving A is precisely the same as though the resistance of the line varied. If moisture be abundant more current leaves A, and the effect at the sending end is the same as though the resistance of the line wire were reduced, but of course the increased current is not received at the other end. If the insulators become dry, less current leaves A, and the effect is the same as though the resistance of the line were increased. In fact, the resistance of the circuit does vary with the amount of moisture deposited on the insulators, and with the amount of dirt which necessarily adheres to them. Rain, fog, dew, and mist affect it. Lines exposed to the spray of the sea or the smoke of manufactories are peculiarly liable to this variation.

The resistance varies also with alterations in the physical condition of the mass of the wire due to heat. As the temperature of a metal increases or diminishes, so does its resistance. Iron wire increases in resistance 0·21 per cent. for each degree of temperature (Fahr.) through which it is raised. The diurnal variations of temperature in this climate are not great. In summer the greatest range is about 30°. This would practically not affect the comparatively short circuits used in England ; but in India and America, where the circuits are much longer, and the daily variation is much greater, considerable difference is observable in the resistance of the wire between midday and midnight.

The amount of variation also largely depends upon the character of the country through which the line passes. The resistance of some lines varies in bad weather as much as 50 per cent. in one day, but remains constant in fine weather. Short lines, as a rule, are little disturbed by variations of short duration, but long lines of 200 miles and upwards are subject

to constant variations due to atmospheric changes at different points. A thunderstorm here, a shower there, excessive radiation at one point, condensation at another—all tell their tale.

Other causes also introduce irregularities which interfere with the constancy of a line. The wires are constantly subject to accidents of various kinds, many of which tend to produce variable resistance.

Now what effect has this variation of the resistance of the line wire upon duplex working, and how is it provided for?

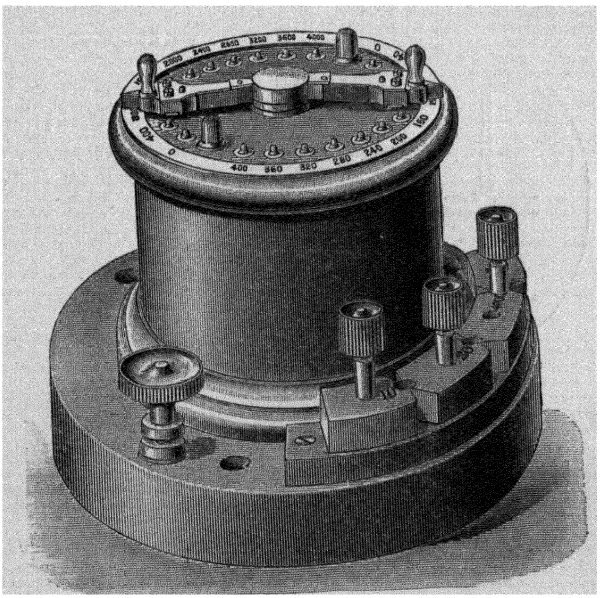


Fig. 92

Clearly it disturbs the equality of the line and compensating currents, and causes the one to preponderate over the other; and if no means were adopted to compensate for this variation duplex telegraphy would be impossible. The resistance, therefore, in the compensation circuit is not made a fixed quantity, but consists of a series of resistance coils by which the resistance of the compensation circuit can be varied in consonance with the variation of the line circuit. This instrument is called a *Rheostat.*

The rheostat shown in fig. 92 is a box of resistance coils, each coil being 'double wound' (as described on p. 320) so

as to eliminate the effects of self-induction, and the whole is so arranged that the resistance can be adjusted by the motion of the arms over the dial. The figures over which these move indicate the number of ohms resistance which will be inserted in the circuit according to the position of the handles. The arrangement is such that each handle can move over only one-half of the dial; the range of one being by gradations of 40 ohms from 0 to 400, and that of the other being by gradations of 400 ohms from 0 to 4000. Thus the maximum resistance which can be inserted in the circuit by these arms is 4400ω. But in addition to this a coil offering a resistance of 4000ω is placed in connection with a switch at the side of the main box, and this can be cut out of the circuit or inserted in it at will by means of a plug. Further, as the arms do not permit of a smaller variation than 40ω being made, two other coils of 10ω and 20ω are also included, so that the range of the rheostat is really from *nil* to 8430ω, by variations of 10ω.

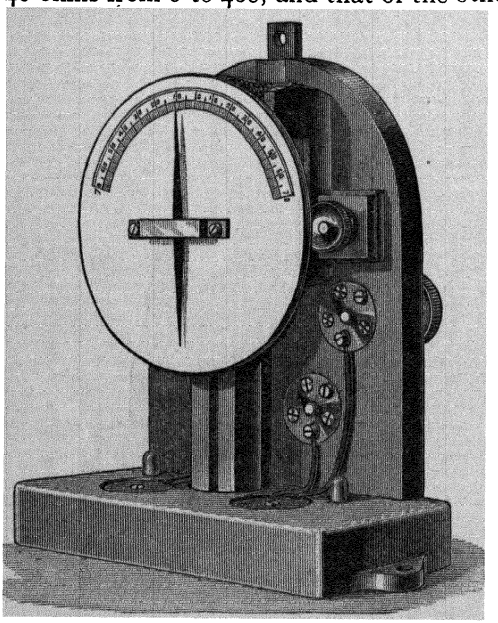


Fig. 93

What plan can be adopted for the adjustment of this compensation circuit? In the early days of duplex working the adjustment had to depend upon the actual sending and receiving of working signals; but the general introduction of *differential galvanometers* has had the effect of greatly facilitating the adjustment.

The most approved form of differential galvanometer (shown in fig. 93) is virtually an induced single-needle coil of Varley's

pattern, but with each coil wound with two wires of precisely the same length, and joined up to form two independent circuits in the same way as the coils of the relay (as described at p. 100). If a current be sent through either of these circuits the needle will deflect to right or left, according to the direction of the current; and therefore if equal and opposite currents be sent through the two circuits no deflection at all will take place. If the currents are not of equal strength, then the stronger will be partially effective to produce a deflection to the extent of its excess. Such a galvanometer, then, is fitted at each end of a duplex circuit, one coil being in the line circuit and one in the compensation circuit. The needle is to show any *difference* of current flowing in the two circuits. Now, the sending of a current from (say) station A should vary the current in both circuits of A's galvanometer equally—that is, A's sending should not cause any variation of the difference between the currents in the line and compensation circuits. Hence, if when the key at A is manipulated the position of the needle changes, then the resistance of the rheostat must be increased or decreased until no much change takes place. In double-current working there is always a current—either positive or negative—being received from the other station, and consequently there is always a deflection on the galvanometer. Assuming that A is balancing, and that B is sending the ordinary 'spacing' current, then, if when A's key is depressed—that is, when A sends a 'marking' current—the deflection is increased, it shows that A's previous spacing current was stronger in the compensation circuit than in the line circuit, and the rheostat resistance should therefore be increased; if, on the other hand, depressing the key decreases the deflection, then the resistance in the rheostat should be decreased. The deflection should be steady when the key is alternately depressed and released. Thus can the varying resistance of the line be provided for in the compensation circuit.

When a quantity of electricity flows through a line in the form of a current, the first portion of the current is retained or accumulated upon the surface of the wire, in the same way that a charge is retained or accumulated upon the surface of a Leyden jar.[1] The quantity accumulated depends (1) upon the length and diameter of the wire, (2) upon its distance from the

[1] See Appendix, Section F, Condensers.

earth and earth-connected bodies, (3) upon the insulating medium surrounding the conductor. Thus, in the case of a submarine cable, the conductor of which is insulated with gutta-percha or india-rubber, and is maintained in very close proximity to the earth, a very considerable charge is held by the wire. An over-ground wire is insulated in air, and though it is maintained at a considerable distance from the earth, yet it is in close proximity to other wires, or to buildings or trees which are in connection with the earth, and it also retains a charge. In fact it is found, in England, that the charge retained by twenty miles of ordinary line wire is about equal to that retained by one mile of a cable of average dimensions. The power of retaining a charge is called the *electrostatic capacity* of the circuit.

Now what are the effects of this electrostatic capacity? In the first place, it absorbs all the electricity of a short momentary current and prevents the appearance of any current at the distant station. And as it absorbs the first portion of every current sent, it has the same effect as if it *retarded* or delayed the first appearance of the current at the distant end. Thus the apparent velocity of the current is diminished more or less in proportion to the capacity of the circuit. In a circuit of very low capacity the current appears practically instantaneously at the distant end; but on a long or a submarine circuit there is sure to be considerable capacity and consequent retardation. Thus between Europe and America, on an Atlantic cable, the current is retarded four-tenths of a second.

In the second place, when a current has been sent through the circuit, the whole of this charge upon the wire must either be withdrawn or neutralised before a second charge of opposite sign can be accumulated upon it. This discharge may occur as a current flowing out at each end to earth, in which case one part of the current—called the *return current*—flows back to the sending station, and the other flows out at the receiving station so *prolonging* the primary current. If one end of the wire, say the sending end, be disconnected, all the charge flows out at the distant end and the prolongation of the current is increased. Again, the charge may be neutralised by a reverse current, which may be sent from the receiving as well as the sending end.

Thus it is seen that the effect of electrostatic capacity is to produce *retardation* at the commencement of a current and *prolongation* at the end.

Again, the electrostatic capacity of a line is unequally distributed, and its working conditions are naturally affected by this distribution. A circuit may be made up of overground wires, underground wires and cables. Since cables have the largest capacity, it is their position which most materially influences the working.

We see then that the working condition of a line is dependent not only upon its quality of resistance but that this other quality of electrostatic capacity must also be considered; and, for duplex working to be satisfactory, the compensation circuit must be arranged to represent the electrostatic or inductive condition of the line as well as that of its electrical resistance. The electrostatic capacity can be represented by a *Condenser*.

'Condenser' is a term applied to an apparatus composed of alternate layers of tinfoil and paraffined paper (or mica) so arranged as to form a flat Leyden jar of large surface, and constructed so as to give any capacity that may be required within a certain range. a, a_1, a_2, b, b_1, b_2 (fig. 94) are square pieces of tinfoil separated by sheets of thin paper steeped in melted paraffin wax. The series a, a_1, a_2, are connected together, and so are the series b, b_1, b_2. A and B thus become connected with what may be regarded as the inside and outside coatings of a Leyden jar; and by putting one pole of a battery to A, and the other pole to B, we can communicate a charge to the plates the quantity of which will depend (1) directly upon the electromotive force of the cells used, (2) directly upon the total surface of each series of conducting plates opposed to each other, (3) inversely as the distance between each pair of plates, and (4) upon the nature of the insulating material used to separate the conducting plates. Insulating material so used is commonly known as a *dielectric*.[1] Thus we can construct condensers of any capacity, giving a charge varying from that accumulated upon a short length

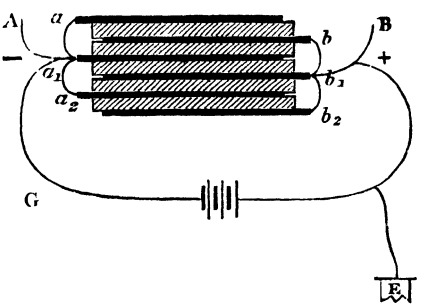


Fig. 94

[1] For further details as to Condensers, see Appendix, Section F.

of overground wire up to that accumulated upon an Atlantic cable. The unit, or standard of reference by which capacity is known, is called the *microfarad*, and it is equivalent to the charge retained by about three miles of cable (see p. 8).

Condensers are conventionally represented by parallel lines as shown in fig. 95, A and B being opposite plates. If a galvanometer be joined in circuit with the battery, say at G (fig. 94), and the battery (with galvanometer) be connected to A and B as shown, there will be a momentary deflection of the galvanometer needle in one direction to an extent dependent upon the capacity of the condenser and the electromotive force of the battery; and if then the battery be cut out of the circuit, there will be an equal (or nearly equal) deflection on the galvanometer in the other direction. These two deflections represent the *charge* and *discharge* of the condenser.

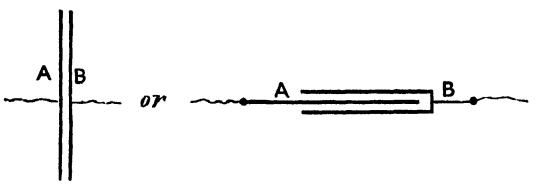


Fig. 95

It will be seen that this charge and discharge are precisely analogous to the electrostatic condition of a telegraph line which has been described. If the line between A and B (fig. 89) has electrostatic capacity and A is working to B alone, the return current will flow back through M and record signals; but if there be inserted in the compensation circuit a condenser whose capacity is such as exactly to represent the electrostatic condition of the line; then A's initial current will charge both the line and the condenser, and the return current from the line passing through one wire of the electro-magnet will be opposed by a precisely similar discharge current from the compensation condenser through the other wire, and so the effects of the electrostatic capacity will be eliminated.

But the discharge due to the electrostatic capacity of the line varies. It is greater in dry weather than in wet. The condensers used are, therefore, made adjustable to permit of compensation for this variation, in the same way as the resistance coils of the compensation circuit; and since, as was pointed

out on p. 106, the capacity of a line may be unequally distributed, the condensers are commonly made in two or more distinct sections, so that they may be inserted at more or less corresponding points of the compensation circuit.

A condenser with two sections is shown in fig. 96. In one

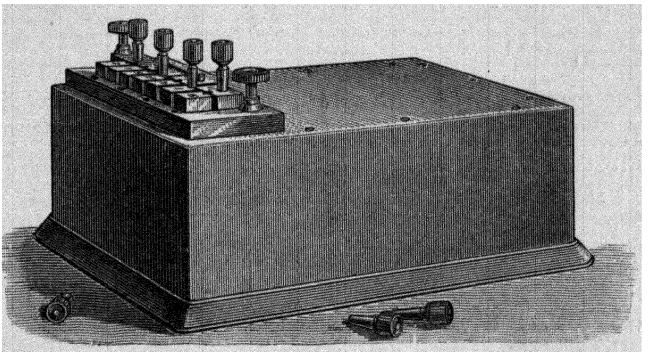


Fig. 96

section the total capacity is 3·75 microfarads, adjustable by gradations of 0·25, while the capacity of the second section is 3·5 microfarads, adjustable by gradations of 0·5. It may be observed that, whereas in resistance coils the resistance is

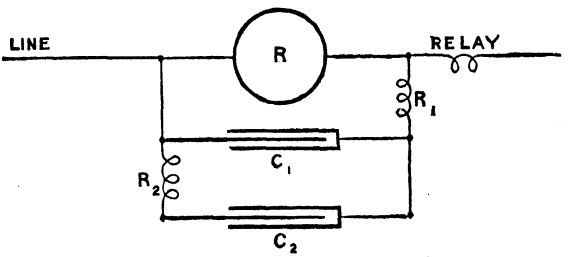


Fig. 97

usually inserted by *removing* the pegs, the capacity of condensers is inserted by *inserting* the pegs.

The method of applying condensers in the compensation circuit is shown by a theoretical diagram in fig. 97. In this arrangement the current in passing to earth through the compensation resistance (rheostat) R charges the condenser C_1 to an extent which can be regulated by the adjustable resistance R_1[1]; and C_2 is also charged to a degree which is still further modified by the

[1] Usually called 'retardation coil.'

resistance (sometimes adjustable) R_2.[1] The discharge from C_1 then takes place through R_1, while that from C_2 has to pass through the additional resistance R_2. Thus C_2 really represents the capacity of the further sections of the line. It should be noticed that the discharge has two paths, one through R and the other through the relay, and it is only that portion which takes the latter course that has an influence on the balance.

The compensation for capacity may be adjusted by aid of the differential galvanometer, but as a rule it is found better to adjust by the passage of working signals. If the adjustment be not right a dot will be formed at the sending station, when the key is depressed if the capacity of the condenser be not large enough, and when the key is raised if it be too large. Received signals also are broken when the key is working, while they are unaffected when the key is at rest. If a marking current be sent from the distant station an unbroken line or signal will appear when the key is worked if the adjustment be right, but if it be wrong the signal will be broken.

The effects of electro-magnetic inertia at the sending office do not introduce any irregularity in the working of the differential system. They tend only to reduce speed of working. The effects of one wire are exactly compensated by those of the other wire, so that no disturbance of signals results.

In practical telegraphy it generally happens that, although the requirements of business in connection with a circuit demand the application of duplex apparatus, it is not always necessary to work it as duplex ; and it occasionally happens that from line variations, &c., duplex working proves temporarily impracticable. In such cases it is desirable to have a means of reverting to ordinary single working, still using the same apparatus. This is provided for by a switch so arranged that when in one position the connections of the apparatus are right for ' duplex,' but when the handle of the switch is turned the connections are so altered as to be suitable for ' single ' or ' simplex ' working.

The full connections of such a set of apparatus for one station are shown in fig. 98, where, besides the switch, R represents the rheostat ; R_1 the retardation coil ; C the condenser ; G the differential galvanometer ; P the relay ; S the sounder, worked by the local circuit of the relay ; and K the double-current key.

[1] Usually called ' condenser coil.'

The switch has six terminals, and the connections in the respective positions ' duplex ' and ' single ' are shown in fig. 99.

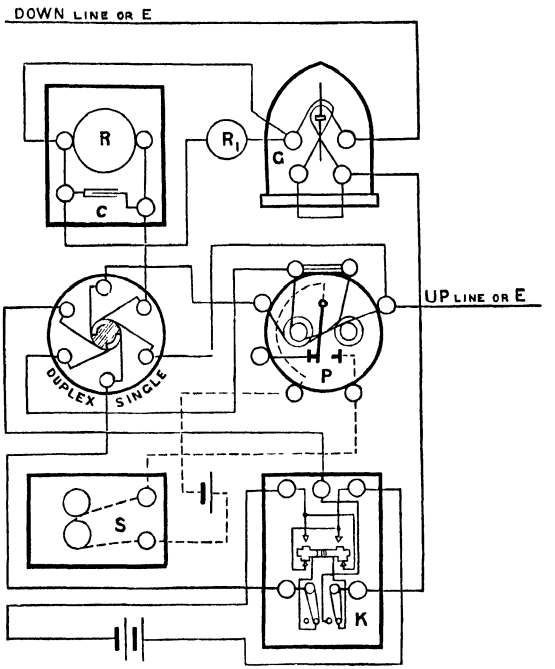


Fig. 98

It will be noticed that the centre line of the lever in each position crosses between the two pairs of terminals connected.

It will be remembered that a switch is used in connection

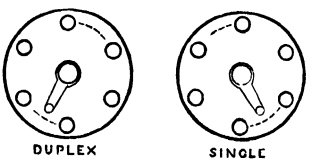


Fig. 99

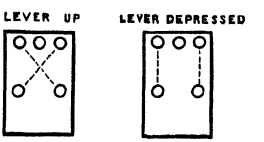


Fig. 100

with the double-current key, having one position to ' send ' and another to ' receive.' This is shown on the key in fig. 98. For duplex working the switch must, of course, be set permanently to ' send,' in which case the connections of the key when the lever is up and when it is depressed are shown in fig. 100. When the switch is turned to ' receive,' the centre terminal at the back

is joined to the front right-hand terminal and the other terminals are disconnected.

On analysing fig. 98, the fact will be noticed that there are two paths for the current to take not only at the relay, but also at the galvanometer. Fig. 101 is a diagram in which the connections for duplex only are shown in a similar simple manner to those of fig 91. From an inspection of this figure, in which only a conventional arrangement of 'double current' is indicated, it will be clear by tracing the current from the centre of the double battery shown (one-half only of which is in use in either position of the key), that it passes in reverse direction through the two coils of the relay; one part goes through the rheostat and one coil of the galvanometer back to the other pole of the battery, while the other part goes to earth. It may then be assumed to traverse the earth to the other station, enter the line, and so back through the line coil of the galvanometer (in the reverse direction from that of the compensation circuit portion) to the battery. Hence the 'double split,' as it is called, does not affect the working.

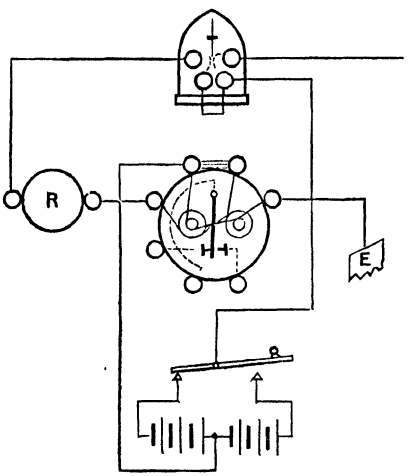


Fig. 101

Fig. 98 shows 'down line or E' and 'up line or E.' This signifies that if the apparatus is fixed at an 'up' station the former connection is taken as line and the latter as earth; while the reverse, without any further change, is correct for the other end or the 'down' station. With the single split system of connections, the adoption of this principle would make the instruments at one end of the circuit double split.

'Up' and 'down' are useful conventional terms which are adopted to prevent confusion in connecting up polarised instruments.

Fig. 102 shows the up station connections of a set of apparatus for double-current working on the universal system, the function

of the switch (see p. 111) being to change the connections so that simplex or duplex working may be resorted to at will. The only special piece of apparatus used is the key.[1] This is of the single-current pattern, provided with a switch by means of which the line may be disconnected from the lever of the key and joined through to the relay. The back contact is joined to one pole of the battery and the front contact to the other, hence when one is joined to line the other is disconnected. If a short circuit occurred in any one set joined up on this principle, all the other sets connected to the same battery would be left without current; furthermore, since the internal resistance of the battery is very low indeed, an abnormally strong current would flow through the short circuit and cause damage by the heat generated. To provide against interruptions consequent upon such a fault, a fuse-wire is placed in each battery lead, so that in the event of the current strength exceeding one ampère the fuse melts and disconnects the faulty set from the battery. As a further precaution against short-circuiting during adjustment of the key, the adjustable contact screw is made of such length that the back and front contacts cannot be connected together through the lever.

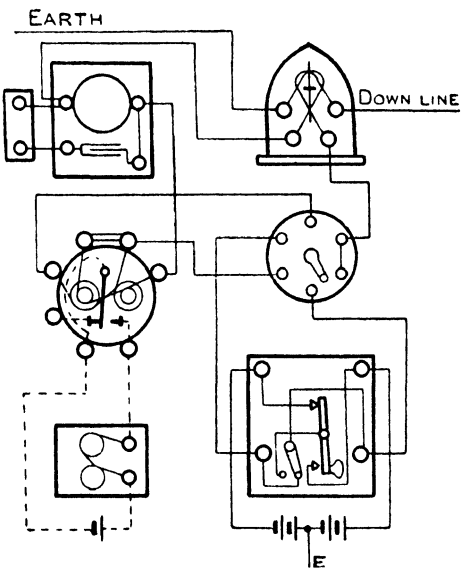


Fig 102

It will be noticed that the arrangement is what is known in practice as the 'single split,' for when the switch is set to 'duplex' the current divides only at the split of the galvanometer. At a 'down' station fitted with a similar set of apparatus the battery connections and the relay connections must be reversed.

[1] Usually called 'Key S.C. with switch.'

2. *The Bridge Method*

We have entered so fully into the working of the differential system, that little remains to be said on the bridge method. The differential principle is dependent on producing an *equality of currents*, whereas the bridge principle depends on producing an *equality of potentials*. Fig. 103 shows the arrangement at two stations A and B. C C′ is the line wire, R is the rheostat, whose resistance is equal to line. *a* C and *a c* are two artificial resistances equal to each other. The key K is connected up with the battery in the usual way. The relay P is fixed between C and *c*. The recorder or sounder, which is worked in the ordinary way by the relay, is for the sake of simplicity not shown in the figure. The apparatus at B is precisely the same as that at A. When A

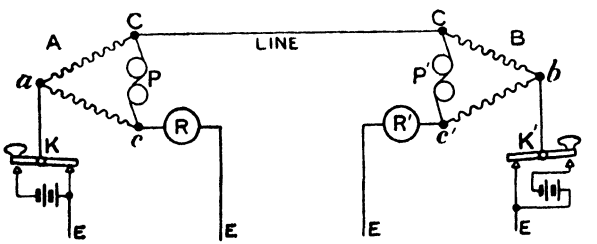


Fig. 103

depresses his key K a current is sent, and this current splits at *a* ; one portion passes through the line wire to B, making earth through the apparatus at that station, and the other passes through the rheostat R to earth at A. These two currents are equal because the resistances of the two circuits from *a* are equal, and as the points C and *c* are electrically equidistant from *a* their potentials are the same, and therefore no current can pass between them. Hence the relay P is not affected when A alone is sending to B. The same exactly occurs at B when it alone is working to A, so that we are able to send currents to a distant station without affecting our own apparatus.

The apparatus at B duly registers the marks when A is sending, for the line current on reaching C′ has two paths open to it—the one through C′ *c*′, the other through C′ *b*. That through C′ *c*′ works the relay, and causes signals to be recorded. The strength of this current will depend upon the relative resistances of the two circuits C′ *b* through key to E, and C′ *c*′

to earth through the combined resistance of *c′ b* and R′. We have assumed the branches C′ *b*, *c′ b* to be equal in resistance to each other, but it is not necessary for these resistances to be equal; they may bear any ratio to each other provided the same ratio is maintained between the resistance in R′ and that of the line circuit. By making the resistance of *c′ b* small compared with C′ *b*, we obviously increase the strength of current passing through C′ *c′*. If we make the resistance of *c′ b nil*, nearly the whole of the current will pass through C′ *c′* if only the resistance of C′ *c′* is small compared with that of C′ *b*; or again, if the resistance of the branch R′ be made *nil*, nearly the whole of the current will pass through C′ *c′*. But in either of these cases duplex working would be impossible, for the balance of potentials which is necessary for it depends upon the ratio of the resistance in *c′ b* to that of R′ being the same as the ratio between the resistance in C′ *b* to that of the line circuit. To maintain duplex working we must establish a balance; that is to say, we must keep the potentials at the points C′ and *c′* equal when B is working to A; hence as we vary the resistance in *c′ b*, we must likewise vary that of R′ in the same proportion if the ratio of C′ *b* to the line remains constant.

But the effect which the reduction of the combined resistances in *c′ b* and R′ has upon the outgoing current, that is, the current which B sends to A, must not be overlooked. The smaller this resistance is made the smaller is the amount of current which will pass along the line to A, as the greater portion will take the circuit *b c′* E. A similar result would of course follow at A if the same thing were done there. Hence it is evident that the resistance of all the branches must bear a given ratio to each other in order to produce the maximum effect upon the relay at each station, and that this ratio will vary with every circuit of different resistance. Generally it may be said that the smaller the internal resistance of the battery the more we can afford to reduce the resistance of the branches *b c′* and R′, and therefore the greater will be the proportion of the current passing through the relay in C′ *c′*; and the larger we can make the resistance of C′ *b*, compared with that of C′ *c′*, the greater will be the difference of potential between C′ and *c′*, and, consequently, the stronger the current passing through the relay.

The best practical results are obtained when the resistance of *c′ b* is half that of C′ *b*—the latter being about half that of

the line. The resistance of the battery should be made as small as possible, and therefore large-sized cells should be used.

The balance may be adjusted by altering the branch *c' b* or R', or by varying both together by means of what is called a *slide*, but in practice it is found better and simpler to alter only that of R'.

It will thus be seen that when A is working to B alone or B is working to A alone, the apparatus at the sending station is not affected, and marks are duly recorded at B or A, as the case may be. When A is sending to B at the same time as B is sending to A, with the resistance in the various branches at A and B duly proportioned, the equality of the potentials at the points C *c* and at the points C' *c'* is disturbed; they vary, currents therefore pass, and these currents are in the same direction and of the same strength as the ordinary currents when one station alone is working. For, looking first at station B when K' is depressed, the potentials at C' and *c'* are equal; but K having also been depressed, a certain portion of the reverse current from A reaches C'; the potential of C' is therefore altered with regard to that of *c'*, and a current flows through C' *c'*, whose strength depends upon this difference of potential, and is manifestly the same as when K' is at rest and no current is flowing from B's battery. Exactly the same reasoning will apply to A, and thus we see that while A is sending messages to B, B can also simultaneously send messages to A upon the same wire.

The chief point of this method which characterises it from that already described is that *it is independent of the character of the apparatus* used for receiving messages. It will work as well with the delicate mirror apparatus as with the roughest Morse recorder: by means of this arrangement the simple Sounder can be manipulated as well as the rapid Wheatstone automatic instrument. No special apparatus is required for its introduction except a supply of resistance coils. This duplex working is applicable to every species of instrument, and it is even possible to work one form of instrument at one station and another form at the other station. For instance, Stearns, to whom is due the application of condensers for compensation purposes, once worked the Morse at one end of a line and the Hughes at the other.

The effects of a variation in the resistance of the circuit

or in its electrostatic capacity are felt in the bridge method of duplex working as much as in the differential method, and exactly the same steps are taken to obviate these in the former case as have been already described in the latter. As at present arranged, the two systems are about equally efficient, and the all but universal use of the differential in preference to the bridge method is to be attributed to the fact that it is more economical as regards the battery power required.

CHAPTER VII

REPEATERS

THE strength of the current received as compared with that sent on a telegraph circuit decreases with the length of the circuit, not only in consequence of the additional resistance, but also from the effects of weather upon the wire and its supports. Of course an increase of battery power will overcome these latter effects to some extent, but it is undesirable to be dependent upon such a condition with every variation of weather, and there is necessarily a limit to such an increase. In England the conditions are such that it is difficult to maintain uninterrupted communication for distances of over 400 miles. In dry climates, and where purely aerial wires are used, much greater distances are possible; but in all countries a distance is at last reached where direct working is impossible, and where it becomes necessary at some intermediate point either to take off the messages and repeat them by clerks, or to introduce a *repeater* or *translator* which, worked by the original currents, will automatically repeat stronger currents similar in direction to, and of equal duration with, those which are passed through it. It is, in fact, an extension of the principle of the ordinary relay, and is introduced into the circuit for a similar reason—the relay is placed in circuit that it may be actuated by currents which would not work the sounder or Morse writer direct, and completes a local circuit in which the receiving apparatus is placed; the repeater is also arranged to relay similar currents to those which actuate it, but, while the relay as ordinarily used is required to work an instrument in the same office, the prime function of the repeater is to retransmit the signals along an extension of the original line. By this means it is possible to work to any distance. Thus

the Indo-European Company now work straight through from Liverpool and Manchester *via* their London office and through Teheran to Karachi in India, a distance of about 5300 miles, by means of thirteen repeaters, and without re-transmission.

The theoretical connections of a repeater are shown in fig. 104. The principle consists simply in converting the lever of the recorder or sounder M or M′ into a key which is moved by the attraction of its armature between two contact points corresponding to the front and back contact points of the key. The electro-magnet of the sounder thus replaces the hands, and the motions of the key at the distant sending station are thus

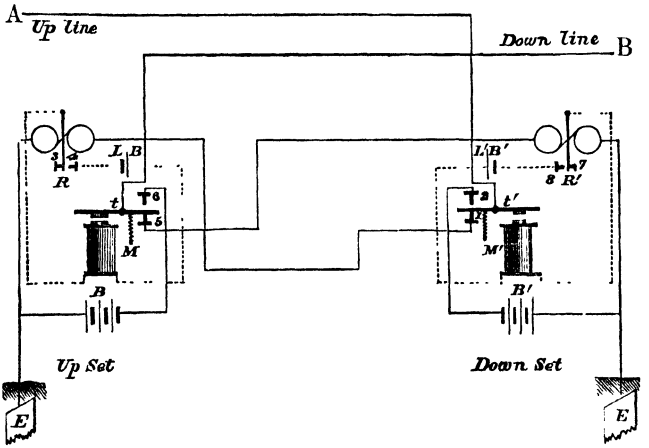


Fig. 104

repeated at the translating station. This automatic key brings into play a fresh line battery B, which sends on a fresh current to the distant receiving station. Let us fix ourselves at the repeating station, where there are two sets of identically similar apparatus, as shown in the diagram, and assume that the up station A is sending to the down station B. The currents from the up line enter the lever *t′* of the recorder M′, and pass by I to R, the relay of the up set of apparatus, which they work ; they then pass to the earth plate E, and return by the earth to A. The tongue of the relay R moves from 3 to 4 ; it thus completes the local circuit of the local battery L B, the armature of the recorder M is attracted, the lever rises from 5 to 6, and the battery B sends currents via 6 and *t* to the down line. These currents correspond precisely with those received from A.

Next let us assume that the down station B is working to the up station A. The currents from the down line enter the lever *t* of the recorder M, and pass by 5 to R′, the relay of the down set of apparatus, which they work, pass to the earth plate E, and return by the earth to B. The tongue of the relay R′ moves from 7 to 8; it thus completes the local circuit of the local battery L′ B′, the armature of the recorder M′ is attracted, the lever rises from 1 to 2, and the battery B′ sends currents *via* 2 and *t*′ to the up line which correspond with those received from B.

In practice the connections are not so simple as those shown in fig. 104. Galvanometers are used on each line wire to show if the currents pass correctly. Also, hand keys are used, which can be thrown into both up and down circuits by means of switches, so that the circuit can be divided, and the repeating station can work independently, either to A or to B.

Varley introduced repeaters at Amsterdam to translate the English double-current system of working into the Continental single-current system in 1858, but in England the Post Office has introduced them to increase the rate of working. There is, however, a limit to the number of repeaters which can be employed on one line. The motion, friction, and inertia, both magnetic and mechanical, of the moving parts and the introduction of disturbing electrical causes, prevent the duration of the contact of the tongue of the relay from being the exact counterpart of that of the sending key. It is of less duration. Retardation therefore takes place, and the rate of working is reduced with each relay added. In few cases in England do we introduce more than one repeater, but by means of that an actual and decided increase of speed is obtained, due to the fact that the speed of working of the whole circuit is that of its worst section alone. Their value may perhaps be best demonstrated by stating that we have now, in the *Fast Duplex Repeater*, an instrument which will mechanically retransmit messages, at the rate of 300 words per minute, simultaneously in both directions, on circuits exceeding 400 miles in length; the highest speed attainable without repeater upon the London-Amsterdam wire is 116, as compared with a speed of 400 words with a repeater at Lowestoft, while the London-Dublin circuit without repeater will give only 120 words and with a repeater at Nevin a possible 450. The latter figure, too, represents the highest

possible speed, not of the line but of the present form of instrument.

The rapid growth of the postal telegraph business in England rendered the introduction of a means of rapid transmission absolutely necessary, and this want was naturally most felt on the longest circuits, where the cost of the erection of lines becomes a very important consideration.

The Wheatstone automatic apparatus,[1] working direct, provides only for the fast transmission of messages over circuits which do not much exceed 200 miles in length, but the difficulty experienced in keeping up speed increases in proportion to the increasing length of the line, even though proportionate battery power be used; and, as already pointed out, there is a limit of power beyond which for several reasons it is not safe to go, for a high power fuses the contact points of the apparatus by the sparks which pass on breaking contact, damages the underground lines by the high potential tending to discharge to earth through the dielectric, and is very apt to fuse the coils of the instruments.

The perfection to which rapid repeating has attained has been due not so much to the introduction of any new principle or to the application of any electrical law which had not previously been practically applied, as to the close observation of, and careful attention to, the requirements of the working, and the systematic elimination or neutralisation as far as practicable of all disturbing causes.

The theoretical repeater, shown in fig. 104, provides only for single-current working, but it will be readily understood that double-current working is essential for fast speed. It is therefore of the first consideration that a fast speed repeater should be worked by means of reversals. This has accordingly been provided for.

The retardation due to the motion, friction, and inertia inherent to the moving parts of all apparatus has been minimised: (1) by making the motion as small as possible—the tongue of the relay which is used describes an arc of only one quarter of a degree (0·25°) in passing from one contact point to the other; (2) by making the moving parts light, and giving special attention to the proper burnishing of their pivots and the bearings in which they move; and (3) by arranging that the

[1] See Chapter IX.

necessary weight of the moving parts shall be as far as possible balanced upon the pivots.

The first consideration in adopting double-current working, as was seen at p. 89, is to find means of putting the line either in connection with the battery or with the receiving (or in this case *repeating*) instrument. This is arranged for in fig. 86 by the switch x; and for repeaters provision must be made to do mechanically under the control of the terminal offices what is in that case done by hand. An instrument called the *automatic* or *electro-magnetic switch* is arranged to meet this requirement. The function of this instrument has already been explained; briefly and specifically it is this. In its normal position it must place the line in connection with the repeating instrument, so

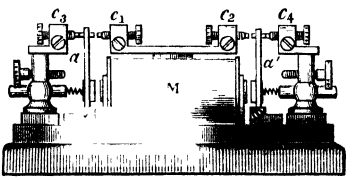


Fig. 105. ½th real size.

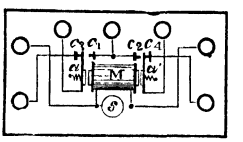


Fig. 106

that the currents from that line may be 'repeated' along the other line; and, when it is required to transmit to the wire to which it is joined, the switch (controlled by the currents sent from the other line) must disconnect its repeating instrument, and join up the batteries, maintaining these connections so long as a message is being sent.

The form of switch which is now generally adopted for this purpose is shown in figs. 105 and 106. The former is an elevation which shows the actual construction of the instrument; the latter gives the electrical connections.

There are two complete electro-magnets placed side by side, one only of which (M) is shown; at each end of the magnets is an armature fixed upon a contact lever which plays between two contact points. These levers, a a', are normally kept against the contacts c_3 c_4 by spiral springs; but when a current is passed through the coils in either direction the armatures are attracted and the levers make contact with c_1 c_2, which are generally connected together and to the middle terminal; in some instruments, however, c_1 c_2 are connected to two separate terminals.

If, therefore, the line be connected to the lever a'; the battery (i.e. that part of the repeater which corresponds to the contacts of the double-current key, fig. 86) to the contact points c_1 c_2; and the repeating instrument to the point c_4; and if also provision be made for the armatures to be attracted when it is required to send currents to the line, the required conditions will be satisfied. The use of the contacts c_1 and c_3 and of the lever a will be understood when we come to consider the connections of the repeater itself

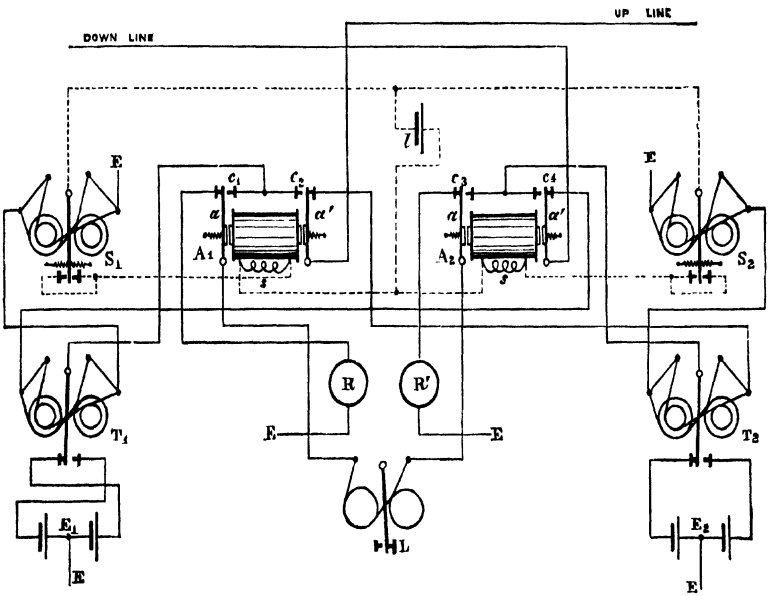


Fig. 107

Having thus glanced at that part of the apparatus which calls for special attention, we may proceed to consider the connections of an ordinary *Fast Speed Repeater*. The general principle upon which the working of such an instrument is based is shown by fig. 107.

T_1 and T_2, called the 'transmitting relays,' are ordinary Post Office Standard Relays. One end of the coils of T_1 is connected through a lever of the automatic switch A_2 to the 'down' line, and one end of the coils of T_2 is connected through A_1 to the 'up' line. The other ends of these coils are connected respectively with the relays S_1 and S_2.

These relays (S_1 and S_2) are known as the 'automatic switch relays.' Their tongues are fitted with adjustable springs by means of which they are kept in an intermediate position between the contact points, being clear of both. When the tongue of S_1 is moved in either direction the circuit of the battery *l* is completed through the coils of the automatic switch A_1; when that of S_2 is actuated the battery circuit is completed through the coils of A_2.

This being premised, we are in a position to trace the effect produced by a series of currents coming from (say) the 'down' line. The currents pass through the coils of the relays T_1 and S_1 to earth, thus actuating both relays. Now, when S_1 works, the local circuit of *l* being completed through the coils of the switch A_1, the armatures are attracted and the levers *a a'* make contact with the inner points c_1 and c_2 respectively. It is obvious, however, that, although the circuit of *l* through A_1 is completed whether the tongue of S_1 be attracted either to the right or to the left, it must be momentarily broken while the tongue is passing from side to side. In order to prevent the levers *a a'* from breaking contact with the points c_1 c_2 while the circuit of *l* is thus interrupted, the ends of the coils of the switch are connected through a shunt, *s* (figs. 106 and 107), which helps to form a circuit in which the current of self-induction due to the demagnetisation of the electro-magnets can circulate (p. 150). This induced current holds over the armatures for a few seconds, so that if an automatic transmitter at the down terminal office is causing the tongue of S_1 to vibrate, the levers of the switch A_1 will be continuously held against c_1 and c_2 by the combined action of the currents from the battery *l* and those induced by the interruption of the same. Thus is utilised an effect which in the case of apparatus which is required for rapid action it is of the first importance to neutralise. The resistance of the shunt (*s*) is made equal to that of the coils.

While the levers of A_1 are thus held over, the tongue of T_1 is vibrating between its contact points in response to the currents sent from the down office, and thus currents, the direction and duration of which are regulated by the direction and duration of those sent from the down line, are retransmitted to the up line from the battery E_1, through c_2 and the right-hand lever of the switch A_1.

It is necessary, however, that the clerk who has charge

of the repeater shall know how it is working. This is provided for by means of a 'leak' circuit, which takes its current direct from the repeating battery and the transmitting relay tongue through a receiver, L, and a resistance R or R′, to earth. The resistance, R or R′, in the leak circuit is such that the current passing is just sufficient to work the receiver and does not, of course, affect the current flowing to the line. In fact, the two branches are worked on the universal battery principle, and consequently, as was explained at p. 91, if the circuits are not very dissimilar they do not affect each other. Thus, when the down station transmits, currents in the same direction and of the same duration are repeated on to the up station and simultaneously recorded (when desired) at the repeating office.

The ends of the receiver coils are so connected, as will be seen, with the levers *a* of A_1 and A_2 that, when A_1 works, the receiver is put on the up leak, the circuit being completed through *a* of A_1, through the receiver to the lever *a* of A_2, and through R′ to earth; while, when A_2 works, the receiver is placed in the down leak, the circuit being through *a* of A_2, the receiver, *a* of A_1, and R to earth.

The effect of the transmission of a series of currents from the down office has been traced, and it is evident that the same description applies to currents coming from the up office. They pass by means of the lever *a′* of A_1, through the coils of T_2 and S_2 to earth. The armatures of A_2 are attracted, and the tongue of the relay T_2 transmits similar currents to the down line, at the same time working the leak circuit, as has been explained above.

In effect, we may look upon the relays T_1 and S_1 and the automatic switch A_1 as a transmitter controlled by the clerk at the down station, and the parts T_2, S_2, and A_2 as a transmitter controlled from the up station. The automatic switch corresponds to the switch of the transmitter, the tongue of the transmitting relay takes the place of the electro-mechanical portion of that instrument, while the currents sent through the coils of the relays represent the starting and motive power.

It is evident that the clerk at the repeating station should not only be able to watch the communication between, but should himself be able to communicate with, the terminal offices, not to transmit messages but to carry on the ordinary service communication of a circuit. In practice this is provided for by keys, one of which is placed in each line.

The key is brought into circuit by means of a switch placed on its base, and the connections are shown in fig. 108, from which, to simplify the connections, the automatic switches are omitted.

The lever C of the switch is normally connected to the contact c_1, so that the key itself is cut out of circuit. When it is wished to communicate (say) with the down station, the switch of K_1 is turned to c, and currents can thus be sent to the down line from the battery E_2, by which it is ordinarily worked. The working of the lever of the key K_1 therefore imitates the action of the tongue of the relay T_2, but, as it is not desirable when the repeater clerk is communicating that he should work his own

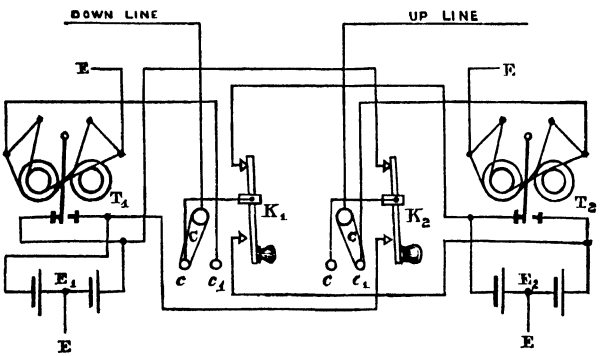


Fig. 108

receiving instrument, the communication is effected without the intervention of the automatic switch. K_2 in the same way works the up line, using the battery E_1.

In addition to the instruments to which reference has been made, both up and down lines are provided with galvanometers to show whether the currents are passing properly.

Hitherto we have considered the repetition of messages when being sent only in one direction at one time, but it is obvious that this arrangement might be duplexed.

The principle of duplex working is fully explained on p. 95 and following pages. We have therefore only to show the method of applying that principle to a fast repeater.

In the first place, it may be observed that on a double current duplex circuit the switch of the key is kept permanently to 'send.' On the duplex repeater, therefore, the automatic switch and its controlling relay, which were found of such great importance on the ordinary fast repeater, may be dispensed with.

Again, as there will be messages being sent in two directions at the same time and the repeater clerk requires to know the state of working in both ways, there must be two receiving instruments on the repeater board, i.e. there must be two leak circuits, one for the up and the other for the down messages.

After these preliminary considerations, if the student has thoroughly mastered the differential duplex principle referred to above, he will be in a position to understand the *Fast Duplex Repeater*, the theoretical connections of which are shown in fig. 109.

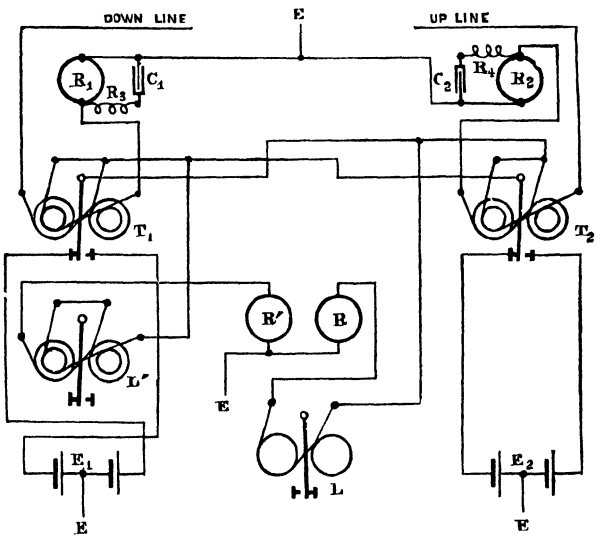


Fig. 109

T_1 and T_2 are, as before, the transmitting relays; R_1, R_2 are the rheostats, in connection with which are placed the condensers C_1 and C_2; and the adjustable retardation coils R_3 and R_4. The rheostats and condensers are to represent the artificial line, and the function of the coils R_3 and R_4 is, as their name implies, to so retard the discharge of the condensers that the effect may more nearly represent that produced by the discharge of a long line. L′ is a standard relay of the ordinary pattern, which works a sounder; it is placed in a leak circuit in connection with the down line: and L is a Wheatstone receiver placed in the other leak circuit, which is connected with the up line. R and R′ are adjustable resistances in series with L and L′.

Although it is not necessary that the repeater clerk should be able to read at high speed on both sides at one time, it is necessary that he be able to do so on either side at will. A switch (not shown in the figure) is therefore provided, by which

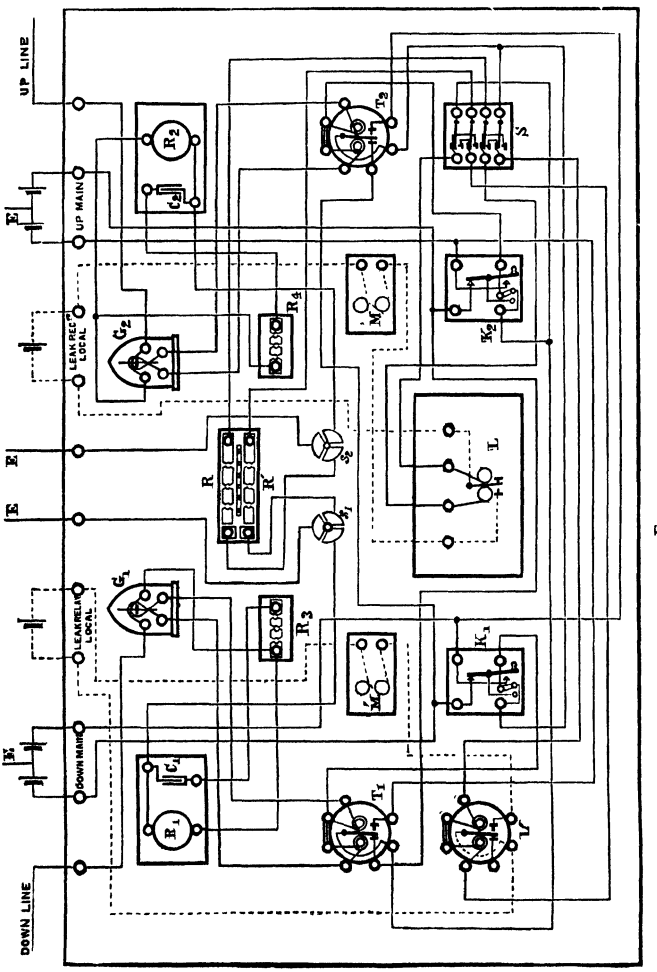


Fig. 110

the receiver can be placed either in the up or down leak, the relay with sounder being at the same time placed in the other.

The tongue of the relay T_1 acts as an automatic transmitter worked at the down office, sending currents from E_1, which divide through the coils of the relay T_2 (therefore producing no

effect upon it), one-half going through the rheostat R_2 to earth, while the other half goes to the up line.

In the same way T_2 acts as a transmitter worked from the up station; and we may again look upon the transmitting relays T_1 and T_2 as actual transmitters (working the up and down lines respectively), manipulated from the terminal offices.

Fig. 110 shows the complete connections of a fast duplex repeater, and gives the various instruments on the repeater

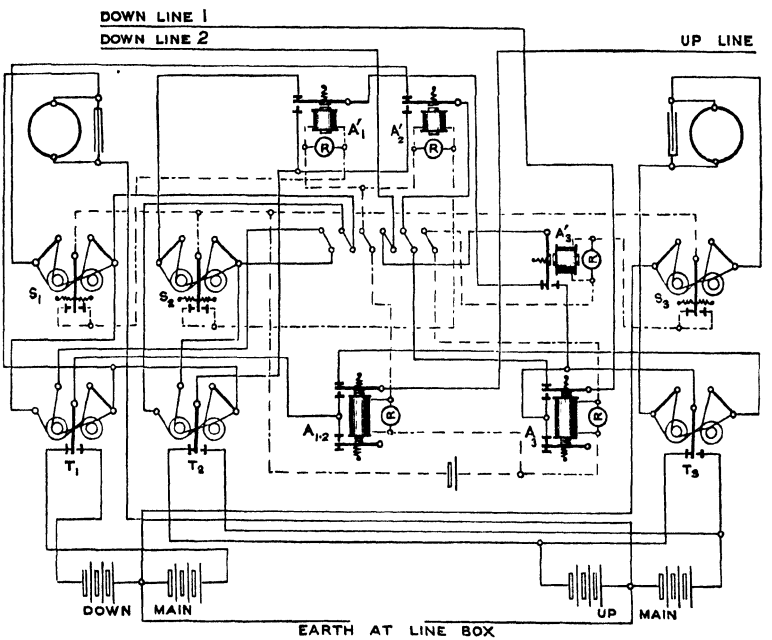


Fig. 111

board in the relative positions which are found most convenient in practice. The several instruments are marked as in fig. 109, and will be easily recognised. G_1 and G_2 are differential galvanometers, placed respectively in the down and up lines, and it will be noticed that the resistances R and R′ are combined as one instrument.

M, M′ are sounders worked by the leak-receiver and leak-relay respectively, and S is the switch, to which reference has been made, for placing the receiver either in the up or down leaks. The receiver L is shown in the up leak, the relay L′ being

in the down, but by moving the bars of the switch to their lower contacts these positions are reversed.

The plug switches S_1S_2 are for disconnecting the batteries from earth when the repeater is not in use. This is effected by removing the pegs from the centre holes.

Many other forms of repeater are in constant use, each arranged to meet some special requirement. One, for instance, provides that by means of a switch the apparatus may be worked either as fast ordinary or fast duplex repeater at will. Another, the theoretical connections of which are shown in fig. 111, is arranged for the transmission of 'news' from one station to two other stations at once through the repeater, provision being made that when either station is sending the other two shall each be able to read, and a special key on the repeater (not shown) works all three lines simultaneously.

CHAPTER VIII

QUADRUPLEX TELEGRAPHY

DUPLEX telegraphy, as was seen in Chapter VI, means the transmission *on the same wire* of a message from (say) station A to station B while B is sending another message to A. If A be able to send two messages to B at the same time on the same wire we have *diplex* telegraphy, and if the two systems—duplex and diplex—be combined, we have four messages being sent at the same time on the same wire, and this is *quadruplex* telegraphy.

Quadruplex working had been suggested by Stark of Vienna, and Bosscha of Leyden, in 1855, but it was not rendered practical until Edison solved the problem in 1874.

His principle of working is based upon the fact that currents of electricity differ from each other in their strength and in their direction. If we have one instrument which works with change of strength only, and another which works with change of direction only, then it should be possible to work the two together if we can alter the strength of the currents without affecting their direction, or change their direction without affecting their strength. This is accomplished by combining double-current and single-current working in such a way that one relay works by the one system of currents and the other relay by the other system of currents. A current is constantly flowing through the line: a change in its direction operates one relay; a change in its strength operates the other. The first relay is a simple polarised relay, deprived of any antagonistic adjustment, and responding to the reversal of the current, whatever its strength; and the second relay is non-polarised, adjusted by an antagonistic spring, so as to fail to

respond to the current, whatever its direction, unless it is considerably strengthened. Thus the two relays are perfectly independent of each other. They actuate separate sounders, and each is under the control of its own receiving operator, who can therefore adjust for himself.

In the early days of quadruplex it was found difficult in practice to get the non-polarised relay to work, especially on long circuits, the reversal of the current producing breaks or

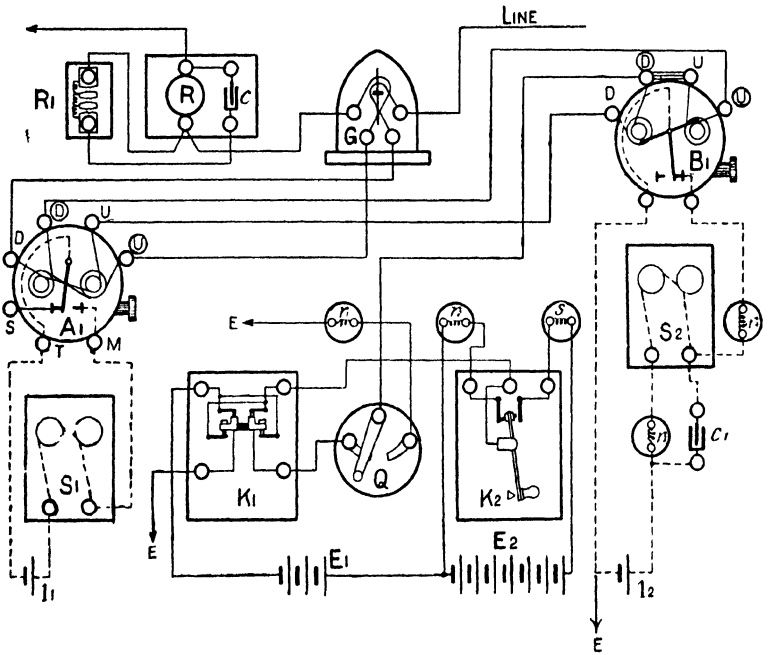


Fig. 112

'kicks.' This defect, however, Mr. Gerritt Smith remedied in 1876 by introducing the pole-changer and compound relay. The fault, however, lay as much with the instruments used as in the principle, and with improved apparatus it has been found possible to revert to a non-polarised relay. The principle of the compound relay was so to arrange a compound tongue and its contact stops that whichever way the tongue moved the local circuit was interrupted.

The arrangement of the apparatus and their connections for terminal offices is shown by fig. 112. Sufficient table room

is provided to seat four clerks. The apparatus is arranged for the two senders to sit together in the centre, the messages to be forwarded being placed between them. The section on the left of the switch Q is known as the 'A' side, that on the right as the 'B' side of the apparatus.

K_1 (fig. 112), the *reversing key*, reverses the direction of the current in the manner shown in fig. 113. The springs, which are shown to the side, are actually in the same position relatively to their contact points as are those in fig. 114. The positive pole of the battery z c is connected to the two springs *c* and c_1, the negative pole to the two springs *z* and z_1. The lever of the key is divided into two parts, insulated from each other, the one, L, connected to line, and the other, E, to earth. L is arranged to touch c_1 before it leaves *z*,

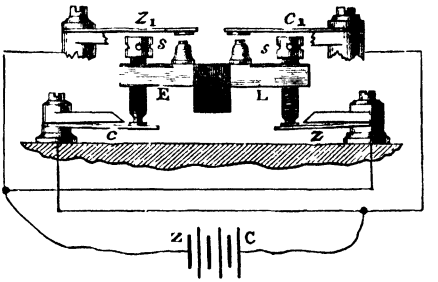


Fig. 113. ½ real size.

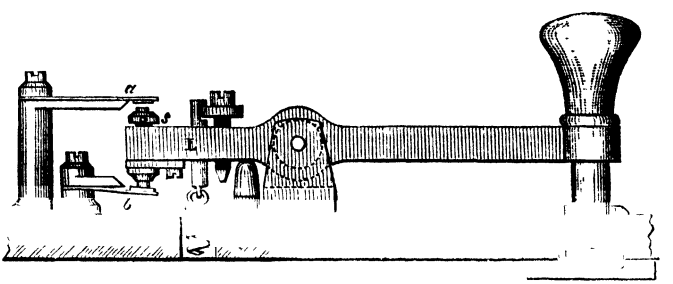


Fig. 114. ½ real size.

and E to touch z_1 before it leaves *c*; the battery z c is therefore momentarily short-circuited. *s s* are two adjusting screws by which the duration of this short-circuit between the reversal is regulated so as to reduce it to a minimum. The figure shows the negative pole to line and the positive pole to earth; but when the handle of the lever is depressed the positive pole is connected to line and the negative to earth, the current being thus reversed.

K_2 (fig. 112) is a simple key, known as the *increment key*;

it is used simply to increase the strength of the current. Its construction is shown by fig. 114. L is a lever which in its normal position makes contact with the spring *b*, but which when depressed makes contact with *a*. The stud *s* is adjustable, and should be so arranged that it will just touch *a* at the moment that the lower contact leaves *b*.

The way in which the keys K_1 and K_2 combine their action is shown by fig. 115. E_1 and E_2 are the line batteries, the one having two and one-third ($2\frac{1}{3}$) the number of cells of the other, so that if E_1 be the electromotive force of the smaller, that of the whole combined battery will be 3·3 E_1. The negative pole of E_1 is connected to *z* and z_1 of K_1, and the positive pole of E_2 to *a* of K_2 through a resistance coil *s*. A wire, called the 'tap'

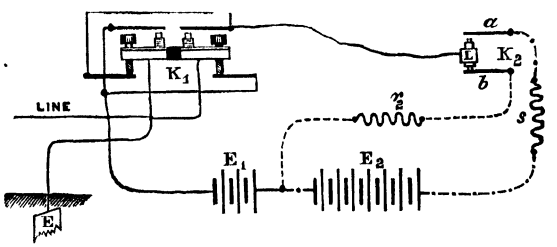


Fig. 115

wire, connects the positive pole of E_1 and the negative pole of E_2 to *b* of K_2. This wire has in it a resistance coil r_2. The springs *c* and c_1 of K_1 are connected to the lever L of K_2. Now, when both keys are at rest, the negative pole of E_1 is to line through *z*, and the positive pole of E_1 to earth through *b* of K_2 and *c* of K_1; the positive pole of E_2 being insulated at *a* of K_2. There is thus a weak negative current flowing to line. When K_1 alone is worked, the current of E_1 is reversed. When K_2 is worked alone, *c* of K_1 is transferred from *b* to *a*, and the *strength* of the negative current going to line is augumented through the increase of the electromotive force from E_1 to 3·3 E_1, for the whole battery is brought into play. When K_1 and K_2 are depressed together, then the negative pole of E_1 goes to earth through z_1; and the positive pole of E_2 to line through *a* of K_2 and c_1 of K_1, and a *positive* current, due to the whole electromotive force 3·3 E_1, goes to line. Hence the effect of working K_1 is simply to reverse the current, whatever its strength, while that of K_2 is to strengthen it, whatever its direction.

The resistance coil *s*, figs. 112 and 115, of 50ω resistance, is called a *spark coil*, because it prevents the high electromotive force of the whole battery from damaging the points of contact by sparking or forming an arc across when signals are sent; the resistance r_2 is 50ω *plus* the resistance of the increment battery, and another 50ω plus that of the entire battery is inserted in the earth connection.

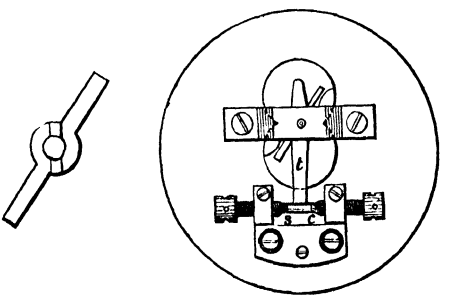


Fig. 110

A_1 and B_1 (fig. 112) are the relays which are used to respond to the changes in the currents sent by the keys K_1 and K_2 at the distant station.

A_1 is a simple polarised relay wound differentially, each wire having a resistance of 200ω, and so connected up as to respond to the working of the reversing key K_1 of the distant station. It acts independently of the strength of the current, and is therefore not affected by the working of the increment key K_2. It

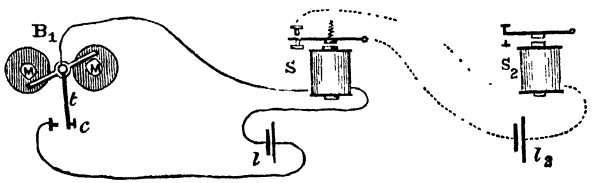


Fig. 117

is connected up so as to complete the local circuit of the sounder S_1 and the local battery l_1, and forms the receiving portion of the 'A' side.

B_1 is a non-polarised relay also wound differentially, each coil having a resistance of 200ω. It responds only to an increase in the strength of the current, and therefore only to the working of the increment key K_2 of the distant station. A top view of the working parts of this relay is given in fig. 116, and the principle of its action is shown by fig. 117. The tongue normally makes

contact with *c*, and the movement of the armatures under the action of a current brings the tongue against the stop *s*. The armatures, one at either end of the electro-magnets, are pivotted in the centre so that each end is attracted towards the near pole of the electro-magnets when a current of sufficient strength passes through the coils; and the armatures are normally held off by the action of a spiral spring. In order to prevent the cores of the magnets and the two armatures from forming a closed magnetic circuit, each armature is made in two sections brazed together, like the needle of the Spagnoletti

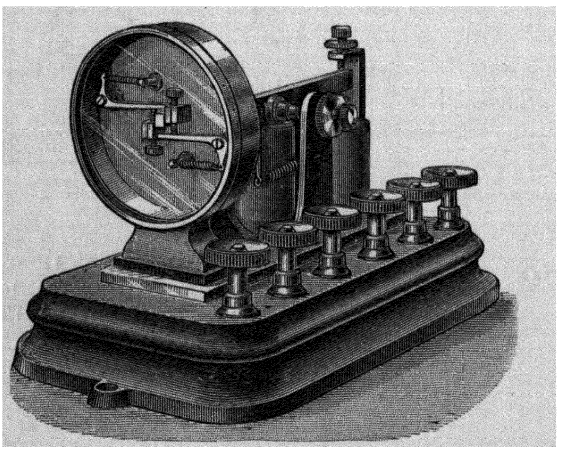


Fig. 118

coil. This is shown to the left in fig. 116. The spring is so adjusted that the armatures are not actuated by the weak current sent from E by the key K_1 (fig. 112).

To prevent the tongue of this relay falling away when the current is reversed on the A side, an earthed 40-volt battery (l_2, fig. 112) is connected in series with an adjustable resistance r_3, a 900ω sounder S_2, and a 50ω coil r_4, to the marking contact of the relay. The tongue is earthed and a condenser six or eight microfarads is joined across the sounder and adjustable resistance. When the relay is actuated, the local battery charges the condenser as well as actuating the sounder. When the circuit is broken, the condenser discharges through the sounder, thus prolonging the signal, and if the break is

momentary, due to the working of the A key, the signal remains continuous.

R (fig. 112) is a rheostat for balancing the resistance of the line, as described for duplex working (p. 103).

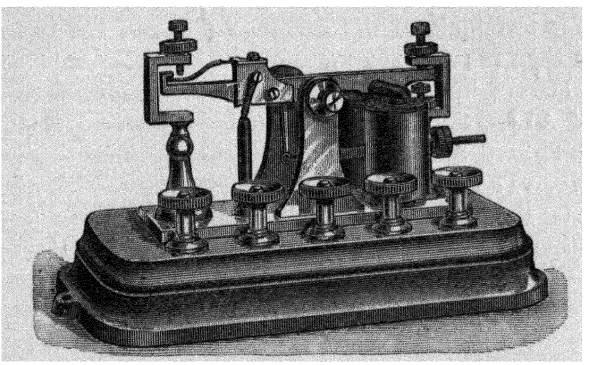


Fig. 119

C is a condenser used for compensating the static charge of the line. It is provided with an adjustable retardation coil,

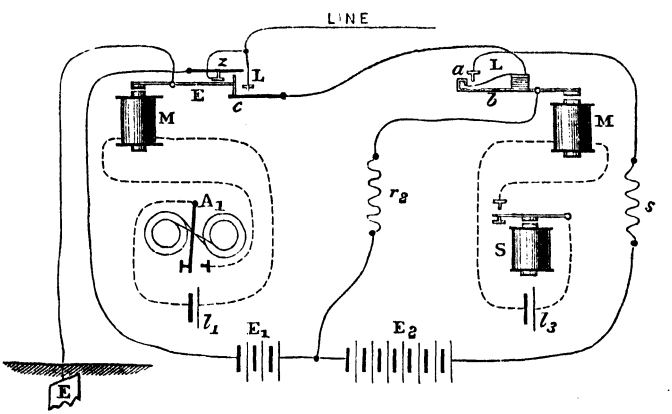


Fig. 120

R_1, to prolong the effect of the compensating current from the condenser.

G is a differential galvanometer, used for testing, and for facilitating adjustment and balancing.

Q is a switch for putting the line to earth, either for balancing,

or for any other purpose. There is on the earth wire leading from Q a resistance coil, r_1, equalling approximately the resistance of the whole battery, 3·3 E_1, and the resistance s.

The connections shown in fig. 112 are for an 'up' office. At a 'down' office it is necessary to reverse the wires on the two lower terminals of the galvanometer and the two battery wires on the reversing key K_1.

The keys K_1 and K_2 are, for repeaters, replaced by 'transmitters.' A reversing transmitter (or pole-reverser, as it is called) is shown in fig. 118, and an increment (or single-current) transmitter in fig. 119. The principle of the joint working of the two transmitters is shown by fig. 120. Each transmitter is worked from a local battery, either by a key or relay.

The two levers shown in front in fig. 118 are normally held by the tension of the spiral springs against contact points on the armature-lever and the case. The armature-lever is marked E in fig 120, the front levers c and z, and the contacts on the case, L.

When the armature is attracted by M, the armature-lever makes contact with lever z, lifting it from L, and at the same time it leaves lever c free to make contact with L; the connections are thus reversed. The action of the increment transmitter is similar—when the armature is attracted, a makes contact with L, and b is disconnected.

These transmitters perform the same function as the keys K_1 and K_2, and being lettered (fig. 120) correspondingly with those keys in fig. 115, their action can be readily traced without a detailed description.

It is now generally arranged to use pole-reversers in place of single-current transmitters, as, besides their being interchangeable, the contacts of the former are protected from dust, &c., whereas those of the latter are not.

The adjustment of this apparatus requires great care and great accuracy. Its good working depends essentially on technical skill that can only be acquired by patience and perseverance.

Faults in working generally arise from careless adjustments, dirty contacts, loose connections, battery failures, and the ordinary line interruptions, but there are no troubles that are beyond the reach of ordinary skill, and it can be safely said that, within moderate distances, wherever and when-

ever duplex working is practicable, then quadruplex working is so too.

There are many varieties of arrangement in use both in England and America. Fig. 121 illustrates one variation.

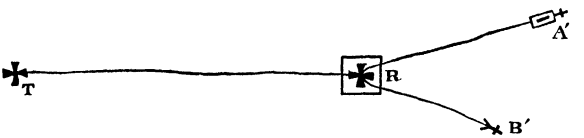


Fig. 121

T and R are fitted with quadruplex apparatus, A′ and B′ with duplex; A′ works the A side, and B′ the B side of R. In this way an office (T) may work duplex on the A side to A′, and duplex on the B side to B′; the circuits to A′ and B′ being common between T and R.

Again, the A side is sometimes worked by Wheatstone's automatic system. For example, between London and Grimsby the A side was worked automatic at 200 words per minute, while the B side was worked at the usual key speed.

CHAPTER IX

AUTOMATIC TELEGRAPHY

ALL the different kinds of apparatus which have been described in the foregoing pages are manipulated by the hand, and though in the A B C and Needle systems little skill is needed to work the sending portion of the instruments, yet in the other systems not only skill but practice and endurance are required to keep up the constant subdivision of time into dots and dashes. The operators tire, and as a consequence not only is the speed of working reduced, but errors are made leading to repetitions and delay. The limit of speed with which the hand can work the key of the Morse instrument is soon reached. It is impossible to maintain by hand the maximum useful power of the system. Signals can be made to follow each other on the simple Morse apparatus far quicker than clerks can send or even write. The muscular motion of the wrist and the directive action of the mind have their limits, both as regards speed and endurance. They cannot reach the recording speed of a Morse receiver on a short circuit. Moreover the sending of a clerk after a time loses clearness and legibility, and health, both of mind and body, affects his speed of working. But if the manipulation of the human agent be replaced by the precision and regularity of a suitably arranged machine, not only can we attain, but far exceed, the highest speed of the ordinary Morse or Sounder. Hence early efforts were made to replace the hand-worked key by some mechanical contrivance which would remove the defects inherent to manual labour and would secure precision in the formation of the characters, accuracy in the despatch of messages, and speed in transmission. Bain in the year 1846 was the first to propose this. He punched broad dots and dashes in paper ribbon which

was drawn with uniform velocity over a metal roller and beneath styles or brushes of wire. This device replaced the key, for whenever a hole occurred a current was sent by the brushes coming in contact with the roller. The recording instrument was his chemical marker. The speed at which messages were transmitted at experimental trials was enormous; 400 messages per hour were easily sent; but when to the defects in the machinery were added the disturbances on the line from causes which were then unknown, it failed to commend itself. Perhaps the real reason for its not being persevered with was that it was really not wanted; but now that telegraphic business

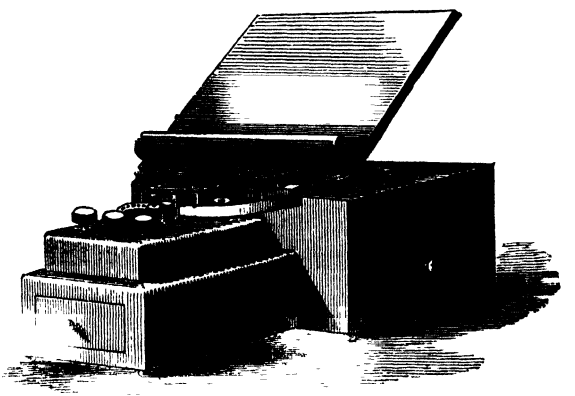


Fig. 122

has increased so enormously that extra wires are needed in every direction, apparatus which increases the capacity of the wires, by sending through them a greater number of messages in a given time, have become a necessity.

Wheatstone's system of automatic telegraphy is that which is used in England. Bain's method of punching has been considerably modified, and the messages are recorded on an exceedingly delicate form of direct ink-writer.

The apparatus consists of three parts; the *Perforator*, by which the message is prepared by punching holes in a paper ribbon; the *Transmitter*, which sends the message under the control of the punched paper; and the *Receiver*, which records the message at the distant station when thus sent by the Transmitter.

The *Perforator*, which is shown in perspective by fig. 122,

and in plan and front elevation by figs. 123 and 124, consists of three levers or keys, five punches, and a groove and a feed arrangement to guide and move forward the paper as it is punched. The paper *p p'* (figs. 123 and 124) is of a white description dipped in olive oil. *a b c* are the three keys which, on being depressed, actuate and drive the punches or perforators through the paper, cutting or punching out clean round holes. 1, 2, 3, 4, 5 (fig. 124) are the punches which perforate these holes in the paper. Key *a* causes 1, 2, and 3 to perforate the paper in one vertical line thus : ∘ ; *b* causes 2 only to punch, thus : ∘ ; and *c* causes 1, 2, 4, and 5 to perforate the paper, thus : ∘∘ .

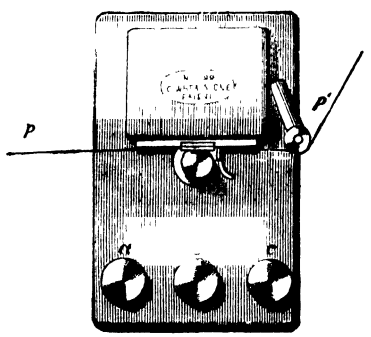


Fig. 123

a corresponds with dots, *b* with spaces, *c* with dashes. The holes made by 2 and 4 are in the centre of the paper, and are smaller than the upper and lower ones made by the other three punches. They admit the teeth of a little star wheel, which is turned through a small space whenever one of the keys

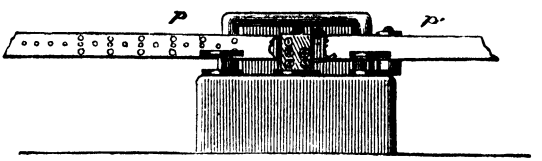


Fig. 124. ½th real size.

is depressed, and which thus moves the paper forward a certain distance for each depression of either key by a species of rack-and-pinion movement. The space through which the paper is moved by *c* for a dash is twice the length of that through which it is moved by either of the other keys. In fact, two central holes, 2 and 4, are punched for each dash required, and the star wheel is made to turn two teeth instead of one as in the case of the other two keys. If *a*, *c*, and *b* be struck or depressed in succession, we have the paper prepared for the letter A ; if *c*, *a*, *a*, *a*, and *b*

be struck, as indicated by the repetition of the letters, we have the paper prepared for the letter B ; and if *c*, *a*, *c*, *a*, and *b* be struck, we have the letter C prepared upon the paper. The word *Paris* thus prepared is indicated by fig. 125.

Mr. Willmot has introduced a punch with a hollow recess at its end, having no centre on which a deposit of oil can take place, and giving a clean perforation. The cutting edge being free from accumulation of paper is better preserved, and is more easily ground when required than the solid punch.

It is difficult to indicate these movements by means of a diagram. Their ingenuity, simplicity, and mechanical perfection are best comprehended by an examination of the perforator itself. The keys are usually struck by small india-rubber-faced mallets grasped by the hands, but at the Central Telegraph Station in London and in other large towns the air-pressure employed to

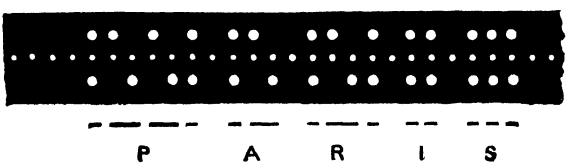


Fig. 125

work the pneumatic tubes is used for the performance of this work. Three piano keys, easily depressed by the fingers, open valves which admit the compressed air into little cylinders fitted with pistons which, when forced down, depress the keys *a*, *b*, *c* (fig. 123). The labour of punching with the mallets is considerable, and this application of air-pressure is very beneficial and is much liked. The power at command is so large that four or even eight ribbons are frequently punched simultaneously at the rate of forty words per minute. An expert operator can punch at the rate of about forty-five words per minute on either plan, but the average rarely exceeds thirty.

Several attempts have been made to manipulate a perforator mechanically, using a typewriting keyboard, so as to increase the speed of perforation, and at the same time to save the heavy manual labour involved in the use of an ordinary perforator.

The most successful perforator on this principle is the *Gell*. With this apparatus, the manual labour is confined to pressing keys on a keyboard very similar to a typewriter keyboard, the actual punching of the slip being done by electrical power.

When any key is depressed, certain levers are moved, special contacts are made, and electrical solenoids actuate the correct punches and the slip is perforated with the correct holes. The labour involved is no greater than that required on the usual typewriter. The electrical power can be provided by any electric lighting or power circuit. Continuous current is necessary at any pressure between 24 volts and 250 volts, and the maximum amount of power required when a key is held on is about 120 watts, but the actual working power is about 30 watts.

The *Transmitter* replaces the key of the ordinary apparatus,

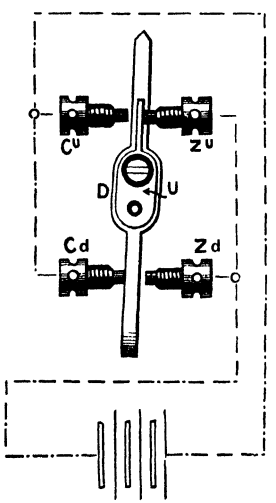


Fig. 126

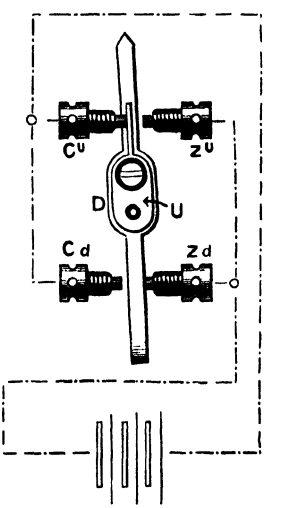


Fig. 127

and it sends the currents by mechanical means under the control of the punched paper. Hence the name of the system—the *Automatic*. The arrangement of the portion of the apparatus which sends the reverse currents is shown in figs. 126 and 127. The contact points, marked C^d, C^u, and those marked Z^d, Z^u, are connected respectively to the positive and negative poles of the transmitting battery. Between these contacts plays the compound lever D U, the two parts of which, D and U, are insulated from each other and connected respectively to 'down line' and 'earth.' The lever is so pivotted and the contacts are so arranged that when D makes contact with Z^d, U is in contact with C^u; and when D moves against C^d, U is changed over to Z^u. Thus reverse currents are sent to line. So long as the upper part of

D U is to the left (as in fig. 127), a 'spacing' current is sent to line; and when it is to the right (as in the other figure) a 'marking' current is being sent. If, therefore, the lever be made to vibrate between the position shown in fig. 126 and that shown in fig. 127 regularly and continuously, a succession of reversals will pass to the line; and if a Receiver be fixed at the distant end of the line a succession of dots will be recorded by it. If, however, the lever remains as in fig. 126 during a sufficient interval a reversal will be missed, and a *dash* will be recorded at the distant station instead of *two dots*. The function of the punched paper is so to regulate the motion of the Transmitter as to produce

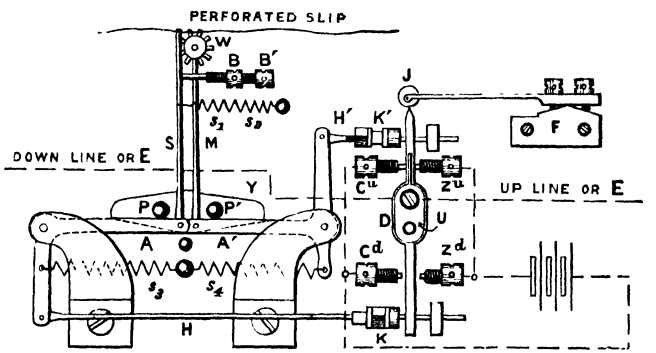


Fig. 128

this effect when required, and thus cause the currents to flow in such a way as to form dots and dashes.

The perforated slip (fig. 128) is carried forward, from right to left, by a little star wheel, W, similar to that which moves it in the perforator, by gearing in the central row of holes. Two rods, S and M, are fixed to the horizontal ends of the levers, A and A', which are pivotted on the front of the instrument, and are maintained at a constant upward pressure by means of the spiral springs s_3 and s_4. The two rods M and S play one opposite each of the two lines of larger holes in the punched paper, so that their ends would project through if there were holes, or would be checked by the paper if there were no holes. The rod S projects through the holes in the lower row on the slip, and the rod M through those in the upper row, and the adjustable studs B, B' and the spiral springs s_1, s_2 are for keeping the rods in position. Y is a beam which is pivotted at its centre and which

can be maintained in a condition of constant equable vibration by means of a small crank driven by the clock-work. Projecting from Y are two steel pins P, P′, against which the bell-crank levers A, A′ are normally maintained by the action of the springs s_3, s_4, so that the levers are kept rocking in unison with Y. The lever A has at its lower end a rod H fixed to it, and the lever A′ has a similar rod H′. The free ends of these rods pass freely through holes in the lever D and work in brass bearings, shown to the right of the lever, so that they do not interfere with the action of the lever. Upon the rods, but insulated from them, are screwed adjustable collets K, K′.

The star wheel W is so geared that the upward movement of the rods S, M, if properly adjusted, takes place when the perforations in the paper slip come exactly opposite the ends of the rods.

The exact positions of the rods are regulated by the screws B, B′. Each of the rods should be so adjusted that it commences to enter a perforation in the slip when the left-hand edge of the perforation is sufficiently clear of the left-hand edge of the rod to allow it to pass through freely. If the screws B, B′ are screwed too much either way out of their correct position, the rods will catch against the edges of the perforation, and the mechanism will not act properly.

The springs s_1 and s_2 pull the rods S, M back against the screws B, B′ when they have become sufficiently withdrawn to be just clear of the slip. These springs, although very light, must be strong enough to cause the rods to return to their normal positions promptly.

When the transmitter trainwork is started, the rocking beam Y is set into vibration, and the pins P, P′ move alternately up and down. When P rises the horizontal arm of A is free to rise also, and the spring s_3 causes it to do so. The rod H is thereby moved towards the right, and the collet K therefore pushes the lower end of the lever D U towards the right also. The pin P′ simultaneously descends, pressing A′ down, and moving the collet K′ clear of the compound lever. The pressure of the jockey wheel J ensures smart and decided action of D U, which in practice cannot maintain the intermediate position shown in the figure (fig. 128). When pin P′ rises in its turn, the reverse action takes place; H is moved to the left, so that K is clear of the lower end of the lever, and H′ is moved to the

right, so that K′ pushes the upper end of the lever smartly to the right.

When the transmitter is running without slip this alternate motion (which, as has been already indicated, reverses the current sent to line) takes place regularly without interruption, and simple, rapid reversals take place, because the bell-crank levers and the rods attached are free to follow the alternate motion of the pins P, P′.

When unpunched paper is inserted, both the rods S, M are pressed downwards, and the pins P, P′ in their motion do not actuate the bell-crank levers A, A′; the lever D U, consequently, does not move, and a permanent current is therefore sent to line.

If slip perforated (say) with the letter  (*a*) be now inserted, then when rod M rises it will be free to pass through the first upper hole, and the lever D U will be moved to send a 'marking' current; when the reverse movement of the rocking beam Y takes place, rod S will be free to pass through the first lower hole, and the current sent by D U will be reversed: a *dot* will therefore have been sent. On the next movement of the rocking beam, M will be free to pass through the second upper hole, and the length of the 'spacing' current is consequently precisely equal to that of the previous 'marking' current (*dot*). The marking current being now on, when the rocking beam leaves S free to rise it is prevented from so doing by the paper, which is not perforated below the second upper hole. In this case, therefore, the marking current is kept on until the rod S is again free to rise, which it can do through the second lower hole and the current is then reversed. It will be seen that the marking current is therefore kept on during movements equal to two dots and the space between, and this is the recognised length of a dash. It is thus clear that when a properly perforated slip is run through the transmitter, any required Morse signals—dots, dashes, and spaces—can be automatically sent to the line.

The lever D U and its contacts form in reality a double-current key, worked automatically by the moving rods, under the control of the punched paper, which takes the place of the hand or fingers. An improvement has been effected in the apparatus of the British Post Office by Mr. Willmot, in the substitution of a permanent magnet for the spring and jockey

roller J. This entirely removes the downward pressure of the spring and greatly increases the holding-over force operating upon the contact lever, thereby causing more perfect impact between the contact points.

The lubrication of the roller is also dispensed with and the consequent liability of the oil getting between the contact points is removed.

The *Receiver*, by means of which the signals sent by the transmitter are recorded, is a direct ink-writer of a very sensitive

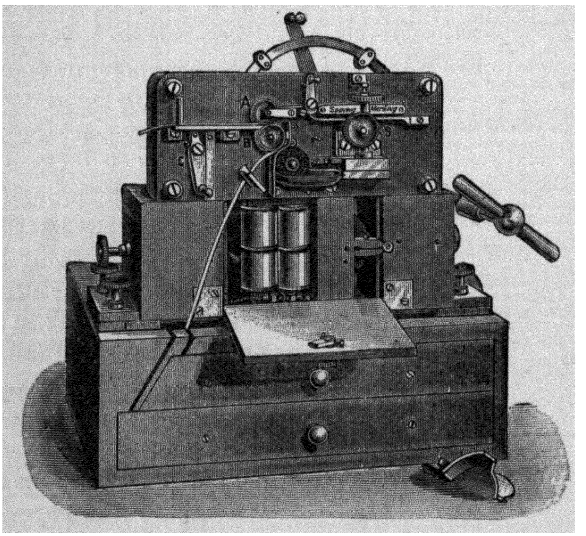


Fig. 129

character. The latest form is shown in perspective by fig. 129. The paper is drawn forward between the two rollers A and B by means of a train of wheels driven by a large weight. Before passing between the rollers the slip is brought near to a small inking disc which is rotated when the clock-work is in motion. The instrument is regulated by a fly to maintain uniform speed, and this fly is so arranged that, by means of the lever seen above the clock-work, the speed of slip can be adjusted to suit recording at any speed between 20 and 450 words per minute.

The light marking disc is fixed to an axle geared with the clock-work, and rotates close to the periphery of a larger disc that moves, in the reverse direction, in a well of ink. This latter disc takes up the ink and feeds the marking disc by

capillary attraction without introducing friction. In the figure the cover of the ink-well is removed and the marking and inking discs can be seen.

The starting and stopping of the clock-work is effected by the lever C.

Passing now to the electrical arrangement of the Receiver, the electro-magnets which work the recording armature can be seen in fig. 129, as the hinged front is shown open. They consist of two bobbins of fine silk-covered copper wire, having cores of carefully annealed soft iron. If these cores were provided with a cross-piece, they would form what is generally known as a horseshoe-shaped electro-magnet; but less electro-magnetic inertia and greater rapidity of action are obtained by dispensing with the cross-piece and providing a second armature at the lower end of the axle, polarised in the opposite direction to the upper armature by means of the other pole of the inducing magnet. The arrangement of the armatures and inducing magnet is shown by fig. 130. Near the top of the axle H, a long bent tongue J is fixed in a similar direction to the armatures N′, S′. In the bent end of J there is a gap in which the axle A revolves, being kept in position by means of the flat spring F, one end of which is screwed to J near the axle H. The marking disc *m* is fixed at the forward end of the axle A.

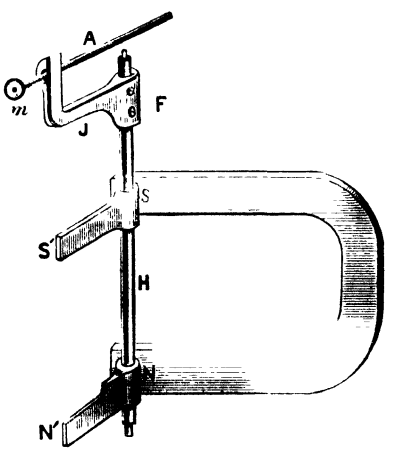


Fig. 130

The adjustment of the receiver towards 'marking' or 'spacing' is effected by altering the position of the electro-magnets with respect to the armatures. This is done by turning the upper edge of the screw S (fig 129) to the left for a spacing and to the right for a marking bias. Turning to the left moves the electro-magnets in that direction, so bringing the armatures more under the influence of the right-hand electro-magnet and tending to hold over the inking disc to the right, which

is the spacing position ; while turning to the right tends to bring the armatures more under the influence of the left-hand electro-magnet and so gives a marking bias. The most sensitive position of the instrument is when the electro-magnets are so adjusted with respect to the armatures that when once a current, however short in duration, has passed through the coils, the armatures remain as placed until they are restored to the other position by a current sent in the reverse direction. A dot is made by sending a current in the proper direction to move the marking disc to the left, and immediately afterwards another current in the reverse direction to bring it back. A dash is made by sending the marking current for a longer time before the reverse current is sent. Normally the spacing current is flowing to line as in the ordinary double-current system, and it has been already explained how the passing of the perforated slip through the transmitter determines the relative duration of the signals which it is required to send.

It will be seen that the working speed of the system is dependent upon the receiver as well as upon the transmitter. The latest transmitter is capable of working up to a speed of 600 words per minute ; but in practice there are other factors which help to determine the speed of transmission, one of which is the rate at which the receiver itself can record.

This rate is limited not only by the mechanical inertia of the moving parts of the instrument, but also by what may be called the magnetic inertia of its electro-magnets. An electro-magnet cannot be magnetised and demagnetised with infinite rapidity. The iron core takes time to magnetise and to demagnetise, and each operation induces an extra current in the coils in a direction opposing the effect required. Thus, when a current passes through the coils tending to magnetise the core, the act of bringing the core from a neutral to a magnetic state has the effect of inducing an extra current in the coils which is opposed in direction to the originating current. This *self-induction* or *inductance* is important in its bearing upon high rates of speed, but, by the application of a small condenser joined across a resistance coil in circuit with the receiver (fig. 131), it can be practically eliminated.

The extra current really results from an opposing electro-motive force, the value of which depends (1) upon the mass and continuity of iron in the core, (2) the strength of the originating

current, and (3) the number of turns of wire in the coils. The strength of this electromotive force for the same coil is invariable for any given primary current, but the extra current resulting therefrom varies with the external resistance of the circuit Hence, it is found that, other things being equal, a high-speed instrument will give better results with a certain current working through a high resistance than with the same current working through a low resistance. The explanation of this is that while the strength of the primary current is the same in both cases, the opposing induced current diminishes in strength as the resistance of the circuit is increased.

The effect of the shunted condenser will be understood from fig. 131. R represents the receiver coils, K being the condenser,

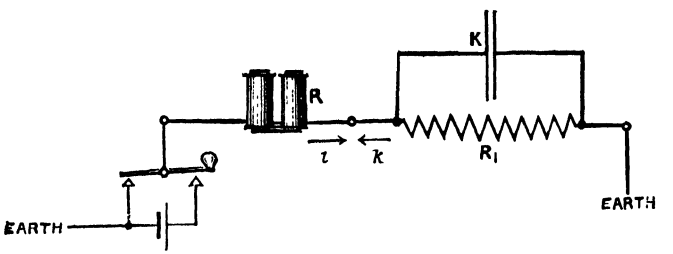


Fig. 131

R_1 the non-inductive resistance, both being adjustable. If a current be sent through the coils, the condenser will be charged to an extent dependent upon the resistance R_1, and this may be so adjusted that when the primary current ceases the discharge current *k* from the condenser may exactly equal the self-induction current *l* from the receiver.

It is not, however, only in connection with the receiver electro-magnets that this disturbing influence is felt; it arises, also, although in a less degree, from the coils of the galvanometer; and in this case a different device is applied for its elimination. This consists in providing another path of discharge, through a simple resistance coil placed as a shunt across each coil of the differential galvanometer. The resistance of the galvanometer coil being 50$^{\omega}$ and that of the shunt 300$^{\omega}$ the reduced effect upon the galvanometer of the working currents is not considerable,[1] while

[1] See Appendix. Section D.

the extra currents from the galvanometer coils circulate much more readily through the non-inductive shunt coils than through the much higher resistance and self-induction of the receiving circuit.

In the local circuit also of receivers and relays, where the primary current is strong and the resistance of the circuit low, the extra current arising from the discharge of the sounder electro-magnet is very considerable; and as the path of this current is across the contact points of the relay or receiver, and sparks oxidise or dirty them, it is necessary to shunt the coils of the sounder.

With no further special provision the fast-speed apparatus as described can send at the rate of 600 words per minute so long as it is working only on a short line, but it has been already

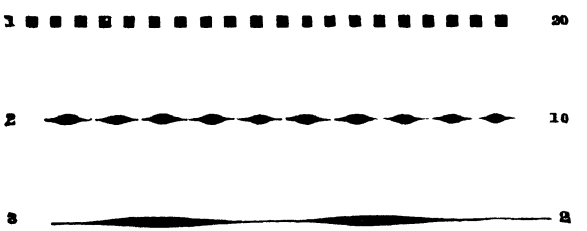


Fig. 132

shown (p. 106) that as the length, or rather, as the resistance, inductance, and capacity of the line are increased, so the rate at which it will allow separate distinct signals to pass is diminished.

The effect of electrostatic capacity upon the recording of signals is clearly shown in fig. 132. This figure represents the effect which would be observed with dots, (1) on lines of little electrostatic capacity, (2) on lines of moderate capacity—say 300 miles of overground wire, and (3) on long cables. While 20 dots can be firmly and clearly recorded in the first case, 10 can be recorded in the same time in the second case, and only 2 in the third. If a higher rate of speed were adopted in the two latter cases the marks would run together and become illegible—on a Wheatstone receiver they would form a continuous line.

If dashes be sent instead of dots the effect upon the speed of working is still more marked. With dots the current from the

sending end may be so regulated in duration as to allow just sufficient current to appear at the distant end to record the signal and no more; then the sending of the reverse spacing current immediately afterwards will almost exactly neutralise the charge. But with dashes the line will get more fully charged, and the charge will not be neutralised ordinarily by the spacing current.

In the practical working of automatic circuits every condition of signal is to be met with. In the case of a dot followed by a simple space, or a dash followed by a letter space, the discharge would be properly neutralised, but with other conditions, the effects of retardation and prolongation result in the distortion of the marks at the distant end either by the loss of dots, by the running together of signals, or by the conversion of dashes into dots and dots into dashes. Letters are thus deformed and even converted into other letters. A dot entering a neutral line becomes a dash from prolongation; a dot following a dash may be lost because its current is entirely occupied in neutralising the return charge of the dash, or it may be only shortened, which may also be the case with a dash. Signals following each other too rapidly will run together because there is no time for discharge and reversal.

These defects cannot be entirely remedied, because they are inherent to the principle of working, but their effect can be considerably diminished by the application of condensers in a suitable way. The need for this arises, however, principally in the case of circuits which include a cable.

Fig. 133 shows the connections of a complete set of the apparatus required for working high speed on a simple circuit.

Beneath the transmitter base there is a triple switch which is actuated by the stopping and starting lever of the trainwork. The three levers are shown in the position of rest of the instrument, in which case the poles of the battery are joined across to the two left-hand terminals, which are connected to the battery terminals of the double-current key, and the down line wire also passes, by way of the galvanometer and the transmitter, to the key, and thence through the receiver to earth. Hence in this position the operator is able to communicate by means of the key.

When the transmitter is started the switch levers join up

the battery to the transmitter contacts and connect the down line to one section of the transmitter lever. The other section of the lever is permanently connected to the up line or earth.

The receiver is arranged to act as a relay for a local circuit, in which is placed a sounder for the purpose of calling attention and also for reading from when the line is being worked by key.

Automatic instruments are employed on nearly all long

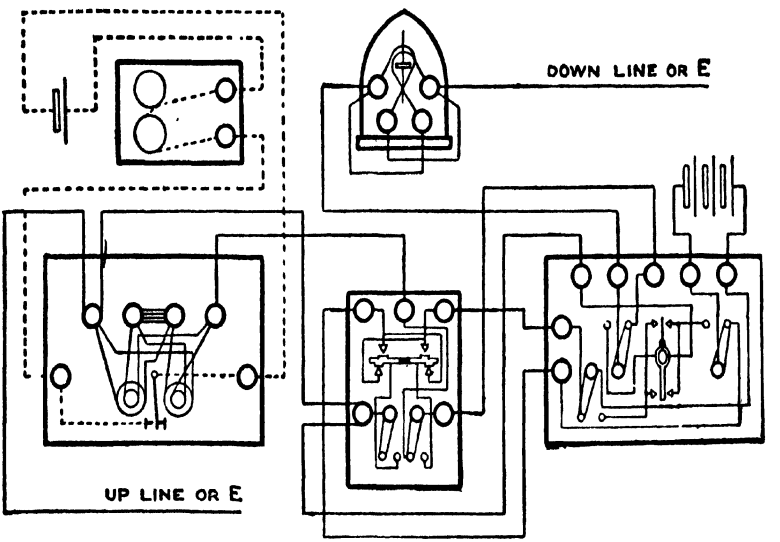


Fig. 133

circuits in England, not only because they increase the capacity of the wires for the conveyance of messages, but because they are specially adapted for the conveyance of news, which is such a distinctive feature of the English system of telegraphy. One batch of news is often sent to a great many different places, and as four or even eight slips can be prepared at one operation, and one slip can be used several times, the labour of preparing for transmission is very much reduced. In fact, without this system it would be simply impossible to transmit the enormous amount of intelligence sent telegraphically all over the country. One million words are sometimes sent on one night. There are many news circuits radiating from the Central Telegraph Station,

having three and four intermediate stations upon them, one or more of which repeat or translate onward to three or four more stations. Thus one punched slip disseminates the news to many places.

It is of course evident that, apart from its extreme accuracy, the chief value of the automatic system is its increased speed of working. It may be said to increase the capacity of wires eightfold. The average rate of automatic working in England, due to the length of circuit, to the amount of self-induction and electrostatic capacity present, and to the various causes that have been enumerated, is about 100 words per minute. A speed of 300 words is, however, often attained, Thus one wire fitted with the automatic apparatus can do the work of eight fitted with the ordinary apparatus. But the former involves additional expense in working and additional delay to each individual message. When a wire is kept going at its full speed, five punchers, one operator in charge of the sending and receiving apparatus, and six writers are required, that is, eleven additional clerks are wanted at each station. The messages are punched and transmitted in batches of five or six. Thus a message has to wait to be punched, and to take its turn in its batch. This involves delay. For these reasons it is not economical to introduce automatic working on short circuits, except for special occasions and for break-downs, and hence it has been confined principally to long circuits.

The automatic system is invaluable when a sudden glut of work is handed in at a station, or when communication is interrupted through storms and accidents. Once, when four out of the five wires then working between London and Birmingham were broken down, the remaining wire, working automatically, did the work of all, but of course with some delay.

A method of utilising the Wheatstone transmitter and receiver in combination with a mechanical perforator has been introduced by Mr. Gell. In the arrangement, the operator—an expert typist—manipulates the perforator described on p. 143. Alongside this instrument is the Wheatstone transmitter, motor driven at a regulated speed, and the perforated slip is fed directly from the perforator into the transmitter, and the signals transmitted to line. At the distant end the receiver prints in clear Morse characters on a slip and the news is transcribed by two

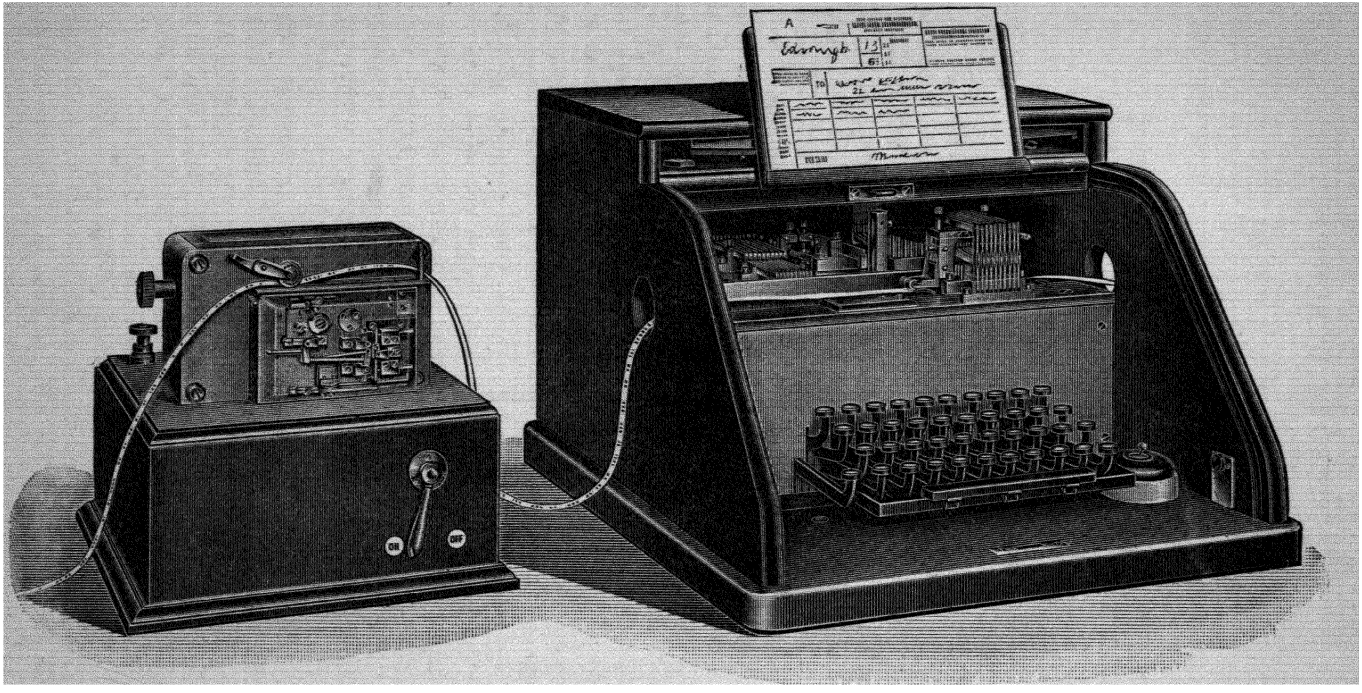


Fig. 134

or more trained clerks. By this method an expert can transmit continuously for some hours news at the rate of 65 to 70 or more words per minute. Fig. 134 gives a general view of the transmitting apparatus.

The Creed Printing Telegraph

This is a special receiving apparatus attached to the normal Wheatstone automatic system. It consists of two machines, one of which receives the dot and dash signals, and converts them into perforations on a slip identical with those on the transmitting slip. To do this, the received signals actuate a relay, and the armature of this relay operates a valve which controls the piston of a compressed air engine. This piston operates another valve controlling a second larger piston, which thus repeats the movements of the relay armature. This second piston operates the punches which perforate the slip. This slip is then fed through the second instrument—the printer. As the slip moves along, various needles attached to slide valve plates pass through the perforations according to the particular combination of perforations; and each combination of needles moved operates one particular piston, which in turn actuates a mechanism that prints the corresponding letter. The mechanism is too complicated to describe here, but it may be stated that speeds up to 100 or more words per minute are transmitted satisfactorily. The advantage of this invention is that the normal Morse code is employed, and therefore no special transmitting apparatus is necessary. All the mechanical movements are actuated by compressed air, and are therefore very positive in action. The apparatus is expensive, but its use leads to an appreciable reduction in the office staff. With the usual Wheatstone automatic, if the messages flow in at the rate of 100 words per minute, at least three, generally four, trained operators are required to transcribe the received slip. With the Creed, one attendant (who could look after several instruments) and a youth, for gumming on the printed slip, are all that is necessary. The capitalised value of the salary of the man, if only one is saved, represents a considerable sum.

This printer is being used by the British Post Office, the Eastern Telegraph Co., other cable companies, and also several foreign government departments.

The Murray Printing Telegraph

The Murray Printing Telegraph is another high speed automatic system which prints the messages in Roman type. The electrically controlled perforator for punching the paper ribbon can be worked by an ordinary typist at the rate of thirty words per minute, and four such, continuously in operation, can feed the transmitter when the latter is working at its highest speed. Between Edinburgh and London a speed of 120 words per minute has been achieved. The keyboard perforator consists of a typewriter keyboard with thirty-two keys operating a group of selecting bars which control the combinations of punches employed to punch the message holes in the paper tape. The work of punching and feeding the tape forward is performed by an electro-magnet, the circuit of which is closed by the depression of any of the keys. The punching takes place on the front stroke and the feeding of the tape on the back stroke of the armature of the electro-magnet. There are five punches and a die-block, and the tape is fed forward by a small sprocket-wheel. A back-spacing lever is provided to pull the tape back letter by letter in the event of error. Depressing a special key then punches the tape full of holes. This obliterates the error in such a way that no trace of the correction, not even a blank space, appears in the printed message at the other end of the line.

The transmitter is of a similar character to the Wheatstone, with this peculiarity, that the clockwork is operated by a motor or phonic wheel, which receives its energy, in the form of electrical pulsations, from a vibrator which is actuated as follows: on either side of an iron reed is fitted an electro-magnet, the circuit of each being alternately connected and broken by the break-and-make contact springs on either side of the reed. One of the magnets is connected with one side of the transmitting motor and the other with the opposite side of this motor, so that alternate pulsations are given to each, thereby maintaining the phonic wheel, which is pivotted centrally between them, in steady and constant rotation, and, as the axle of this wheel transmits its power to the clockwork inside, a perfectly uniform speed is secured for the transmitter.

At the receiving end is a vibrating reed which can be adjusted by a weight movable on its free end. It is set to vibrate at

a speed a little in advance of the transmitting one. Flexible contact springs, one on either side of the reed, are connected respectively with the spacing and punching electro-magnets of the recorder. The amplitude of the vibration of the reed is limited by two resilient or buffer springs, one on either side of the free end of the reed. The effect of these buffer-springs is to make the reed very sensitive to variations of current, thus enabling the rate of vibration of the reed to be controlled by the arriving signals. The recorder is arranged, by aid of the spacing and paper-feeding magnets and a tape previously furnished with centre holes, to punch, electro-magnetically, perforations precisely similar to those originated at the sending station. The contact spring on one side of the vibrating reed, a local battery, the spacing electro-magnet, and a shunt-wound motor combine to give the proper feed for the paper tape.

The method adopted by Murray to produce a type-printed page from the record perforated on the tape is a mechanical arrangement like an ordinary typewriter of the Barlock pattern. The keyboard is retained for filling in any letters that may have been accidentally dropped, or for making necessary corrections. The received paper tape is passed over a wheel, the teeth of which engage in the centre holes and lead the paper over the face of a die-plate having five holes, corresponding in size and in distance apart to any five possible combinations of perforations in the tape. Facing these holes are the points of five longitudinal rods capable of penetrating through the holes in the die-plate by the action of a motor-driven cam. These rods have teeth cut out of their front edges like those of a comb, and are designed to engage, in certain combinations, with the key-connected levers so as to operate any particular letter key. As the paper passes over the die-plate it presents to the points of these five reciprocating rods a certain number of perforated and unperforated spaces, according to the specific letter. The former admit the passage of certain rods through the die-plate, while the latter block the passages of others. The rods, therefore, take up a certain position for each and every symbol, and the particular alignment of their teeth at any time determines the action on the printing levers and the letters connected therewith. This mechanical device can attain a speed of 150 words per minute. The great advantage of the Murray system is that, as with the Creed, it replaces human writers by automatic Roman-

type printing, which is economical to the Post Office and convenient to the receivers of messages.

Accuracy and economy of labour are of more value than speed of transmission; 1000 words per minute can be transmitted electrically, but the handling of messages containing so many words without delay is a difficult and expensive process.

The Pollak-Virag Writing Telegraph

The Pollak-Virag Writing Telegraph was brought out in 1899, and has since been perfected. It is essentially a high-speed system, with a photographic record in written characters. It is not in everyday use as a commercial system, but has features which possess peculiar interest and which are full of promise. The apparatus consists of two telephones connected to a double line. One telephone is looped in, the other is between the loop and earth. Rods are attached to the diaphragms of the tele phones, which move when currents circulate, and cause oscillation in a small concave mirror supported upon one fixed point and two movable points. One telephone moves the mirror about a horizontal axis, the other about a vertical axis, so that, acting simultaneously, the telephones can cause the reflected spot of light to trace any desired curve. The source of light is a stationary glowing filament, surrounded by a metal mantle in which a helical slit is cut, the helix having one complete turn. In consequence, when the mantle is turned about its axis, the source of light falling on the mirror moves in effect uniformly from right to left, and the spot of light on the paper from left to right by reflection. The mantle and the sensitised paper strip are automatically started at the commencement of a message. A perforated strip is used in the transmitting station, five slip rings connected to batteries and two brushes connected to the line. The strip is so perforated as to allow of currents passing which will suitably operate the telephones at the distant end, and cause them to supply through the mirror and reflected spot of light the vertical and horizontal components necessary for the closed curves of written characters. For producing the vertical movements a positive current and an equal negative current, and a positive current of double their voltage serve; for the horizontal motion a positive current and a negative current of approximately equal voltages are required. The exposed strip

is carried forward by clockwork into a developing bath and then into a fixing bath, when it is ready for delivery. When tried between Pressburg and Budapest a message of 250 words was transmitted with this apparatus in only fifteen seconds, and between Berlin and Königsberg a speed of over 600 words per minute has been attained.



The above is a facsimile of the writing reproduced on the photographic slip at the receiving end of the line.

CHAPTER X

MULTIPLEX TELEGRAPHY—BAUDOT SYSTEM

WITH ordinary Morse signalling by hand the speed of working is at the best about 40 words a minute; with Wheatstone high speed automatic sending it is possible to transmit 400 words a minute. It is thus evident that in hand sending the line is in use for not more than 10 per cent. of the available time, and if it were possible to employ ten operators with ten instruments at each end of the line and enable each pair to be rapidly connected one after the other separately on to the same line, this line could serve ten circuits instead of one. This is the object of a multiplex system.

The most practical and successful multiplex system in use at the present time is the Baudot. It was the invention of a distinguished French telegraph engineer, who first introduced it about 1880. Since then it has been largely modified and improved; and now has spread to most countries in Europe, to India and other parts of the world.

With this system two ' distributors ' are connected to the two ends of the line. Each distributor is essentially a circle of segments over which a rotating arm travels at a high rate. The segments are divided into groups of contacts, the first group being connected to one circuit, the second to another, the third to another, and so on, and, by means of a switch, either a transmitter or a receiver can be inserted in any one of these circuits. The greatest number of circuits now employed on the one line wire is six (sextuple), but as each can be worked duplex, this means actually twelve distinct circuits to the one conductor. The more normal arrangement is four (quadruple) working circuits, though two (double) working circuits are not uncommon. Duplex working, though easy, has not come into use very largely up to the present.

BAUDOT ALPHABET

1	2	3					4					5		
LETTERS	FIGURES						KEYBOARD V	IV	I	II	III	SPACING DISC		MARKING DISC
A	1	+	−	−	−	−			●					A
E	2	−	+	−	−	−				●				E
Y	3	−	−	+	−	−					●			Y
J	6	+	−	−	+	−		●	●					J
X	,	−	+	−	−	+	●			●				X
U	4	+	−	+	−	−			●		●			U
G	7	−	+	−	+	−		●		●				G
T	!	+	−	+	−	+	●		●		●			T
H	H	+	+	−	+	−		●	●	●				H
W	?	−	+	+	−	+	●			●	●			W
C	9	+	−	+	+	−		●	●		●			C
M	)	−	+	−	+	+	●	●		●				M
S	;	−	−	+	−	+	●				●			S
FIGURE SPACE		−	−	−	+	−		●						
L	.	+	−	−	−	+	●		●					L
E′	&	+	+	−	−	−			●	●				E′
I	8	−	+	+	−	−				●	●			I
B	8	−	−	+	+	−		●			●			B
K	(	+	−	−	+	+	●	●	●					K
Z	:	+	+	−	−	+	●		●	●				Z
O	5	+	+	+	−	−			●	●	●			O
D	O	+	+	+	+	−		●	●	●	●			D
P	%	+	+	+	+	+	●	●	●	●	●			P
N	No.	−	+	+	+	+	●	●		●	●			N
Q	/	+	−	+	+	+	●	●	●		●			Q
L	=	+	+	−	+	+	●	●	●	●				L
V	'	+	+	+	−	+	●		●	●	●			V
F	F	−	−	+	+	−		●		●	●			F
R	−	−	−	+	+	+	●	●			●			R
*	*	−	−	−	+	+	●	●						*
LETTER SPACE		−	−	−	−	+	●							

Fig. 135

This system does not use the Morse alphabet. Each letter is represented by five current impulses, some of which are positive, and some negative. Fig. 135 gives the full Baudot alphabet.

The Sender or Key Board is a simple apparatus consisting of five keys like those of a piano (figs. 136, 137), arranged in two groups, keys I, II, III forming one group worked by the right hand, keys IV and V forming another group worked by the left hand. Between these groups is placed a 'Send and receive' switch.[1] Each key is permanently connected to one segment in the distributor (described later), and in the normal position connects that segment either to the negative pole of the line battery if the switch is turned to 'Send,' or to the coils of a line relay if the switch is set for 'Receiving.' If, when sending, a key is depressed, its segment is connected to the positive pole of the line battery. The operator therefore, when transmitting, has only to press down the key or keys corresponding to the position of the positive impulse or impulses required. The black dots in column 4, fig. 135, indicate the keys which must be depressed. To ensure that the segment is connected to the correct pole of the battery when the rotating arm passes over it, the key when depressed is held down by a detent D (fig. 137), but is automatically released after the impulse has gone to line by the electro-magnet E; a warning signal called the 'cadence' is also given when it is time for the operator to press down his keys for signalling.

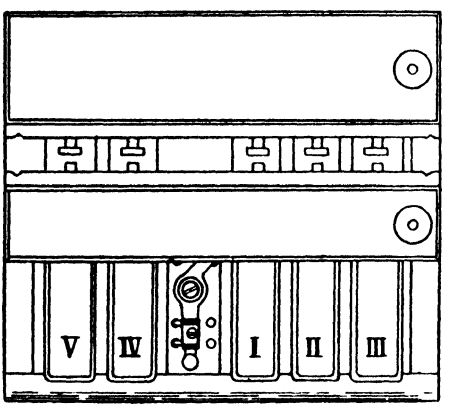


Fig. 136

The *Distributor* is the most important apparatus: one is fitted to each station, and its duty is to consecutively connect the one line to the several sending or receiving instruments in its own station.

[1] In the latest patterns this switch is placed on one side of the keyboard.

The principle is that of two nearly synchronously driven rotating arms connected to the two terminals of the line, which make contact with a series of segments arranged on the circumference of a circle. If the two arms travel synchronously, whenever one arm is in contact with one special segment the other arm would at the same moment be in contact with the corresponding segment, so that if an impulse flows out from the one it will be received at the other.

These two distributors must therefore run so that the five impulses sent out by each particular sender shall be received

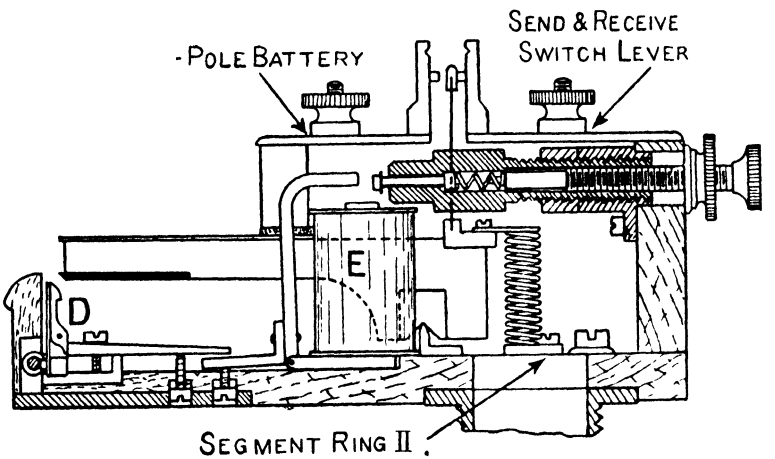


Fig. 137

by the corresponding receiver; and two, four, or more pairs of instruments must be served similarly in rotation.

Each station is supplied with one of these distributors, which serves all the senders and all the receivers in that station working over the one line, and which is able to control the running of the distant distributor or be controlled thereby, as may be arranged; as will be seen later, it also controls the running of its own group of receiving apparatus in its own station. Further, the duty of releasing the depressed transmitting keys at the right moment falls on this apparatus, and that of warning the operators when they should depress their keys for signalling the subsequent letter.

All these duties are performed by various rings of segments traversed by various arms carrying contact brushes, which

arms are all driven by one mechanism (either clockwork or electric motor).

The distributor for quadruple or sextuple working has two vertical ebonite plates mounted back to back on the front and back of a brass box. Each plate carries concentric and insulated rings of segments, there being six rings on the back plate and four rings on the front plate. Three arms rotate on the back plate and two arms on the front plate, and each arm carries a pair of metallic brushes metallically connected together. Each brush travels round one ring of segments.

All the rotating arms are carried on one axle which passes through the centres of the two plates, this axle being driven by the special mechanism at a definite speed.

The six concentric rings of segments on the back or fixed plate are numbered from outside, inwards; and the first three outer circles, known as rings I, II, III, are each divided into twenty-four equal and insulated segments (see fig. 138). Ring IV has five segments, four of which each cover the same arc as five segments on the outer rings, the fifth covering an arc equal to four of these segments. Rings V and VI are unbroken. The three pairs of brushes travelling over these segments connect rings I and IV, II and V, III and VI respectively.

The four concentric rings on the front plate corresponding to rings I, II, IV and V on the back plate are known as rings VII, VIII, X, XI: the other two rings (IX and XII) are in position, but are not used. Ring VIII has twenty-four similar segments to ring II. Ring VII has twenty segments of a smaller size,[1] and these do not complete the circle, the gap left being filled by a large movable segment. Outside the twenty small segments is an almost complete ring which encircles, and has teeth which occupy the spaces between, these fixed segments, but insulated therefrom.[2] Ring X is made up of two unequal segments $\frac{20}{24}$ths and $\frac{4}{24}$ths respectively of the circumference of the circle. Ring XI has five segments, four of them each $\frac{5}{24}$ths and one $\frac{4}{24}$ths of the circumference of the circle. Two pairs of brushes, carried on two arms which rotate over

[1] So that only the maximum amplitude of the current impulses is utilised, and that any overlapping of currents should be prevented if there be a momentary change in speed of one of the distributors.

[2] The teeth support the brush as it slides off the shortened contacts in ring VII.

Line
E
To Segment 14 of Ring II
" Sector IV of Ring II
" Segments 16,17,18,19 & 20 of Ring II
To Segments 16,17,18 & 19 of Ring III
" " 16,17,18,19 & 20 of Ring III
To Sector IV of Ring VI
To Segment 14 of Ring III
" Sector I of Ring IV
" Segments 6,7,8 & 9 of Ring II
To Segments 6,7,8 & 9 of Ring III
" " 6,7,8,9, & 10 of Ring I & of Ring VIII
To Sector II of Ring VI
RECEIVER IV.
RECEIVER II
KEYBOARD IV
KEYBOARD II.

this plate, couple rings VII and X, and VIII and XI. The front plate is movable as a whole.[1]

Fig. 138 shows the connections of the different rings and segments. On the back plate the first twenty segments of ring I are connected one to each of five electro-magnets in each receiver; the remaining four segments are not used. Twenty segments of ring II are connected one to each key in each of the four keyboards. The other four serve special purposes. Certain of the segments in ring III are used for the releasing and warning apparatus at the four transmitters, and for the correction magnets in the receivers. The first four segments of ring IV are each connected to the switch on each keyboard, and if any switch is set for transmitting, the corresponding segment is connected to the tongue of the *'leak' relay*. The fifth segment is unused. Ring V is connected to line, and ring VI to one pole of a local battery.

On the front plate the twenty-one segments on ring VII are all connected together and to the tongue of the *line relay*. The first twenty segments of ring VIII are connected respectively to the five electro-magnets in each of the four receivers, the remaining segments being unused. Of the two segments of ring X the longer one is connected to the coils of the *local relay*, and the shorter one to a *correction magnet*. Four segments of ring XI are connected to the switches on the four keyboards; and if any switch is to 'receive,' the corresponding segment is connected to the tongue of the local relay.

We thus see that the line is connected *via* rings V and II to each key consecutively of the four transmitters, and to the four *'Send and Receive' switches*. If the switches on any of these senders are turned to 'Receive,' the line is further connected to the coils of the line relay. When any switch is turned to 'Send,' either positive or negative impulses, according to the position of the key, go to line as the brush passes over the respective segments.

These impulses also actuate the 'leak' relay which is tapped off the line, and the pair of brushes coupling rings I and IV connects the tongue of this relay with the corresponding receiver magnets. This is for the purpose of recording locally the signals sent out. The third pair of brushes on the back plate couples rings III

[1] For adjustment so that the received signals arrive on the correct segments.

and VI and connects a local battery to the releasing and warning apparatus of each transmitter in turn. The releasing apparatus is the electro-magnet E (fig. 137) on the keyboard, which de-clutches any depressed key after its group of segments has been passed over by the brush. The same action also gives a warning signal (the cadence), which is for the purpose of instructing the operator to depress his keys for the next signal. If that circuit is receiving, these brushes transmit currents to the receiver, and actuate its speed-regulating apparatus as will be shortly explained.

The pair of brushes on the front plate which couples rings VII and X connects the tongue of the line relay to the coils of the local relay. The other pair of brushes in this plate connects rings VIII and XI, and thus couples the tongue of the local relay to the electro-magnets in the various receivers if the corresponding send-receive switch is turned for receiving. Thus when a switch is turned to receive, the impulses flowing at the right moment in from the line actuate the line relay *via* rings V and II, this relay repeats the impulses to the local relay *via* rings VII and X, and the local relay repeats the positive impulses only to the various receiver magnets *via* rings XI and VIII. When transmitting, the impulses flow from the line batteries to the keys and to line *via* rings II and V and also actuate the leak relay, which repeats the positive impulses to the receiving apparatus *via* rings IV and I.

These distributors are usually driven by clockwork, worked by a weight, the speed being regulated by a governor and being also controlled by certain synchronising arrangements described later.[1]

The *Receiving Apparatus*, of which there is one for each circuit, is of rather a complicated nature. This instrument automatically translates and types in Roman characters on a flowing tape the groups of impulses received from the line.

This apparatus has five electro-magnets, E (of which one only is shown in fig. 139), each of which is connected to a segment on ring I and a segment on ring VIII. The armatures (A) of these magnets are normally held 'off' by a spring *y* and carry extension pieces of brass, *p*, with curved ends, overhanging the horizontal arms of five steel levers, *l*. These levers are carried on a spindle *o*, and have two arms at right angles to one another. The horizontal arm is normally held in the position

[1] The use of electric motors is now becoming more common.

shown in figure by a notched spring r, which keeps the vertical arm e' clear of a pin x. Each of these five pins (x) carries another lever, c, known as the 'seeking' lever, of the shape shown in fig. 140 (c_5), and the lower ends or tails of these seeking levers rest in a groove on the drum R.

When a positive impulse is transmitted to one of the electro-

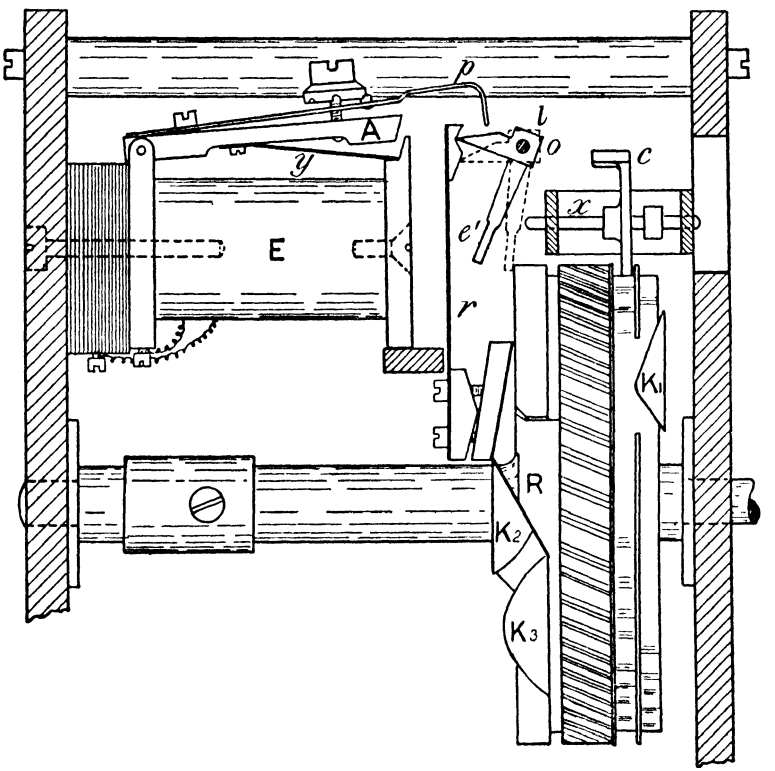


Fig. 139

magnets either from the leak relay or from the local relay, the movement of the armature releases the lever l, forcing the end of the vertical arm e' against the pin x; this in turn moves its seeking lever c horizontally to the right. It will be seen that the drum R on which the tails of these levers c rest has two grooves which at one point are not separated. If therefore the junction between these grooves is opposite the tail of a seeking lever at the moment that it is given a horizontal

motion, the end of the lever will be transferred from the normal groove to the outer one (or from the 'resting' groove to the 'working' groove). There are five magnets and five of the seeking levers, but only the positive impulses from the line are transmitted to the magnets; therefore as the five impulses forming one signal follow consecutively and the connections to the magnets do the same, each positive impulse actuates a magnet, and the corresponding seeking lever is transferred to the 'working' groove. It is therefore obvious that the five levers take up positions corresponding to the positive and negative impulses, the former being pushed into the working groove, the latter remaining in the resting groove.

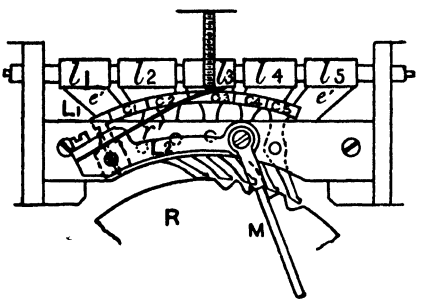


Fig. 140

It will be noticed in figs. 140, 141 that the five '*seeking*' levers have square heads, contiguous to one another, forming, together with a sixth head L_1, a segment of a circle, and whether the tails of these levers are in one groove or another this segment is not broken. L_1 has no tail and it is not capable of the horizontal movement. It has however an outer arm L_2, against which a flat spring, *r'*, presses, tending to rotate L_1 clockwise (fig. 140), which pressure is communicated to the heads of all the seeking levers.

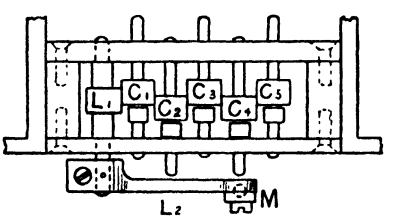


Fig. 141

On the drum (usually termed the '*combiner*') it will be seen that a cam K_1 is opposite the opening between the two grooves; this guides the tails of the seeking levers from the resting to the working groove when the sliding motion is given to the pins *x*, and also guides these tails back to the resting groove just before the completion of the revolution of the drum.

On the left of this drum there is a double cam K_2 K_3 (the

'go and return' cam). As the combiner revolves, K_2 engages against any lever e' which has been released by a magnet armature, and which, in consequence, is pressing against the edge of the drum. The lower ends of these levers pass round the cam K_2 as the drum rotates, and this assists the horizontal motion of the pin x, and also helps to push the tail of the corresponding seeking lever c through the gap between the resting and working grooves; the lever l is then guided by K_3 back to its normal position when it is held by the spring r.

It will thus be seen that when five consecutive impulses are received on the line relay, those which are positive are repeated by the local relay to the corresponding electro-magnets of the receiver; the armatures of these magnets are attracted, and by means of the levers l and the cams K_2 and K_3 the tails of their seeking levers c are caused to enter the working groove, whilst those corresponding to the negative impulses remain in the resting groove. (For instance, with the letter T the 1st, 3rd, and 5th impulses are positive, therefore the tails of levers C_1, C_3, C_5 are pushed into the working grooves, whilst the tails of C_2, C_4 are in the resting groove.) They remain thus separated until the revolution of the drum is completed, when those in the working groove return to the resting groove, being guided there by the cam K_1.

The floors of these two grooves are notched as shown in fig. 135, col. 5, the shaded squares representing notches or deeper hollows. Now if the five tails of the levers c—some in one groove and some in another—were all simultaneously over notches, the spring acting on the outer arm L_3 would cause the five heads of these levers to make a movement to the right, the tails falling into these hollows, but as the drum is rotating at a fair speed, the tails are promptly ejected and the heads given a sharp motion to the left; this motion causes the free end of the outer arm L_2 to move quickly in an upward direction. This movement actuates a rod, M, attached to the printing mechanism, and causes the correct letter to be printed on the slip, at the same time moving forward the slip. The axle carrying the drum also carries the type wheel, so that the correct letter for printing is in position as the seeking levers are jerked out of the hollow.

This axle carrying the drum and type wheel is driven by

clockwork regulated by a governor and controlled by the synchronising apparatus.

Speed regulation is attained thus :

One of the pair of distributors acts as the correcting apparatus, the other is the corrected apparatus, and each distributor also corrects its own receivers.

The correcting distributor regulates the speed. The corrected distributor is set to run slightly faster. One of the two spare segments in ring II of the correcting distributor is connected to a positive pole and one to a negative pole of a battery. A positive and a negative impulse therefore consecutively flow to line as the pair of brushes pass over these two segments. The impulses travel to the corrected distributor and are received on ring V and transmitted by the pair of brushes to ring II and to the coil of the line relay. These impulses are received at the time the brush is on the shorter segment of ring X. If the other brush is at that moment on the movable contact in ring VII, the impulse is repeated to the correcting magnet. When the distributors are running in synchronism the negative impulse will be received on the movable segment, but as the magnet is connected to the negative pole of a local battery, it will not be affected : if however the corrected distributor should be in advance of the correcting distributor, a positive impulse will be received ; this will actuate the correction magnet, a brake is applied, and the speed checked. The segment in ring VII is movable so that close adjustment can be made when starting up.

For regulating the speed of the receivers, each distributor has segments on ring III which are connected to a correction magnet on the various receivers. These receivers are set to run faster than the distributor, and at each revolution of the brushes connecting rings III and VI an impulse is transmitted to a brake magnet which momentarily damps the speed of the governor if another pair of contacts are closed. These latter contacts are closed once momentarily every revolution, and if the receiver mechanism is in synchronism, these contacts are not together at the moment the impulse flows from ring III, so that the brake is not actuated. If, however, the speed of the receiver being too fast, the impulse arrives when the contacts are closed, the magnet is then actuated and the speed is checked.

For a *Baudot double* the distributors have only one ebonite

plate, fitted with six concentric insulated rings. Rings IV, V, and VI (fig. 142) are continuous. Rings II and III have thirteen insulated segments, but Ring I has three independently movable parts each provided with projecting handles. One carries one segment only which is known as the movable contact, the second carries five segments and the third carries six segments. Three arms each carrying a pair of brushes travel over these six rings.

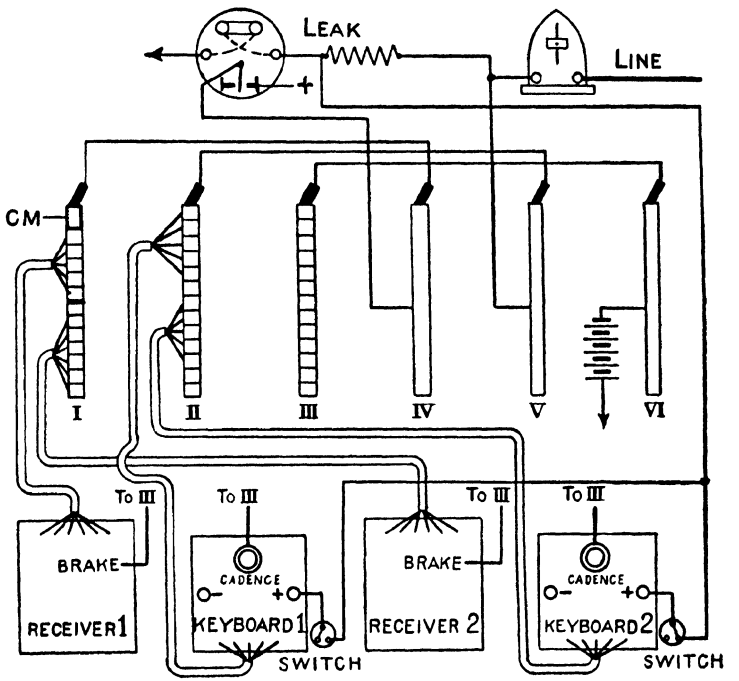


Fig. 142

The two groups of segments on ring I are connected to electro-magnets in the two receivers; the independent segment is connected to the correction magnet for speed regulation.

Ten of the segments on ring II are connected to the keys of the two keyboards. Segments in ring III are used for the releasing and warning signals and for correction of the local receivers. Ring IV is connected to the tongue of the relay, ring V to the line and through a 'leak' resistance to the relay, and ring VI to the local battery. The brushes connect rings I and IV, rings II and V, and rings III and VI (fig. 142). When transmitting, the impulses pass from the keyboard in ring II,

thence to ring V and line, and by means of the leak resistance actuate the local receiver. The received impulses flow to ring V and by the brushes to ring II, and *via* the keyboard switch to the relay.

For *duplex working* an artificial line is connected to one coil of the line relay and the line to the other, whilst ring V, instead of being connected direct to line, is connected to these two coils (fig. 143). The 'leak' relay is tee'd off the connection between ring V and the line relay, and is not affected by incoming currents,

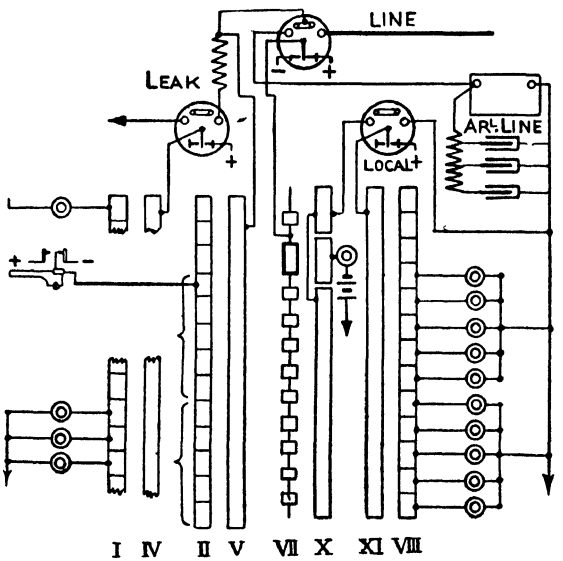


Fig. 143

owing to the high resistance of this path in comparison with that offered *via* Rings V and II through the key battery. Each duplex station with a quadruple set has eight receivers, four for receiving signals from the line and four to record the signals transmitted, the latter being connected to ring I and the former to ring VIII.

The normal speed of working with the Baudot is thirty words per minute per operator. A line over which a Baudot sextuple duplex is worked can thus transmit 360 words per minute. Twelve operators would be required; but on the other hand the received slip is in printed letters and no perforated slip is required at the transmitting end.

CHAPTER XI

COMPARISONS OF TELEGRAPH SYSTEMS

THE simplest means of transmitting signals by electricity are by the Single Needle, the Sounder, or the Morse Inker systems. But with these systems even the most expert operator cannot transmit steadily at speeds exceeding thirty words per minute, whilst the average speed does not exceed twenty-five words per minute. To render a telegraphic circuit more efficient—that is, capable of transmitting signals at higher speeds—more elaborate systems have been introduced, and at the present time these systems are very numerous. In this text-book we have described those which are looked upon with most favour. These are :

1. The Duplex.
2. The Quadruplex.
3. The Baudot double, or four-arm, simplex or duplex.
4. The Wheatstone automatic.
5. The Gell-Wheatstone with mechanical perforators.
6. The Creed-Wheatstone with mechanical perforators.

In Great Britain and on the Continent, the Murray and the Siemens High-speed systems have found some favour; and in the United States, the Barkley-Buckingham, the Morkum, the Wright, and others are in use to a considerable extent. But for general purposes the above six systems may be taken as the most important.

The question then arises as to which one of these six would give the greatest satisfaction. This, however, is a most difficult question to answer, as local conditions and local traffic requirements have considerable influences.

In order to make a fair comparison between these various systems, it is essential to take into consideration (1) the traffic which has to be handled, (2) the number of operators required,

their grades, and the actual pay received by the different grades of operators.

Unfortunately, as this last point varies very considerably in different parts of the world, it is impossible to deal completely with this particular, and really the most important, point. In order to give a fairly close comparison, it is assumed in the following statement that there are three grades of operators required for telegraphy: (1) the trained operator, or transcriber, or attendant; (2) the good typist-telegraphist, or key-board operator, or perforator; (3) the gummer (whose duty is to tear off the slip and gum the strips on a form for delivery). It is further assumed that grade (2) receives 0·8, and that grade (3) receives 0·6, the pay of grade (1). Comparisons can thus be made in terms of trained operators.

For a line over which traffic not exceeding thirty words per minute in both directions has to be transmitted, the choice lies between the Baudot double simplex and the duplex.

FOR TWO STATIONS

System	Approximate outlay	Approximate maintenance	Staff per shift	Equivalent in trained operators
	£	£		
Duplex . . .	120	4	4	4
Baudot double simplex .	1,000	50	4	2·8 (1 keyboard operator and 1 gummer at each station)

The higher outlay and maintenance for the apparatus with the Baudot system would thus appear to be counterbalanced by the saving in staff, as the extra capital outlay of £880 would not exceed an annual charge of £52 8s. per annum; and this, with the additional maintenance, is less than the average pay for a trained operator in most countries. In addition to this, there are the advantages with Baudot of eliminating the duplex balancing, and—what is still more important—that the messages are recorded at both ends in Roman characters; also that, in times of pressure at either station, both circuits can be used for transmission in the same direction.

The Gell-Wheatstone working simplex, and alternating the direction of working, could handle this traffic; it would cost

approximately £400 and £50 per annum maintenance, and would require four men—equivalent to 3·6 trained operators (two typists, and two trained operators for transcribing). This system would save the duplex balancing, but the operators would have to transmit at sixty words per minute. This is quite possible with well-trained typists, but it might be obtained with difficulty in some countries.

For a line over which the traffic to be dealt with is about fifty words per minute the choice lies between :

1. Quadruplex.
2. Baudot double duplex.
3. Baudot four-arm simplex.
4. Gell-Wheatstone.

FOR TWO STATIONS

System	Approximate outlay	Approximate maintenance	Staff per shift	Equivalent staff
	£	£		
Quadruplex . . .	150	30	8	8
Baudot two-way duplex	1,100	75	8	5 6 (4 keyboard operators, 4 gummers)
Baudot four-arm simplex	1,200	100	8	5·6
Gell-Wheatstone duplex	400	50	6	5 6 (2 typists, 4 transcribers)

If a Creed outfit were used, the total outlay would be at least £2,100, and the maintenance £100–£150, but the staff could be reduced to an equivalent of 4·8 trained operators (one attendant, one typist, and one gummer at each end). In this case, the saving in staff is barely counterbalanced by the additional capital outlay and maintenance.

The Gell-Wheatstone would therefore seem to be the more advantageous for this amount of traffic.

If the traffic over one line amounted to a hundred words per minute in each direction the choice of system lies between :

1. Wheatstone automatic duplex.
2. Wheatstone automatic duplex with mechanical perforators.
3. Baudot four-arm duplex.
4. Wheatstone Creed automatic with mechanical perforators.

FOR TWO STATIONS

System	Approximate outlay	Approximate maintenance	Staff per shift	Equivalent staff
	£	£		
Wheatstone duplex .	250	20	18	16·4 (2 attendants, 8 transcribers, 8 perforators)
Wheatstone mechanical perforators . .	450	50	14	13·2 (2 attendants, 8 transcribers, 4 typists)
Wheatstone Creed mechanical perforators, duplex . . .	2,100	150	10	7·6 (2 attendants, 4 gummers, 4 typists)
Baudot four-arm duplex	1,200	120	18	13·2 (2 attendants, 8 keyboard operators, 8 gummers)

In this case, though the Creed costs more on outlay and maintenance, the saving in staff of the equivalent of five trained operators would amply counterbalance this additional outlay, even if, as is often found desirable, a complete duplicate outfit is installed in each station.

The advantage with ordinary Wheatstone automatic is that in times of stress the traffic dealt with could be doubled, whereas the Creed receiver can hardly be counted on ever to exceed a hundred words per minute. The advantage with Baudot is the greater ease with which errors can be rectified and the less elaborate mechanical apparatus employed. There is also less strain on the staff manipulating this apparatus.

A Baudot six-arm simplex, costing about £1,600, would deal with 180 words per minute and would employ fourteen men (six keyboard operators, six gummers and two attendants, equivalent to 10·4 trained operators, or possibly twelve keyboard operators and two attendants, equivalent to 11·6 trained operators). As no duplex balancing would be necessary in this case, this apparatus might sometimes be found more suitable than the Creed.

It will thus be seen that the choice really lies in every case between a Baudot and a Wheatstone, with or without a Gell or Creed additional labour-saving apparatus. At the present time, most Governments prefer the Baudot, either double, four-arm, or six-arm, mainly because of the greater simplicity of the apparatus required and the less strain thrown on the staff. But where rigid economy must be practised, assuming no serious difficulty in maintaining a duplex balance, and an efficient staff of mechanics, the economic advantage lies with the Wheatstone-Gell or the Wheatstone-Creed—the choice between these latter depending on the amount of traffic to be dealt with.

These last two systems have also one undeniable advantage, in that should the special apparatus fail, the stations can fall back on ordinary Wheatstone working without trouble, whereas should a Baudot plant fail, either hand-signalling must be employed or a complete spare Wheatstone outfit be installed.

In a country where the principal stations are so far apart that messages have to be re-transmitted at an intermediate station, the Creed apparatus has a distinct advantage over all other systems, inasmuch as the messages are received at the intermediate station on a perforated tape which is ready for passage through a Wheatstone transmitter to the distant station. The labour of re-perforating the messages is thus obviated.

CHAPTER XII

TELEGRAPH SWITCHING SYSTEM

THE object of a telegraph switching system is, temporarily, to connect directly two telegraph offices for the transmission of messages in order to save the retransmission otherwise necessary at the Central Office to which both circuits are connected.

The first system introduced was that known as the 'Umschalter,' or universal switch. This system consists of two series of insulated metal bars fitted at right angles to each other, each bar of one series crossing all the bars of the other. Connection between these bars is made by means of metal plugs inserted through and in contact with both bars at the crossing point.

The Telephone Exchange has modified one's views of telegraphic switching. Not only are fewer instruments used for the same number of local branch circuits in most central stations, but in London all metropolitan local circuits are brought to a large switchboard at the central office. This board is a 'multiple board,' arranged on what is known as the central battery system, that is to say, all the energy for working the circuits, both at the out-stations and in the central office, is supplied by one battery.

The board is divided into sections, each section consisting of two parts, one of which is again subdivided into three sections, called 'home sections'; and the other part is one panel called the 'multiple panel.'

The home sections and the multiple panels are made up of 'jacks,' mounted in strips. Under each jack on the home sections is fixed a small electric lamp, and under each jack on the multiple panel is fixed an indicator.

Each circuit controlled by the switchboard first goes to a test board, and from thence is taken to one particular jack on

one of the home sections and also to one jack on each of the multiple panels. Each line is therefore connected to one home section and to all the multiple panels.

The line is also permanently joined to the armature of a 'cut-off' relay, which, when the relay is not excited, connects the line to one terminal of the magnet of a 'line' relay, the other terminal being joined to the negative pole of a 24-volt battery. The positive pole of this battery is to earth. The armature of the 'line' relay, when the latter is excited, completes a circuit which causes the lamp under the corresponding jack on the home section to glow.

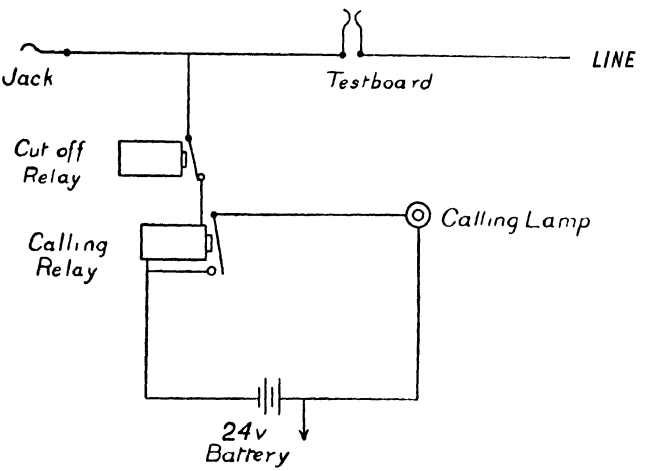


Fig. 144

Fig. 144 shows these connections. It will be seen that earthing the line at the out-station lights the lamp at the home section, unless the 'cut-off' relay is actuated. This lamp is termed the 'calling lamp.'

The 'jacks' (fig. 145) consist of two springs of unequal length and a collar or socket. The lines in all cases are connected to the shorter springs, the longer springs are connected to the negative pole of the 24-volt battery, and the collars are connected to one terminal of the electro-magnet of the 'cut-off' relay controlling the same line, the other terminal being connected to the earthed positive pole of the 24-volt battery.

This 'cut-off' relay when excited also completes by means of a second armature the circuit of the indicators on the multiple

panels, under the jacks connected to the same line, which then show white discs. These connections are shown in fig. 145.

The pegs (or plugs) which fit into these jacks consist of metal barrels with an insulated metal tip. The tip is connected to the insulated conductor in a cord attached to the peg. When a peg is in a jack this conductor is in metallic contact with the shorter spring of the jack, and therefore with the line. The barrel metallically connects the longer spring and the collar, thus completing the circuit from the battery through the 'cut-off' relay.

The pegs are coupled by the cords in pairs.

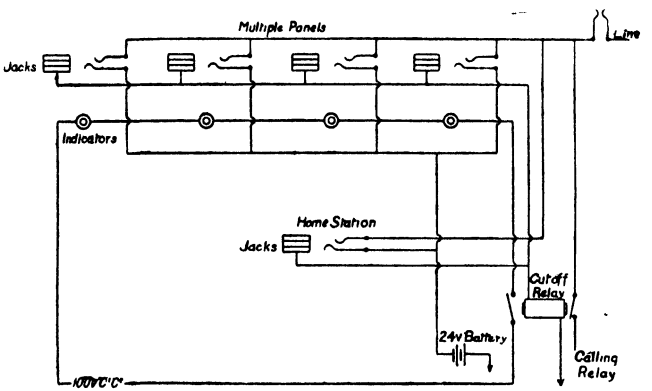


Fig. 145

Each operator, of which there are three to a section, is provided with a certain number of the cords and pairs of pegs.

In circuit with each cord is a 'speaking key,' a pair of translating relays, and a small electric lamp.

The speaking keys are for the purpose of bringing into circuit the operator's signalling key and receiving apparatus, in order that she may communicate with a calling office.

The translating relays are required for the intercommunication between stations.

The lamp is for the purpose of indicating when communication between stations is finished. It is called the 'clearing' lamp.

These connections are shown in fig. 146.

Each out-station equipment consists of a sensitive polarised sounder and Morse signalling key and a special plunger, which when depressed is held down by an electro-magnet, in which

case the indicator attached to the plunger shows a white star. These connections are shown in fig. 147.

The working of the system is as follows:

When the operator at an out-station wishes to communicate

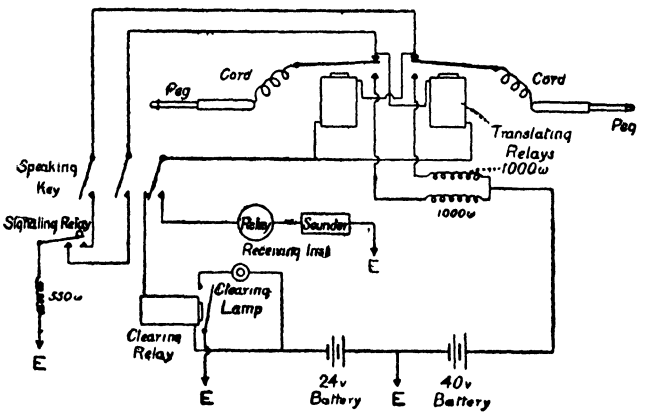


Fig. 146

with another station, he presses down his plunger. Under normal conditions a small current flows from the 24-volt battery through the line relay at the central office to the out-station

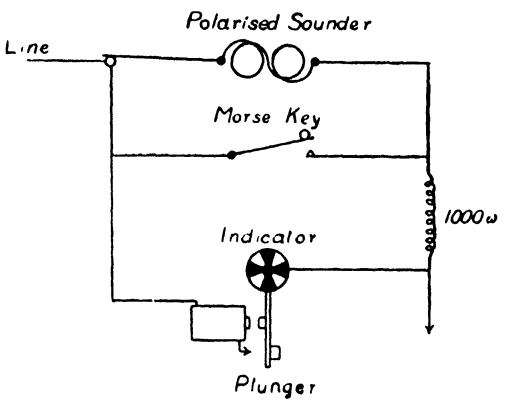


Fig. 147

polarised sounder, and a resistance of 1000 ohms to earth (see fig. 147). Both the relay and sounder are so 'biassed' as to be unaffected by this current. Immediately the plunger is depressed the resistance and sounder are short-circuited, and

the current increases sufficiently to actuate the line relay, and thereby causing the calling lamp to light.

The operator may, in place of depressing the plunger, work his key, which, by cutting out the polarised sounder, augments the current sufficiently to actuate the line relay. The working of the key thus makes the calling lamp flicker.

When the switchboard operator sees the lamp lighted she takes one of her pegs and places it in the jack immediately over the lighted lamp. As the peg is being inserted the tip touches the jack collar. This momentarily causes a current to flow through the 'cut-off' relay, which then opens the line circuit and releases the plunger at the out-station. This notifies the operator at the out-station that his call is being attended to, and he then commences to call the station required with his Morse key.

The switchboard operator having pushed her peg home, the calling lamp is extinguished and the indicators of that line on all the multiple panels are actuated and show white discs; she then puts over her speaking key and brings her sounder into circuit. Upon hearing what station is wanted she takes the other peg on the cord to which the one in the jack is fixed, and pushes that peg into the jack on the multiple panel which connects to the line now required, unless the indicator under that jack shows a white disc. When this peg is inserted, the indicators on all the multiple panels connected to that line are energised and show white discs.

This operation puts the out-stations in direct communication, and on the multiple panels both lines are indicated as 'engaged.'

When these connections are completed and neither station is working, a permanent 'spacing' current flows out to both stations through the 'clearing' relay and the pair of non-polarised translating relays, each of which is biassed against this small current. Each time the key at station A is pressed down, the current flowing through relay 2 is augmented, and this relay is sufficiently energised to attract its armature, thus sending a current from the 40-volt battery direct to the out-station B. When B is sending, relay 1 is actuated, and currents from the 40-volt battery are transmitted to A. The clearing relay is unaffected by these working currents.

When communication is finished both stations depress their

plungers; this augments the spacing current sufficiently to actuate the clearing relay (see fig. 146) and causes the 'clearing' lamp to glow; the operator then removes the pegs from the jacks, releasing the plungers at both stations as before by the peg tips touching the jack collars, thus notifying the out-stations that their lines are clear.

Special Apparatus

Every operator's section on the switchboard is provided with a special 'engaged' test-peg and lamp. These are only intended for use in the event of a failure of the indicators on the multiple panels from any cause.

The apparatus is simply a peg connected to one terminal of a glow lamp, the other terminal being earthed. If the peg tip is put against the collar of a line jack when the line is engaged the test lamp glows, the collars being connected to the negative pole of a battery, the positive pole of which is earthed; but if the line is disengaged the lamp is unaffected, for no peg being in any jack connected to that line the collars are not 'alive.'

In the common lead from the battery to the calling and clearing lamps is placed a 'pilot' relay, its function being to light a pilot lamp—of which there is one to each section of the board—or to ring a night bell in order to attract attention to a call during the slack time, when one operator is working several sections. A three-position switch is inserted, so that either the bell or the lamp may be in circuit, or neither of them.

Fuses are inserted in all circuits at convenient points, for the protection of apparatus in the event of short circuits occurring.

Continental cities are adopting similar apparatus. At Brussels the board is provided with indicators for calling and for ringing-off as in a telephone switchboard. In addition, when two circuits are in connection, lamps are illumined to indicate to the operators at the board that the circuits are engaged. When a call is received for connection to another line, as there are two commutator or operators' positions, it is necessary to test whether the circuit is free. This is arranged to be done by aid of the head on one plug of a pair, and a relay which is caused to come into action and ring a bell if the line is available, the plug being inserted part way into the jack, and thrust home when such intimation is given. The introduction of the switching system

has permitted the reduction of instruments in the Brussels Central to 53 for 121 lines and has secured the highest economy in the staff, as no idle moments need exist, the operators at the board switching on circuits which work Brussels, to any instrument that is available at the moment. The staff is thus reduced to the smallest number requisite for the traffic. There is also a saving of work in joining direct offices of small traffic, which formerly would have exchanged their messages through the medium of the Brussels Central. Further, supervision is rendered less costly, as the board affords knowledge of all that is going on, of vacant and of occupied lines and instruments, and of the time taken up in the exchange of telegrams.

CHAPTER XIII

THE TELEPHONE

THE telephone is an instrument employed for the reproduction of speech at a distance. The history of the development of the electric telephone is full of absorbing interest, but the scope of this work does not allow of more than the briefest reference to a few of those who have taken part in the evolution of this important branch of practical electrical science. The production of sound by electrical means, which was shown by Page in 1837 to be possible by transmitting a rapid succession of currents round the coils of an electro-magnet, seems to have excited the conception of the electrical transmission of speech. Farrar in 1851 and Bourseul in 1854 pointed out that the transmission of sound would be possible if a piece of apparatus could be devised which would be affected by the impact of sound waves in such a way as to vary the strength of an electric current. Philip Reis of Fredericsdorf in 1861 was the first to put the idea into actual form. He fully grasped the conditions of the problem, studied the action of the ear, and devised an instrument that actually reproduced speech ; but it was reserved for Graham Bell to produce a really practical and commercial instrument (1876). Before describing this piece of apparatus it is desirable to consider what sound is, and how it is transmitted from one body to another. The word ' sound ' is commonly used to denote the physiological sensations conveyed to the brain through the organs of hearing ; it is, however, frequently employed to denote the actual cause of the effect upon the ear. When any body—a tuning fork or stretched string, for instance—is made to vibrate rapidly it emits sound ; therefore, sound must consist of a series of vibrations, and when these vibrations reach the ear we experience the sensation

of hearing. How these vibrations are transmitted to the ear will be best understood from the following analogy. Imagine a number of small balls to be placed in line upon a smooth table ; then if the ball at one end be struck smartly, it will collide with the one next to it, and its motion, thus transmitted to the second, will in turn pass to the third, and so on until the last ball is reached, and that being free will move clear of the rest of the balls, showing that the impulse has been propagated from one end of the row to the other by successive transmission from ball to ball. In the case of vibrations transmitted from a body emitting sound to the ear, the intervening particles of air or other medium react upon one another in a manner similar to that of the balls in the foregoing example ; thus : suppose a tuning fork to be set in vibration and consider one limb of it ; when this limb moves to the left the air particles in immediate contact with it on that side are struck by the fork and tend to move away from it ; in so doing they strike against the next air particle, which in turn strikes the third and so on ; the compression of the air particles travelling outward from the limb. Meanwhile the fork has changed its direction of motion, and is now moving to the right ; this will cause the air particles to follow it by virtue of the pressure of the air on the side remote from the limb of the fork ; there will consequently be a rarefaction of the air particles following each compression, and these alternate compressions and rarefactions will be kept up as long as the fork continues to vibrate. Such motions are known as *waves* of condensation and rarefaction. That sound is transmitted by the particles of air is conclusively proved by placing the vibrating body *in vacuo*, when no sound will be heard, the inference being that the absence of sound is due to the fact that there is no material in contact with the vibrating body to take up the vibrations.

When the vibrations of a body are regular the sensation produced upon the ear is pleasing, and we say that such a sound is *musical* ; but if the vibrations be irregular the sensation is more or less disagreeable, and we call such a sound a *noise*. We are chiefly concerned in the former, since the sounds produced in the act of speaking consist principally of a rapid succession of various musical notes.

The character of a musical note depends upon three conditions : (*a*) pitch, (*b*) timbre or quality, (*c*) intensity. The *pitch*

of a note varies as the rate of vibration of the body emitting the note; the higher the rate of vibration the higher the pitch of the note. The *quality* of the note depends upon the nature of the body which is vibrating; for instance, the same note may be obtained from a violin string as is obtained from a flute, but there is a marked difference in the quality of the sounds. The *intensity* or loudness of a musical sound depends upon the amplitude of vibration of the body emitting it. Any piece of apparatus used for telephone purposes must therefore be capable of reproducing these three acoustic properties.

Turning now to the electrical conditions, when a piece of iron placed near to the pole of a magnet has its position with respect to the magnet-pole changed ever so slightly, a redistribution of the magnetic field takes place; and if a coil of wire be wound around the magnet pole this redistribution of the lines of magnetic force will cause a current of electricity to be induced in the coil; the current being in one direction when the iron approaches, and in the reverse direction when it recedes from, the magnet-pole. If the iron be made to vibrate in the direction of the axis of the magnet there will be first a current in one direction and then one in the other direction for every vibration of the iron. The frequency of the reversal of the current is the same as the frequency of the vibrations of the iron, and the strength of the induced current depends upon the number of magnetic lines of force cutting the coil in a given time; that is to say, the current induced varies as the amplitude of vibration of the iron. Conversely, if currents alternating in direction be sent through the coil they will alternately strengthen and weaken the pole of the permanent magnet and thus vary the attraction exerted upon the iron, which will therefore vibrate once for every alternation in the current flowing through the coils. If these facts be borne in mind no difficulty will be experienced in comprehending the action of Graham Bell's telephone.

This telephone in its first practical form is shown in plan by fig. 148. A is a compound permanent magnet of the horseshoe type, each pole being fitted with a soft iron extension part of which forms the core of an electro-magnet shown at C. The coils are joined in series in the usual way, and the free ends brought out to terminals. Immediately in front of these polarised cores is a thin flexible soft iron disc D fixed about its periphery to a

wooden support, which is recessed slightly to allow the disc to vibrate freely. Through the wooden support and opposite the centre of the disc a hole is cut into which is fitted the mouthpiece M; the whole arrangement being placed on a wooden base. The action is as follows: the sound waves entering the mouthpiece impinge upon the iron disc, which, being somewhat elastic, takes up the vibrations, thus causing the distance between the poles of the magnet (i.e. the soft iron cores) and the disc to vary. As already explained, this will cause undulatory currents in the coils which, as they correspond exactly with the varying motions of the disc, coincide also with the condensations and rarefactions of the originating sound waves. It is obvious that if these undulatory currents be allowed to pass through the coils of a second instrument similar in every respect to that just described, the fluctuations produced in the magnetic field will cause the iron disc to vibrate in the same manner as the disc in the first

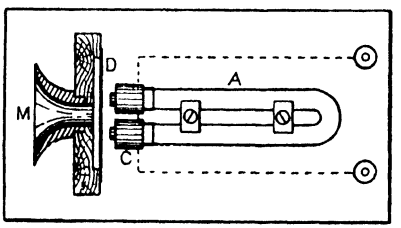


Fig. 148

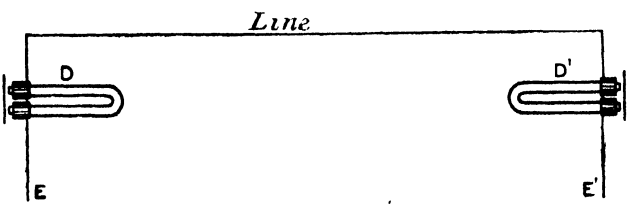


Fig. 149

instrument, and if the ear be placed opposite the mouthpiece the vibrations of the disc will be communicated to the ear. Since the sounds thus produced must be exact reproductions of the original sounds, the words spoken at one instrument will be distinctly heard at the other. With such an instrument Bell succeeded in speaking along a wire more than sixteen miles in length. The arrangement of two such telephones is shown in fig. 149. The instrument of the present day differs only in detail from the one already described, and is shown in partial

section in fig. 150. The case is of ebonite,[1] circular in cross-section, and the coil connections are made to the brass blocks shown at the lower end of the case, where also the screw which holds the permanent magnet in position is seen. This screw also clamps the brass loop which forms a convenient fixing point for the flexible cord carrying the external connecting wires and thus prevents any strain being put upon the connection wires themselves should the instrument fall. The soft iron cores are arranged to approach very near to the iron disc. This disc or diaphragm, as it is termed, is clamped by the mouthpiece of the instrument.

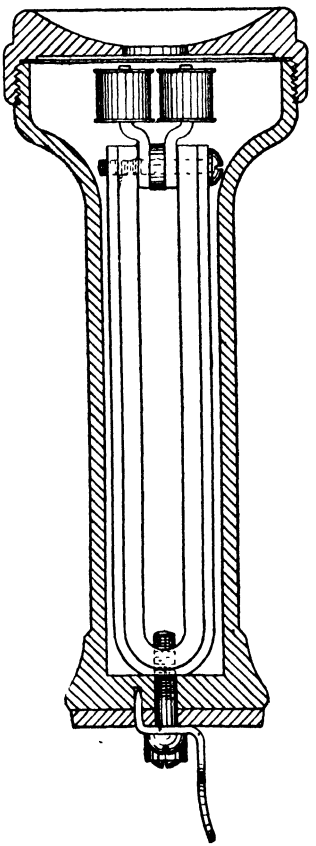


Fig. 150

It will be noticed that in the arrangement shown in fig. 149 there is no battery; there is no accessory apparatus whatever. The two instruments are reversible; they may be transmitters and receivers in turn. When D is held before the mouth to transmit speech, D′ should be held against the ear to receive the spoken words. Simple and beautiful as this apparatus is, it has one serious defect: the electromotive force induced by the movement of the disc D is of microscopic strength, while the resistance opposed to it is necessarily comparatively high, and the sounds reproduced are consequently a mere echo of those transmitted. It is evident also that the first disc, D, is able to take up only a portion of the sonorous vibrations of the speaker: and in this way also much of the actual energy of the voice is lost. Hence it is essential for practical purposes to devise some means of raising the electromotive forces causing the currents to flow through the line.

[1] Or often of drawn brass enamelled or with a thin ebonite sheath.

Edison did this in 1877 by the invention of the first form of carbon transmitter. This transmitter is constructed as follows: A disc of carbon is clamped between two platinum discs which act as electrodes. One electrode is fixed to a soft iron diaphragm by a cork pad, and the other banks against a screw passing through the framework of the instrument and by means of which the pressure on the carbon disc or button may be varied. Now when the diaphragm vibrates due to the impact of sound-waves upon it, a varying pressure upon the carbon will result, and the variation will correspond with the pitch, quality, and intensity of the sound producing the vibrations. As the pressure upon the surface of the carbon varies, so will its electrical resistance; and if a current be flowing through the carbon its strength will vary with the resistance, and therefore also with the sonorous vibrations impinging upon the diaphragm.

The function of the carbon transmitter is therefore restricted to the production of variations of electrical resistance in the circuit, which variations cause proportionate inverse variations of current; that is to say, an increase of resistance will produce a proportionate decrease of current, and a decrease of resistance a proportionate increase of current. Now, for a given movement of the vibrating disc the actual change in resistance will have a given value whatever the total resistance of the circuit may be, and in order that this change may produce its maximum effect it is necessary to make the total resistance as small as possible. For instance, assuming the change in the resistance of the carbon transmitter for a given movement to be one ohm, then, if the total resistance of the circuit be (say) 5 ohms, the variation in the strength of the current will be $\frac{1}{5}$, but if the total resistance be 1000 ohms the variation will be only $\frac{1}{1000}$, and in order that the same effect might be produced upon the receiver in each case the normal strength of current in the latter case would have to be two hundred times that in the former. Such an increase would be clearly impracticable. Acting upon a plan already used by Elisha Gray in 1874, Edison got over this difficulty by applying an induction coil to his transmitter.

The induction coil consists of a core made up of a bundle of soft iron wires surrounded by a few turns of thick 'primary' wire, and over this many turns of thin 'secondary' wire. If a steady current pass through the primary wire the core is magnetised and the two wires are in a magnetic field. So long

as this field remains constant no effect is observed in the secondary wire; but if, by varying or stopping the primary current, this magnetic field is changed, then a momentary current will be induced in the secondary wire, assuming, of course, that that circuit is complete. Now, as each turn of wire in the coil is in the same magnetic field, the electromotive force (E.M.F.) induced in each turn will be equal, and the total E.M.F. at the ends of the coil will be in proportion to the number of turns. Thus with a comparatively low electromotive force in the primary circuit it is possible to get momentary secondary currents due to a very high E.M.F.

The application of the induction coil to telephonic transmission is shown in fig. 151. B is a Leclanché battery which

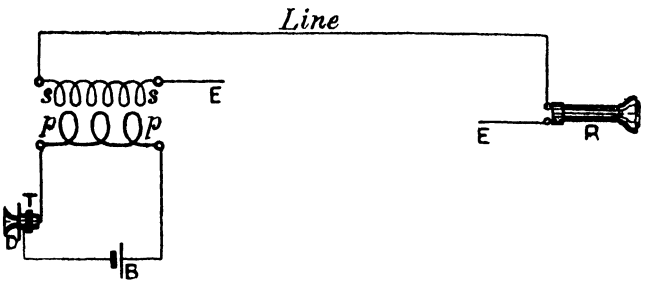


Fig. 151

is joined in circuit with the transmitter T and the primary wire *p p* of an induction coil. The total resistance of this circuit is very low, being made up of the resistance of the battery, the primary wire (less than 1 ohm), and the telephone transmitter itself. These constitute the sole resistance of the transmitter circuit, quite irrespective of the length of the line. Hence variation in the resistance of the transmitter itself will have a very considerable effect on the strength of the current in the primary wire.

One end of the secondary wire (*s s*) of the induction coil is put to earth, and the other is connected to the line-wire, which at the distant end is connected through a Bell telephone, R, to earth. Now, when everything is quiet a steady current flows through the primary wire, and no current flows through the line-wire; but if there be any variation in the primary current, then for every increment in that current there will be a secondary

current flowing through the line in one direction, and for every decrement there will be a secondary current in the reverse direction. Moreover, these secondary currents will vary exactly in number, form, and strength with the variations of the primary current, and as this varies in exact ratio with the sonorous vibrations impinging on the disc D, it follows that these currents will produce the same effects upon the Bell receiver R as the currents induced by the Bell transmitter.

But, as was just shown, these secondary currents are due to an electromotive force which is very high compared with that

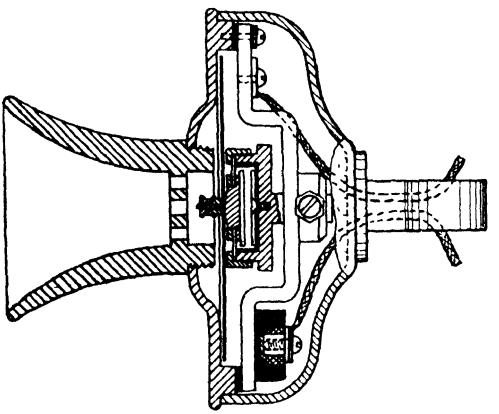


Fig. 152

which gives rise to the induced currents of the Bell instrument when used as a transmitter; and hence the total resistance in the secondary or line circuit is a matter of smaller importance. The Bell instrument is now used solely as a receiver.

Prof. Hughes discovered another property due to the influence of sonorous vibrations which has still further improved telephonic operations. It is that if two conducting bodies lie against each other in loose contact, and a current of electricity flows through them, there will be resistance at the point of contact, and their vibrations will vary this resistance in exact ratio to the cause producing the vibrations. Metals and all conducting substances are subject to this effect, but carbon, probably because it is inoxidisable, is the best material, and although strenuous efforts have been made to produce a telephone

transmitter without using carbon, no other material has been found to answer as well. This effect is so sensitive that Prof. Hughes was able with his *microphone* to render evident sounds that otherwise were absolutely inaudible.

The most common forms of carbon transmitter in use at present are the 'solid back' (fig. 152) which is used in all fixed transmitters, and the 'capsule type' (fig. 153) which is used in hand micro-telephones.

In each of these transmitters, carbon discs are used as diaphragms, and these are separated from a back carbon block by a space which is filled with carbon granules, loosely packed.[1] The diaphragm is connected to one pole of the local battery and the back block to one terminal of the primary winding of the induction coil, the other terminal of this winding being connected to the other pole of the battery. A circuit is thus completed by the carbon granules. When the diaphragm is caused to vibrate in unison with sound waves, the resistance of these carbon granules, and therefore the current flowing in the local circuit, varies correspondingly. This impresses similarly pulsating current of higher potential in the secondary of the induction coil and on the line which is connected therewith.

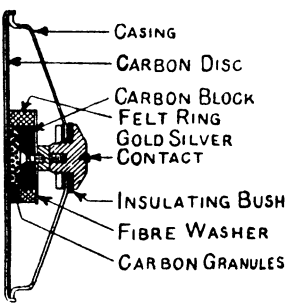


Fig. 153

In all instruments at the present time the receiver when not in use hangs on a hook carried by a pivotted arm. In the position then taken up by this arm the local circuit is broken. As soon as the receiver is removed, the arm is pulled up by a spring and the local circuit is closed.

With telegraphic circuits, the universal practice is to use a single line wire with an earth return. This, however, is found most undesirable with telephone circuits. Even with two telephones connected over a short distance, where an independent overhead line is used, poor speaking, extraneous noises, and various other troubles are likely to occur. When more than one circuit is run on a line of poles, the use of an earth return

[1] In fig. 152 the diaphragm is of metal and carries a separate carbon block fixed to the centre.

is fatal, so far as satisfactory conversation is concerned. The first rule of telephone communication should be that each circuit must be metallic, that is, there must be two wires between each subscriber's telephone and the exchange.

The essential feature of a telephone system is *the exchange*, whereby any one telephone instrument (generally called a station or a subscriber) can be connected to any other telephone instrument in the system. Each station has two wires (generally known as the line) entering the exchange, and normally these wires must be connected to some indicator, to enable the user of a station to call up the exchange whenever he wishes to be connected to any other station. Means must also be provided at the exchange so that the operator can call up any one of the subscribers.

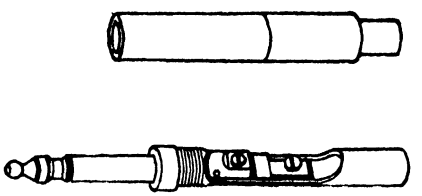


Fig. 154

The simplest method of doing this is to supply each station with a magneto generator (MG, fig. 155), and to terminate the two ends of his line L_1 L_2 on an electro-magnet (called an indicator —D, fig. 155) at the exchange, the armature of which, when attracted, releases a small flap or shutter, which falls and attracts the attention of an operator when that subscriber calls, i.e. turns the handle of his magneto generator. The operator is provided with '*cord circuits*' which consist of two *plugs* (fig. 155) the tips of which are insulated from the sleeves, both tips and both sleeves being connected by two insulated conductors. Fig. 154 shows a more elaborate plug with three separately insulated parts, the 'tip,' the 'ring' and the 'sleeve.' These are used for multiple boards. With plain magneto boards the 'ring' is not required. A two-way double pole switch, known as the 'ringing and speaking key' (fig. 155), is inserted in these two cord conductors, and so arranged that when the handle is pushed over in one direction, a magneto generator in the exchange is bridged

across the two conductors, and when the handle is pushed over in the other direction the operator's telephone is brought into circuit. When the handle is vertical the conductors are 'through.' A 'jack' (J, fig. 155) is fitted underneath each indicator, and consists of two pairs of springs carried by a cylinder or bush, each spring of one pair making contact with one spring of the other pair. The two line wires are terminated on the outer pair of springs, and the other pair is connected to the terminals of the indicator. Every line is thus normally connected to an indicator.

When a subscriber turns the handle of his magneto generator, his indicator shutter drops. The operator then inserts one of

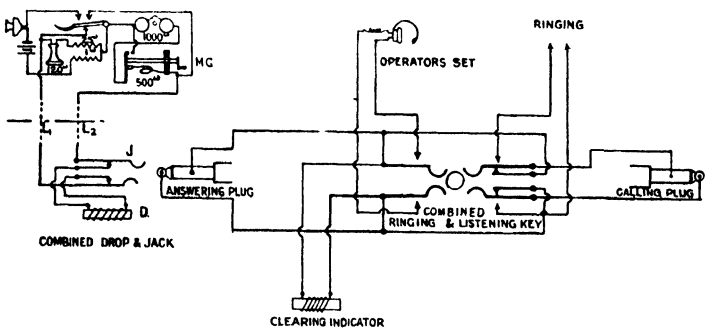


Fig. 155

a pair of cord plugs into the jack underneath that indicator. This plug disconnects the calling line from the indicator and connects the line to the cord circuit (fig. 155); she then pushes over the switch handle so that her telephone is brought into the circuit, and is thus able to speak with the calling subscriber, and to learn what is wanted. On ascertaining the required number, the operator inserts the second plug of the same cord circuit into the jack of the wanted subscriber, pushes over the switch handle to the opposite position, and turns her magneto handle to ring his bell. She then returns the switch to normal position, leaving the two subscribers connected through. If she wishes to know that the subscribers are in proper communication, she switches in her telephone.

The operator also wants to know when the conversation is finished, so that the cord circuit may be used for another connection. For this purpose another indicator (the clearing or

supervising indicator) is fitted across the cord circuit. When the subscribers have completed their conversation, they are expected to again turn their magneto handles; this actuates the clearing indicator and gives notice to the operator that she can withdraw the plugs. This is substantially the arrangement for all plain magneto boards.

The shutter of a line indicator falls by gravity when the armature, being attracted, releases the catch holding up the same.

For magneto systems, the subscriber's apparatus includes the transmitter and receiver, a call bell, a magneto generator, and two Leclanché cells; also a lightning protector and fuses. The former is often mounted on the instrument, whilst the latter are fitted at the point where the lines enter the house. For many reasons it would be far better to insert both the fuses and the lightning protector at this point, and thus obviate the possibility of lightning causing damage in the house. The latest practice is to combine lightning protectors, fuses and heat coils on one block, which is fixed at the point of entry of the line.

In what is known as the '*ring through*' system, the calling subscriber is informed by the operator when the connection is made, and he then rings up the wanted subscriber himself. For clearing in this case each subscriber's instrument is provided with a press button, which, when pressed, actuates a special indicator in the exchange.

It is obvious that though one operator can only attend to a certain number of calling subscribers, she may want to connect any one of these subscribers to any other line in the exchange. Normally one operator can take charge of 100 subscribers, but the exchange may contain 1000 subscribers or more, any one of which must be within reach. This necessitated the introduction of what is known as the *Multiple Board.*

A multiple board consists of several operators' sections. On the shelf in front of the operators are arranged 12 or 15 pairs of cords, each pair terminating in two plugs and containing the ringing and speaking key and a clearing indicator. Above this shelf is a row of the clearing indicators, one for each cord circuit. Above these again are the 100 or so local indicators, that is the indicators on the subscribers' lines dealt with by this operator. Above these indicators are the 100 or so local jacks to which

the same 'local' lines are connected. Above these again, usually spread over every 3 operators' positions, is a set of the 'multiple' jacks for the whole number of subscribers in the exchange. Fig. 156 shows the multiple jack connections for the line A B. To enable an operator to find out whether the wanted subscriber is already engaged, each jack is fitted with a fifth insulated spring (*c*), which normally presses against the jack bush. A metallic strip runs the full length of the board closely adjacent to each row of multiple jacks. This is connected to an earthed battery. When a plug is inserted into any one of these jacks, the fifth spring is forced into contact with this

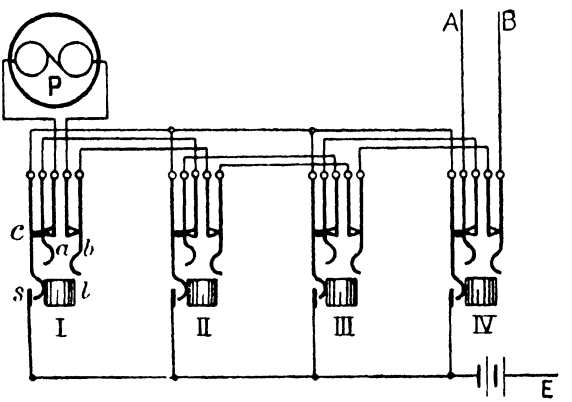


Fig. 156

metal strip. These fifth springs of every multiple jack serving one subscriber's line are all connected together. Therefore, if any line is engaged, all these springs and all the jack bushes serving that line are earthed through the local battery. The middle point of the coil in each operator's receiver is also earthed. If therefore she touches a jack sleeve of an engaged line with the tip of a plug, a circuit through this receiver is completed, and she hears a 'click.' This indicates that the line is already engaged.

In order to overcome the labour of returning each actuated indicator shutter to the normal position by hand, the *mechanically restored indicator* has been introduced. With this indicator the movement of the plug entering the jack lifts a lever which returns the shutter to its vertical position, fig. 157.

This necessitates the indicator and corresponding jack being

close together; these boards therefore have alternate horizontal rows of jacks and of indicators.

Mechanically restored clearing indicators have also been introduced, the motion of the plug and cord to its normal position on the shelf being utilised for this work.

The next important advance in the exchange board equipment was the introduction of the *Central Battery* system and the use of incandescent lamps as indicators, but as this system also led to the use of lamps on the magneto type of board, it will be better to describe this last equipment first.

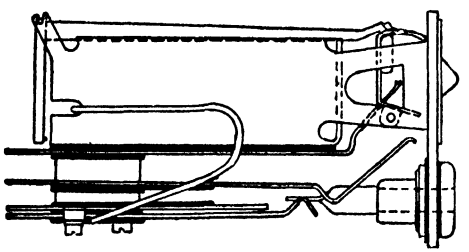


Fig. 157

To adapt lamp signalling to these boards, the ordinary indicators are replaced by relays, usually mounted on special racks. These relays have two windings, one (1000ω resistance) connected

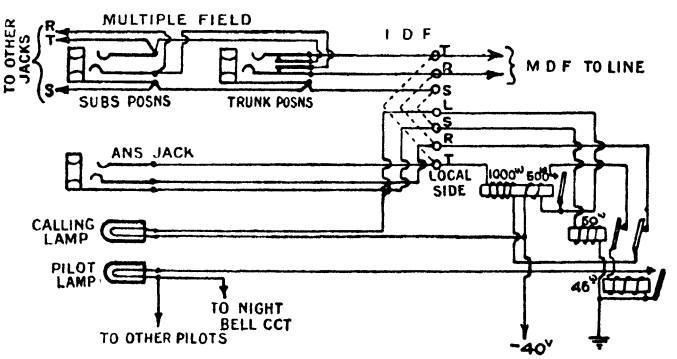


Fig. 158

to the subscriber's line known as the 'line coil,' the other (500ω resistance) to a local battery, the circuit of which is completed when the armature is attracted; this is known as the 'holding coil.' The armature also completes, when attracted, a second circuit, in which is connected a lamp fitted on to the board in place of the indicator. When the operator inserts her plug, a second relay (50ω resistance)—the 'cut-off' relay—is energised, the armature of which in its 'off' position is included in the

holding coil circuit, and when this armature is attracted the circuit of this line relay holding coil is broken (fig. 158). The insertion of the plug also disconnects the subscriber's line from the calling relay.

For clearing, a relay and lamp can be used connected across the cord circuit, actuated by the subscribers' magnetos, but sometimes an automatic arrangement is introduced. One method is to insert in the cord circuit a relay with two windings, one coil terminal being connected to one of the two cord conductors (fig. 159) and the other terminal to earth, the second coil being connected to the other conductor and to an earthed battery. When the plug is inserted in a jack, if the subscriber's receiver is off the hook a circuit is completed, from the positive pole of the battery through one winding of this clearing relay out to line, through the subscriber's induction coil and receiver, back by the other line, through the other winding of the relay to earth and to the negative pole of the battery. This attracts the armature of the clearing relay, which, as it forms part of a lamp circuit, then breaks that circuit. When the subscriber returns his receiver to the hook, he disconnects his line circuit and breaks the relay circuit, the armature falls back and the lamp lights. If condensers are inserted in both conductors of the cord circuit, two clearing relays can be provided, one for each subscriber; the operator is thus able to supervise the working of both lines, having an indication of the moment the called subscriber answers the telephone and of the time each subscriber returns his receiver to the hook.

This automatic clearing system with lamps can be used equally well on lamp signalling boards or on ordinary or on mechanically restored magneto boards. The great advantage of this system is that in many places subscribers will not trouble to ' ring off,' i.e. to give notice when the conversation is finished. By utilising the automatic arrangement, the subscriber is saved this labour, and the operator knows at once when the cord circuit is no longer required. By this means it is possible to reduce the proportion of cord circuits to local subscribers. It must, however, be borne in mind that, to ensure satisfactory working with this system good insulation must be maintained on the lines.

The Central Battery system is the most advanced system employed on manual boards, and undoubtedly simplifies the

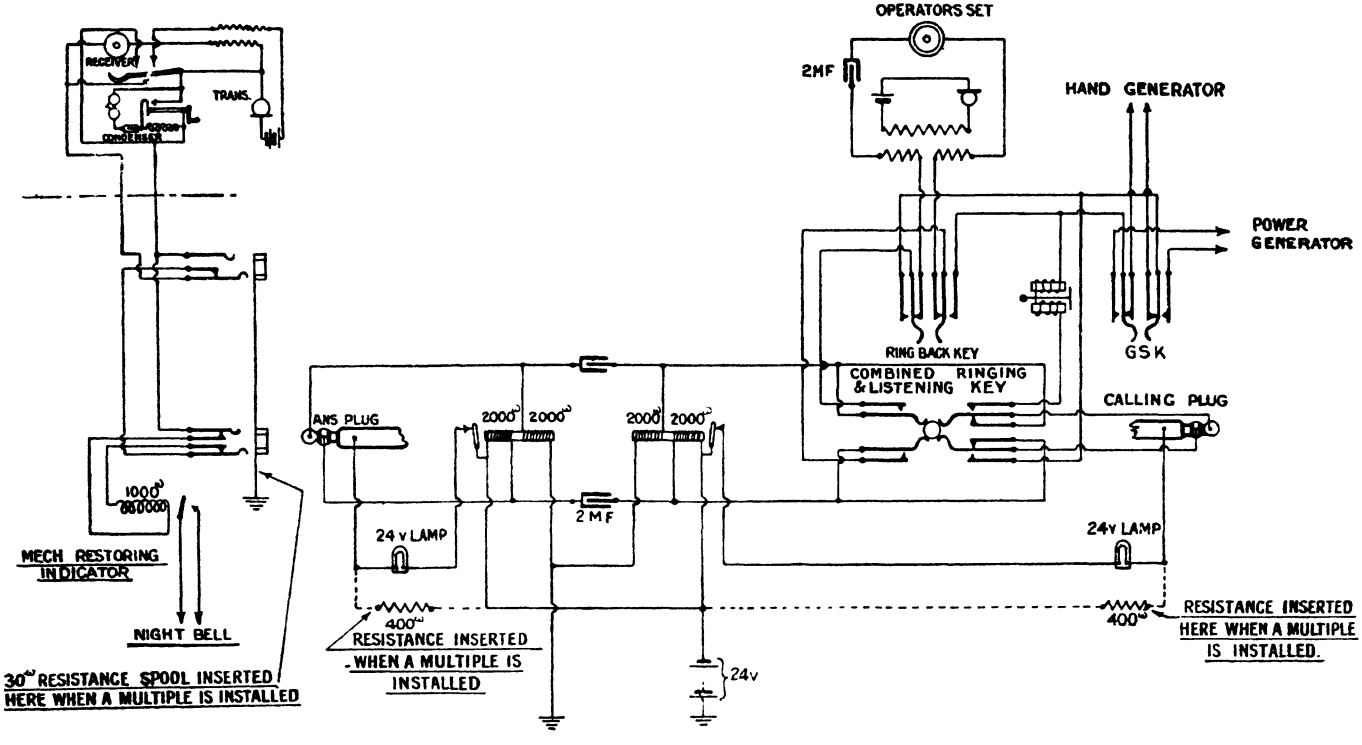

OPERATORS SET
2MF
HAND GENERATOR
POWER GENERATOR
RECEIVER
TRANS.
CONDENSER
RING BACK KEY
COMBINED RINGING & LISTENING KEY
GSK
CALLING PLUG
ANS PLUG
2000Ω
2000Ω
2000Ω
2000Ω
1000Ω
2MF
24v LAMP
24v LAMP
MECH RESTORING INDICATOR
NIGHT BELL
400Ω
RESISTANCE INSERTED WHEN A MULTIPLE IS INSTALLED
400Ω
RESISTANCE INSERTED HERE WHEN A MULTIPLE IS INSTALLED.
24v
30Ω RESISTANCE SPOOL INSERTED HERE WHEN A MULTIPLE IS INSTALLED

Fig. 150

method of connecting subscribers together, of calling, and of clearing. In this system the subscriber's station consists simply of a receiver, a transmitter and bell, with the usual switch hook for connecting the local circuit when the subscriber lifts off his receiver. Fig. 160 shows the connections in the subscriber's station. When disengaged the two lines are bridged by the bell, the transmitter and receiver being disconnected. On lifting off the receiver the line is connected through the receiver

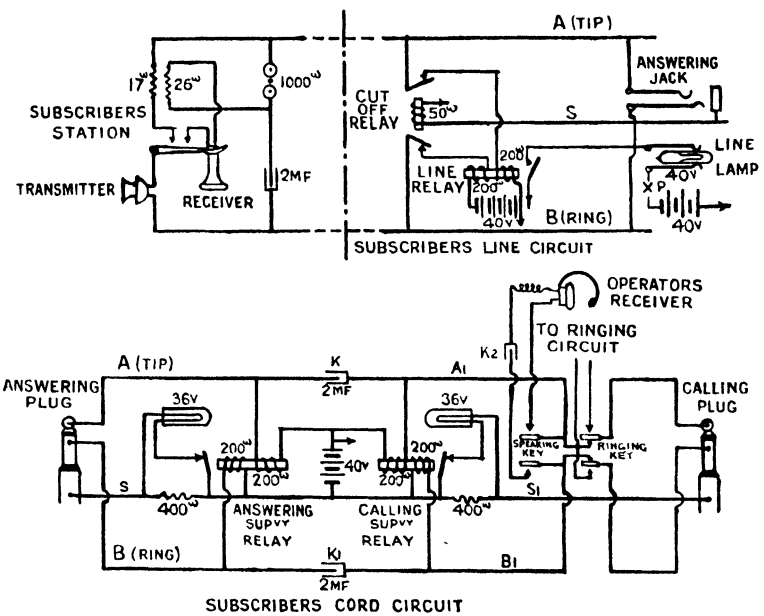


Fig. 160

and induction coil. It will be noticed that a condenser (2 mf.) is inserted in the bell circuit.

At the Exchange, each line is connected through a 'line' relay to a battery. No current flows so long as the bell is in circuit, as the condenser is also included; but immediately the receiver is lifted off the hook, the circuit *via* the induction coil is 'through,' the relay is then actuated, its armature attracted, and the calling lamp circuit on the board completed; the lamp then glows. In the line relay circuit is also inserted the armature of a cut off relay. The jacks on the boards have two springs only. The line is connected to the two springs (fig. 160).

The coil of the cut off relay is connected, one terminal to the jack bush of that particular line, the other terminal to earth.

On these boards the cord circuit has three conductors, and the plugs have three insulated portions known as the tip, the ring, and the sleeve, each pair being interconnected (fig. 154).

Taking the Peel-Conner circuit as the simplest (fig. 160), the conductors joining the two plug tips and the two rings are broken only by condensers and the speaking and ringing key. In the third conductor joining the plug sleeves are inserted two 400$^{\omega}$ resistance coils. Across these coils are connected the two supervisory or clearing lamps, one lead to each lamp being completed by the armature of the supervising relay. These relays are wound with two coils, one bridged across between the conductor joining the rings, and the conductor joining the sleeves; the other is bridged similarly between the conductor joining the tips and the negative pole of the battery, the positive pole of this battery being connected to the centre of the conductor joining the sleeves. As soon therefore as a plug is inserted into a jack, a circuit is completed through the relay nearest that plug (the subscriber's receiver being off the hook) and the supervising lamp is extinguished. The called subscriber's receiver being on the hook, its supervising lamp circuit is complete, as this circuit is completed through the armature of the 'cut off' relay whilst in its 'off' position, and the lamp is illumined. But as soon as this subscriber lifts his receiver off the hook, the relay circuit is completed and the lamp is extinguished.

The Western Electric circuit is somewhat similar, but instead of condensers being inserted in the line, two repeaters or transformers are used and inserted between the battery and the lines (fig. 161). Also the conductor joining the tips has two non-inductive shunts bridging the supervisory relays, instead of the supervisory lamps which are now in the sleeve conductors. Other manufacturers have other modifications, but these two circuits show clearly the principle of the system.

As a rule the local jacks and the local lamps are mounted in strips of ten, and the strips of local jacks and local lamps are fixed alternately. The multiple jacks are mounted in strips of twenty.

Usually all the relays are mounted on separate frames apart

from the board itself, so as to simplify the wiring. Even then this work is of a distinctly complicated nature.

The overhead wires or underground cables are terminated on a *main distributing frame*, which also carries fuses, heat coils and carbon lightning arresters for the protection of the exchange. Connections from that frame are taken to an intermediate distributing frame, and all the cables from the local and the multiple boards are also terminated on this frame. The main object of this intermediate frame (I.D.F.) is to provide a convenient point for the re-distribution of lines so as to equalise an operator's load. An operator's load is taken to be the maximum number of calls she can handle during the busy hour—which is normally about 250. But some busy subscribers may make ten or even twenty

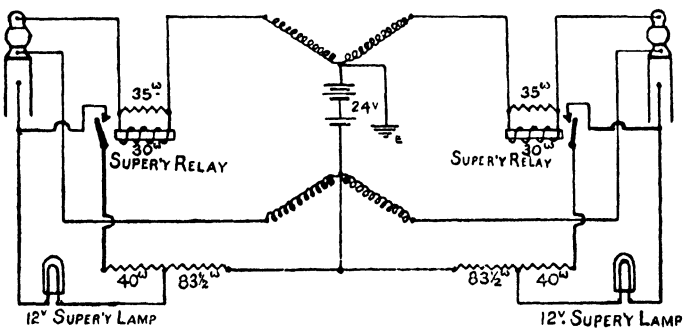


Fig. 161

calls in the hour, others not more than one or two. As an operator serves some 100 lines, it would obviously be impossible to handle 100 busy subscribers, they must therefore be sorted out so that one operator has a certain proportion of busy ones and non-busy ones. Further, as any subscriber's calls must vary according to his business, there can be no final adjustment of subscribers and operators, so constant changes must be made. This work is done at this intermediate frame. The subscribers' lines all terminate on one side of the frame, and also the multiple connections; the local connections are brought to the other side. By using what are called ' jumper ' wires, any subscriber can be connected to any local jack. It is of no consequence to an operator what subscriber she is dealing with. A lamp lights, the plug is inserted, the wanted number ascertained, and the other plug is inserted in the corresponding multiple jack. These multiple jacks are never altered and run in sequence with their numbers.

Secondary batteries are invariably used with Central Battery systems, usually giving 24 volts, though in several cases at the present time 40 volts are used in preference. This one battery actuates all the apparatus on a board and also supplies the current for speaking. Calling a subscriber is done by an alternating current supplied by a motor-generator which actuates the bell notwithstanding the presence of a condenser in the circuit.

The use of meters for registering subscribers' calls is largely coming into use. On Central Battery boards a key is provided in each cord circuit for this purpose. The meter is an electro-magnet, the armature of which is attracted when the key is pressed and in its movement actuates a wheel carrying an indicator, which rotates a disc marked in units; this is geared to a train of wheels actuating other discs for the

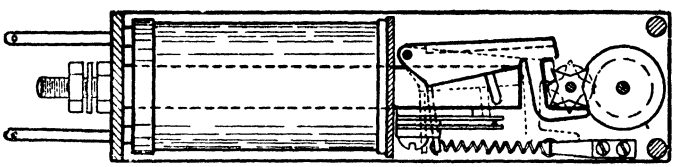


Fig. 162

tens, the hundreds, and the thousands (fig. 162). Usually the meter is connected between the battery and the sleeve conductor in the cord circuit, and as soon as a call is through the operator presses the key which actuates the meter.

With a Central Battery system it will be noted that a potential is invariably on the subscribers' lines. If the insulation of these lines is good the resulting leakage current is negligible. But if the insulation is poor the loss of current by leakage is serious, and, as the current flowing on the line actuates the receiver, the insulation has a very considerable influence on the speech transmitted. It is, therefore, found that in damp tropical climates all the advantages of a C.B. system are nullified by the unavoidable leakage effects, so that the use of this system is unadvisable unless a purely underground system of the highest character can be afforded.

Automatic Telephones.—Various systems of automatically completing the desired connections are now being introduced The apparatus used for selecting and connecting up the required lines is manipulated by a series of impulses, the necessary im-

pulses being transmitted by a rotating disc or similar appliance attached to the subscriber's instruments. These impulses actuate step by step contact makers controlled by various relays. The whole plant is too intricate to be explained in this book. There are undoubtedly great possibilities with these systems and most countries are now testing installations of considerable size.

Trunk or Junction Lines.—A trunk or junction line is a line connecting two distant exchanges, and as a rule, on any except the very smallest exchanges, these trunk lines are connected to a separate section on the main board, and manipulated by a special operator. Each local operator's section is provided with a 'call' wire to the trunk section. When a subscriber wants a trunk call, the local operator speaks with the trunk operator, passing on the call. The latter then, if the line is engaged, notes the call, and when it matures calls up the distant subscriber and plugs him through to the calling subscriber on her multiple.

A trunk operator thus has in front of her a section containing all the trunk lines and a multiple containing all the local subscribers.

Telephone Circuits.—These circuits may be divided under two headings: (*a*) Subscribers' circuits; (*b*) Trunk circuits.

Subscribers' circuits connect the subscribers with the exchange. They may be overhead or underground. For overhead lines either copper or bronze wire is used. For short distances, not exceeding two miles, bronze wire weighing 40 lbs. per mile is very largely employed. The wire has a resistance of 45 ohms per mile and a breaking strain of 200 lbs. It is the lightest wire which it is advisable to use. For longer distances, copper wire is superior to bronze. Up to 5 miles, wire weighing 70 lbs. per mile is sufficient, but beyond that distance it is well to use wire weighing 100 lbs. per mile. This 70 lbs. wire has a breaking strain of 200 lbs. only, which, for country lines, is not sufficient.

For underground cables, either 10 or 20 lbs. conductors are used. It is now becoming the general practice to use 10 lbs. conductors only.

Trunk Circuits.—When two exchanges in one town or in one district are connected, the connecting lines are generally termed junction lines. When the exchanges are serving two distinct areas, the connecting lines are known as trunk lines.

In America junction lines are known as trunk lines, and the long distance line is called a toll line.

The size of conductor required for trunk lines depends entirely on the general lay out of the whole trunk system. The main object of a trunk system is to provide every telephone subscriber in the whole country with a means of satisfactorily communicating with any other subscriber. The two intercommunicating subscribers may be 10 or 100 or 1000 miles apart, but clear speech must be possible. Clear speech depends on the total resistance and on the insulation, the capacity, and the inductance of these interconnecting lines, and such speech is impossible if a certain limit is exceeded.

To arrive at definite standards of comparison of various sizes of conductors, a universal standard has been fixed, and the qualities of all manner of lines are calculated in terms of this standard.

The standard of measurement is an underground cable with twin conductors weighing 20 lbs. per mile, insulated with paper and air space, the cable being lead covered. It is found that, with such a cable, speech is possible over a length of 40 miles, but for commercial speech, that is for satisfactory conversation, the limit is nearer 35 standard miles. The aim in laying out a trunk system is to so arrange the various lines that in no case would any two subscribers be separated by lines having a total equivalent of more than 35 standard miles. To arrive at this it is necessary to know the equivalents of the various sizes of conductors used in telephone systems. Table B gives the closely approximate values per mile of loop (that is for the pair of conductors in the circuit) assuming a high-class insulation of the lines.

TABLE B

Conductor. Lbs.	Approximate equivalent in standard cable miles per mile of loop.
70 copper	0·33
100 ,,	0·12
150 ,,	0·09
200 ,,	0·07
300 ,,	0·05
400 ,,	0·04
600 ,,	0·03
40 bronze	0·35
70 ,,	0·25
10 copper underground cable	1·65
20 ,, ,, ,,	1·00

The normal method of laying out a trunk system is to divide the country into zones, each zone having a centre with a special

trunk switchboard. The zones are subdivided into smaller areas sometimes called trunk areas, each also having a centre containing a switchboard which is directly connected to the zone central board and which in turn serves all the local exchanges in that area. In densely populated countries the zone areas are collected into primary areas with primary central boards serving the zone centre boards, the primary centres being interconnected by trunk lines.

The total equivalent in standard miles between any two subscribers should not exceed thirty-six standard miles. Under the above organisation such a connection might include two subscribers' lines, two connections between trunk centres and local exchanges, two connections between zone centres and trunk centres, two connections between primary and zone centres, and one connection between the two primary centres—nine lines in all. It is usually easy to limit the equivalent in the local circuit to two standard miles and, the connections between local exchange and trunk centres being fairly short, the equivalent for these can be limited to three standard miles. The connections between trunk and zone centres should be allowed an equivalent of four standard miles, as also the connections between zone and primary centres. Thus the total equivalent for the circuit between a primary centre and a subscriber might be thirteen standard miles. The main trunk line connecting primary centres should therefore not exceed an equivalent of ten standard miles. But it must be remembered that an equivalent of 0·5 to 1 standard mile should be allowed for each exchange through which a connection passes.

For small countries, zone centres take the place of primary centres, and thus the main trunk lines interconnecting zone centres may have an equivalent of about eighteen standard miles.

When dealing with a system in a tropical country, the poorer insulation of the lines attainable must be taken into consideration. It is therefore desirable in such cases to reduce the maximum equivalent to thirty or even twenty-six standard miles and eliminate the subdivisions so far as possible. The ideal arrangement is to have local exchanges and trunk centres only, the latter being all interconnected; but this is not always feasible, and the country must be divided into two or three zones, the zone centres only being interconnected. With this arrangement the total exchanges through which a connection

passes would not exceed six, and by limiting the equivalent between a zone centre and any subscriber in that zone to nine standard miles, the main trunk lines could have an equivalent of twelve standard miles; but if twenty-six standard miles is made the limit, then an equivalent of eight should not be exceeded for trunks connecting zone centres.

A 400 lbs. copper circuit has an equivalent of four standard miles per 100 miles, so that with a limit of twelve standard miles a 400 lbs. conductor would be sufficient for 300 miles, or if the limit is eight standard miles such a conductor would be sufficient for 200 miles.

In fairly dry climates the use of Pupin or loading coils greatly extends the possibilities of good speech over far longer distances, and also facilitates the use of underground or submarine cables,

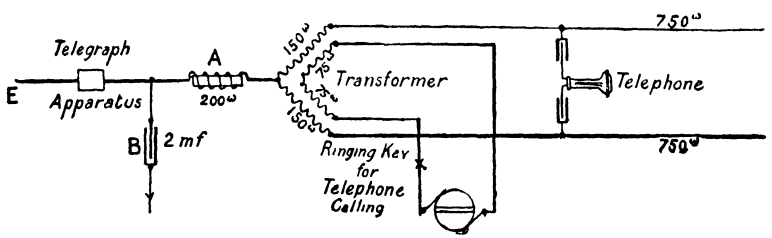


Fig. 163

but in damp climates the difficulty of keeping up the insulation of the line practically debars their use.[1]

Superimposing.—By the addition of a translator, or repeater or transformer, as it is variously termed, it becomes easy to superimpose a telegraph circuit on a telephone circuit, or to superimpose a third telephone circuit on two other telephone circuits. The translator consists of two separate windings, one of them—the secondary—having a third terminal connected to the middle point of the winding. Fig. 163 shows the usual method of connecting a telegraph circuit to a trunk telephone line. The telephone is connected to the two conductors through two condensers. These two conductors are also connected to the two end terminals of the secondary winding of the translator; and the telegraph apparatus is connected to the middle point terminal, through a resistance A, and an earthed condenser B

[1] Experiments are now being made with relays as a means of extending the distance over which speech can be transmitted, and those tried by the British Post Office with the Brown relay are extremely promising.

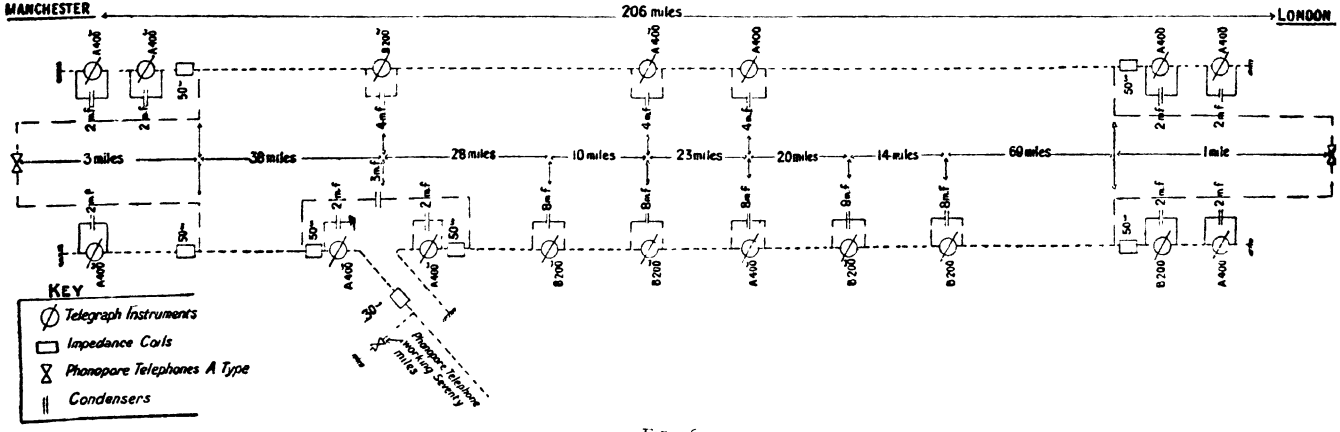

MANCHESTER
206 miles
LONDON
3 miles
38 miles
28 miles
10 miles
23 miles
20 miles
14 miles
60 miles
1 mile
KEY
Telegraph Instruments
Impedance Coils
Phonopore Telephones A Type
Condensers
Phonopore Telephone working Speech

Fig 164

is tapped on to this connection, the object being to prevent disturbance in the telephone circuit due to rapid fluctuations of the potential in the telegraph circuit.

For superimposing a third telephone circuit on two other telephone lines, the two pairs of lines are similarly connected to two translators, the additional circuit being connected to the two middle point terminals, and usually the two telephones which are served by the two separate lines are connected to the primaries of the translators and not direct as in the figure.

For superimposing a telephone on a telegraph line, the phonopore instrument is largely used. In this instrument the induction coil is specially wound. An impedance coil is inserted between the terminal telegraph instrument and the line, and any intermediate telegraph instruments are bridged by a condenser, and an impedance coil is usually inserted in the battery circuit. Fig. 164 shows the arrangement on the Great Central Railway between London and Manchester, where a phonopore circuit is superimposed on two telegraph lines and gives complete satisfaction. The calling on the telephone circuit is done by the use of a buzzer.

The 'phantophone' is another instrument of a somewhat similar character and used for the same purpose.

CHAPTER XIV

CONSTRUCTION (MATERIALS)

TELEGRAPH lines are divided into two great classes: (1) Those in which open, that is overground, wires are employed; (2) Those in which covered wires, whether subterranean or submarine, are employed.

When the choice lies between these there is no hesitation whatever in selecting the former; for not only is their first cost less, but faults occurring upon them can be far more readily traced and rectified.

In England open or overground wires are for the most part erected either by the sides of the roads or along the banks of the railways. Occasionally they are put up by the edge of the canals, although as a general rule the road and the railway are to be preferred.

The advantages which road and rail respectively offer as routes for telegraph lines are so numerous that it is no easy matter to say which is to be preferred. Although the first cost of the erection of a telegraph line upon a road is greater than upon a railway, its subsequent maintenance, under certain conditions, is cheaper. The supervision of it is also likely to be more perfect, for the fact that the poles are erected along the side of a road induces better inspection. The inspecting officer can hardly help inspecting every wire and insulator, and little imperfections are thus easily detected and removed before they have time to become injurious. The lineman placed in charge of a length of road line must walk his length. Upon the railway, on the other hand, walking is difficult, and is consequently too often neglected—the lineman contenting himself with travelling by train, from which close inspection is next to impossible.

The repair of faults again is as a general rule more

speedily carried out upon roads than upon railways. In the case of the former, the lineman can start immediately the fault is reported to him: with the latter, he has not only often to wait some time for the starting of the train, but frequently is carried past the fault, and has to return, perhaps many miles, on foot. Hence it is that not only is the number of faults less, but they are also of shorter duration upon roads than upon railways.

It has been generally assumed that a line by road is more liable to wilful damage than one upon the railway. With the earliest telegraph lines this was true, but experience of late years does not favour the assumption. Insulator breaking is the main evil which has been met with on roads; but the examples made of offenders in this direction have acted as a wholesome lesson to others who may be similarly inclined.

The materials employed in the construction of an open line of telegraph may be classed under the four following heads: (1) Poles; (2) Arms; (3) Wire; (4) Insulators.

1. Poles

The choice for these lies mainly between wood and iron. There are, however, positions where it may be found more economical to employ steel rails or ferro-concrete.

In deciding what type of pole should be used on any line, the following points must be taken into careful consideration:

(1) Purchase price of article.
(2) Cost of transport.
(3) Cost of erection.
(4) Annual maintenance charge.
(5) Probable length of life.

In some countries even though trees suitable for use as telegraph poles grow in the near neighbourhood, the cost of maintenance and their very short life due to decay or the ravages of insects prove that it is more economical to utilise iron poles obtained from this country, notwithstanding the cost of transport. In other places, the rapid destruction of iron poles when exposed to sea breezes may result in showing that ferro-concrete poles constructed on the spot are still more economical than either wood or iron.

In England, wood poles are almost universally used, and are almost exclusively of round red fir obtained from Norway

and Sweden. Terminal poles,[1] however, are exceptional, as it is generally convenient to have them square

The dimensions of poles will, of course, vary with the number of wires which a line is intended to carry. Experience has suggested the convenience of classing three sizes of timber under the heads of (*a*) light, (*b*) medium, and (*c*) stout; the first being used for a maximum of five wires, the second for a maximum of ten wires, and the third for more than ten wires; The diameters will, of course, vary with the length of the pole in order to give approximately the same strength to all poles of the same class. The dimensions shown in the following table of the diameters at top of pole and at a distance of five feet from the butt will indicate the present practice in this matter.

TABLE C

Length of pole in feet.	Diameters in inches.					
	Light		Medium.		Stout.	
	At top.	5 feet from butt	At top.	5 feet from butt.	At top.	5 feet from butt.
20	5	6	5½	7½	—	—
26	5	6¾	5¾	8¼	7½	10¼
40	5	8	6	9¾	7½	12

The trees are felled in the winter months when the sap ceases to rise, and those selected should be sound, hard grown, and free from incipient decay, large or dead knots, and other defects. The age of larch when fit for telegraph purposes ranges from twenty-five to fifty years, according to the soil on which it is grown. Its average life as a pole, if not specially prepared to resist rot, may be set down at about seven years. The poorer the soil on which the timber is grown the harder and more durable it is, and the lighter and more porous the soil in which it is planted the shorter its life.

These poles are now invariably creosoted. Creosote is one of the numerous products of coal-tar, and is obtained from it by distillation. When applied to timber it not only acts as a powerful antiseptic, destroying the germs of vegetable life, but, by filling the pores of the wood with an oily substance, it checks the entrance of air and moisture and the consequent growth of

[1] By a *terminal* pole is meant not only the last pole at each end of the line to which the wires are terminated, but also any pole at which the wires form any angle approaching to 90°.

germs. The process can be advantageously applied only to well-seasoned timber; upon green wood it is entirely thrown away, and is in fact worse than useless, for it encloses without reaching and neutralising the septic germs, and thereby fosters rather than prevents the progress of decay. The poles to be creosoted are placed in a cylinder which is rendered air-tight, and from which the air is very carefully exhausted. Creosote is then applied, and forced in at a pressure varying according to the contents of the cylinder; the time during which it is applied will likewise depend upon the contents of the cylinder and the condition of the timber. When in proper condition timber ought to absorb from ten to twelve pounds of creosote per cubic foot.

Of all the processes which have as yet been devised for the preservation of timber, creosoting has been attended with the most beneficial results, and has given universal satisfaction. It would, in fact, be difficult to assign a limit to the life of a properly creosoted pole.[1] Instances have occurred in which, after the lapse of only a few years, it has been found necessary to renew creosoted poles, but in such cases it is more than likely either that decay had commenced before they underwent the process, or that being improperly seasoned they were not in a fit state to be subjected to it. The antiseptic properties of creosote are due mainly to the presence of carbolic and cresylic acids; but these, which in former days were to be found in very large proportions in commercial creosote, have of late years become so extremely valuable as articles of commerce that they no longer exist to anything like the same extent as previously in what is now sold as creosote. How far this may affect the value of the process it is at present impossible to say. Creosoted timber after being planted for a few years has in some cases been served with a coating of tar, but the economical advantage of this is doubtful under ordinary conditions in view of the life of properly creosoted poles without it.

Creosoted poles cannot be painted satisfactorily. Where, for ornamental purposes, paint must be employed (p. 241), the difficulty may be partly met by dipping the butt ends of the poles to a distance of about six or eight feet in boiling creosote and painting the remainder.

Iron Poles.—As has been already remarked, iron is but little employed in England for telegraph supports, and when it becomes

[1] Evidence given in 1911 shows that the average life in England for these poles is some twenty years.

necessary to use it, the poles are usually of a light and ornamental description to suit the wishes of those who insist upon their use. But in countries where wood is extremely perishable, either from natural decay or from the attacks of the white ant, and where preservative processes, on account of their expense,

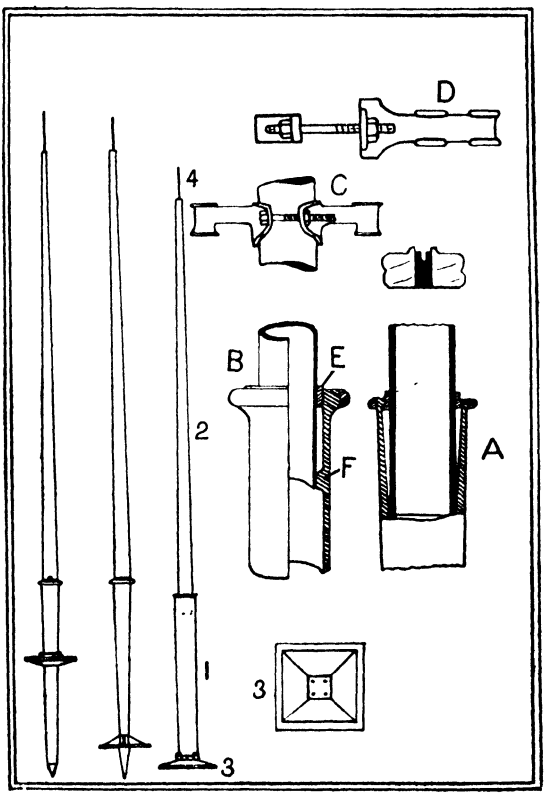


Fig. 165

cannot be introduced, as well as where the means of transport are limited, iron poles are very extensively used. On account of their weighing less than wooden poles and being manufactured in pieces of convenient weight and bulk, they can be more easily conveyed from place to place.

The pattern of iron pole most extensively used in all parts of the world is the tubular pole (fig. 166). This consists of four parts : (1) a cast iron base; (2) a wrought iron welded taper upper tube ; (3) a buckled plate of wrought iron or steel sheet, bolted

TABLE D

Dimensions						Weights.			
Length of pole.	A. Length of taper tube.	B. Length of base.	C. Diameter of tube at top.	D. Diameter of tube at bottom.	E. Size of steady plate.	Tube.	Base.	Plate.	Carrying weight. (Factor of safety of 2.)
ft. in.	ft. in	ft in.	in.	in.	in. square	lbs.	lbs	lbs.	
18 0	13 6	4 6	$1\frac{5}{8}$	$3\frac{1}{2}$	12	44	56	12	100 A test of twice
20 0	15 6	4 6	$1\frac{5}{8}$	$3\frac{1}{2}$	12	54	56	15	90 this weight
20 0	13 0	7 0	$1\frac{5}{8}$	$3\frac{3}{4}$	21	64	100	15	200 applied 12
20 0	13 0	7 0	2	$4\frac{3}{4}$	28	118	189	36	500 in. from the
20 0	11 0	9 0	3	6	36	140	396	100	900 top of the
25 0	18 0	7 0	$1\frac{5}{8}$	4	24	135	140	24	200 tube should
30 0	23 0	7 0	2	5	28	250	190	36	250 not give a
35 0	28 0	7 0	2	6	28	360	195	36	250 perceptible
40 0	33 0	7 0	2	6	28	420	195	36	150 permanent
40 0	33 0	7 0	2	5 $4\frac{5}{8}$	28	225 130	195	36	140 set.
	(Upper tube in two parts)								

to the lower end of the base; (4) a top spike which acts as a lightning rod.[1] The upper tube fits into the cast iron base, and the form of joint which finds most favour is that known as the screw ring introduced by Siemens Brothers. The base has a rough thread cast inside the mouth for two inches. The upper tube has parallel sides at the bottom. This is encircled by a loosely fitting split ring and when dropped into the base, the ring, which has a male thread corresponding to that in the base, is then screwed into the base, gripping the tube tightly (A, fig. 165).

Another joint was introduced by Bullers Limited. The base of this pole is tapered at the mouth and the tube has a corresponding taper ring E shrunk on four inches from the butt. When the tube is dropped into the base the ring fits into the tapered mouth and the butt rests on a projection F within the base B (see fig. 165).

Table D gives the various sizes of these poles, the dimensions and weights of their parts, and the strains they are able to carry.

When selecting poles for a line of wires, the two main points to be considered are:

(*a*) The probable maximum number of wires.

(*b*) The number of poles per mile.

A pole has to withstand the weight of the wires carried, and also the pressure likely to be put on these wires by the wind.

As a rule, the maximum pressure allowed for with the wind is 17 lbs. per square foot (i.e. a strong gale of 70 miles per hour).

With this pressure the following table (E) gives the effective pressures on single wires of various gauges with various span lengths:

TABLE E

No. of poles per mile.	Span.	Bronze wire		Copper wire				Iron wire.	
		40 lbs.	70 lbs.	100 lbs.	200 lbs	300 lbs.	400 lbs.	200 lbs.	400 lbs.
	yds	lbs.	lbs	lbs.	lbs.	lbs.	lbs	lbs.	lbs.
30	60	8 5	11·1	13·43	19 04	23·29	26·86	20·57	29·07
25	70	9·92	13·09	15 67	22·22	27·10	31·33	24·0	33 92
22	80	11·33	14·97	17 91	25 39	30 98	35·81	27·43	38·76
20	90	12·75	16·83	20·15	28·57	34·85	40·28	30·86	43·61

Wind pressure on wires = length of span in feet × ⅔ (diameter of wire in feet) × pressure per square foot.

[1] Occasionally a spindle insulator takes the place of this lightning rod, but when lightning is prevalent, this practice should not be followed.

The total allowable weight per pole should be the total weight of wire per span *plus* the above figure per wire. That is to say, with poles having a carrying weight of 200 lbs. and of which there are 25 to the mile, ten 100-lbs. copper wires would exert a total weight of 40 + 156·7 or 196·7 lbs. on each pole in a heavy gale. Such a line would require staying if it had to carry more than ten such wires, and if heavy gales were likely to be experienced.

Another type of pole which is used largely in India and in other places is that known as the Hamilton pole. These consist of riveted tubes made of galvanised (see p. 223) steel sheet fitting into cast iron sockets having sole plates. The tubes are all 8 ft. in length, but vary in diameter, there being eight sizes known as A, B, C, D, E, F, G, H, each tube fitting into a tube the size larger. Each tube has also a base of the corresponding letter. The ends of the tubes are so arranged that the corresponding end of a smaller tube exactly fits in. Any tube will similarly fit its corresponding size of base, and caps are provided to fit the top tube. The bases are cast with a male thread at the lower end, and the sole plates screw on to this.

In this way poles of any length can be built up of these tubes varying from A and B tubes with B socket (12 ft. 5½ in. above ground) to A, B, C, D, E, F, G, H, with H socket (58 ft. 2 in. above ground). Fig. 166 gives dimensions, weights, and strengths of these poles.

2. Arms and Brackets

In order to carry several wires on one pole, arms or brackets are required.

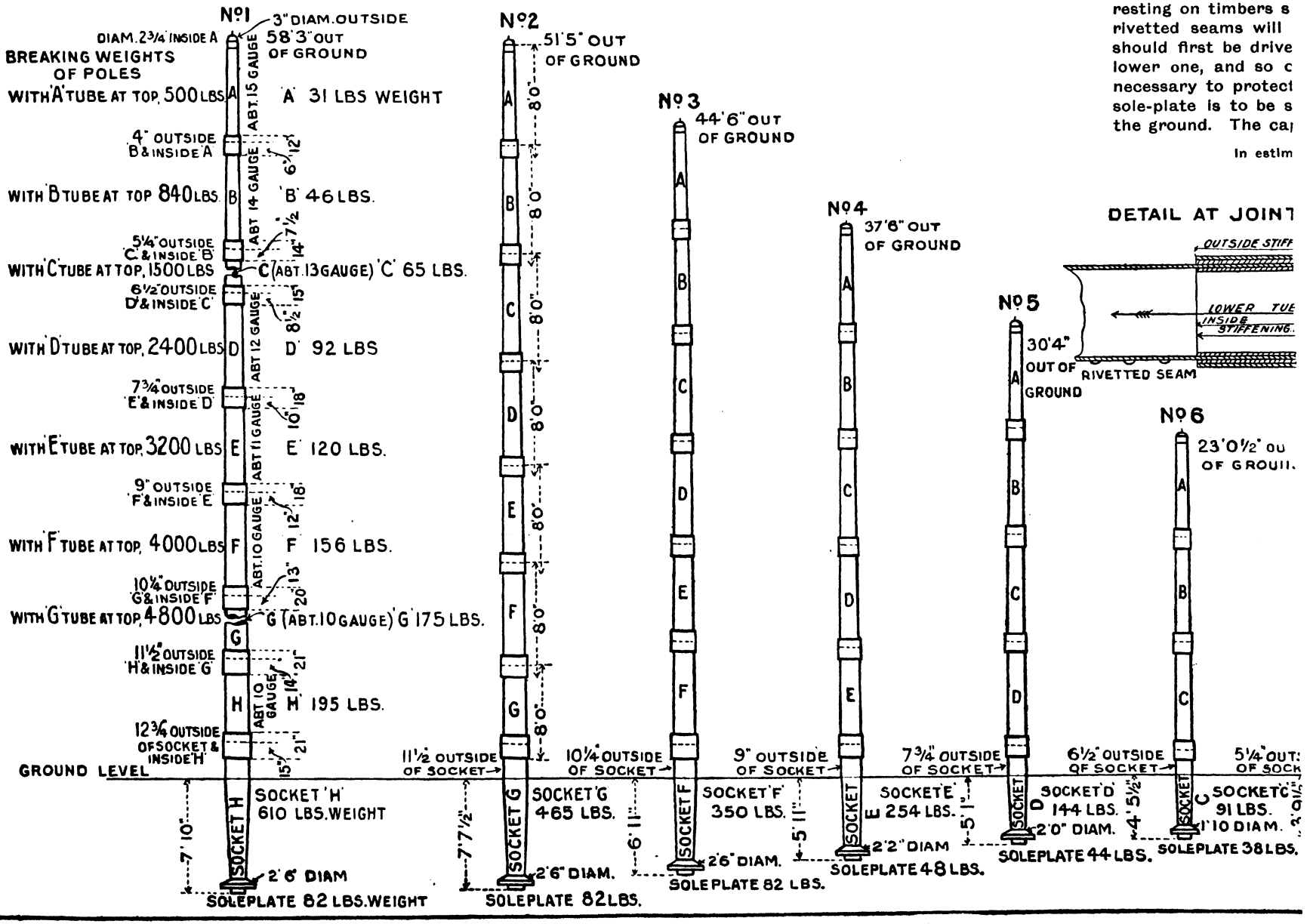
Arms may be made of wood or iron. In England, well seasoned oak is invariably used for the wood arms. In other countries where good hard wood grows locally it is naturally cheaper and therefore advantageous to use that material.

Wooden arms carrying any wire less than 400 lbs. per mile in weight have a cross section of 2½ in. × 2½ in.; for heavier wires they are usually 3 in. × 2½ in., and for terminal poles 3 in. × 3 in. Arms should be placed 12 in. apart, and for wooden poles the topmost should be 9 in. from the top. With iron poles 3 in. is, however, sufficient.

On all main lines with 4-wire arms, the insulators should be

RIVETTED STEEL TUBULAR TELEGRAPH POLES.

"HAMILTON" PATTERN.



In putting the poles resting on timbers s rivetted seams will should first be drive lower one, and so c necessary to protect sole-plate is to be s the ground. The ca

In estim

Fig. 166

spaced 12 in. apart, and 15 in. between the two insulators on either side of the pole.

For short telephone distribution lines, 4 in. to 6 in. is sufficient space between the insulators carrying the two conductors of one line, but 6 in. to 9 in. should be allowed between those carrying conductors of separate lines. The outside insulator is usually $1\frac{1}{2}$ in. to 3 in. from the end of the arm.

Iron arms are made of wrought iron tube $1\frac{1}{16}$ in. diameter welded with butt joints and galvanised.

When tubular iron poles are used special seats are required to fix the arms to the poles. Fig. 167 shows the type used for iron arms. For wooden arms the piece on which this arm rests is of angle iron, the dimensions of which vary with the size of the arm. These are made of galvanised malleable cast iron, the arm, seat and back strap being held together and to the pole by two galvanised iron bolts.

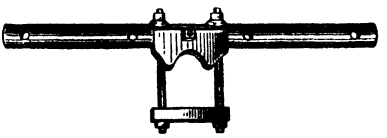


Fig 167

Where a line of poles carries only a few wires, galvanised malleable cast iron brackets (single or double) are often employed in preference to arms. They are clamped to the pole either singly with back straps or in pairs back to back (fig. 165, C and D).

3. Wire

In selecting wire for telegraphic purposes the points to be borne in mind are strength and durability, combined with low resistance to the passage of electricity. Copper is the material which most closely fulfils every condition, but iron is largely employed for aerial lines. Iron is much cheaper, but its resistance is higher and its life very considerably less. Bronze wire is used for extra long spans owing to its light weight and high breaking strain.

Iron Wire.—Only charcoal iron is now used for wire for telegraph purposes. It is usually Swedish iron, and owes its value not only to the comparative purity of the native ores, but to the fact that, as it is smelted entirely with charcoal, it is not contaminated with sulphur and other impurities which in English iron so materially reduce the conductivity.

The mode of manufacture of all kinds of iron wire is very

similar. The ' pigs ' of iron from which the ' best best ' wire is drawn are first of all ' puddled ' in a furnace ; the ball of puddled iron is then placed under a very heavy hammer, by which it is beaten out into a compact form. It is then passed between a series of rollers, from which it finally emerges in the shape of a bar, much increased in length and reduced in thickness.

The bar is then passed through what is technically known as the ' rolling mill.' This machine consists of a series of rollers, placed in pairs alternately horizontal and vertical. Each is grooved, but the size of the groove diminishes with each succeeding pair of rollers. Thus as the bar passes through these its diameter is reduced to whatever extent may be desired. The speed of each pair of rollers is controlled by separate driving gear arranged to make them revolve at a regularly increasing speed, for the length of the bar increases between every pair, so that what enters the mill very slowly finally issues from it at a considerable speed, the increase varying of course according to the diameter to which the bar has been reduced to convert it into wire.

Flaws in a newly erected wire, due to impurities in the shape of cinders, &c., which have been allowed to find their way into the bars from which the wire is drawn during the process of manufacture, will make themselves evident on the occasion of the first frost by the wire breaking at the points where they exist. For this reason the bars should be carefully selected from the best material only, and the danger may be still further obviated by using, instead of one solid bar, a mass of metal composed of several different pieces laid together. Thus if eight pieces of iron be piled together—say four 1½-inch billets boxed up in 5-in. tops and bottoms with 3-in. sides—and if these be well wash-heated, and rolled out into bars of about 1½ in. diameter, they will when passed through the rolling-mill produce an entire length of about one-third of a mile of the 400 lbs. size. Iron wire manufactured in this way is found to combine the ductility of strand with the homogeneity of solid iron, and reduces to a minimum any danger of breakages occurring through flaws.

A wire is reduced to a gauge smaller than the minimum size to which it can be rolled by being forcibly drawn when cold through a series of dies whose diameters diminish regularly until the desired size is reached. The drawing operation hardens

the wire, so that from time to time during the process it has to be annealed.

The largest iron wire employed for telegraph purposes in England weighs 800 lbs. per mile, and has a diameter of 242 mils. It is used, however, only under exceptional circumstances, or (because of its low resistance) upon very long circuits. The wire in general use for all through circuits weighs 400 lbs. per mile (diameter 171 mils). Two hundred pounds wire (121 mils diameter) is used for circuits of minor importance. For binding purposes a smaller wire (diameter 66 mils) of the best selected charcoal iron, highly annealed, very tough, soft and pliable, is employed.

Iron wire if left unprotected in the open air speedily becomes oxidised, and to prevent this it is covered with a protective coating of zinc—commonly termed *galvanising*. On the first exposure this zinc coating becomes superficially oxidised, and the oxide being insoluble in water ordinarily protects the remainder of the metal from further attack. Where, however, the air is more or less charged with acid vapours the zinc coating is quickly destroyed and the life of the wire correspondingly shortened. Of late years considerable improvement has been made in the method of galvanising; the most approved combines into one the three processes of annealing, cleaning, and galvanising the wire:—The hard iron wire is first tempered by being passed through a heated tube; it is then drawn for a few seconds through a bath of hydrochloric acid, which serves to remove all the surface impurities; it is next guided by means of rollers through a bath of molten zinc. After leaving this the wire passes through a mass of different material—including sand, &c.—which acts as a gentle scraper, and is finally wound on the coiling drums in a thoroughly galvanised state.

The wire should be manufactured in as long lengths as possible, consistent with convenience in handling it when being erected; but on no account should it be welded, for, in the great majority of cases where wires break from any other cause than that of being damaged during their erection or chafed after they are up, it will be found that the breakage occurs at a weld.

It is essential that the wire employed in telegraphy should be free from flaws, welds, and impurities—and that its power to resist breaking strain should be uniform throughout. Both these requirements are tested by one and the same process,

which is as follows: The galvanised iron wire is placed on a simple loose wheel, or 'swift,' as it is technically termed; from this it is drawn alternately over and under three or more small pulleys arranged in the manner shown in fig. 169. It then passes round a large V sheave, and is finally wound upon a drum which is turned with a velocity greater by about 2 per cent. than that of the V sheave. The strain, which it will be seen is thus put upon the wire, not only tests its strength, but makes evident any defects which it may contain. As a further precaution the coils of wire previously to being issued should be carefully examined by the eye.

There are three mechanical tests to which iron wire may be subjected in order to prove its quality. (1) It should be capable of being bent backwards and forwards at right angles to itself a certain number of times without breaking; (2) It should be

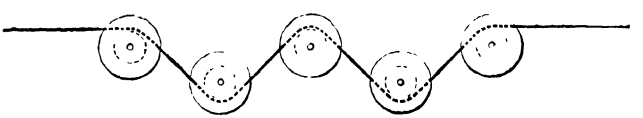


Fig. 168

able to bear a certain number of twists in a given length without splitting—this is the torsion test usually applied; (3) It ought to be able to carry a certain weight or resist a certain stress without breaking. This test is carried out either by means of a special machine or by a scale and weights. In the former method care must be taken that the additional strain in testing is not too rapidly applied, otherwise, the wire not having had time to yield to the previous strain, the machine will really show a higher breaking stress than the wire actually possesses; with the latter the additional weights should not be put on until the wire has been allowed ample time to stretch under the influence of those previously in the scale. It is convenient to set the machine at the specified breaking stress in the first instance, so that the wire may certainly take that as a minimum. The breaking strain will of course vary according to the gauge of the wire; that for 400 lbs. should not be lower than 1240 lbs. and for 200 lbs. not less than 620 lbs. Galvanising, although it does not seem to have any appreciable effect upon the breaking strain of the wire, to some extent hardens the iron, and thus diminishes the coefficient of elongation.

Table F gives particulars of the various tests to be complied with by iron wires.

TABLE F

Weight per mile.	Approximate S.W.G.	Standard diameter	Minimum breaking weight	Minimum No. of twists (in 6 in.)	Standard resistance per mile.	Approximate weight of coil.
lbs.		in	lbs.		ohms.	lbs
Iron wire						
600	5	0·209	1800	19	8·88	105
400	7½	0·171	1200	24	13·32	105
200	10½	0·121	600	30	26 64	105
Copper wire						
800	4½	0 2235	2400	15	1 0984	120
600	6	0 1935	1800	20	1·4645	120
400	8	0 158	1250	25	2·1968	120
300	9½	0·137	950	30 (in 3 in.)	2 9291	120
200	11½	0 112	650	20	4·3936	100
150	13	0 097	490	25	5·8582	100
100	14	0 080	330	30	8·7873	100
70	16	0·066	216	20	12·74	70
Bronze wire						
150	13	0·097	710	8	12	100
100	14	0 079	485	10	18	100
70	16	0 066	340	15	26	70
40	18	0 050	200	20	45	70

Copper Wire.—The great superiority of copper over iron wire as regards conductivity has been pointed out.

In order to attain high conductivity in copper wire great care has to be exercised in its manufacture; thus, Matthiessen found that contact with air when the metal was in a molten state reduced its conductivity 24 per cent., and a mere trace of arsenic reduced it as much as 40 per cent.

For overhead lines, although the question of conductivity is of very great importance, tensile strength and durability are of even greater. When telegraphy first came into practical use copper wire was tried, but proved itself deficient in these requirements. Its ductility and its want of tensile strength and elasticity rendered its use impracticable. The improvement which has taken place of late years in the manufacture of copper wire is due to the attention directed to its production necessitated by the exacting demands made by the users. The result is that 'hard drawn' copper wire can now be produced which has a breaking strain of 28 tons on the square inch; that required

of iron wire according to the foregoing specification being about 22½ tons. Copper wire is also less affected by impurities of the air, which is a very important quality, for, in some localities—such as the neighbourhood of chemical works—where iron wire is destroyed in a few months, copper wire has stood eight years' exposure without deterioration. The principal advantage, however, which the use of copper wire presents is its superior electrical qualities. Gauge for gauge its conductivity is more than six and a half times that of iron; its electro-magnetic inertia is negligible, and its capacity (which varies directly as the diameter of the wire) is materially reduced. Hence the employment of copper wire leads to an actual and important increase in the possible speed of signalling on fast-speed circuits, as well as in distinctness of speech and in the actual possible speaking distance upon telephone circuits. For long telegraph lines, therefore, and for telephone circuits, copper is being very generally introduced, and it is probable that its use will be much extended.

Table F, p. 225, gives particulars of the various tests to be complied with by copper wire.

Bronze Wire.—In special circumstances, where a stronger material than copper is required, bronze is used, but it is of a lower conductivity than copper. A silicium bronze wire weighing 100 lbs. per mile is often employed which has a breaking strain 50 per cent. higher than that of copper wire of the same weight, but its conductivity is only half that of the copper. Bronze wire is, however, preferred in some localities where violent storms are prevalent, and where branches of trees are liable to be thrown upon the line, the extra strength obtained being a consideration.

Table F, p. 225, gives particulars of the various tests to be complied with by bronze wire.

For ordinary purposes, probably the usual plan of referring a gauge of wire to the dimensions of its diameter is the most practicable; but where, as in the case of telegraph wire, the range is limited to a few easily recognisable sizes, it is quite open to question whether the gauge may not with advantage be referred to some other function of the wire. And when it is remembered that wire is purchased, transported, and distributed along the line by weight, that its breaking strain is in proportion to its weight, that its electrical resistance—varying inversely as its sectional area—is a function of its

weight, and, finally, that weight is invariable in all temperatures and latitudes, it will be admitted that multiples of a unit of weight are the natural telegraph-wire gauge. A size of wire dependent upon a number of pounds per mile will be constant as long as pounds and miles exist, and if these units be adopted as a basis there is a ready means of correcting the gauge at all times. Modern specifications in almost all cases describe telegraph and telephone wires by the actual standard weight per mile.

4. Insulators for Aerial Lines

In England and all British Dominions and Colonies practically the sole material employed for insulators is porcelain, though brown earthenware is occasionally used where cheapness is essential. In America and certain parts of the Continent glass insulators are largely used, and it is claimed that they give superior results to porcelain.

Porcelain has a high insulating power and possesses a good smooth surface; but it must be perfectly vitrified throughout, so as to be homogeneous, impervious to moisture, and free from flaws.

The finest china clay for this material is obtained in Cornwall; this clay makes a tougher porcelain, which is therefore less likely to suffer from breakage during transport than that made from similar clay obtained elsewhere. The finished insulator is well glazed, but insulating tests should be carried out before the glaze is put on, thus ensuring that the porcelain has been thoroughly vitrified during manufacture.

The Form.—Equally important as the material of which an insulator should be composed is the form which should be given to it. In considering this, the main object to be kept in view is the same as in the selection of the material, viz. the highest possible resistance to leakage of the current; at the same time the strength of the insulator as a support must not be altogether lost sight of. Seeing, however, that the insulators have little more than the weight of the wire to withstand, except at the terminal poles, no trouble is experienced in suiting the form of insulator to this. The main difficulty which has to be surmounted is the leakage which takes place more or less at every support; every insulator is to a certain extent at fault, and the magnitude of the fault depends upon the form which

the insulator possesses. The resistance to the passage of the current depends not so much upon the mass of the insulator as it does upon the configuration of the surface; the most perfect form of insulator will be that in which the surface exposed is a minimum, and the wire is as far as it can be from the insulator's support, due allowance being of course made for the insulator itself being sufficiently strong.

Numerous forms have from time to time been tried. The principle of the two cups, or *double-shed* as it is called, is now generally adopted in all insulators (fig. 169). The object gained by this form is improved insulation, as the current, to escape from the wire (which is bound into the groove shown), must make its way over the entire surface of the two cups before it reaches the bolt and so gets to 'earth.' It will be seen that while the outer surface is exposed to the cleansing action of the rain to remove any dust or dirt which may have adhered to it, the inner cup is kept dry during wet weather, and consequently continues to offer considerable resistance to the escape of the current.

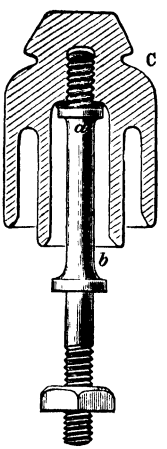


Fig. 169. ½th real size.

The Cordeaux type of screwed double-shed insulator is now almost invariably used (fig. 169).

The principle of this insulator is as follows: a coarse thread is formed on the head of the bolt, and a corresponding hollow thread is made in the porcelain cup. The bolt is also provided with a shoulder *a*, upon which an elastic ring is placed, and the cup is screwed down upon this shoulder. By this means not only can the cup alone be easily removed at any time to allow of renewal or cleaning, which is a very great advantage, but the india-rubber ring admits of the unequal expansion of the bolt and cup without fracture of the latter, and when from any cause fracture occurs, it is more readily detected and the insulator removed. For terminal insulators see p. 260.

Lightning Protectors.—These are most essential adjuncts to all telegraph and telephone lines. Where a line is entirely overhead, such protectors should be inserted at the point where the line enters a building. Where lines are partially overhead, and partially underground, these protectors should be inserted at the point of connection.

Two forms of protector are in general use. The P.O. pattern (fig. 170) consists of two carbon plates separated by a thin sheet of mica, in which are a certain number of perforations. One plate is connected to the line, and the other plate to earth. This protector is very largely used, but the one drawback to it is that with heavy lightning discharges carbon powder is carried

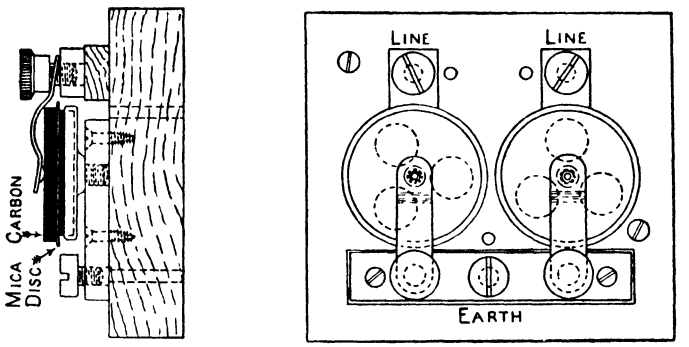


Fig. 170

across the gap and connects electrically the two plates, thus earthing the line. For telephone lines, the shape of this type of protector is modified in order to save space, but the principle is identical.

Another form of protector is that known as the vacuum tube protector. Fig. 171 shows the design supplied by Siemens Brothers. Inside an exhausted tube are placed two small blocks of carbon separated by a short distance; one of the opposing faces is serrated, the other plain. This type of protector is largely used for telegraph and telephone lines, and they are generally mounted in pairs on a porcelain base. A heat coil, i e. a small coil which fuses should a heavy current flow on the line, is often mounted on the same base and included in the line circuit for further protection.

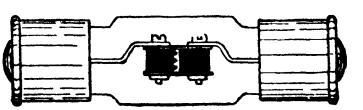


Fig. 171

Other more elaborate and expensive forms are used for special purposes (see p. 268).

Great difficulty is invariably experienced in maintaining good insulation upon lines which skirt the sea-coast, no matter

what material is employed or what form of insulator is adopted. The insulator becomes coated with salt, which, being more or less moist, conducts in all except the driest possible weather. The difficulty is greatly increased when the prevailing wind is from the sea. Iron wire is practically useless. Wire covered with prepared tape is occasionally employed in extreme cases of this nature; but by chafing against the insulator the tape gradually gets rubbed off, and leaves the wire exposed just at the point where protection of this nature is most required, and it is usually found more economical to use copper wire, but in some positions even this metal is rapidly corroded away. Open wires skirting the sea-coast should therefore be resorted to only when no other route by which they might be carried is available.

CHAPTER XV

CONSTRUCTION (OPEN WIRES)

A.—OVERGROUND TELEGRAPHS

Surveying.—The route for a line of telegraph, whether by road or by rail, having been decided upon, the next point is to make a careful survey of it. For this purpose the surveying officer should be provided with a book prepared upon the following plan, in which are inserted the requisite particulars to enable him to estimate the total quantity of stores which will be required, and to provide for their being laid out, as well as to make arrangements for obtaining permission to erect the poles where such permission is required.

State here the Locality, Town, Village, Bridge, or Landmark by which the spot to which the first entry relates can generally be identified. _____ _____

1	2	3	4	5	6	7	8
No.	Distance in Yards	Position of Pole	Length of Pole	Double or Single Stays	Length of Strut	Reference to Schedule of Consents needed	Remarks

Each page contains the particulars required with regard to 13 poles or supports.

Column 1 should show the number of each pole consecutively from terminal station to terminal station.

Column 2. The spans, or the distances between the poles.

Column 3. Their distances from some fixed object, such as the rails on a railway ; water on canals ; hedges, walls, or ditches on roads. This is done to guide the hole-diggers in case the marks are lost.

Column 4. The length of the pole required; A-poles and double poles being so marked.

Column 5. The position and number of stays

Column 6. Details of struts.

Column 7. Reference to the schedule of private consents needed.

Column 8. The general remarks should contain any special instructions to the foremen, such as points where terminal insulators, guards, leading-in cups, &c., are necessary, where the line crosses a road, diverges through private property, &c.

The surveying officer should have at least two assistants. They should carry with them a supply of wooden stakes and a can of white paint to mark the positions of the poles, and they should likewise be provided with three or more surveying rods, six or eight feet long, shod with a conical spike so that they may be stuck into soft ground. They should be painted in black and white sections each one foot long. These are indispensable if an accurate survey is to be made, especially for a line carrying several wires, for only by their means can an estimate be formed of the amount of the curve, and the consequent strain to which each pole will be subjected ; and without this information the requisite provision for suitable timber and proper staying or strutting cannot be made. The positions of the poles may be marked in various ways : the plan which has been found to answer best is the insertion of wooden stakes in the ground, aided by a distinctive mark of white paint on neighbouring walls, fences, &c., to provide against the stakes being removed.

Hole-digging.—The operation of digging a hole for a telegraph pole, although to all appearance simple enough, yet requires more experience than at first sight would be imagined. The holes should invariably be dug in the line of the wires, as at A, and never at right angles to it, as at B (fig. 172), the object being to get the solid natural earth as much as possible in the line of the lateral stress of the wires. The rectangular opening which

is thus made averages about four feet in length by one in width: this size is continued to a depth of about two and a half feet below the surface, whence, by a step-like arrangement, the length of the opening is gradually curtailed, until at the bottom it does not exceed one foot, as shown in C.

As little of the ground as possible should be disturbed, for no matter how well the punning and ramming may be done after the pole is planted, yet a considerable time will always elapse before the earth settles back to its former condition, and the more the ground has been disturbed the less is the pole able to withstand any strain that may be put upon it during this time.

For this reason various tools have been devised whose object is to remove only just sufficient earth to admit of the pole being planted; and which, in addition to effecting this, combine

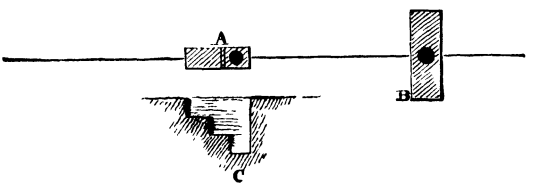


Fig. 172

several other incidental advantages of considerable value. When it is borne in mind that in order to dig a hole four feet six inches deep for an ordinary telegraph pole, by the pick and shovel in the usual method, no less than twenty-three cubic feet of soil, representing a weight varying from 2,600 to 3,000 pounds, according to the nature of the ground, have to be removed, whereas not more than three and a-half cubic feet, or about 376 pounds, need actually be disturbed, it will readily be understood that many attempts at improvement in this branch of telegraph construction have been made.

One of the earliest efforts made in this direction was in Spain, where a tool, since known as the *Spanish Spoon*, was devised. Various modifications have from time to time been introduced, but they are all constructed on the same principle, which is that shown in fig. 173.

It consists of a segment of a metallic disc *a*, the chord of which serves as a cutting edge. The periphery is fitted with a ledge *c* two inches in height, which serves to retain the accumulation of the soil upon it. The whole is fitted to a wooden handle *b*.

The adjunct to the spoon is a long bar, by means of which the soil is first loosened: the spoon is then inserted, and a rotating motion is conveyed to it so that the earth is heaped up on the blade; the whole is then removed, and the bar again employed.

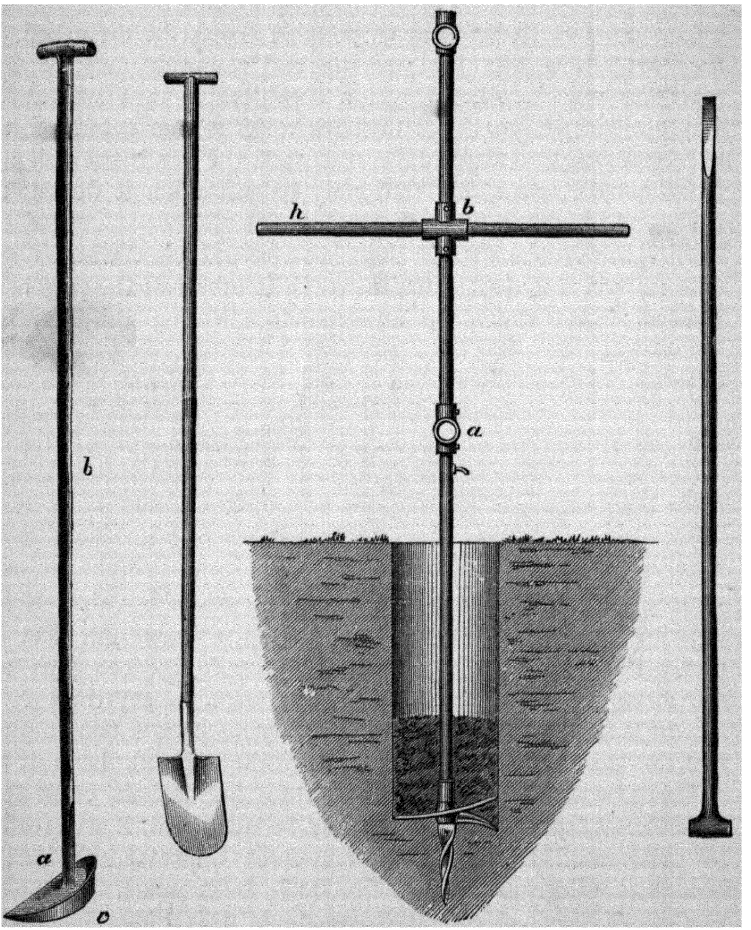


Fig. 173. $\frac{1}{16}$ real size. Fig. 174. $\frac{1}{24}$ real size.

For light lines, on which the poles need not be inserted to a greater depth than four feet, the *Spanish Spoon* answers the purpose for which it is intended very fairly; but for heavy lines, where holes varying from six to seven feet in depth are required, it cannot be pronounced a success. The difficulty of loosening and collecting the soil increases to a very great extent with the depth,

and the advantage which at the outset it possesses over the pick and shovel in point of speed is almost, if not entirely, lost before a six or seven foot hole is completed.

Earth Borers represent more elaborate attempts to provide for the excavation of holes. Various kinds have been tried, but those most generally known are the inventions of Spiller, Bohlken, and Marshall.

Spiller's is but a modification of the ordinary ship's auger on a large scale, which is forced into the ground, and in clay or sand has been found to work well.

Marshall's borer, although resembling Bohlken's, has several distinctive features about it. The general arrangement of the apparatus is shown in fig. 174. The cutting blade consists of a metal disc cut from the centre to the circumference, and having the two edges bent into the V-shape shown. The lower forms the cutting edge, and as the apparatus is rotated the earth passes through the radial V opening on to the upper surface of the blade from which it is removed from time to time by lifting the apparatus out of the ground. The stock to which the blade is attached is squared at the end, and has screwed on to it a tapering metal point, which, in addition to serving as a nut, plays the part of a drill in front of the cutting-plate, and so to some extent facilitates its work. The stock is attached to two or more sections of tube, according to the depth of the hole: these are provided with cross sockets, as shown at *a* and *b* in fig. 174, to admit of the insertion of the handle *h*, which is employed for rotating and lifting the apparatus.

The 'punner bar' forms an essential feature of Marshall's borer. It is shown to the right in fig. 174. One end of this is tapered down to the form of a chisel, with the point tempered to deal with stones, and is used for loosening the soil as well as breaking and removing as far as possible whatever obstacles are met with in the hole: the other end, which is shaped like a punner, is employed for ramming and consolidating the soil around the pole when once planted. The borer is rotated by two men walking steadily round and pushing the handle before them: at intervals it is lifted, and the earth removed: the chisel end of the punner bar is inserted, if need be, to loosen stones or other obstacles, and the process repeated. A shovel attached to a long handle, shown to the left in fig. 174, should likewise accompany the apparatus. In sandy or gravelly soils it is employed

to remove the loose earth which does not adhere to the blade of the borer.

In the latest form of borer brought out by Marshall, the tapering metal point is entirely dispensed with, and the cutting-plate itself is in the form of a screw, and thus acts both as a drill and cutting-plate. This apparatus is cheaper than the earlier issue, and for light work can be worked by one man. Beyond this it possesses no other feature calling for special remark.

An evident drawback to the general employment, even in suitable soils, of a borer of this form, is the impossibility of working it by the sides of fences, where, in road telegraphy, poles have generally to be placed. Another drawback is the great strain thrown upon the men when lifting a load out of the hole, especially when some considerable depth has been attained: for in a clay soil, or if the ground is close, not only is there the weight of what has accumulated on the plate to be lifted, but that of a superincumbent column of air as well. The difficulty was got over by inserting a small valve which can be opened at will by the workmen, and greatly facilitates the raising; perhaps the best cure, however, is to lift the borer more frequently, and not to accumulate such heavy loads upon it. The difficulty in raising heavy poles so as to let them slip into the holes which have been prepared for them is a decided disadvantage inherent to the employment of all earth borers: light poles can be handled easily enough, but the same cannot be said when poles from thirty to forty feet in length, or even more, have to be dealt with. The only possible way of lifting them is by means of shears, which have to be carried about with the gang of workmen employed; and although the work can then be performed with comparative ease, the multiplication of tools is always a disadvantage more or less, and, in countries where roads do not exist along the routes of the telegraph lines, should be avoided to the utmost.

Thus the disadvantages incidental to the employment of special appliances of the above type are found in practice to outweigh their advantages. They cannot be employed in rocky soils, they are of no service for stay holes, nor can they be used for strutted or A-poles where blocks or ties have to be bolted on below the ground. Sets of ordinary tools must therefore be carried, and on modern heavy lines the use of special borers is thus so very restricted that it is scarcely worth while to burden

the gang with their extra weight. Only for comparatively light lines in other than rocky soils can such tools be used with advantage.

Pole-setting.—Poles are, as a general rule, planted in the ground to a depth of one-fifth of their length when under thirty feet long. They should never, however, be buried less than four feet, and need not as a rule be more than six in good solid earth, but for very long poles or in soft ground a greater depth should be allowed. In embankments, and all made or loose ground, they are planted about a foot deeper; whereas in rock, where blasting has to be had recourse to for the purpose of excavating the hole, they may be set a foot less than in the general case. As a check upon this portion of the work being honestly performed, the poles, before being issued, are branded at a distance of ten feet from the bottom with a distinguishing mark, and beneath this is given the year in which they were felled. Poles planted upon a curve should invariably be set a trifle 'against their work'; that is to say, they should bear slightly against the lateral strain of the wires. If this is done it will generally be found that by the time the ground has set perfectly hard the tension of the wires will have pulled them into the perpendicular position; whereas, if this precaution be neglected, and the pole be planted perfectly upright at first, the stress of the wires is almost certain to remove it from the perpendicular, and, apart from any other consideration, make anything but a sightly object of it.

Too much stress cannot be laid upon good sound punning. The earth, as it is thrown in, should be thoroughly well punned at every stage: the hole should not be hastily filled up, but ample time be given to the punners to do their share of the work. Stones, if available, may be employed with advantage to assist in ramming the pole against the side of the hole where the earth has not been disturbed. Upon the punning and ramming of the holes being carried out as they ought to be depend to a large extent the stability and good working of the line when once erected.

The number of poles per mile and their length will vary according to the route and the number of wires which they are intended eventually to carry. No hard-and-fast line can be drawn. For minor road-lines, or the branch lines upon railways, twenty or twenty-two to the mile may be adopted; but on trunk lines the number should be between twenty-six

and thirty to the mile. The length of the poles will depend not merely on the ultimate number of wires to be supported, but also on the obstacles which have to be surmounted. On roads 22 feet is the minimum length except on one-wire extensions, where 20 feet may be employed. On railways 20 feet is the usual length, although on branch lines 18 feet, and even 16 feet, have been occasionally used. One foot is then allowed in addition to these lengths for every two wires that have to be erected. The lowest wire should never be less than 12 feet from the ground; and at all crossings, whether on roads, railways, or anywhere else, the minimum is raised to 20 feet. When it becomes necessary to vary the length of the poles, the variation should take place gradually: the appearance of the line is thereby not interfered with, and the increased vertical stress which would otherwise be thrown upon the insulators is avoided. For instance, if in a line of 22-feet poles the necessity arises for employing a 26-feet, the pole on each side of it should be a 24-feet.

Upon roads and railways poles should be planted upon that side where the prevailing winds would tend to blow them off the roadway or rails. Similarly, if the route is tortuous, the inside of the curve should be selected, so that the wires may be kept as clear as possible of the traffic. Due regard should at the same time be had to the facilities for staying or strutting; and for this reason, as well as to prevent the possibility of vehicles coming in contact with them, they should be planted as close as possible to the fences on roads, and as far as possible from the metals on railways, retaining them, however, within sight of passing trains to allow for the observation of breakdowns. An exception to this rule must be made when the railway runs through thick woods or heavy jungle. In such cases the poles should be planted as far from the edge of the clearing as possible, so that falling trees may not carry away the line. On embankments and cuttings they should be placed just so far down as will admit of their being stayed both ways, and in such a position that in the event of their falling they may fall on the embankment and clear of the traffic; they are then protected also from the violence of the winds. In the case of steep cuttings the top is to be preferred to the slope, and the poles when so placed should be stayed on both sides, as shown in fig. 175. This applies to poles in any exposed position, no matter in what direction the lateral strain of the

wires may be; for the influence of the wind upon the area exposed to it, and more especially when the wires are coated with snow, must be carefully guarded against in every direction.

Although it is very desirable to preserve the poles as nearly as possible in a straight line, yet it is highly objectionable to do so when to attain this object they will have to swing either across or over the roads. Every crossing of a road by the wires introduces

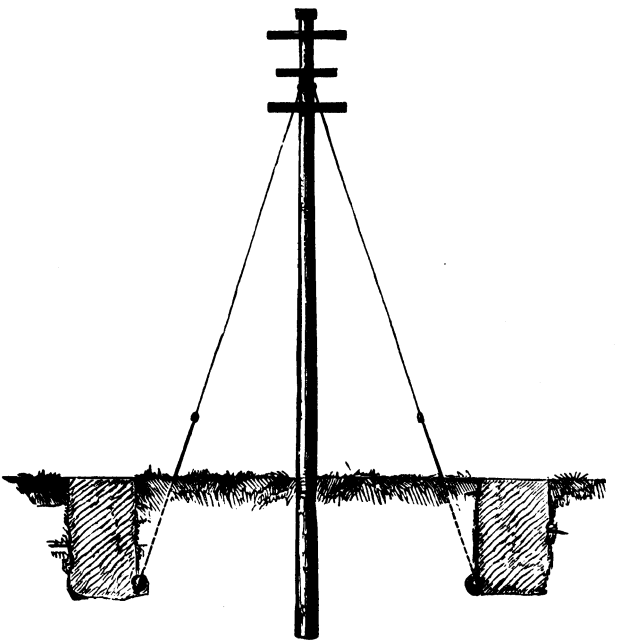


Fig. 175

an element of danger, and should be had recourse to only when absolutely essential: more than one accident has arisen from their breaking or running back at these points in gales, frosts, or snow-storms. Occasions may of course arise when by crossing the road a decided advantage is gained, as, for instance, when by so doing the inside of a curve is secured for some distance; and less danger results from taking this step than by leaving the wires to follow the outside of the curve.

At points where no facilities for staying or strutting exist, or where, on account of the number of wires, sound timber of sufficient strength cannot be obtained, A-poles are made use of.

One of these is shown in fig. 176. It consists of two ordinary poles scarfed at the top so as to fit into each other closely, and united together by means of two bolts, shown at A, A′. The distance between them at the base varies according to circumstances, but should never be less than 18 in. Rather

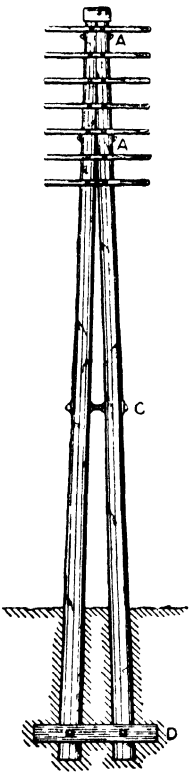


Fig. 176

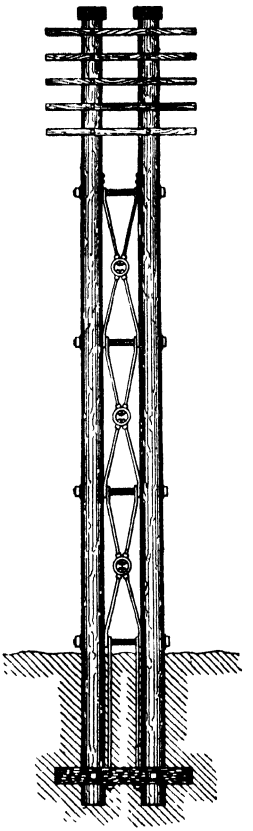


Fig. 177

more than half-way down, at C, a tie-rod is inserted to aid in holding them together, whilst at a distance of about 18 in. from the butts a piece of timber, D, is mortised and bolted on to both. Without this there is a tendency for one pole to cant the other out of the ground, which the superincumbent earth over D prevents.

Where several lines converge or where the number of wires is very large, H-poles are employed. Such a combination is

shown by fig. 177. For ordinary telegraph lines the poles are placed 3 ft. apart and for telephone lines 18 in. apart in the clear; the general construction is, however, the same. At the upper extremities the poles are united by arms of suitable length, and a timber brace is notched in and bolted to the butt ends. In order to secure lateral rigidity a system of trussing is resorted to, converting what would otherwise be two independent supports into the equivalent of a lattice girder. The truss rods (in the case of poles 18 in. apart) are 3 ft. long by $\frac{5}{8}$ in. in diameter, and they are attached to the poles by $\frac{3}{4}$ in. tie-bolts, over each of which is placed a wrought iron tube of 1 in. internal diameter of sufficient length to keep the ends of the truss rods well against the poles. The other end of each rod is screwed and passes through a ring; two locking nuts are provided so that the requisite tension may be placed on the rod. The ring and nuts also afford a means of tightening the rods should they subsequently become elongated. The lowest tie-bolt is placed 6 in. above the ground line, and three sets of truss rods are employed.

Tarring.—Poles erected in their natural condition, without having been subjected to any preservative process, should be allowed to remain until well seasoned, when the ground should be opened out around them to the depth of a foot. They should then be tarred to a height of three feet above the ground line, and upon roads where by any possibility they could be run against they ought to be painted white for three feet or more above that, so as to render them clearly visible at night. Above this they may be painted or tarred, according to circumstances. Tarring is to be preferred, unless there are local objections to its being done. The tar usually employed consists of three parts of Stockholm tar to fourteen parts of gas tar well boiled, and three parts of slacked lime added; the following is the mixture for paint usually adopted in England:

For 100 lbs. of paint—

White lead	70 lbs.
Driers	8 lbs.
Ochre	$\frac{3}{4}$ lb.
Umber	$\frac{1}{2}$ lb.
Raw linseed oil	7 quarts
Boiled oil	$3\frac{1}{2}$ quarts
Turpentine	3 pints

Numbering.—Upon every telegraph line exceeding a mile in length the poles should be numbered and dated after the line has been erected. The work of maintenance will be thereby greatly facilitated, for no difficulty then exists for the inspecting officer to indicate the position upon the line of whatever requires attention.

Staying and Strutting.—It has been already remarked (p. 237) that the stability and efficient working of a line depend in a great measure upon the manner in which the punning is done, but however well this is done it does not, of course, prevent the pole from bending or taking a set above the ground line; and occasions frequently arise when poles cannot be made sufficiently strong or stable to resist unaided the forces which are brought to bear against them. Artificial means must then be had recourse to in order to supply the additional strength required; and for this purpose *stays* and *struts* are employed. By a *stay* is meant whatever takes the pull or tension of the forces acting upon the pole; by a *strut* is understood whatever takes the thrust or pressure of such forces. The former consists of an iron wire, rope, or rod; the latter, in England, is usually timber of the same class, and subjected to the same treatment, as the pole which it is intended to strengthen.

Stays.—The wire rope forming these stays is as a rule supplied specially manufactured for the purpose, but it is frequently found necessary to make them of wire upon the spot, in which case No. 7½ (400 lbs.) iron wire is employed. Several lengths—their number depending upon the work which the stay is required to perform—are twisted together by hand in long lays. Close twisting should never be had recourse to, nor should the wires be simply placed together without a twist; for under either of these conditions each single wire is not certain to take its proper strain, so that the total strength of the stay may be thereby reduced. No definite rules can be laid down as to the number of wires which should be used in the formation of the stay, seeing that so much depends upon the angle which it will make with the pole when fixed; yet upon roads stays of less than three wires laid together should never be employed, and this number should be increased according to the number of wires on the pole, the curve on which the pole is placed, and the angle which the stay makes with it. On straight roads it may generally be said that for a line of six wires a strand of three

No. 7½'s will be sufficient, and for any number from that to thirteen wires seven No. 7½'s.

The main object to be kept in view in the formation and fixing of the stay is to obtain the maximum of efficiency out of the materials which are employed in it. For this purpose it should be fixed at, or as nearly as possible at, that point where the whole force which it is intended to counteract may be supposed to be collected—known in mechanics as the *resultant point*—and it should be placed in such a position as to form with the pole as great an angle as possible up to 90°. The resultant point may be assumed to be about midway between the top and bottom wires. The best possible direction in which the stay can act is at right angles to the pole; as it falls from this and gradually approaches the line of the pole itself, its effective power to resist the horizontal stress of the wires becomes less; and to make up for this loss of efficiency increased strength of material is necessary.

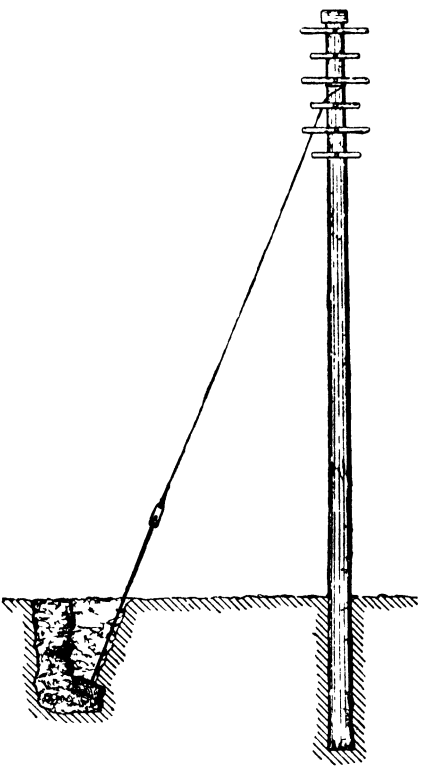


Fig. 178

The lower end of the stay is fixed to the eye of a galvanised iron rod (fig. 178) from 6 to 8 ft. in length. This stay rod is passed through a block of creosoted timber 3 ft. to 4 ft. 6 in. in length; the square head of the rod banks upon a suitable iron washer under the block, which is then buried to a depth of from 3 ft. 6 in. to 5 or 6 ft. in the ground. The hole for the stay-block should be under-cut in the manner shown in fig. 178, so that the stay-block may have firm solid earth to press against, and thus be prevented from drawing.

The attachment of the stay-wire to the pole and the stay-rod is a matter of considerable importance. Where the stay passes through the eye of the stay-rod an iron thimble should be employed. The stay-wire is first bent around this and made to lie closely in the groove of the thimble at a distance (according to the number of wires in the stay) of from 13 to 22 in. from the end. This end is then unstranded and the splicing effected by means of the tool shown in fig. 179. Pick

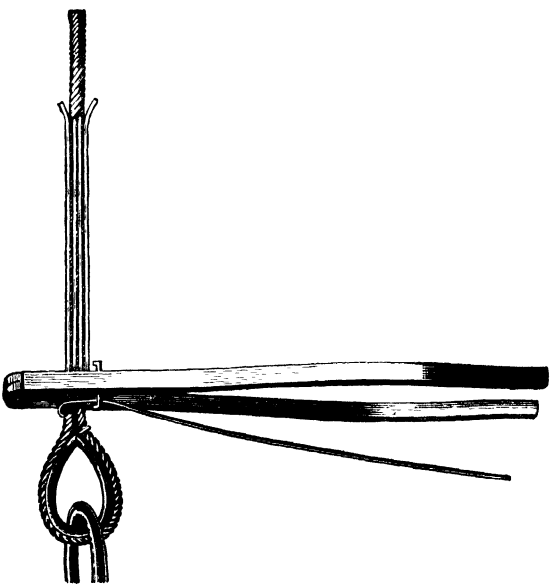


Fig. 179

out one strand and lay the others longitudinally around the main stay, the tool being placed over all with the single strand beneath the hook on the thimble side. By gripping the tool and revolving it, the single strand will bind closely around the stay and the remaining wires. It should make eight laps. There will of course still be a considerable length of the remaining strands not bound in, and one of these should be similarly selected and bound round the remainder, and so with the other loose ends until all have been bound round the main stay. The attachment of the stay to the pole is effected by first taking a double turn with the stay round the resultant point on the pole, fastening with suitable staples, and splicing the loose end and the main stay with the tool as just described.

Should any difficulty exist in the way of fixing the stay at the resultant point, a forked stay similar to that shown in fig. 180 should be employed, whose wires, coming from E and D and uniting at B, are continued on and fixed to the stay-rod. In such cases the two forks should be so placed that the main stay A B, if continued in a straight line, would strike the resultant point C.

After having been erected for some time stays are liable to become slack, especially if the strain upon them is not constant. A *stay-tightener* therefore becomes necessary, and is fixed at the upper extremity of the stay-rod. A very useful form consists in a galvanised iron loop riveted hot into a malleable cast-iron cross-head. Through this cross-head passes the end of the rod, upon which a screw-thread is cut, and the screwing down of a nut upon the rod serves to tighten the stay.

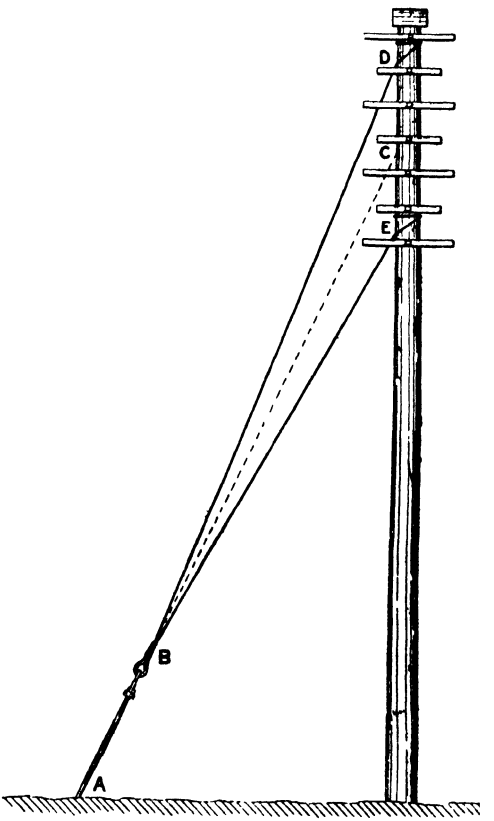


Fig. 180

Where a single stay does not suffice, or where it is inconvenient to remove the loop and alter the position of an existing stay, a second stay may be employed. If this be done, both stays may meet at the same point, a rod and block of suitable size being employed; and each branch of course having a tightener. A better plan where the original stay is not fixed in the resultant position, or where that position has been shifted by the addition of more arms to the pole, is to provide a second

stay parallel to the first, and to fix it as much below the resultant point as the other is above it.

As there is always a danger that faults may arise from the wires expanding and touching the stays, by means of which the current finds 'earth,' the stay-wires should be at least three inches distant from the line wire nearest to them, and where this cannot be effected by applying the ordinary means of affixing the stay to the pole, an iron arm or bracket to take the stay clear of the arms should be employed.

Upon a line carrying a very large number of wires it is very advisable to stay the poles on both sides *in the line of the wires* at a distance of about every quarter of a mile. The object of this is to prevent the poles from being drawn from the upright in the event of an accident occurring to the line. The breakage of the wires, either through a pole being knocked over or (in the case of overhouse work) from fire, imparts a sudden strain, which, unless it be resisted, makes itself felt for a long way upon the poles on both sides of the accident.

The greatest care must be taken in staying all terminal poles, for they form as it were the keystones of the line, and upon their being properly seen to its appearance to a great extent depends. To guard as far as possible against their yielding, iron rods may be employed, although wire stays can be made quite effective. The strength of the stay should obviously be equal to the sum of the breaking stresses of all the wires terminated on the pole, allowance being made for the fact that the actual stress on the stay will vary inversely as the distance between the point where it is anchored and the base of the pole; this distance should, as a rule, never be less than the height above ground of the terminal pole. Under these conditions, the maximum stress on the stay will be roughly equal to one and a half times the sum of the breaking stresses of the wires terminated. Thus, with twelve wires, each having a breaking stress of 1200 lbs., the maximum stress along the stay will approximately equal 1700 lbs. for each wire; and a one-inch iron rod with a breaking stress of twenty tons per square inch will satisfactorily resist this stress.

If a stranded stay of No. 8 steel wire with a breaking strain of 1400 lbs. for each wire be employed, the number of wires in the stay should be one-fourth more than the number of line wires to be terminated under the same conditions as above.

If the stay base should necessarily be shortened, then the strength of the stay (whether it be a solid rod or a stranded wire rope) must be proportionately increased. The stay-blocks employed for terminal poles should be much larger than those for ordinary stays; they should be buried in the ground to a depth of from six to eight feet, and the ramming and punning carried out with even more than usual care. Where it is possible to attach the rod to a good sound permanent building instead of using a stay-block at all, it is advisable to do so. Upon terminal poles where the wires form an angle anything nearly approaching a right angle it is preferable to place two stays, one in the line of each component strain, rather than a single stay in the direction of the resultant of these; for by doing so provision is made against accident—in the same way as staying a crowded line in the line of the wires (p. 246)—from any sudden stress being thrown from either quarter upon the pole.

Struts.—It is more difficult to erect struts to satisfactorily withstand heavy stresses than is the case with stays, so, as a rule, where the latter can be safely employed they are to be preferred. In fixing a strut the same object must be kept in view as in fixing a stay, but it is preferable to fix the strut at that point of the pole which, allowing for future requirements of the line, will ultimately be the resultant point. The guiding principle in the erection of struts is so to fix them that they will act both as struts and stays, and thus be able to withstand both pressure and pull.

But the more convenient method of fixing a strut is shown by fig. 181. It is placed in the ground to a depth of not less than four feet, and attached to a creosoted block B (similar to the stay-block) which is slightly mortised into the strut and fastened by a bolt; and a similar block A should be attached to the bottom of the pole. The strut, like tne stay, should form as great an angle as possible with the pole, for the same principle regulates the direction of both. The pole should not be weakened by being cut in any way where the strut is attached, but the top of the strut should be neatly scarfed, so as to fit the pole as closely as possible. At the points of contact both should be carefully tarred or painted for the purpose of making the joint watertight. The pole and strut are firmly secured together by means of one $\frac{1}{2}$- or $\frac{5}{8}$-in. bolt. The strut should be fitted to the pole at the resultant point, or, if the line is not

fully fitted, at the position which will become the resultant point when the pole is carrying the full complement of wires. Where four-wire arms are employed it often becomes necessary to fit the strut below the arms, and extra stiff poles must then be used (fig. 181). For iron poles fig. 182 shows a useful type

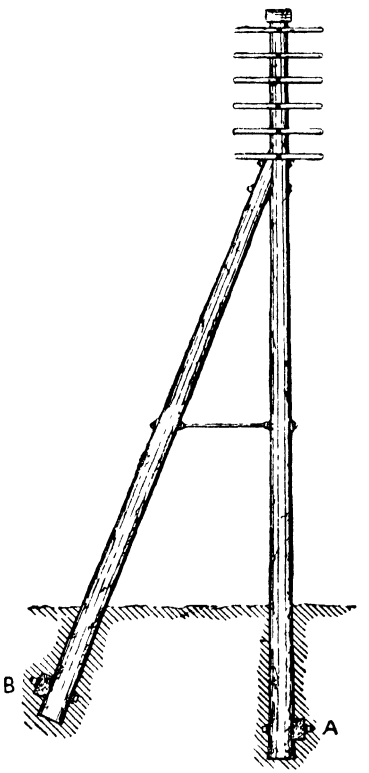


Fig. 181

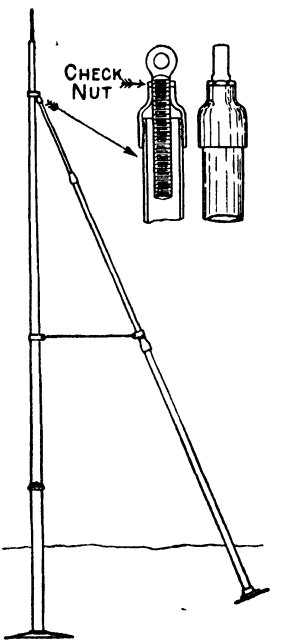


Fig. 182

of iron tubular strut with special connection and tightening screw piece at the head.

Fitting-up the Pole.—With the exception of placing the spindles and insulators, this is always done before the pole is planted in the ground. The first point in fitting-up the pole is to protect the top from the effects of the weather. For this purpose galvanised iron roofs of the shape shown on the pole in fig. 183, and of a uniform size, are invariably employed in England. The pole is cut to fit them, and they are then nailed on with two 2-in. clout nails. Before the roof is nailed on, the

top of the pole should be either painted or tarred. If a wire is to be run along the top of the pole a support for the insulator, of the form shown in fig. 183, known as a *saddle bracket*, or simply a *saddle*, is placed over the roof. A small aperture about an inch square is cut in the middle of the roof, and a hole about an inch deep in the top of the pole. The insulator spindle is passed through the saddle and the roof, and tightly screwed up by a nut on the under side. The whole is then fixed to the top of the pole by 3-in. galvanised iron nails.

One most important part of the fitting of a pole has yet to be described. If an insulator becomes faulty a portion of the current passing along the wire attached to it leaks away; and, provided there be no other wire upon the line, makes its way entirely to earth by means of the pole. The only evil resulting from this is a weakening of the signals, which, until the defect is made good, can be remedied by increased battery power. But if there be two or more wires upon the line, the leakage from any one will then, instead of going to earth, partly pass to the other wires—not entirely, but to an extent depending upon the electrical resistance which the pole offers in comparison with the materials intervening between all the wires. The working of wires is thereby more or less interfered with —the wires appear to be in 'contact.' An increase of battery power, instead of doing any good, is now positively injurious, for it serves merely to increase interference arising from the leakage. The only way to get rid of the inconvenience which is caused is to afford the leakage a path to earth the resistance of which is inappreciably small compared with that which exists between the wires. This path is afforded by the *earth-wire*, a 400-lbs. galvanised iron wire which is carefully stapled to the pole, passing from above the roof to the butt, with a sufficient length to admit of a spiral or two being formed below the pole so as to ensure good contact with the ground. The earth-wire should be placed beneath the washers of the bolts that fix the arms, being stapled close round the arms if fitted on the up side of the pole. The wire is carried, clear of the roof, a few inches above the pole, so as to serve as a lightning conductor, protecting the pole and wires from damage by lightning.

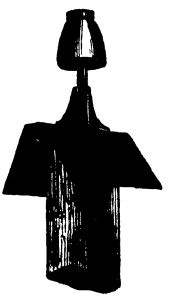


Fig. 183

It is of the utmost importance that the earth-wire should make good earth; if this cannot be secured it is better not to fix one at all, for it would merely tend to promote contact amongst the wires rather than to prevent it. In dry sandy soil, or in rock, earth-wiring is therefore to be avoided; but if any considerable extent of line is so situated it may often be found advisable to carry a special wire along the poles for the earth-wires to some spot where a good earth can be found. Of course insulators are not required for such a wire.

Upon long lines earth-wires render most important service, whether an insulator is actually faulty or not; for, seeing that up to the present time no really perfect insulator capable of withstanding the effects of weather has been devised, the slight leakage which inevitably takes place at each would otherwise pass into the neighbouring wires, and the sum-total of these would on a line of considerable length tell upon the working of the circuits, more especially if delicate fast-speed instruments are employed. It has been urged as an argument against the use of the earth-wires that the inductive capacity of the line-wires is increased where they are adopted. There can be no doubt that this is the case, but no practical inconvenience has ever been found to result; and even if it did, the evil could be but slight compared with that which the employment of earth-wires successfully prevents.

On iron poles earth-wires are, of course, unnecessary except on wood arms, where such are used.

Fixing Arms.—If the pole be a wooden one, wood arms are invariably used, and are fitted into grooves cut on one side of the pole. The grooves are never more than 1½ in. in depth and are placed 12 in. apart centre to centre, the top groove being 9 in. from the top of the pole. The arm is held in the groove by means of a galvanised iron bolt which passes right through both pole and arm. The head of the bolt beds on a washer on the side of the pole opposite the groove, and a nut with another washer clamps the arm in position.

With iron poles either iron tubular arms or wood arms are used. In both cases an arm seat is required to clamp the arm to the pole. The type used for tubular arms is shown in fig. 167, p. 221.

The pattern used for wood arms, called *Combination Brackets*, is of much the same type as for iron arms, but the seat on which

the arm rests is a malleable iron casting like a short length of angle iron, but shaped at the back to grip the pole when the bolts are tightened.

It is most essential that the nuts holding the seat to the pole should be tightened before those holding the arm to the seat are screwed up.

Fixing Insulators.—When the pole is raised, the next step is to fix the insulators in the supports, whether arms or brackets, by placing the spindles into the holes prepared for them, and securing them from beneath by a nut and washer; it is essential that this should be made as tight as possible. Where, as in tropical countries, the nuts are liable to become loose and drop off owing to the arm shrinking, it is advisable to twist a short piece of galvanised iron binding wire securely round the spindle just below the nut. The insulators, before being actually fixed, should be thoroughly well cleared of all dust and dirt adhering to them, for this, if left, would tend seriously to impair their efficiency.

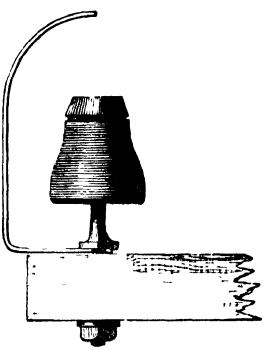


Fig. 184

Guards.—Upon every curve, or even upon the straight, where, in the event of the insulator being broken, there is a possibility of the wire coming into harm's way, guards should be employed. They are of two kinds, hoop and hook. The hoop guard is now practically never used in England, for, in winter, snow adhering to the hoop in time brings wire and arm into contact with each other, and, when it begins to melt, leads to a deterioration in the insulation of the line. The hook form is shown in fig. 184. It serves the purpose for which it is intended very well. These guards are fixed in the position shown; and it is needless to observe that every care must be exercised in making them as tight as possible, so as to prevent their coming by any possibility into actual contact with the wire. This danger is now provided against by a small lug at the lower end of the guard, which rests against a flattened part of the flange of the insulator bolt.

Wiring.—The poles having been properly fitted-up, stayed or strutted as the case may be, raised and fitted with insulators,

the running of the wire is then proceeded with. The coils as supplied from the manufacturers are mounted upon drums which, for convenience of transport on roads, can be fitted on hand-barrows—with iron wire. One end of the wire is then taken by two men and drawn out, the drum being steadily revolved so as to avoid kinking the wire. Copper and bronze wires require more careful handling, as if the surface of the wire is damaged in any way its strength is at once impaired. To guard against this

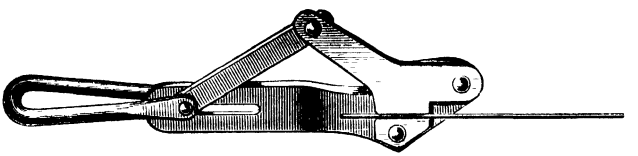


Fig. 185

it is therefore necessary to carry the drum-barrow and pay out the wire from it. As each pole is reached the wire is lifted into position, and this is continued until the whole coil is drawn out.

The wire is then stretched; and too much importance cannot possibly be attached to this portion of the construction

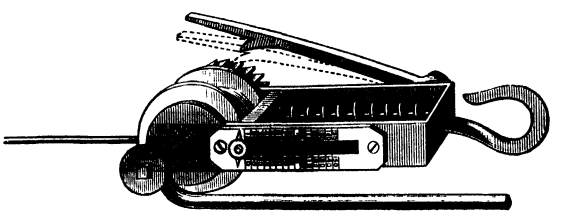


Fig 186

of a telegraph line. The stretching is at first accomplished as far as possible by hand; light blocks and tackle are then applied to the wire, a species of vice, technically known as the *draw-tongs* (fig. 185), being used to grip it. By means of this the wire is drawn as tight as may be required, and the actual stress to be put upon the wire is then regulated as follows. One end of a cord, or more frequently a wire, is attached to some fixed point, usually the pole or arm, and the other to the drum of a *tension ratchet* of the form shown in fig. 186. This drum is fixed across the end of an iron frame, and is provided with a ratchet-wheel acted upon by a suitable pawl. On this frame

is arranged a graduated spring balance with a hook. The wire which is to be pulled-up is gripped at a convenient point by the draw-tongs, which is hooked to the tension ratchet by the loop. On revolving the drum by means of the key, and so winding-up the cord, the tension on the wire is increased until the indicator shows that the proper stress is being applied. If the wire were pulled up too tightly it would break; if it were left too slack, it would be liable to get into contact with the others in its neighbourhood: both extremes must be carefully guarded against. When simply placed on to the arm the wire dips or hangs in a curve. This curve diminishes and approximates more closely to a straight line the tighter the wire is drawn; in other words, the dip or *sag* depends upon the tension of the wire. In countries where very low temperatures occur in the winter time, and where allowance must be made for stresses due to accumulations of ice and snow on wires, the maximum tension to which wires should be drawn is one-fourth of their breaking stress; for instance, 600 and 200 lbs. wire, whose breaking stresses are respectively 1860 and 620 lbs., should never be drawn up with a tension greater than 465 lbs. for the former and 155 lbs. for the latter. Where low temperature and snow are unusual, wires may be safely pulled up to one-third of their breaking strain. In tropical climates where high summer temperatures give rise to increased sags it is desirable to employ an even greater tension in order to minimise the possibility of contacts occurring between the wires in windy weather.

Wires are usually erected in England in the summer, since conditions for outdoor work are then more favourable. Now since metals expand with a rise of temperature, it follows that the wire will be longer at summer heat than at ordinary winter temperature, and if the wire when erected were subjected to a tension equal to one-fourth its breaking stress, the contraction which would result from the fall to winter temperature might cause the tension in the wire to become equal to the breaking stress. Indeed, until proper precautions were adopted, it was quite common for a line erected in summer to break at several points when the first frost of the succeeding winter set in.

In order to facilitate the erection of wires, and to avoid the above difficulty, the sags and stresses for various usual spans at varying temperatures have been calculated and issued

in tabular form by the British Post Office. These tables are based upon the following formulæ, allowing for a factor of safety of 4 at low winter temperature.

Let l = length of span in feet;
d = sag (or dip) in feet at minimum temperature (at 22° F.);
d_1 = ,, ,, ,, higher ,,
s = stress in pounds at minimum temperature (at 22° F.);
s_1 = ,, ,, higher ,,
w = weight in pounds of one foot of the wire;
L = true length of wire in feet;
T = difference of temperature Fahr.;
k = coefficient of expansion per degree Fahr.

Then

$$d = \frac{l^2 w}{8 s} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$d_1 = \sqrt{d^2 + l^2(\mathrm{T} \times \tfrac{3}{8}k)} \quad . \quad . \quad (2)$$

$$s_1 = s\frac{d}{d_1} \quad . \quad . \quad . \quad . \quad . \quad (3)$$

$$\mathrm{L} = l + \frac{8d^2}{3l} \quad . \quad . \quad . \quad . \quad (4)$$

For 400 lbs. iron, w = 0·075758 lb. per ft.
,, 200 ,, ,, w = 0·0378 ,, ,,
,, 400 ,, copper w = 0·0756 ,, ,,
,, 300 ,, ,, w = 0·0568 ,, ,,
,, 200 ,, ,, w = 0·0378 ,, ,,
,, 150 ,, ,, w = 0·028409 ,, ,,
,, 100 ,, ,, w = 0·018939 ,, ,,
,, 70 ,, bronze w = 0·01325 ,, ,,
,, 40 ,, ,, w = 0·00756 ,, ,,

for iron, k = 0·00000683
for copper, k = 0·00000956
for bronze, k = 0·0000115

The Tables are given as Appendix Sections K, L, and M.

If one wire upon a line of poles is once properly regulated, the regulation of all the succeeding wires that are run may be taken from it and becomes a very simple matter: for, assuming that they are all of the same metal, they will all (although

it may be, of different gauges) take exactly the same dip with the same proportional strain.

On any line exceeding a mile in length which carries telephone

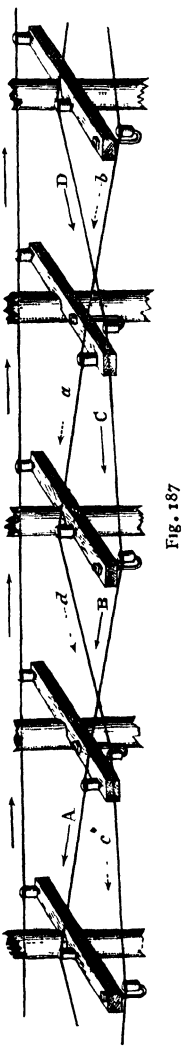


Fig. 187

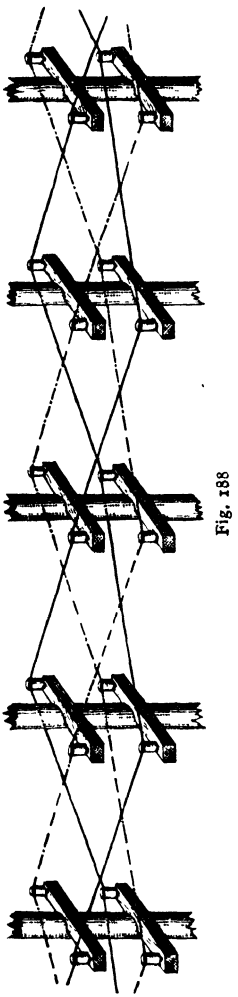


Fig. 188

wires it is necessary either to rotate the wires, or to transpose the wires at certain points on the line, in order to eliminate inductive disturbance in the telephone circuits. Fig. 187 shows the plan where a single telephone circuit is erected amongst

ordinary telegraph wires, and rotated. Fig. 188 shows two telephone circuits, each pair of wires diagonally situated, being used for one circuit; a complete revolution is made in every four spans, and it is essential that the insulators and the arms should be equidistant. The usual practice is to fix them 12 in. apart. Where transposing is in use (and where the line carries a large number of wires, this is the only available system); the number of times any one circuit should be transposed depends on the total number of circuits on the line of poles.

With two circuits only, it is sufficient to transpose one of them halfway. If a third is added, it can be transposed twice, and the transpositions should be made halfway between those

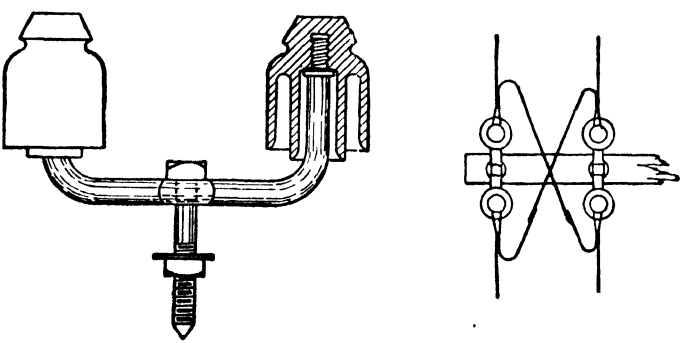


Fig. 189

on No. 2 circuit. When more circuits are carried, the transpositions must be more frequent.

For the transposition the best practice is to use U-bolts and two insulators, as shown in fig. 189.

Although there is no serious objection to the carrying of telegraph and telephone circuits on one line of poles if the telephone circuits are properly rotated or transposed, it is preferable to employ separate lines if there are many circuits of both descriptions, and especially if the telephone lines are for long distance trunk purposes. In the cases where one line of poles carries both descriptions of circuits, it is advisable to run the telegraph wires above the telephone wires, and not underneath them.

Binding.—The wire, when duly strained, is placed in the groove of the insulator, and, if iron, is very tightly bound to it in the manner shown in fig. 190. No. 16 galvanised soft wire

is always used for binding iron wire. It is applied as follows: Two laps are taken over the line wire at A. The inner end is then taken round the neck of the insulator to the under side of the line wire at B, and, after one complete lap, is taken back round the insulator to A and lapped on the line wire for about a dozen turns to C. The other end of the binding wire is taken from the under side of the line wire at A round the neck of the

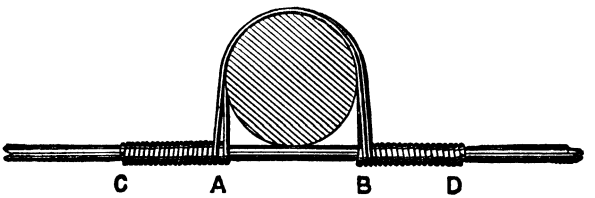


Fig. 190

insulator to the upper side at B, and similarly lapped over the line wire to D.

For copper wire the following method is adopted (fig. 191): The line wire is first served from A to D with a sheath of copper

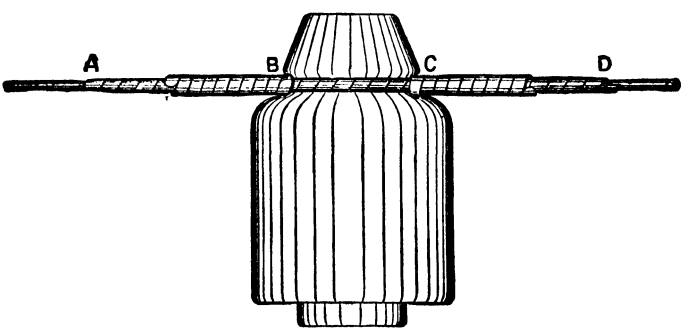


Fig. 191

tape 22–28 mils thick. The binder (which consists of wire more or less corresponding to the line wire, with its ends rolled flat) is then placed round the neck of the insulator and the ends (brought *over* the conductor at B and *under* it at C) closely wrapped around the served portion of the conductor as shown. The wrapping is done by hand, and it is then tightened by means of two pairs of gas-nipple tongs supplied for the purpose.

If the position of a pole has to be altered, care should be

taken that every trace of the old binders is removed, unless, indeed—as at road-crossings—they have been soldered to the wires. Portions allowed to remain are apt to wear the line wires so that they break at the first touch of frost.

Numbering of Wires.—The wires when erected should each have a distinguishing number, and should, if possible, occupy the same position upon each pole on the line along which they are carried. The following system, applicable to both road and railway, and independent of the side on which the poles are planted, is now generally adopted: Where a wire is run on a saddle, that is invariably known as No. 0; then, standing with back towards the up station—that is to say, looking at the up side of the pole—the wire on the left-hand side of the top arm is No. 1; that on the right-hand side, No. 2; the wire on the left-hand side of the second arm, No. 3; that on the right-hand side, No. 4; and so on. The numbering of the wires where there are four upon an arm should be as shown in fig. 192, so that at points where the wires are transferred to short arms, 3 and 4, 7 and 8 naturally fall into their proper places.

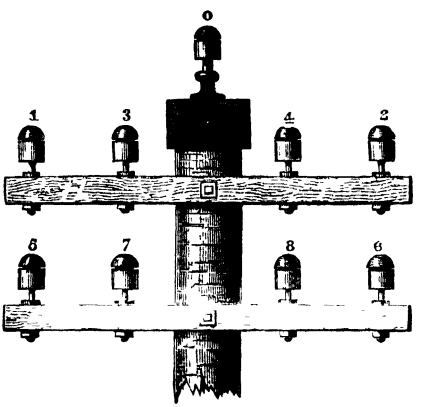


Fig. 192

Joints.—Bad joints in telegraph wires have given rise to more trouble than any other defect, for the faults caused by them being intermittent, the time spent in localising them is greater than is the case with faults of any other description; and as each joint in open wires is generally at some little distance from the support the search for the defect is a tedious and difficult matter.

The form which is now universally adopted is known as the '*Britannia*' *joint.* It is shown in fig. 193, and is made as follows: The ends of the wires are carefully scraped clean and laid side by side for a distance of about two inches; they are then bound firmly together with the ordinary No. 16 binding-wire, which should be cleaned before being applied; over this is

smeared a prepared flux known as 'Baker's fluid.' Chloride of zinc, known as 'spirits of salts,' should not be used. The solder, without which no electrical joint can be considered perfect, being then applied, welds the whole together in one solid metallic mass, and renders the electrical continuity complete. The joint should be carefully washed so as to remove all

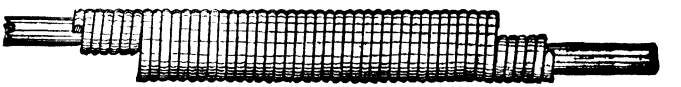


Fig. 193

surplus soldering fluid. The waste ends of the two wires should be cut off as close as possible to the joint, so as to prevent their hooking into the neighbouring wires and causing contacts when swayed by the wind. Originally the ends of the wire were bent at right angles after the joint had been whipped, but, as in a well-made joint the hooked ends serve no useful purpose, the practice has been discontinued. Tinned copper jointing-wire is used in making joints on copper wire.

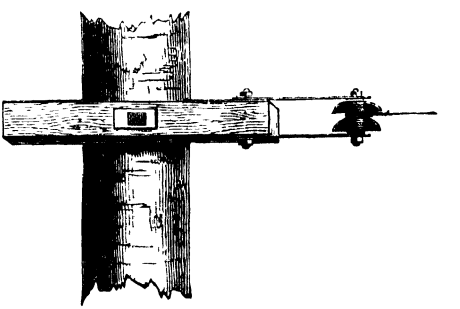


Fig. 194

Another form of joint is that known as 'McIntyre's.' This consists of two tubes of copper well brazed together.[1] The size of these tubes depends on the gauge of wire to be jointed, each tube being of such diameter as to allow the end of the wire to be pushed through.

For jointing, the two ends of the wires are threaded through the two tubes in opposite directions, and a special tool is then used to give the pair of tubes four spiral turns, one end of the joint being firmly gripped whilst the tool at the other end is rotated four times.

Terminating.—The wire is sometimes terminated on a shackle. This shackle is fixed and the wire is attached to the shackle as shown in fig. 194. The wire is simply bent round

[1] Or one sheet rolled up to form two tubes.

the porcelain and bound in exactly the same manner as an ordinary joint with the exception that it need not be soldered.

Shackles are, however, electrically very imperfect: therefore the terminal insulator, shown in fig. 195, is now more generally used, and acts much more efficiently as an insulator.

When the wire has to be terminated at intermediate points with shackles, or '*shackled off*,' as it is termed, the following is the mode of procedure which should be adopted: A double shackle is fixed, and each side is first 'tailed'—that is to say, a wire is passed round the porcelain and bound in the ordinary

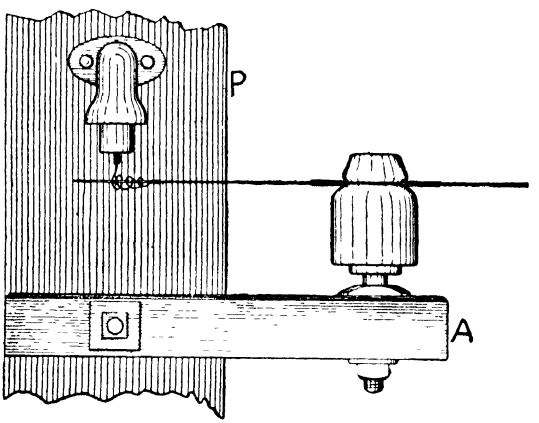


Fig. 195

way, leaving one end projecting to a distance of from 18 in. to 2 ft. To this end the line wire is firmly bound and soldered, and is then bent round at a distance of not less than 6 in. from the pole, and similarly dealt with on the opposite side. Thus, the line wire itself is continuous.

Where line wires are terminated for the purpose of being led into an office, a tail-piece should be left on the end of the wire where it is secured to the insulator, and to this the leading-in wire is connected and soldered.

The leading-in wire from the terminal pole (fig. 195) usually consists of a copper conductor insulated with pure and vulcanised india-rubber and protected with lapping of insulating tape and an outer coating of strong braiding well compounded. This wire is bared for a distance of several inches, then wound round the tail-piece of the line wire and soldered only at the end so as

to admit of its being disconnected for testing purposes if required, and as india-rubber when exposed to the effects of wind and weather rapidly deteriorates, the wire is carefully protected in a casing down the pole until it is led inside the office.

The small portion that is unavoidably left unprotected is passed through a 'leading-in cup' which prevents leakage where the wire enters the troughing. On square terminal poles a hollow facing is fixed, through which the leading-in wires are led. This is preferable to cutting grooves, which tend more or less to reduce the strength of the pole.

In some countries gutta-percha-covered wire is used, but it does not withstand varying weather conditions so well as rubber. A new form of insulation for leading-in wires, consisting of a flexible enamel usually protected with a covering of cotton or silk, is now much favoured, but sufficient experience of its durability has not yet been had to warrant its general adoption in place of rubber and gutta-percha. For telephone lines twin twisted rubber or enamel insulated and lead-covered wires are the most satisfactory.

For actual terminations, special large terminal insulators on extra strong steel spindles are employed. The arrangement is shown by fig. 195. The pole P is of rectangular section, and the arm A is bolted to one side in line with the wires.

An important point to notice is that in no case should gutta-percha be brought into contact with creosoted timber, as the oil of the creosote exercises a destructive influence upon it. Care should also be taken that the leading-in wires, when carried underneath the flooring, should be protected from the possible attacks of rats, which in more than one instance have been known to gnaw through the gutta-percha, and, having laid bare the conductors, brought them into contact with each other. The leading-in wire should likewise be kept clear of *leaden* gas-pipes; a distance of not less than six inches should intervene between them, for during a thunderstorm great risk is incurred if there is a possible line of discharge between the leading-in wire and a leaden gas-pipe. Several instances of damage have occurred owing to the lead having been fused and the gas ignited by lightning. The same danger does not, of course, exist with an *iron pipe*.

For leading in telephone lines the British Post Office has adopted a special form of insulator, invented by Messrs. Purves

and Sinnott. Fig. 196 is a sectional drawing of a pair of such insulators as wired on the arm. The line wires are bound to the grooves *g g'*, and the tail piece is led through a hole into a cavity in the insulators (*b* in the insulator B). In B this tail piece is connected to the two conductors in a length of twin lead-covered cable. This twin cable is passed through another channel *d*, led down the iron spindle and along the arm up the A spindle and into the cavity of A. The insulators have two vertical channels; the second one in B is filled up with compound. In

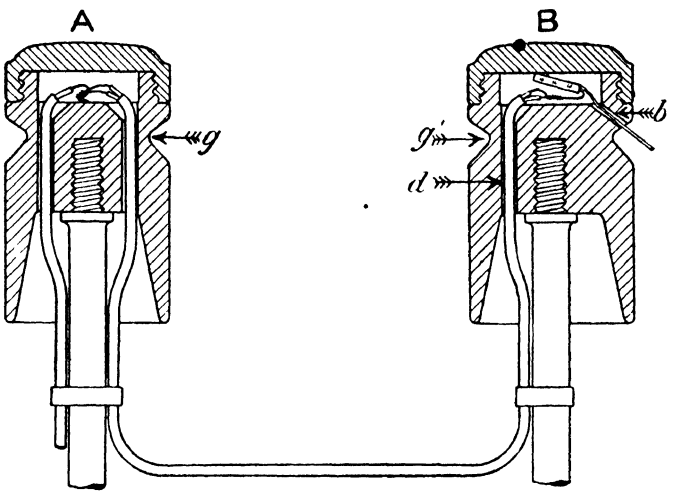


Fig. 196

the cavity of A the two conductors led from B are joined together and connected to one conductor in another length of twin lead-covered cable, which is led up through the other channel. The second conductor in this cable is connected to the tail of the line wire terminating on A. This twin cable is led down the pole and terminates in a joint box fitted on the pole or a cable head or in an underground chamber, or is taken direct into the building.

The cavities in the insulators are filled up with bitumen, and the tops screwed on.

In the tropics where the overhead lines may run some distance it is essential to use a pole joint box—or possibly a pillar box fitted at the base of the pole—containing lightning protectors for each conductor (see p. 290).

Earth.—This, although it is the last point to be seen to in the construction of a telegraph line, is one of the most important, for without a good earth-connection satisfactory working upon any circuit becomes an impossibility. The first object to secure is a good damp soil, and, next to that, as large a conducting surface as possible; for this reason a metal pump or, better still, the iron water-pipes of a town are taken advantage of, and in most instances good earth is obtained by soldering the earth-wire securely on to them. But if there are no water-pipes, and an *iron* gas-pipe is at hand, it will be found to answer the purpose; when both gas and water-pipes exist the earth-wire should be well soldered to each. Upon no account whatever is a leaden gas-pipe to be employed for the purpose of affording earth; the danger incurred by their being even near to the wires has been indicated; that danger is increased considerably when the wire is attached to them.

When neither iron water-pipes, a pump, nor iron gas-pipes can be procured, a plate of metal from two to three feet square, usually of galvanised iron, is buried in the ground at a depth sufficient to ensure its being always damp, and the earth-wire is attached to that. Care must be taken that, on short circuits, or circuits where delicate instruments are employed, earth at each end is obtained by a plate of the same metal. Unless this is seen to a permanent current is set up; for the two dissimilar metals being united by a conductor the necessary conditions for a current are present. For instance, iron water-pipes at one end and a copper plate at the other would give rise to this, and the combination of different metals must therefore be avoided.

It is also most essential that the earth wire shall have no angles and be as direct and short as possible.

B.—Overhouse Telegraphs

In large towns, where it becomes impossible to plant poles for the support of the wires on the ground level, overhouse telegraphs are had recourse to. They should be adopted, however, only when the number of wires is comparatively small; if many wires have to be run, or are likely to be required, underground work is to be preferred.

In the construction of overhouse lines nothing but the

very best materials should be employed. The supports are iron standards, whose length will vary according to the conditions of the work. They are fixed into sockets planted upon the ridges of the houses or placed in 'chairs.' These chairs are generally made of iron, although occasionally wood is employed. A hole is cast or bored in them, as the case may be, and into it the pole is firmly fixed. Poles employed in overhouse work should be stayed in every possible direction.

The conductor employed is, if of iron, a strand of three No. 16 wires; but more generally copper or silicium bronze wire is preferred. Where exposed to the action of smoke or the gases which are given off in the neighbourhood of most of the centres of industry, the iron wire is covered with tanned tape saturated in a composition of ozokerit and Stockholm tar; but copper needs no such protection.

Every effort must be made to reduce to a minimum the risk arising from the breakage of the wires. Thoroughfares should be crossed as far as possible at right angles, and not longitudinally; the shorter the length of wire hanging over them, the less liability is there of danger to the public.

In soldering the joints at each point of support the utmost caution should be observed in the use of the fire-pot. Instances have occurred where, from carelessness and negligence with it on the roofs of houses, the leads have been melted and the buildings set on fire. In leading-in from iron standards as well as from all iron supports, extra precaution must be observed to avoid leakage in consequence of deterioration of the covering of the wires.

When the standards cannot be fixed, and chimneys have necessarily to be taken advantage of instead, great care should be exercised in their selection; none but those which upon examination are proved to be perfectly sound should be used, and brackets should never be inserted even in these, but an iron band encircling the entire chimney should be employed.

A very frequent objection urged by the owners of buildings against the attachment of the wires is the noise which they cause. If the binding be imperfectly performed, or the wire be strained too tightly, the vibration conducted down the solid walls proves to be an almost intolerable nuisance; in frosty weather, as might be expected, it becomes worse and worse as the wire contracts. Various efforts have been made to

surmount this: the bolt of the shackle has been padded with chamois leather, india-rubber, and the like, the wire itself as it passes round the insulator being encased in the same material. This has been found to answer fairly; but the plan which effectually puts a stop to the noise is the insertion of a small section of chain in the line-wire upon each side of the shackle. To the extremity of the chain, which, of course, does not form part of the circuit, the wire is doubly bound and soldered. Perhaps the most satisfactory plan is to use only light copper or bronze wire, not too tightly strained.

Too much care cannot be exercised by the workmen in the erection of overhouse wires. The damage done to the buildings where the supports are fixed, as well as to those intervening over which the wire has to be drawn, should in every instance be rectified the moment it is observed; the dislodgement of slates and tiles, unless speedily seen to, becomes in time the source of great expense, and forms one of the main barriers in the way of overhouse telegraphs.

C.—Submarine or Subfluvial Lines

It is beyond the scope of this book to deal with submarine telegraphy generally, but as in many countries it is necessary to carry telegraph lines across wide rivers and narrow straits, a short description of the forms of cable used for such purposes will be found useful.

In such cables, whether they contain one or several conductors, each conductor is separately insulated and the complete core well protected and armoured. Two forms of insulation are used: india-rubber and gutta-percha; the usual practice being to employ rubber for river cables and gutta-percha for submarine work only, as gutta-percha cable must be kept in a tank, and it is often impossible to transport cable up country in such tanks. The type of cable used for crossing tropical rivers is manufactured as follows:—

The conductors are made up of seven strands of No. 23 S.W.G. high conductivity copper, uniformly tinned. This weighs 65 lbs. per mile. Over this conductor is put three layers of rubber, the first being pure india-rubber, the second and third being vulcanised. This insulation should have an external diameter of 0·25 in. Samples of this insulation are tested by being subjected to one hour of dry heat of 270° F. and to three hours

of moist heat of 320° F., which they must withstand without being impaired in quality or changed in appearance. Other samples are stretched to four times their length for twenty-four hours, and they must afterwards return to within 25 per cent. of their original length within fifteen minutes.

The core is then covered with thin prepared tape, vulcanised, and afterwards drawn through ozokerit compound. A serving of tanned jute covers this and the whole is sheathed with galvanised iron wire.

It is of great importance that this iron wire shall be carefully prepared from what is known as ball furnace puddled iron. Such iron has a long fibrous nature and resists oxidation far better than any steel wire. With this type of cable the iron wire has a diameter of 160 mils, and is put through the usual tests for breaking strain, twists, and elongation.

Two coatings of compound and two servings of jute are laid alternately over the armouring.

The core is tested for insulation before being armoured, and for this purpose it is first immersed in water at 75° F. for 24 hours, and should have an insulation resistance of at least 5000 megohms per mile after one minute's electrification. Its capacity should not exceed 0·34 microfarad per mile. Such a cable is usually supplied in lengths of 1000 yds.

With gutta-percha insulated cable for submarine work a very useful type is one having a stranded copper conductor weighing 105 lbs. per nautical mile (2029 yds.), the interstices being filled with Chatterton's compound; the insulation should weigh 150 lbs. per mile and be put on in three layers. Over this core is laid one layer of prepared tape, then a layer of brass tape, and finally a covering of ozokerit cotton tape. This core is served with best tanned jute, and the whole is sheathed with a layer of galvanised iron wire similar to that described above.

For positions where the chance of damage from ships' anchors is possible, it has been found desirable to use two layers of iron wire, one 128 mils diameter, the other one 160 mils. This sheathing is covered with two layers of jute yarn steeped in Stockholm tar, and two coatings of compound laid alternately.

The insulation resistance of the core for this cable must not be less than 500 megohms per nautical mile and the capacity should not be more than 0·34 microfarad per nautical mile.

It is very desirable that, for submarine cables, lengths should

be obtained sufficient to cover the whole distance without any joint. But where this is impossible, the joints must be carefully made by hand when the cable is laid.

For the rubber river cable, cast-iron joint boxes can be used.

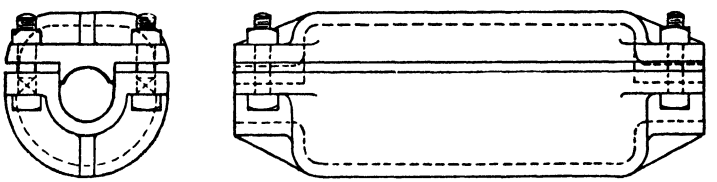


Fig. 197

Fig. 197 shows a type supplied by Siemens Brothers. At each end of the cable the armouring is cut away and the ends of the iron wire are bent back for some seven inches, puddings being formed with yarn and the ends which completely fill the holes in the box. The box is made in two parts which are

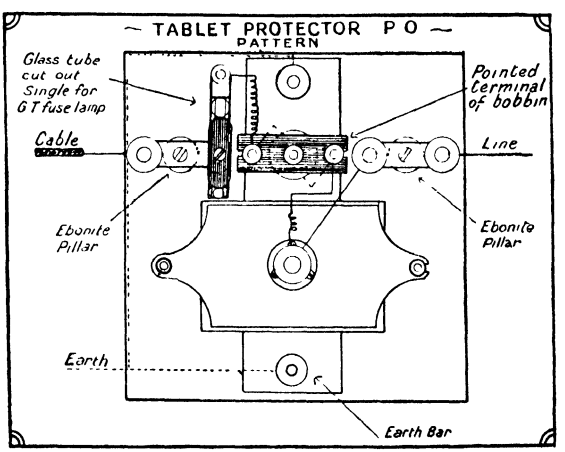


Fig. 198

strongly bolted together, and after the conductors have been soldered together the whole is filled with compound.

Special precautions must be taken to protect such cables from damage by lightning. It is most desirable that only the very best type of protector should be used for this purpose. Two well-known types are:

(1) P.O. tablet protector (fig. 198);

(2) Natal pattern Lodge protector (fig. 199).

With the tablet protector, the overhead line is connected to one of a pair of terminals supported on an ebonite pillar, the second terminal being connected to an upper brass plate which is separated by perforated mica from an earthed lower plate. The upper plate is also connected to a pointed terminal of a bobbin (which acts as a choking coil), the point of the terminal being closely adjacent to the earth plate. From this bobbin the connection goes to a fuse enclosed in a glass tube, which burns out with one ampère. This fuse and the cable terminal

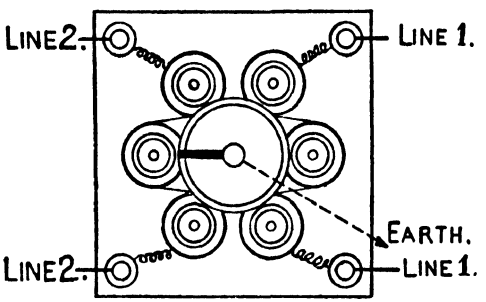


Fig. 199

to which it is also connected are carried on a second ebonite pillar.

The other type of protector has a central disc with a sharp edge, which is connected to earth; round this disc are two sets of three bobbins, each carrying, and connected to, smaller brass discs with sharp edges placed closely adjacent to the earthed disc. The three bobbins are wound with different lengths of wire of different diameters, and the line is connected to the first bobbin whilst the cable is connected to the last bobbin. Each disc can be rotated.

These bobbins or choke coils are inserted to act as a block to lightning discharges, forcing the latter to jump the gap between the discs and go direct to earth.

CHAPTER XVI

CONSTRUCTION—(COVERED LINES)

UPON open lines short lengths of covered wire should be avoided as far as possible, but occasionally they are rendered necessary by local causes; whilst through tunnels and in towns they are decidedly to be preferred, not more for economical reasons than on the ground of safety in working. From the first, copper has been invariably employed as the conductor for underground lines, but the insulating material has varied considerably. Gutta-percha, india-rubber and paper are largely used, but the most usual at the present time is paper, loosely wrapped round the conductors.

Gutta-percha or India-rubber Covered Wires.—Covered wires through railway tunnels used to be laid in wooden boxing, the top of which was tied by iron wire or screwed on, and the boxing was supported upon hooks driven into the brickwork of the tunnel. The timber employed for this purpose should be tarred, but never on any account creosoted if gutta-percha insulation is used, because, as already stated, creosote in contact with gutta-percha exerts a marked influence upon it, and speedily leads to its deterioration; under no circumstances should these two materials be brought together.

The earliest underground wires placed upon the roads in England were laid in grooved boarding formed from creosoted Baltic timber. This plan was after a short time discontinued, and is now entirely abandoned. In place of boarding, cast-iron pipes are now generally employed for telegraph lines. These pipes are dipped while hot in a composition[1] which leaves a hard 'glaze' upon the metal. Glazed earthenware, set in cement,

[1] Dr. Angus Smith's composition consists of: coal tar, 1 cwt.; tallow, 7 lbs.; slaked lime, 10 lbs.; pine resin, 4 lbs.; and coal naphtha, sufficient to thin the composition to a degree suitable for proper coating.

is now largely used with lead-sheathed paper-insulated multiple cables, or armoured cable is laid direct in the ground.

The gauge of the pipes will vary according to the number of wires that are to be, or are likely to be, drawn into them before their renewal becomes necessary. In no case is it advisable to lay a pipe of smaller gauge than 2 in. in internal diameter, and generally 3-in. pipes would be preferable. The labour charge in connection with the laying of the pipes is such an important factor that the increase in the cost as between a 2-in. and a 3-in. pipe may often be justified in view of possible extensions.

As an indication of the accommodation afforded by the different sizes of pipes it may be assumed that 2-in., 3-in., and 4-in. pipes should not be expected to take respectively more

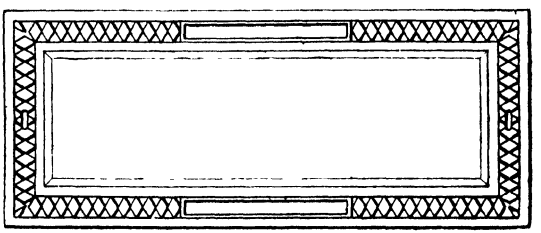


Fig. 200. $\frac{1}{12}$ full size.

than 40, 80, and 120 No. 7½ prepared G.P. covered wires or 60, 120, and 180 No. 18 india-rubber covered wires.

The interior of the pipes should be carefully scraped and cleaned before they are laid, for the purpose of removing any inequalities on the surface due to imperfect manufacture. If these are allowed to remain, the risk of injury to the insulation is incurred when the wires come to be pulled in. Steel dies or cylinders, rather smaller than the interior of the pipe, may be used for this purpose; or, if there is any difficulty in procuring these, a heavy iron chain drawn to and fro in the pipes will be found to answer the purpose very well.

Cast-iron pipes are generally laid at a depth of 2 ft.; in no case should the depth of the trench be less than 1 ft., and where the traffic is exceptionally heavy the limit should be increased to at least 2 ft. 6 in. In towns the pipes should as far as possible be laid under the pavement, where the traffic, being mainly confined to foot-passengers, is comparatively light. The joints in the pipes should be made

as follows: First a layer of tarred yarn is inserted into the socket and hammered in tightly with a special tool. Then the remainder of the socket space is filled in with molten lead, which, finally, is caulked or hammered tightly into the joint. In filling up the trench every care should be exercised to remove all stones of any size until a layer of 6 in. of good mould has been punned down over the pipes.

As each pipe is laid in its place, an iron wire of No. $7\frac{1}{2}$ gauge is threaded through it; to the end of this the cable to be pulled in is attached. The iron wire is carried through the pipes at the time they are being laid; it is next to impossible to thread it through for any length after they are laid; the difficulty

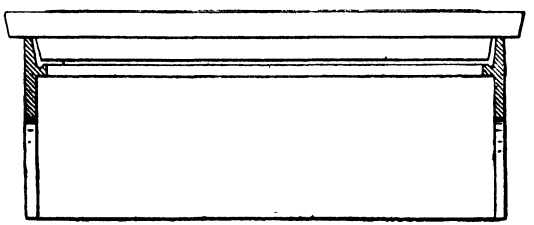


Fig. 201. $\frac{1}{12}$ full size.

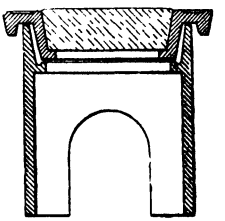


Fig. 202. $\frac{1}{12}$ full size.

in doing so is almost incredible until it has once been experienced. Bamboo sticks capped and fitted with screws joined together like chimney-sweeps' rods are sometimes used. At distances of 100 yds. apart where the line is straight, and less if the route is at all tortuous, 'flush' boxes are laid to facilitate the operation of pulling in. The name 'flush box' was originally given to these from the fact of their being laid level with the surface of the ground, which is still the practice in London and some other paved towns where the pipes are laid beneath the pavement. As the cable to be pulled in should be manufactured in lengths of 400 yds., every fourth box of this class becomes a joint box, in which the junction with the succeeding section of cable is made. These boxes are of cast iron, measuring about 2 ft. 6 in. in length by 11 in. in width and 1 ft. in depth; they have an opening at each end sufficiently large to admit the end of a pipe at any angle. Figs. 200, 201, and 202 show the construction of one of these boxes; being respectively a plan of the lid, a longitudinal section of the box, and a transverse section. The pipes are led into the boxes so as just to project

inside them, and the space around each pipe is stopped, in order to prevent the ingress of dirt. The figures show the kind of box that is fitted flush with the pavement, the lid consisting of an iron frame filled in with stone; but for buried boxes closely fitting iron covers are used. In order that the position of these buried boxes may be readily ascertained a distinguishing mark should be placed on the ground. The Postal Telegraph Department use a recognised cast-iron 'marker,' but, failing that, a wooden stake or a paving-stone will suffice to indicate the place.

Solid Slide Pipes.—Where it is not convenient or desirable to use a 'flush box,' a solid slide pipe is employed. This is of cast iron of slightly larger internal diameter than the pipe itself and usually about four feet in length. Before the cable is drawn in, the slide is slipped back over the pipe on one side of the joint, and subsequently it is drawn forward over the completed joint, and over the end of the pipe at the other side of the joint, which it is made to overlap about three inches. The ends of the slide are then caulked with yarn and lead in the usual manner. On a joint which is fitted with an air nozzle, a flanged coupling with a groove for the air nozzle is used. The joints between the flanges are made watertight by means of yarn and a mixture consisting of three parts of white lead and two parts of red lead. Electrical Continuity between the coupling and the pipes is maintained by the ends of the coupling being caulked and leaded in the usual way.

The wire hitherto largely employed for tunnel and underground work in England is that known as No. 7½ prepared gutta-percha. The copper conductor is No. 18 gauge, and is insulated with gutta-percha up to the gauge of No. 7½; it is then served with a covering of tanned tape which has been drawn through a composition of Stockholm tar and melted ozokerit. When several wires have to be drawn in at the same time, they are first of all laid side by side and tied together at short intervals, forming what is technically called a 'cable.' As they are pulled into the pipes the binders are cut and removed. Occasionally the plain gutta-percha wires are laid parallel to each other, and the whole are then served over with a covering of prepared tape. A true cable, however, is more generally used, formed of a strand of four plain gutta-percha wires laid (that is, twisted) together and protected with a coating of tape

prepared as above, or braided with hemp so as to form a neat rope or cable.

The 'cable' is coiled on a clean tarpaulin laid at a convenient distance from the flush-box where the work is commenced so as to prevent its chafing as it is drawn into the pipes. To guard against damage to the cable, in drawing-in a wooden roller is placed at the mouth of the pipe; and a mat is spread at the bottom of the box, which has been previously well cleaned out, so as to prevent the cable from dragging any dust or dirt along with it. The ends of the copper wires of the cable are stripped for two or three inches of their covering, and are twisted on to

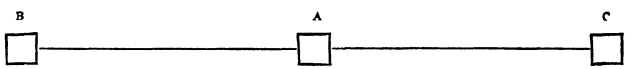


Fig. 203

a loop formed in the end of the iron wire which, as already remarked, has been threaded through each length of pipe as it was laid; and the ends are then lapped over with tape and yarn to prevent abrasion of the gutta-percha as the wires are drawn through. The work of hauling-in commences, in a straight length of 400 yards from the central box (fig. 203): one end of the cable is drawn from A to B, and the other from

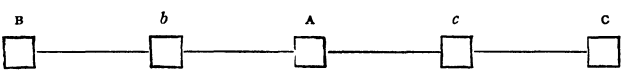


Fig. 204

A to C. Where there are two or more intermediate boxes, the operations in pulling-in are increased with each additional box; thus, in fig. 204, one-half of the cable would first of all be drawn from A to *b*, where it would be carefully coiled, and subsequently drawn in from *b* to B; while on the other side an exactly similar course would be adopted by drawing in the second half first to *c* and then to C. The coil being placed so as to give a straight lead to the cable into the pipe at the first hauling-box, the work of pulling-in is commenced. One man sees to the proper uncoiling of the cable, another attends to the lead, and the rest pull the iron wire through at the further box until the end of the cable makes its appearance there. In the case of intermediate boxes, such as at *b* and *c*, the cable drawn out of the pipes between A and those points is coiled there as in the first instance at A, care being taken to protect it from friction by means of a small

roller as it emerges from the pipe. Before being pulled into the sections *b* to B and *c* to C the cable is ' turned over ' by being re-coiled on the opposite side of the boxes at *b* and *c*, in order to give it a fair lead to the mouth of the pipe in the proper direction.

When the section of cable is got into the pipes the numbering of the wires is proceeded with. From a small portable battery a current is sent along each wire and noted at the further end upon a galvanometer ; corresponding numbers are then affixed to the ends of each wire in succession until all have been gone through. These numbers consist of small leaden pellets with the numerals imprinted upon them.

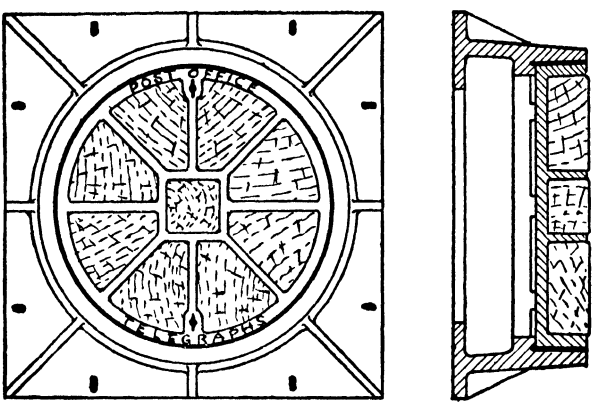


Fig. 205

Should it at any time be necessary to increase the number of wires in an existing line of pipes, the method adopted is as follows : Let B A C (fig. 203) be a section of line with joint-boxes at B, A, and C, and containing seven wires ; it is desired to increase the number to eleven. A cable of eleven wires, equal in length to the distance between B and A, is first of all formed and joined on to the end B of the existing cable. The same precautions are adopted to protect the wires from friction as in the case of a new line ; the new cable is then pulled in at B, the old one being drawn out at each intermediate flush-box between B and A in succession until the section B A is completed. To the old seven-wire cable, after it has been carefully examined and tested, and any damage which the covering may have sustained has been repaired, four new wires are added, and the

eleven-wire cable thus formed is drawn in from A to C. This operation is repeated throughout the entire line until the work is completed. In this way only one set of eleven joints—viz. that at the second box—becomes necessary; at each joint-box the four new wires have of course to be jointed.

Under no circumstances should any attempt be made to draw new wires into pipes which already contain existing wires without removing the latter. The friction which inevitably takes place between the old and the new wires leads to the abrasion of the protective covering in both, and lays the foundation of innumerable faults, which may only begin to make their appearance and interfere with the working of the circuits some time after the laying of the additional wires has been completed.

Fig. 205 shows the latest P.O. design for a roadway manhole cover which covers a brick pit.

Dry-core Cables.—Of late years paper insulated and lead covered cables have come into use, both for underground telegraph and telephone lines, as well as for overhead construction. Each wire is enclosed in strong specially prepared paper, free from metallic particles, applied spirally or longitudinally, in such a way as to completely cover the wire, and perfectly insulate it from its neighbour. For telephone purposes the wires thus insulated are twisted in pairs, and the copper conductors vary, according to the use for which they are destined, from 10 to 200 lbs. per mile in weight. For the smaller sizes, 800 pairs or more can be made up into one cable, and such cables for underground work in large cities, while occupying small space, are highly convenient. The lead sheath varies from 0·108 to 0·183 in. in thickness according to the number and size of conductors which it contains. The sheath, as specified by the British Post Office, is of the finest English lead, applied at a temperature not exceeding 600° Fahr., the quality and durability of the tube being of the highest importance. The electrostatic capacity of dry-core cables is only one-fourth that of gutta-percha or india-rubber. They are therefore well adapted for telephone purposes. With the lead sheath and all other wires connected to earth the electrostatic capacity per mile of each 20- or 40-lbs. conductor of twisted pairs, as ordinarily put up, is not more than 0·08 microfarad in cables containing 300 wires, at a temperature of 50° Fahr. The mean electrostatic capacity from wire to wire of each pair

in any length of cable (all the wires in the cable and the testing battery and apparatus being insulated) does not exceed 70 per cent. of the mean wire-to-earth capacity, tested as above described.

Although these cables are sheathed with lead they cannot be safely placed underground without some protection from mechanical injury. In some instances the lead sheath is armoured (see p. 288), but the more general practice where several cables may have to be laid is to provide ducts or conduits into which they can be drawn. Various types of conduit are in use in different parts of the world, but the scope of this book does not admit of more than the three Standard types used by the British Post Office being described. These are cast iron pipes, wrought iron pipes, and glazed earthenware ducts. The cast iron spigot-and-socket pipes used are described at p. 270. They are made with internal diameters of 4 in., 3½ in., 3 in., and 2 in., and in 9 ft. lengths for the first three sizes, and 6 ft. lengths for the 2 in. size. To facilitate the drawing-in of cables under the varying conditions of street level, and alignment between joint boxes, spigot-and-socket bends, both solid and split and of various radii, are used. Solid bends are employed in preference to split bends if the curve is such that the cable can be drawn through, but at points where a sharp turning is taken a split bend is necessary.

At proper intervals and at suitable positions, gaps are left in the line of pipes for the insertion of flush boxes (see p. 271), solid slides (see p. 272), or other means of access. At jointing chambers (see p. 288) the gaps will be such that the pipes will extend 1½ in. beyond the brickwork to allow for bonding (see p. 277). For solid slides the gap will be 6 in. less in length than the slide, thus allowing an overlap of 3 in. at each end for yarning and leading.

Where small cables are laid, as to subscribers' premises, wrought iron pipes are frequently employed. They vary in diameter from ½ in. to 2 in., and each length is screwed at both ends and fitted with a screwed socket at one end. The screwed portions are oiled at the time of manufacture and the pipes dipped while hot in composition similar to that described at p. 269.

The glazed earthenware conduits used by the British Post Office are made in 18 in. and 24 in. lengths with a minimum internal diameter of 3½ in. They are made of clay of suitable

quality, thoroughly burnt and glazed on the inside surface. They are of octagonal outside section and are laid in horizontal nests of as many single ducts as may be required. Split ducts of 6 in., 12 in. and 18 in. lengths are used for effecting repairs to ducts containing cables.

In laying ducts the depth of the trench should be such that the average depth from the surface of the ground to the uppermost surface of the top duct will be 2 ft. if under the footway and 3 ft. if under the carriage way. The ducts are laid in the trench on a foundation of concrete which is reinforced with lengths of steel of T-section $2\frac{1}{2}$ in. $\times$ $2\frac{1}{2}$ in. $\times$ $\frac{1}{4}$ in. embedded in the concrete. The number of the tees and the thickness of the concrete foundation and walls vary with the number of ducts and the character of the road or footway in which they are to be laid. The ducts are laid in cement, mortar and, to prevent the mortar getting inside, a strip of waterproofed calico 20 in. long $\times$ $4\frac{1}{2}$ in. wide, is wrapped round each joint. The spaces between the ducts are completely filled with the mortar. A mandril is inserted into each two ducts to maintain their alignment, and this is linked up with further mandrils as each successive duct is added, until a train of twelve mandrils is connected together, thus ensuring the alignment of twelve ducts at a time. The whole of the ducts in one horizontal layer should be laid in this manner for eight or nine yards, and while the mandrils are still in the ducts, concrete should be filled in between the outside ducts and the walls of the trench.

This form of duct is more flexible than the cast iron pipe, owing to the lengths used being short, and they therefore better lend themselves to slight bends that may have to be made to clear obstructions. The best type of conduit for any country will always depend upon local conditions, and the possibilities of the locality for the making of suitable ducts on the spot. The exact point at which the British Postal Department find it economical to employ the earthenware ducts cannot be stated, but the practice is to use cast iron pipes where less than six conduits are to be laid.

Where electrolytic action due to stray currents from lighting or power undertakings is likely to affect lead-covered cables, the cables should be metallically bonded together and to the iron pipes (if used), the whole being efficiently earthed at each main joint chamber.

The cost per conductor for dry core cables is only one-fourth to one-third that of the other forms of insulated cable. The lead-covered cables, iron pipes, and earthenware conduits are almost imperishable under the conditions in which they are applied, and if properly laid their durability should be very great. The cables are, however, not without disadvantages. For their success it is essential that the paper insulation should be kept dry. Therefore any defect in the lead sheathing or at a joint will probably cause faults on all the circuits in the cable. Further, this type of cable involves increased risk of damage from lightning.

In the course of manufacture, as the cable is laid up it is wound on an iron drum which is subsequently placed in an oven and subjected to heat until all moisture is driven off. The temperature of the oven is not allowed to exceed 225° Fahr. After passing through the lead press, the ends are sealed to exclude moisture.

The length of cable that can safely be drawn into a line of pipes or earthenware ducts varies with the number of wires, the weight of the cable, the alignment of the pipes or ducts, and other conditions.

Heavy cables should, as a rule, be ordered in such lengths as may be conveniently drawn into a pipe or duct from box to box. Lighter cables may generally with advantage be ordered in the maximum lengths which a drum will hold.

In drawing into a section of pipe which contains a bend the cable should be fed in from the end further from the bend; so that the shortest possible length of cable may have to pass the difficult point.

In all cases the cable should be two yards longer than the distance from centre to centre of the joint boxes, to allow for waste in pulling-in, jointing, testing, &c., and in the case of manholes the length may have to be still further increased to meet local conditions.

It is most economical to manufacture multiple dry-core cables in long lengths. Where the standard lengths cannot be employed and the use of short lengths is unavoidable, they should be aggregated into longer lengths within the limits laid down as the practical maxima in the tables. These maxima are determined in some cases by the capacity of the drum and in other cases by the weight and limit of flexibility of the cable.

When ready to commence the drawing-in the drums of cable are carted to the work, preferably in a low wagon, technically known as a 'float,' and care should be taken not to roll the drum about more than is absolutely necessary. The drum is fixed immediately over the end of the pipe or duct through which the cable enters, and in such a position that the cable will pay out from above in a curve of large radius. A steel spindle, square in the central portion and round at the ends, is passed through the centre of the drum to form an axle; under each end of the spindle is placed a lifting jack, and by this means the drum is raised to a sufficient height above the ground to admit of its revolving freely on its axis.

The ground over the drawing-in slide pipes or boxes should be opened to a convenient sized hole, and a rope, three or four inches in circumference, drawn through the pipes or ducts. This is done by means of the drawing-in wire when one is provided, or by threading through the empty pipes a length of sweeps' rods. The former is the more expeditious and less costly method where the pipe is to be used at once, but it should not be resorted to when the wire is likely to be left in the pipe for any considerable time.

At one end of the rope is fitted a split link, and the other end is attached to a crab-winch, which should be securely anchored down either to bars driven in the ground or to the line of pipes itself. When the latter course is adopted, a small hole in the ground should be opened at a distance of at least four yards from the drawing-in pipe, and the winch placed over it.

A clip is used for attaching the rope to the cable. These clips are made in various sizes, and it is important that a size be selected exactly fitting the cable to be drawn in.

When about to be used the clip is fixed over the end of the cable without removing the seal from the latter or exposing the wires to moisture, and the positions of the four holes in the side of the clip are carefully marked on the lead sheathing with a pointed tool. The clip is then removed, and two holes are bored with a small gimlet right through the sheathing, care being taken that they emerge on the far side in the position marked. A drift pin having been driven through in order to clear a passage for the screws, the clip is replaced and screwed up tightly. The end of the cable is, finally, dipped into a narrow pot of thoroughly melted paraffin wax, in which it is left immersed to a depth of

three inches beyond the clip. When the wax has thoroughly sealed the interstices between the screws and the screw holes it is withdrawn and allowed to set.

The end of the cable is attached to the rope by means of a split link, which when sprung into place should be lapped with tape or yarn to prevent its becoming loose in passing through the pipe. All is then ready for pulling-in.

Grip.—Another and more convenient form of cable grip is now on the market. It consists of a number of fine flexible wires interlaced into an open tubular shape with all the ends at one end bound together and terminated on a thimble to which the split link is attached. This grip is slipped over the end of the cable to be pulled in. The loose end is bound tightly round the cable, and when a strain is placed upon the other end the meshes close in and grip the cable tightly. Another form of this grip has both ends open and is fitted with two tail-pieces so that it can be used at an intermediate point on a length of cable.

Petroleum-jelly and black-lead are the best lubricants for drawing-in cables. When a single cable is drawn into a pipe, the former is preferred, but where, exceptionally, two or more cables must be accommodated in one pipe black-lead should be used. The lubricant should be applied to the cable as it enters the pipe.

The cable is steadily hauled in by two, or not more than four, men at the winch, and the pull on the rope should be in the line of pipes, snatch blocks being introduced if necessary.

The remainder of the men are engaged in the meantime in revolving the drum and feeding the cable into the pipe from over the drum in a curve of such radius as will cause it to enter horizontally, without strain, bends, reverse twists or other injury. The hole through which the drawing-in operations take place should be sufficiently long to ensure a straight lead for the cable.

When the cable has been pulled in, the end to which the clip is attached should be cut off with a hack-saw, and the interior examined to ascertain if moisture has entered. If free from wet, the conductors should be driven back within the lead by means of a dry punch to a depth of about a quarter of an inch; a disc of lead of the exact size should be fitted in the recess thus formed and securely soldered to the pipe, thus providing an absolutely watertight seal which will remain intact until the time for jointing arrives.

The exposed length should be laid in the trench and (when the jointing cannot be proceeded with at once) carefully protected by pieces of timber, 3 in. by 9 in., one on each side and one on the top, over which the loose soil can be filled in and punned. The timber is needed to protect the cable from damage in filling in or in subsequently opening the ground for jointing. The space between the cable and the end of the pipe should be filled with cotton waste to prevent the entry of soil. Where the size of the cables will admit of both ends entering the slide pipe, the latter should be used as a protection instead of the wood slips, the interstices between the slide and the pipes being filled with waste.

Ample room must be allowed for jointing purposes. For a heavy cable a hole about 6 ft. long, 3 ft. broad, and 3 or 4 ft. deep should be opened over the proposed joint, to admit of two workmen engaging in the operation, the trench being also opened to a sufficient length to admit of the slide-pipe being slipped along the end of one pipe. For a small cable a reduction in the size of the hole may be permitted.

The sides and the bottom of the hole are protected by sheets of ungalvanised iron of No 22 gauge, 3 ft. by 2 ft., which are placed immediately around the place where the joint is to be made. The object is to protect the exposed cable from moisture, which rises freely, especially when charcoal braziers, subsequently referred to, are introduced. Galvanised iron is unsuitable, as solder droppings which have been in contact with galvanised iron cannot again be used.

Two planks, 10 ft. long, 9 in. wide, and 3 in. thick, are then placed along the sides of the hole, and two ordinary jointers' tents, fitted end to end, are mounted on them.

Where water abounds the earth is banked up along the supporting timbers to prevent its entry, and in rainy weather a tarpaulin is placed over the top of the tents to make them absolutely waterproof. The windward end of the tent must always be kept closed to prevent currents of air, which are always more or less damp, from passing over the joint.

If the subsoil be saturated a sump hole should be sunk in a suitable position outside the tent, to admit of the use of a pump for removing the water as it accumulates. The water should on no account be baled out because of the liability to splash the joint.

In the case of mixed soil or gravel, it is necessary to shore-up the whole with timber to prevent the sides falling in during operations. For this purpose the hole should be lined with vertical planks known as 'poling boards' 3 ft. 6 in. by 9 in. by 1 in., supported by two horizontal planks, 'whalers,' 6 ft. by 9 in. by 2 in., which are kept in position by 'putlogs.'

In the case of cables of any considerable size, it is generally desirable, where a joint is to be made, to open the hole overnight in order that an entire working day may be available for the process of jointing. When once commenced, the work must be continued until the joint is finished.

Before jointing is commenced the whole of the interior of the excavation must be covered with canvas sheets, so as to ensure absolute cleanliness in all subsequent operations.

When the preliminary arrangements are complete the jointing is commenced thus:

(*a*) The surplus length of each cable is cut off, leaving an overlap.

(*b*) Next, the required length of lead sheathing is removed from each cable, care being taken not to damage the paper insulation. When the lead sleeve has been passed over the end of one cable the conductors are tied in half layers and are turned up at right angles. For cables $1\frac{1}{2}$ in. in diameter and over, a slit about one inch in length is previously cut in the centre of the sleeve and dummied outwards, for a purpose to be explained later.

(*c*) The other end is then similarly tied in half layers and turned up at right angles, and the first copper joints (those of the central pair of the bottom half of the outer layer) are made. The method of jointing the copper wires is explained on p. 283.

(*d*) Paper insulating sleeves are next drawn over the conductor joints and tied together with thread in order to prevent them from being moved out of position during the subsequent operations.

(*e*) A strip of insulated paper is now wrapped spirally round the pair so jointed, and is tied at the end with thread to keep it in position. This spiral wrapping of paper is necessary to complete the insulation of the wires in consequence of a portion of each conductor being left bare in the process of jointing.

(*f*) The jointing of the remaining pairs of the bottom half

layer and the six pairs forming the bottom half of the second layer in the cable are dealt with in a precisely similar manner.

(*g*) The next half layer towards the centre of the cable and the central pair having been dealt with, the jointing of the cable is continued in reverse order towards the outside half layer, and the joint is thus completed so far as the insulation of the pairs is concerned.

The paper insulating sleeves are carefully dried in a tin vessel in which they remain until required for use. This vessel is placed in a clean thoroughly dried galvanised iron bucket kept hot by a spirit lamp in the jointer's tent.

The wrapping of paper, which in the cable itself is placed between successive layers, is not interposed in the joint, as it would delay the final drying described later. An external wrapping of paper is, however, wound round the completed cable.

When dealing with main trunk wires great care must be taken not to introduce any crosses between neighbouring pairs during the process of jointing, as it is of the utmost importance that the conductors shall occupy the same relative positions throughout the entire length of the cable. Checking the accuracy of the jointing should be made a part of the test instituted after the completion of each joint, and should any crosses be discovered they must be removed before the work is proceeded with. Such crosses as may be needed to avoid mutual induction must be made subsequently and in a systematic manner.

In town telephone systems the cables may be divided into two classes: (*a*) Those used for long junction circuits, which must be treated in all respects in the same manner as trunk line cables. (*b*) Those containing smaller gauge of conductors to be used for local circuits. This may apply to 40-lbs. conductors. The relative positions of the pairs of conductors in these cables need not be maintained, but the utmost care must be taken to ensure that pairs shall be through to pairs.

The actual method of jointing the copper wires varies slightly with the gauge of the conductors. With 100-lbs., 150-lbs., and 200-lbs. wires, the two are cut so as to abut when drawn out straight; the paper insulation is removed for a distance of about three inches on one side and one inch on the other and tied with linen thread. The ends of the wires are cleaned and tinned, a copper jointing sleeve of the right gauge and a paper insulating sleeve are slipped over the wire from which

the three inches of insulation has been removed, and the copper sleeve is drawn forward so as to enclose both conductors equally. It is then soldered and the paper insulating sleeve drawn over the joint. No flux but resin must, under any circumstances, be used.

The companion wire of the pair is then similarly dealt with, the only difference being that if the greater length of insulating paper has been in one case removed from the right-hand wire, then, in the companion wire, it should be removed from the left-hand one. It will thus be seen that, although this necessarily leaves each conductor bare for a length exceeding that of the paper sleeve, as the two jointed conductors are bared on opposite sides of the joint, the bare portion is insulated from

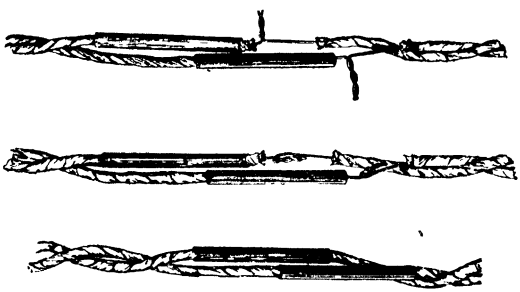


Fig. 206

its neighbouring conductor by the original insulation of the latter.

The pair of conductors so jointed is then wrapped spirally for a length of eight inches with strips of insulating paper of the same character as that employed in the manufacture of the cable.

With smaller gauge conductors the use of copper jointing sleeves would be troublesome, therefore the following practice has been generally adopted. The two wires are cut off so as to overlap to the extent of 1½ in., the paper sleeve is passed over one of the wires, each wire is bent ¾ in. from the end at right angles to itself, and the two ends are then grasped with the pliers and carefully twisted together with just sufficient tension to straighten the main conductor. The end of the twist is snipped off, the twist is tipped with solder, and bent back to lie parallel and close to the conductor, and finally the paper sleeve is drawn forward. Three stages are shown in fig. 206.

Two sleeves are required for each pair, the joints in the conductors being alternated as usual and the sleeves correspondingly spaced out, as indicated in fig. 207.

It is necessary to modify slightly this process in the case of pairs of 40-lbs. conductors with S-type insulation. In this case, the pair of wires being enclosed together, large sleeves are necessary and each sleeve is passed over the pair of wires.

After the conductors are jointed, and before they receive the final wrapping of insulating paper, the joint should be thoroughly dried by means of charcoal braziers. Two men



Fig. 207

should be engaged in this operation, each commencing at opposite ends of the joint at the point where the lead sheathing emerges from the iron pipe. When the sheathing has been thoroughly warmed on both sides, the braziers are gradually moved forwards towards the centre of the joint until it is judged that every particle of absorbed moisture has been expelled.



Fig 208

Great care should be taken not to carbonise the paper, and in order to avoid this the braziers should be moved slowly backwards and forwards, parallel to the line of the cable. With large cables, even under favourable conditions as to weather, this operation should last an hour, and it should be continued until a mirror, which has been kept cool, shows no trace of moisture when applied to the joint. The joint is next wrapped spirally with insulating paper, a hole being cut opposite the point at which the hole in the sleeve will come.

The lead sleeve is next drawn over the joint, and secured in place by a thoroughly well made plumber's wiped joint at each extremity, as shown in fig. 208. The heat necessary for this purpose tends to expel any moisture absorbed in jointing,

and it is to admit of its escape that the slit is cut in the lead sleeve. As a further precaution, however, the braziers are again applied to the completed joint and moved to and fro until the mirror referred to above shows no evidence of condensation when applied to the vent-hole. The edges of the slit which were dummied out to form the vent are now dubbed down as closely as possible, sealed with a hot iron and completed with a carefully made plumber's ' patch-pipe.'

The vent is not needed for small cables—those less than 1½ in. external diameter.

The careful and judicious use of the braziers is imperative in order to obtain a high degree of insulation, and a plumber of the highest skill only should be employed in making the wiped joints, as joints which appear well made, and which would suffice for a water pipe, have failed some months after they have been made, owing to minute imperfections.

Finally (fig. 209) if an iron slide pipe is used, it is drawn



Fig. 209

into place, caulked and leaded at the ends, the soil filled in, and the joint-box marker fixed. But the usual practice is to use joint chambers or cast-iron joint boxes (see p. 288).

Where a cable stretches across a long gap in the pipes, care must be taken that it shall be properly supported in suitable positions.

A method of testing the perfection of a wiped joint is known as the dry air test. For this purpose an air-pump and a desiccator are employed. The latter contains calcium chloride and a cotton-wool filter, through which the air is driven, in order that it may be thoroughly dried before it enters the cable. When the pressure has been applied to the cable for a sufficient time for it to reach the joint under test, a defect in the plumber's work will, in most cases, be evidenced by a whistling sound, or the escaping air may be detected by passing the hand round the joint. To make yet more certain, however, the flame of a lamp or taper should be passed round the wiped portion of the joint. By this device the most minute leak may be readily discovered.

Where cables are being laid from a post office the pressure should, when possible, be supplied from the pneumatic service of the office. This will admit of the testing of cable joints within a radius of about half a mile.

When this distance is exceeded a portable apparatus is necessary, and it should be connected by means of a flexible pressure tube to the far end of the jointed cable, the lead cap being temporarily removed for the purpose or an air nozzle fitted. Air nozzles must not be permanently attached to cables in manholes or underground boxes.

A pressure gauge connected to the pump, if carefully studied, gives valuable information to the officer in charge. When a cable is full of dry air the indicator remains steady; when the cable has not been fully charged with air, and there is no defect in the sheathing, there is a gradual and uniform fall; when there is a defect in the lead sheathing or the wiped joint, the fall of pressure indicated is irregular.

Where there is, at an intermediate point, a cable connection or other form of test box, the pressure applied to the cable for a joint test, or for drying out a fault in a cable must be less than where there are no such testing points; for, whereas 20–25 lbs. air-pressure per square inch may be safely applied to a dry-core cable pure and simple, the same pressure on a cable having a cable head intermediate on it would be likely to result in much damage.

The air driven into the cable must be absolutely dry, otherwise actual lowering of the insulation will result. The calcium chloride must therefore be renewed periodically, but a fixed time for this renewal cannot be given, as much depends on the humidity of the atmosphere, as well as the extent to which the calcium chloride may have been used. If there is a choice of position, the pump should be placed where the air to be drawn in is coolest and driest.

A useful indication that the calcium chloride needs renewal is afforded by the depth to which it has sunk in the containing trays. Under no circumstances should it be allowed to fall to less than half its original height. The amount of water drawn off from a cylinder is another indication of when the supply of calcium chloride requires attention. If the air driven through the desiccator be very moist, fresh supplies of calcium chloride should be added frequently.

The function fulfilled by the desiccator is so very important that its condition demands the most careful attention on the part of those responsible for its use.

The stock of calcium chloride should be kept in airtight canisters or jars.

In many countries, especially in the Colonies, the type of cable mostly used is the armoured lead-covered dry-core cable. This cable is made up with 26, 52, 104 and 208 10-lbs. or 20-lbs. conductors. Outside the lead sheath are laid two strips of canvas 2 in. wide saturated with Stockholm tar and ozokerit composition, the first strip completely covering the sheath and the second strip wound in the reverse direction completely covering the first strip. Over this, a steel tape 40–45 mils thick is laid with a 2-in. right-hand lay. This tape is $1\frac{3}{4}$ in. wide, except for the smallest cable, when $1\frac{1}{8}$ in. is used. Over this tape is laid a second one of similar dimensions, laid centrally over the gap left by the first. Over this again are two servings of jute, saturated with Stockholm tar and ozokerit composition, laid in reverse directions.

This cable is laid in trenches from 18 in. to 30 in. deep—according to the location of the road and the traffic using same—and over the cable is laid a covering of stoneware tiles 9 in. × $4\frac{1}{2}$ in. and 1 in. thick.

Where a number of cables are to be laid it is necessary to provide jointing chambers, and these are made either in the footpaths or roadways as may be most convenient. These chambers vary in size with the number of cables to be accommodated and the amount of jointing work to be done. They range from 6 ft. in length by 3 ft. in breadth and 3 ft. in depth to 8 ft. × 5 ft. 6 in. × 6 ft. respectively, and it is wise to err on the large side with a view to future development rather than to make the chambers small and cramped. They are usually built with brick or concrete and they are provided with manhole frames with covers. For footpaths these frames and covers are of cast iron, of light construction, approximately 3 ft. × 2 ft. In roadways a heavier type, capable of resisting heavy road traffic, is required. As far as possible jointing chambers should be made watertight, and where the ordinary drainage facilities do not permit of this, as in water-logged localities, it is necessary to build the chamber on a foundation of asphalte, and to surround the chamber with a coating about $\frac{1}{2}$ in. thick of the same material,

care being taken to carefully join this coating with the underneath layer, thus forming a complete envelope of asphalte.

For distribution purposes the practice of the British Post Office for some years past has been to terminate the Main Cables in cast iron distribution boxes having removable cast iron covers. They are fitted with gun-metal linings, or junction sleeves, and are fixed to the walls of the Junction Chamber. The cables are leaded to these sleeves, and the joints on the conductors are made in the usual manner inside the box, the object being to give easy access to the wires in the event of a re-distribution of the circuits being required. Admirable though this system is, it admits of interference with the wires on the part of irresponsible workmen, and it is now giving way to a more permanent method of distribution by means of lead Y or multiple sleeves. With these the whole joint is completely sealed, and the possibility of damage arising from slack maintenance work is removed.

Where armoured cables are employed, jointing chambers are as a rule dispensed with, the joints being made by lead sleeves in the usual manner, and placed inside cast iron boxes made for the purpose and equipped with a means of metallically binding the box to the armouring of the cable. Similar boxes, but of T shape, are employed for distribution purposes, the usual practice being to take off from the main cable as many pairs of conductors through the T as may be needed to meet the requirements of the building or distribution pole to be served.

When a dry core cable is taken into a building it should be carried to a point where it can be most conveniently terminated, or again subdivided if required into a number of smaller capacity cables for distribution to the various floors and offices. A lead Y or multiple joint is made at this point. Each distribution paper core cable should be terminated with about a yard of enamel and cotton-covered lead-sheathed cable which is connected to a distribution case, from which again lead-covered wires should be employed to connect with the various telephones. The terminal end of the enamel and cotton cable should be treated with bees'-wax by means of a vacuum pump apparatus, so as completely to seal up the cable and prevent the possibility of moist air penetrating the paper-covered wires. This apparatus consists of one hand air-pump converted to vacuum, one small portable container, one 3 ft. and one 6 ft. length of flexible

tubing, one borer for lead, and one clamp for vacuum pump and lead-covered cable. The bees'-wax should be melted in a suitable vessel, and in the process it should be almost continually stirred, and should not be left unattended so long as heat is being applied to it. The lead is stripped from the cable to a sufficient distance back. At a distance of about 6 in. from the end of the cable a hole is bored through the cable, and in doing this care must be taken not to push the borer so far through as to damage the wires. The shorter length of flexible tube is now fixed to the cable by means of the clamp, and it should be seen that the hole in the tube comes opposite the hole in the lead. The cable from which the lead has been stripped should then be carefully bent to an angle with the sheath and the bend placed in the melted bees'-wax. The wires at their entrance to the lead sheath should previously be opened out as much as possible to allow the free ingress of the wax. The hand-pump should now be worked steadily at a rate of about one stroke per second for about five minutes and the cable end should then be removed from the bath. The pumping should be continued until the wax commences to solidify, the whole then being allowed to cool gradually. The clamp having been removed, the hole in the lead sheath should be plugged with the small disc removed by the borer in the first place, which should be enlarged by flattening, and carefully soldered over.

The latest form of distribution case introduced by the British Post Office is of wood, fitted with ebonite strips with soldering tabs and screw terminals mounted on them. They are made in standard sizes to correspond with the cables. The cable wires are permanently soldered to the tabs, and the wires leading to the Instruments are connected to the screw terminals. The ebonite strips are so arranged as to afford a means of cross connecting wires when necessary.

Where a branch cable is taken to a distribution pole for connection with open wires a twenty-five pairs cable should, in a general way, be used, as this is the maximum number of open wires that should be carried on a pole line for distribution purposes. The cable should be run up the pole, to a position well out of reach, inside a galvanised wrought iron pipe which affords protection for the lead sheath (see fig. 210), and terminated either in a pothead (see p. 292) or in the 'airtight' compartment of a pole distribution and protector box, several types

of which are now made for the purpose. These are of cast iron. A typical box is divided into two compartments, the dividing partition being part of the casting. The dry-core cable is led into the rear compartment through a gland at the bottom of the box. This gland is fixed by means of a union screw, and is therefore removable so that it can be wiped on to the lead sheath of the cable, and afterwards screwed up when the paper-covered wires have been inserted into the box. The front compartment is fitted with vacuum lightning arresters, or, more frequently, ordinary carbon lightning arresters and fuses. Connection between the arresters and the dry-core cable wires is got by means of small wires insulated with ebonite collets, which are tightly wedged in holes in the dividing partition. The dry-core conductors are soldered on to their respective connecting wires, and the cover plate is bolted on. Between the cover plate and the edges of the box a gasket of rubber or other suitable material is employed to ensure an airtight joint. An air vent, normally closed by means of a gas plug, is provided at the top of this compartment in order that dry air may be periodically pumped through. The front cover of the box is usually hinged for the convenience of the lineman when examining the carbons and fuses. The lead-covered twin wires leading to the open lines are frequently taken through glands at the bottom of the front compartment, in which case they are bent round the bottom of the box, and carried up the pole in as neat a manner as can be

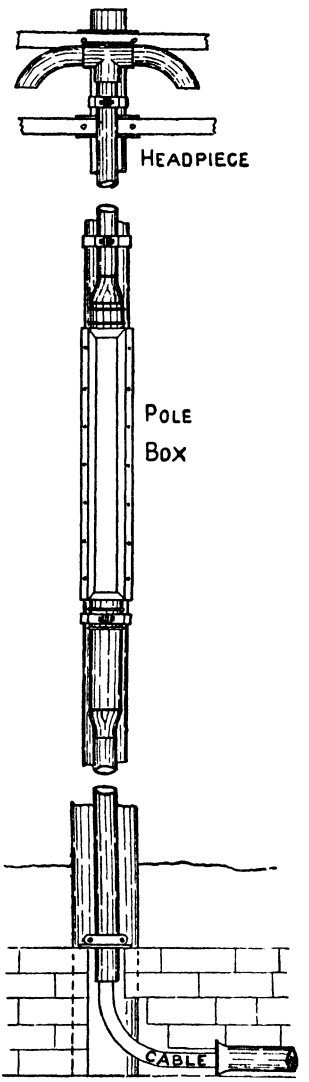


Fig. 210

arranged. A better method is to have the outlet for these wires at the top of the box, and in this case a galvanised iron pipe ending in a T at the top should be used (see fig. 210).

Where the dry-core cable is terminated in a pothead, lightning and current protectors are required, and although these may be fitted in strong teak boxes where the climatic conditions are not likely to affect them detrimentally, it is preferable in a tropical climate to use cast iron boxes. Where wooden boxes are used, the connecting wires between the pothead and the protectors should be rubber insulated and the pothead made as follows: The requisite number of twisted pairs of rubber covered wires should be cut to the length required, and a lead sleeve of suitable length and diameter and fitted with an air nozzle at its bottom end is slipped over the cable. The lead sheathing is then removed from the cable for a distance of about one foot, and the paper-covered pairs are jointed and soldered in the usual manner to the rubber-covered pairs, paper sleeves previously slipped over the wires being used to cover the joints. These joints should be distributed as much as possible. The lead sleeve is then drawn over the joint to a position from 9 to 12 in. above the conductor joints, and a wiped joint is made on to the ead cable. The sleeve is then carefully packed with cotton wool to a depth within one inch of the air nozzle to prevent the compound blocking the air nozzle and running into the paper cable. In melting the compound care should be taken to see that it is not burned, and it should be carefully poured into the sleeve so that it will run between all the wires and completely seal up every part. If it should be found that the compound settles in the joint as it cools, a further quantity should be poured in so that it will be exactly level with the top of the sleeve. The most suitable compound for this purpose consists of: resin, 8 parts; palm pitch, 4 parts; ozokerit, 2 parts; and oil, 1 part. When cool this mixture is capable of bearing an air pressure equivalent to 30 lbs. per square inch.

Where a cast iron protector box is used a more satisfactory junction between the paper cable and the protectors is obtained by the use of enamel and cotton insulated pairs, impregnated with bees'-wax and lead sheathed. In this case an ordinary lead sleeve joint is made between the two cables, and the lead sheath of the enamel cable is wiped on to the gland of the cast iron box. The terminal end of the enamel cable should be treated with

bees'-wax (see p. 290) so as to ensure air-tightness, and an air nozzle should be fitted to the bottom end of the lead sleeve, in order that dry air may be pumped periodically through the cables.

This method of drying out the cable is almost peculiar to the British Post Office. In the United States and other parts of the world solid joints are used. All sizes of this dry-core cable are supplied in definite lengths, with both ends hermetically sealed. When laying the cable, the seals are left intact until the lengths of cable are in place. Before cutting the seals, a basin of paraffin wax is got ready and thoroughly melted. One seal is then cut, 2 ft. of lead are cut off the cable, and then as much as possible of the wax is poured into the cable end, leaving the stripped ends of the conductors loose and free for joint making. The other seal is then removed and the cable similarly treated. When these wax seals have thoroughly solidified, the joints are made, a lead sheath is wrapped round, and paraffin wax again poured in until the whole joint is one solid mass. This ensures a thoroughly dry joint and prevents any moisture creeping into the cable. No pumping of dry air is possible, but many years' experience has proved that such treatment is quite unnecessary. So long as the cable is not damaged from the outside, no faults will occur. If damage is done, whether dry air pumping is allowed for or not, that length of cable must be replaced. In all probability this method of jointing would be found more durable in the tropics and give rise to a less number of faults than any other system, but it has not been given a practical trial up to the present.

Lead-sheathed dry-core cables are also successfully used overhead, and are a great convenience in large towns where the liability to contact and interruption, with bare wires, is considerable, and where there is no objection on the part of the local authorities to heavy cables overhead. They are also used with much advantage in telephone exchange distribution, as they can be erected at little cost compared with that of laying cables underground. The standard capacities in which these cables are made are 10, 15, 25, 50, and 100 pairs. Their electrical qualities are practically the same as those of the dry-core underground cable, but the lead sheathing is lighter.

Whether carried over housetops or on a line of poles, they should be supported by *hangers* from steel stranded galvanised

wires as shown in fig 211, as they are not sufficiently strong in themselves to support their own weights in the spans usually met with. The suspender wire should be attached to the roof structures, or poles, as low down as is compatible with the clearance required for the cable, and where open wires are also carried in the same support the suspender wire should be placed below these. These hangers are often made of zinc or galvanised iron. Raw hide has been tried, but whilst it is satisfactory in England, in the tropics it quickly perishes. The most satisfactory material is tarred marline made up in suitable lengths with galvanised iron hooks

In some countries damage has been caused to aerial lead-covered cables by holes being bored through the lead sheathing

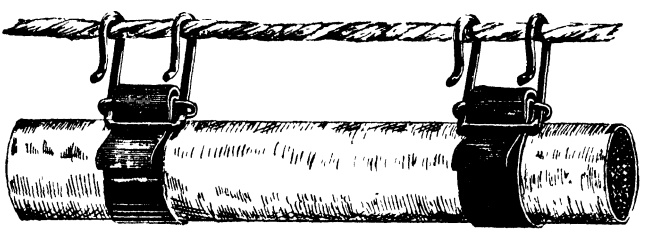


Fig. 211

by an insect somewhat resembling the bee, but in no case has the damage done been so serious as to cause hesitation in the employment of this type of cable. In other directions underground lead-covered cable has been destroyed by a species of ant, but instances of the kind are so rare, that they may be practically disregarded.

In certain localities the lead sheathing has been attacked by chemical constituents in the earth, and where such conditions are known to exist, it is necessary to protect the cables by laying them in stoneware troughing which, when the cable is laid in position, is filled with bitumen. The troughing is made from stoneware clay, hard burnt, well vitrified and glazed all over. It is not less than $\frac{1}{2}$ in. in thickness, and is usually supplied in 2 ft. lengths. Bridge pieces are placed about 18 in. apart in the troughing, and these are of such thickness as to allow about $\frac{1}{2}$ in. of space all round the cable, which is filled up with the bitumen.

The question of development in any particular building or area is an important one with telephone cables, and most telephone administrations make a careful 'development' study

before a decision is come to as to the capacities of the cables to be laid, and the method of distribution to be adopted. Upon the care and foresight with which this study is carried out much depends; as while on the other hand, an over-estimate will involve the administration in unremunerative outlay on idle ducts and cables, an under-estimate will involve further expenditure or additional plant, probably involving the taking up of roads or footways at an earlier date than is desirable. A sound basis for a development study is that of a fifteen years' estimate for ducts and ultimate capacity of switchboards, and an eight years' estimate for underground cables, local distribution, and exchange equipment.

CHAPTER XVII

FAULTS

THE faults to which every circuit is more or less liable may be divided into three classes, viz:

1. *Disconnections.*
2. *Earths.*
3. *Contacts.*

Total disconnection is such as that produced by a broken wire with its end insulated, a wire off its terminal, an open switch in an office, &c.

Intermittent disconnection is caused by a bad joint, which, moved either by the wind, by passing objects, or by heat, makes and breaks contact irregularly; dirt or dust accumulating on contact points will frequently produce the same effect.

Earths may be *total*, *partial*, or *intermittent*, and are indicated by an increase in the strength of the current at the sending end, and by a decrease in the strength, or its entire cessation, at the other end.

Full or *total earth* (sometimes termed *dead* earth) is due to the wire resting on the damp ground, or touching a stay or some good conductor in connection with the earth. In the case of a cable it would be caused by the conductor being in contact with the water.

Partial earth is the result of the insulators being cracked or defective; or it may be produced by the wires resting upon walls, posts, trees, or other imperfect conductors in connection with the earth.

Intermittent earth is produced by the wire touching at intervals conducting bodies in connection with the earth, either by being

blown against them by the wind or by expanding and dropping upon them under the influence of heat.

Contacts are indicated by the signals from one wire passing into another wire.

Full contact (sometimes termed *metallic* contact) is that which is produced by the wires being hooked or twisted together; or by being joined across by means of another piece of wire making firm electrical connection with each.

Partial contact is that which is produced by imperfect conductors being thrown across the wires, by bad earths or by defective insulation on lines not earth-wired.

Intermittent contact is produced by the wires touching each other at intervals, and is due to a variety of causes which will be alluded to hereafter.

A.—Faults in the Battery

Disconnections, or apparent disconnections, in the circuit are the chief faults which occur in the battery. Total disconnection would be evidenced by no current being obtained from it. This may be due to the battery wires being knocked off the terminals, or it may be caused by the two battery wires being in metallic contact with each other. In the latter case, a 'short circuit' is formed, and no current whatever proceeds to the line. One of the cells may be empty, and this would produce the same effect. In the trough form of battery this may be caused by leakage chiefly owing to the marine glue having been either imperfectly applied or not being of the required consistency. In the Leclanché it may result from a fractured glass cell. If any of the cells in a battery be faulty, either from leakage or from any other cause, it should be bridged over and so cut out of circuit. This can be done by joining the plates on each side of it by means of a wire, as shown in fig. 212. A battery wire, again, may be broken either mechanically or by the chemical action of the cell; as already mentioned (p. 19), the free ammonia in Leclanché's battery not infrequently eats through the wire.

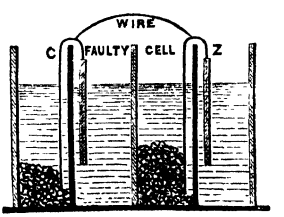


Fig. 212

Intermittent disconnection in the battery—that is, when the current occasionally fails—is usually to be attributed to the wires being loosely fixed instead of being firmly connected by the terminals.

Apparent disconnections are often due to the battery having been allowed to work too long without being attended to. Or the solutions may have mingled too much by diffusion, or have become either too strong or too weak, as the case may be. Dirty plates, cracked porous cells, corroded and dirty terminals, all tend to diminish the strength of the current. A similar result is also produced if the battery be standing in a damp place, since the damp exterior partially short-circuits the battery or partially earths it.

On a Morse Omnibus circuit, where one pole of the battery is permanently earthed at the instrument, this condition will not only reduce the strength of the outgoing signals, but it will interfere with all through signals. The remedy is to provide proper battery stands or racks and to effectively insulate these from the floor of the battery room. An easy way of doing this is to use ordinary porcelain insulators fixed to spindles screwed into the battery rack supports.

B.—Faults in the Instruments

The Needle.—Faults in the needle instrument, and in fact, in the instruments generally, may be due to either mechanical or electrical causes. The indicator on the dial of the needle instrument often sticks against one of the ivory pins, the result either of damp or of the pin being partially worn away. In the former case the fault is removed by wiping the pins with a cloth, and thus making them perfectly dry; in the latter case they ought of course to be replaced by others.

Disconnection, or apparent disconnection, in the needle instrument, evidenced by the needle failing to respond to the currents, may possibly result simply from a broken pivot. Weak currents sent to line may be due to the axles of the tappers being oxidised, but loss of magnetism in the permanent magnets employed for polarising the needle will also cause an apparent high resistance fault. The carrying power of these magnets should never be less than ¼oz.; in the event of its falling below this, the magnets should be re-magnetised. Lightning is a

source of trouble not only in this but in every form of instrument. Apart from the occasional demagnetisation or the reversal of the magnetism of the permanent magnets, the coils of the instrument are liable to be fused by the intense currents induced, and special measures have to be taken, which will be described further on (p. 310), in order to guard against them.

Considerable difficulty is sometimes experienced in working the single-needle instrument on account of the earth currents, which prevail at certain periods with more than their usual strength. Their effect is to deflect the needle permanently; and in order to get rid, at least to some extent, of the inconvenience which is thereby caused, the dial is so constructed as to be capable of rotation. When the earth currents make their appearance the dial should be turned round upon its centre, until it stands at a suitable angle for the needle to work independently of the earth currents.

To prove that the single-needle instrument is in working order, it is only necessary to short-circuit the instrument, by joining together terminals A and B (fig. 28) with a piece of wire, and depress the keys. Should the needle not respond, the fault will be either a failure in the batteries, a loose connection of the wires with the terminals, a bad contact between the tappers and contact springs, a broken wire in some part of the apparatus, a fused coil, or a broken needle-axle pivot. Should the needle respond properly, it will show that the instrument under test is in order.

The Sounder.—The Sounder, on account of the extreme simplicity of its mechanism, is less liable to faults than any of the other forms of instrument which are employed. Those which are to be met with are usually due to bad adjustment, and are the result of ignorance or inexperience on the part of those employed to work it. The antagonistic spring will, in the course of time, get weak and refuse to do what is required of it, but its replacement is a simple and inexpensive matter.

In the key the only faults likely to arise are disconnection caused by dust or waste getting on to the contact points; a constant current, owing to the battery and line terminals being connected with each other, either by a weight pressing on the key, and the antagonistic spring being too weak to pull it on to the back stop, or from a conductor, such as a metallic pen, or the like, connecting the two parts together. If the axle

of the key be loose or dirty, a high resistance is introduced and weak currents will flow to line.

The Ink-writer.—The same faults as are to be met with in the Sounder must also be looked for in the Ink-writer, but in addition to these there are several others from which the Sounder is free.

The clockwork in the Ink-writer is more or less liable to become deranged; broken stop work, caused chiefly by its being over-wound, is the accident which most frequently happens. Grit again, or dust, or the 'fluff' from the paper slip making its way into the driving gear, will prevent the paper from running, and the friction among the various parts renders it necessary to overhaul them from time to time.

Another source of trouble inherent to the Ink-writer is to be met with in the inking arrangement; the passage between the well and the reservoir may get choked, and the disc being unsupplied with ink no marks whatever are recorded; or, the ink becoming too thick from the accumulation of dust in the well, will render the marks altogether illegible.

As the electrical arrangement and the method of working are precisely similar to the Sounder, in case of failure or defect in either the clockwork or the ink, the clerk should revert to reading by sound.

The Relay.—The only specific fault to which the relay is subject is due to the spark which passes between the points of contact every time the local circuit is completed or broken. It is the effect of the extra currents due to the self-induction of the coils of the receiving instrument in the local circuit, and is strongest at the moment the circuit is broken. It is more marked in wet than in dry weather, owing to the fact that the motion of the tongue of the relay is then more sluggish; the more rapid the movements of the tongue, the less is the inconvenience felt from the spark. As far as possible to prevent the contact points from being burnt away they are made of platinum, and a small piece of roughened watch spring should from time to time be gently passed between them for the purpose of removing any metallic dirt that may have gathered there. Paper should on no account be used for this purpose, as the roughened platinum damages the surface of the paper, fibrous matter adheres to the tongue or the contact stud and prevents the one from making electrical contact with the other.

Several methods have been suggested to prevent the spark itself from forming. The coils of the receiving apparatus (the sounder or inker) may have their ends connected with a condenser whose capacity is regulated by the length of wire in the coils and the strength of the local battery. A plan which answers equally well is to connect either the contact points of the relay or the ends of the receiving coils through a high resistance acting as a derived circuit and forming what is technically called a *shunt*. This resistance, which ought to be varied according to the strength of the local battery, should never be less than five times, and need not be more than forty times that of the receiving apparatus. The induced current will then traverse this resistance rather than pass through the air in the form of a spark. This latter plan is now generally adopted by the British Post Office, sounder coils which are wound to 20 being shunted by a resistance of 500ω.

The A B C.—The delicate mechanism of the various portions of the A B C apparatus renders it more liable to faults of a mechanical nature than any of the instruments already alluded to. In dealing with the question of the adjustment of the A B C, reference has been made to the difficulty sometimes experienced from the endless chain in the communicator, and the method of adjustment adopted in order to overcome this. Other faults of a mechanical nature to be met with in the communicators are:

(*a*) Damaged teeth in the driving-wheels. This results either from a lack of oil or from the driving gear having been taken to pieces and so put together again that the teeth do not properly come into gear with each other.

(*b*) The jewel against which the armature axle is fitted may be broken, or the adjustment screw may work loose, which will permit the armature to be drawn against the poles of the large compound horseshoe magnet, so that the handle cannot be turned.

(*c*) The socket in which the axle of the armature works is sometimes insecurely fastened, or it gradually gets loosened, and then it produces the same fault as the broken jewel.

(*d*) Bad oil, becoming hard and clotted, will lead to indifferent working; only good watch-oil should be employed in the treatment of the apparatus.

The chief complaint which is made as to the working of the

A B C is that of either 'gaining letters' or 'losing letters.' This, as has been already remarked (p. 70), is generally a question of defective adjustment, but it may be due more or less to one of the causes named above. Disconnections, either partial or total, are by no means rare. The former are mainly due to oxidation of the terminals or contact points; the latter are chiefly caused by the contact-maker K (fig. 65) in the communicator taking up a position midway between the line and earth contact-points without touching either. This is mainly to be attributed to the spiral spring L being too weak. This fault was at one time an extremely troublesome one, as it was apt to come on at any time and disappear before it could be localised, but in instruments of later pattern the contact-maker normally short-circuits the communicator coils, so that its being out of adjustment cannot disconnect the line but only bring in the coils.

Duplex Apparatus.—The causes of the irregularities in duplex telegraphy have been already dwelt upon (pp. 101 *et seq.*) when treating of the subject generally. The smallest fault will speedily make itself felt on a duplex circuit, and in the event of earth currents, thunderstorms, or any other electrical disturbance appearing on the line, the system, being in a state of balance, is specially subject to interference. It is for this reason that duplex circuits must always be worked by skilled telegraphists who thoroughly understand adjusting. A line worked upon the duplex principle is, so to speak, subjected to a constant test, and faults which with ordinary working would probably escape observation, at once show themselves in duplex working.

Automatic Apparatus.—Only upon well-insulated lines can the full advantages of automatic telegraphy be gained. A loss of insulation is felt sooner with this than with the ordinary apparatus; it compels a reduction of speed with the automatic instruments before it is felt in general working. Still, the lowest speed of the former is always above that which can be done by hand-sending in the same circumstances.

The mechanical faults to which the different portions of the automatic apparatus are subject are as follows:—

(*a*) *The Perforator.*—Defective spacing is one of the main faults; it may be due to defective adjustment of the mechanism, or to the rubber pads beneath the punching keys being too thin.

Blunt punches and loose screws are to be guarded against. Care should also be taken that the paper is properly moved forward, and does not stick in any way.

(*b*) *The Receiver.*—The paper at times runs irregularly, owing to the friction discs becoming greasy, to dust or grit interfering with their action, or to friction in the rollers, &c., by which the paper is fed forward from the coil.

(*c*) *The Transmitter.*—Apart from dirty contacts, which should be carefully guarded against in every form of telegraphic apparatus, but in none more carefully than this, the chief faults which are met with in the Transmitter are broken spiral springs, or loose adjusting screws. The same difficulty of irregularity in the running arising from smooth or greasy discs is experienced with the Transmitter as has already been referred to in connection with the Receiver.

Quadruplex.—Faults generally arise from careless adjustments, dirty contacts, loose connections, battery failures, and the usual line interruptions.

It is essential to keep the platinum points of the up-righting sounder, where this is used, and the relays in good condition. Bad working is sometimes caused through the batteries for the A and B sides being of disproportionate strength (see p. 133), and it becomes desirable to test the condition and comparative strength of the batteries at the instrument. In order to do this, request the distant office to ' put to earth,' which will cause the needle of your galvanometer to stand at zero. Then increase the resistance in the rheostat by 4000$^{\omega}$ (this may be done on most circuits by simply withdrawing the 4000$^{\omega}$ plug). Note the deflection, which should be not less than 12° of the differential galvanometer. Then depress the B side key and again note the deflection, which should be not less than twice that of the first deflection. Now depress the reversing key; if it reverses properly the needle of the galvanometer will be moved over to the opposite side.

Restore the original line resistance balance and instruct the distance office to ' cut in.'

The *battery resistances* are liable to become heated if the resistance of the batteries is allowed to fall very low. When this happens the solution in the zinc cells should be partially removed and replaced with water. It is also desirable to remove such porous pots as are found to be of too low resist-

ance and to replace them by others of greater resistance. The resistance should range from 2 to 3 ohms per cell.

The duplex and quadruplex systems apply a constant test to a line, and line faults of all descriptions should therefore be easily detected and remedied without loss of time, as it is impossible to maintain a balance for many seconds with an intermittent earth or contact.

C.—Faults in Office Wiring and Connections

Faults under this head may be due to a variety of causes, all of which are preventable if proper care be exercised in leading the wires in and connecting them up. Where leading in wires are terminated on a test box, they should be soldered on to the shanks of the terminals inside the box, and not fixed by screw terminals. The latter are liable to work loose, and set up intermittent disconnection troubles. The earth wire to the test box should be similarly treated.

A disconnection may arise from a wire connection breaking off at an instrument terminal owing either to the wire being nicked during the process of removing the insulation, or to its being cut by the sharp edge of the terminal during the screwing up of the latter. The stapling of wires down walls, and under instrument tables, is a fruitful source of trouble. The staples are liable to corrode, especially in a damp atmosphere, and eat into the insulation and eventually through the wire itself, and cause a disconnection. To staple two insulated wires together is to invite trouble, as, if the points of the staple do not cut through the insulation and put the two wires in contact, the corrosive action referred to will sooner or later have this effect. The remedy is obvious: never use staples on insulated wires. Where several wires are carried together, they should be protected either in tubing or casing, and where they run under the instrument table they should be neatly fixed with wood cleats or with leather straps. Where there are two or three wires only they may be fixed by means of saddles or clips.

Where a single earth wire is employed, as is usual, for a number of earth connections on an instrument table, a separate earth connection, soldered on to the main earth wire, should be taken to each earth terminal. The practice of doubling the

earth wire on to each successive earth terminal on the table should not be resorted to.

Earth and disconnection faults are liable to occur where rubber-covered wires are led into a galvanised iron building owing to the insulation chafing against the edges of the iron. This should be guarded against by the leading-in tubing or casing being extended through the iron, or by the use of a porcelain or other leading-in tube. A safer plan is to use lead-sheathed leading-in wires (see p. 261).

Damage to indoor wires, and even danger to the building itself from fire, is often caused by rats gnawing off the insulation, and particularly at points in the wire ways where the wires are so bulky as to impede the free run of the rodents. Where rats abound in an office it is necessary that every possible point of ingress into the wire ways should be blocked up, and a determined effort made to exterminate them by means of traps; but if this should be ineffectual, it is then advisable to have the wire ways sufficiently large to allow the rats a free run through them.

D.—Faults on Open Lines

Total disconnection upon the line is the result of a broken wire. The breakage may be due to a variety of causes, but among the principal of them may be mentioned the following:

(*a*) A concealed weld or other flaw in the manufacture of the wire.

(*b*) The wire having been carelessly nipped by pliers when first erected by the workmen.

(*c*) Friction of the wire against the insulator (the result of imperfect binding in), or against a chimney or other object in its neighbourhood.

(*d*) Friction of an old binder which has been allowed to remain on the wire.

(*e*) The wire having rusted away.

(*f*) The wind, fallen trees or boughs, travelling cranes and high loads, snowstorms, &c.

Intermittent disconnections and high resistance are faults invariably the result of bad joints; attention has been already drawn (p. 258) to the importance which attaches to the joints being carefully seen to.

Metallic contact is the result of the wires being twisted or hooked together, or connected either by means of a short piece of wire thrown across them, or by dropping on to a metallic roof, chimney, iron post, or other conductor. When the line is being erected great care should be taken to remove all pieces of short wire that may have been cut off; if any of these are left lying about, they are very likely sooner or later to be thrown across the line wires by passers-by. Apart from the ordinary causes which bring the wires together, such as the wind, high loads, &c., workmen engaged in building operations near them, &c., a frequent source of trouble in this respect is bad regulation. This is especially the case when wires of different metals are

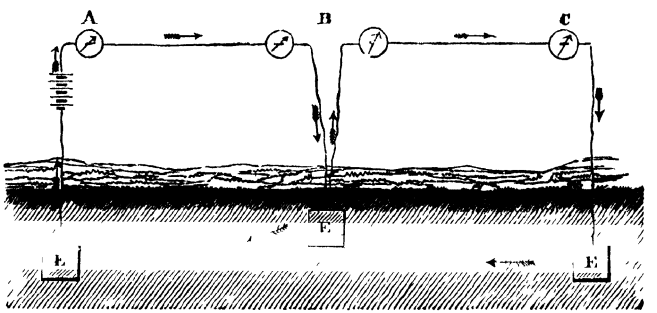


Fig. 213

vertically over each other. The sun's influence upon such wires causes them to expand unequally, and so drop one upon the other; if the line runs through a cutting and is thus exposed for only a short time to the sun's rays, or if the sun becomes obscured by clouds, the wires soon return to their normal position, and the fault often disappears before the lineman can reach its locality.

Partial contact between two or more wires is caused by bodies which offer considerable resistance to the passage of electricity, such as kite-strings or cotton waste, hanging across them, or by their resting simultaneously against an imperfect conductor such as a brick chimney or a scaffold-pole.

Partial contact not infrequently results from *bad earth*, which is often a source of trouble, especially in rocky, chalky, or sandy ground. Thus, in fig. 213, let station B communicate with stations A and C by means of a separate circuit to each; if the earth

at B is bad while that at A and at C is good, then a part of A's current, on reaching B, instead of going to earth there, will take the course of the wire to C, working C's apparatus, and go to earth at C. The effect is the same as though the wires A B and B C were actually in contact with each other, and the strength of the contact will depend upon the resistance which the earth at B offers as compared with the circuit B C. If the steps named at p. 263 are not sufficient to secure a suitable earth at B, the only way of overcoming the difficulty is to run a wire from there to the nearest point where good earth can be found.

Weather contact is a form of partial contact to be met with chiefly in foggy or rainy weather, and mainly upon poles which have not been earth-wired. The leakage which takes place at the insulators there, instead of going to earth by means of the earth-wire, finds its way into the neighbouring wires, and the working of all is more or less impaired. The effect of weather contact upon the working of a circuit is very similar to that of indifferent earth; the latter, however, makes itself felt more or less in all weathers, while the former makes its appearance only during fogs, rain, or snow.

Weather Losses.—On wires skirting the sea, and especially where they are supported on iron poles, heavy leakages are liable to occur at periods when the prevailing wind is off the sea bringing with it a 'sea fog,' and the trouble is particularly felt during cloudy weather. The atmosphere becomes charged with saline vapour, which envelopes the line and gives a comparatively easy passage for the current to earth at each pole, the resultant loss being so great that the wires will at times be quite unworkable. In sunshine the salt moisture is evaporated and the trouble disappears. The difficulty can to some extent be overcome by an increase of battery power, but this remedy should be applied with caution, as if too much power be used there will be a danger of key contacts being fused, and of other parts of the sending circuit becoming overheated. In some parts of the world this trouble has been so serious that wires have had to be diverted to other routes on which they have had protection from the salt air (see p. 229).

Intermittent contacts are almost entirely due to bad regulation. The wires are swayed to and fro by the wind and brought from time to time against each other, more especially if those upon the same arm differ in gauge, and are therefore not equally

influenced by the wind. Pieces of wire thrown across the line wires and loosely adhering to them will also give rise to intermittent contacts.

Full earth may be due to one end of a broken wire lying in water or resting upon damp ground; it may likewise be caused by the line-wire being in metallic connection with some conductor affording good earth, such for instance as an iron post, an iron stay, or the earth-wire.

Partial earth is most frequently due to broken or otherwise defective insulators; it may be also produced by the wire resting upon imperfect conductors in connection with the earth, such as walls, the guards or arms on wooden posts, trees, &c. Trees form a great barrier to the erection of a line of telegraph, and their interference is one of the main points to be guarded against in the selection of the route. When it is impossible to avoid them permission must be obtained to lop the branches where necessary.

Intermittent earth is due to the wires being blown by the wind or otherwise brought from time to time into contact with some conducting body in connection with the earth.

E.—Faults in Underground Wires

Underground wires are free from most of the dangers to which overground wires are subject. Most of the faults which make themselves evident in underground wires, apart from those which arise from the deterioration in the materials due to age, are the result of either imperfect manufacture or carelessness on the part of the workmen engaged in laying down the line. Among these may be mentioned flaws in the copper wire employed as the conductor; imperfections in the insulating covering; bad joints and abrasion of the insulating covering whilst the wires were being drawn into the pipes. If reliance could be placed upon the manufacture of covered wires, if due care were exercised upon the work of laying them, and in working them after they are laid, it is difficult to see what faults could arise until they were decayed to an extent calling for complete renewal.

Rats sometimes find their way into the pipes by getting in at the bottom of the flush-boxes; they then eat through the gutta-percha and either bring the wires into contact or put them

to earth. Their ingress may, however, be provided against by setting the flush-boxes in cement mixed with pieces of broken glass.

In localising a fault upon one of a number of wires lying in the same pipe, considerable difficulty is experienced in selecting from the bundle that in which the fault exists. At each joint-box the wires are numbered, and no difficulty is found there in getting hold of the proper wire; it is at intermediate points, where the wires are not numbered, that the inconvenience is felt. The old practice of 'pricking' the wires should never be had recourse to. The holes which were made were either imperfectly closed up or not closed up at all, and in time developed into faults causing far more trouble than the original fault in search of which they had been made. An instrument known as the *wire-finder* well answers the purpose in picking out any wire that may be required without doing any injury whatever to it. The wire-finder consists of a magnetic compass, beneath which the several lines are brought in succession, until a permanent deflection of the needle indicates that upon which a constant current is passing. This constant current is put on the wire which it is required to trace. A yet more satisfactory way of tracing such faults is by passing intermittent currents, giving either certain definite 'beats' or a musical note, along the wire to be traced. The lineman then carries a coil with a hollow core, so formed that a wire can be placed within it, and, the ends of this coil being connected to a Bell Telephone Receiver, the beats or note can be distinctly heard. The advantage of having distinct beats is that, as the signals can be heard faintly on all the wires, the lineman may be somewhat doubtful as to which is the wire he wants; but in such case on cutting the selected wire and joining it to his galvanometer (detector), the beats should be reproduced, so that he may be quite certain as to whether he has the right wire or not.

If an underground wire becomes earthy, owing to the insulating covering being partly destroyed, and a positive current flow to line, an oxide of the metal forming the conductor is deposited at the point of leakage, and as this is a non-conductor, the insulation of the wire appears to be improved. This, however, is only temporary, for the metal is gradually transformed into its oxide, and the wire is thus disconnected. The action of the negative current is the reverse of this; its effect being to keep

the wire clean, and thus to maintain the leakage. For this reason negative currents should invariably be used in testing covered wires, for leakages will be brought to light by them which, with positive currents, would in all likelihood escape notice.

F.—Faults due to Lightning

Lightning is the most fruitful source of faults upon telegraph circuits in countries where thunderstorms are rife, and atmospheric electricity is undoubtedly the greatest enemy which those employed in their maintenance have to encounter. The damage done by it to the telegraph plant may be subdivided under two heads, viz.:

a. That affecting the poles, wires, and insulators.

b. That affecting the apparatus.

It is only in the case of very severe thunderstorms, when powerful lightning discharges take place, that the former is to be met with. The poles are then shattered, or have grooves cut out from the top to the ground line: the insulators are sometimes smashed, and the line-wires occasionally fused. Underground wires are free from these injurious effects of lightning, provided they are not connected to an open section of line. If, however, the latter is the case, they are liable to be affected, and numerous faults arise. Some form of lightning protector is therefore usually employed at those points where the open and covered sections are connected with each other. If the lightning finds its way into a covered wire, it will, in all likelihood, ruin the insulation at one or more points by bursting through the dielectric in its passage to the earth. The earth-wires alluded to at p. 249 play the part of efficient lightning conductors to those poles which are fitted with them. Instances of earth-wired poles being affected by lightning have occurred, but the damage has never gone farther than the point at which the earth-wire commences: for this reason earth-wires should always be carried above the roof of the pole. Upon single-wire lines or loops where earth-wires are not required for the prevention of contacts, it is always advisable, as a protection against the effects of lightning, to earth-wire at least the last five supports on each side of every office.

The dangers of damage to instruments which rise from

the powerful currents which are induced by lightning discharges have been practically surmounted by the use of various forms of *lightning protectors*, all of which are based upon the different behaviour of electricity of high and low potential.

It was observed that when two silk-covered wires were knotted or tied together, electricity of high potential discharges across this knot in preference to going through the loop. When a discharge takes place through a dielectric, such as dry air, at the moment of discharge the resistance along the line of discharge is broken down so as to allow the passage of the greater part, if not the whole, of the current; in point of fact, at the moment when the discharge occurs through a layer of air or other elastic medium, a conductor of very low resistance is formed. Hence, as a current divides itself in reverse ratio to the resistances opposed to it, the greater portion, if not all, flies across the knot or shunt. This is only an example of Faraday's well-known experiment in which a long wire in air is so bent that two parts, *a b* (fig. 214), near its extremities, approach within a short distance, say a quarter of an inch. If the discharge of a Leyden jar be sent through such a wire, by far the largest portion, if not the whole, of the electricity will pass as a spark across the air at the interval separating *a* and *b*, and not by the wire *c*. If, on the other hand, the source of electricity be a galvanic battery instead of a Leyden jar, the entire current will take the path of the wire *a c b*. Acting upon this principle, Mr. C. F. Varley, in the old form of single-needle coils, simply twisted together the two ends of the coil-wire before they were attached to their proper terminals, and it was found that this acted as a protector, the lightning discharging through the silk covering in the twist in preference to going through the coil. In order to make this idea more practically workable two wires covered with silk of different colours were twisted together and wound on a small boxwood reel, one wire being then connected to each end of the coil. As it was found that damp affected these wires and so caused contacts, the wires were still further protected by being drawn through melted paraffin. This '*reel*' protector

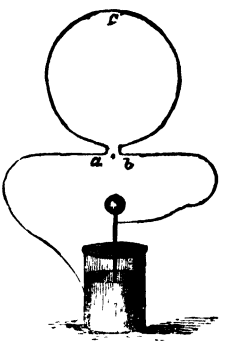


Fig. 214

is interesting as having been the first practical form of lightning protector introduced in this country, but it has long been superseded by improved arrangements. Although it protects the apparatus fairly well there is a very serious objection underlying its principle, inasmuch as whenever a discharge occurs through the protector at least a part of the circuit is broken down until the faulty protector is removed.

Probably the most efficient form of protector yet introduced is the 'plate' protector, originally devised by Siemens. This is now made in several patterns, but the principle is, of course, the same in each. It consists essentially of two conducting plates superposed, and separated from each other by a thin air-space. The line is connected to one plate, while the earth connection is made to the other. The lightning discharge takes place across the air-space. As originally devised the protector consists of two iron plates finely corrugated on their opposing surfaces, the corrugations of the upper plate running at right angles to those of the lower. The plates are prevented from making contact one with the other by the insertion between them of thin ebonite washers. Great care has to be exercised in order to keep the surfaces clean and prevent the accumulation of dust between them—a fault to which they are very liable. This description of plate protector is still used very extensively in India and certain colonies, but in England it is not employed, the British Post Office pattern being very much superior and more reliable. In its original form it consisted of two brass plates, the opposing surfaces of which are perfectly plane and carefully tinned to prevent oxidation. The faces of the plates are kept separate by a sheet of thin mica (talc), considerable perforations in which provide the necessary air-space, while the mica itself serves to exclude dust (see p. 229).

In later and improved forms of this apparatus circular carbon plates take the place of the brass plates. Other special forms of protectors are described on pp. 229, 268.

With every form of lightning protector it is imperative that the 'earth' to which it is connected be good. The earth wire should be taken by the shortest and most direct route possible (see p. 263), and all sharp turns and twists be entirely avoided. The most efficient protector will be rendered ineffective and made an actual source of danger, if this important point be disregarded.

CHAPTER XVIII

INSTRUMENTS FOR TESTING

ALL materials and instruments employed in the construction and fitting-up of telegraph circuits that have to do with their resistance or insulation should be subjected to electrical tests before being brought into use; in practical working also, it is most desirable to test the electrical condition of lines and instruments from time to time. Hence the necessity arises for various forms of testing instruments, some of which will now be described.

The Q. & I. Detector is a most useful instrument in the hands of a lineman, as with it he is able to obtain practical indications of the condition of batteries: while in the tracing of faults in wires, locating wires in cables, and such like work, the instrument is indispensable. It has two coils of 100ω and 0·2ω respectively. The latter, the quantity coil, is usually fitted with a 1/5 shunt operated by a switch. This, when brought into circuit, reduces the deflection to one-fifth its full value. The intensity coil should give a deflection of approximately 45° with 10 ma. and the quantity coil 25° with 140 ma. The intensity coil is used when currents of low value are tested, and it is also useful for indicating the comparative E.M.F. of cells. For the every-day testing of batteries, the low-resistance coil is generally used, and with this, each individual cell in a battery should give practically the same deflection. The instrument is usually supplied in a portable leather case with shoulder-strap.

For locating those faults on working wires which the instrument-room staff have to deal with most frequently, a galvanometer much used by the British Post Office and also by several

Colonial Administrations is that known as the *Test-box Detector*, fig. 215. The resistance of the coil is 200ω and the needle should deflect 25° with a current of 3 ma. A plug switch is provided in the face of the instrument, and the connections of this are so arranged that any of the ordinary tests required can be easily made. The battery used when testing line faults should not be stronger than about 20 volts, and it should be of a constant and reliable type.

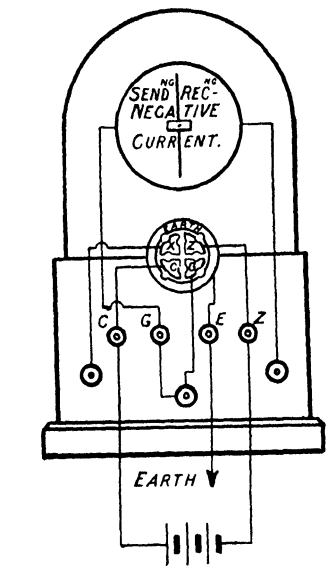




Fig. 215

G.P.O. Detector No. 2.—Quite a variety of testing instruments of the D'Arsonval type (see p. 320), but with the moving coil pivotted, is now available. These are used mainly for the purpose of measuring the E.M.F. and current strength of batteries, and a very useful form introduced by the British Post Office for use where greater accuracy of measurement than that attainable with the Q. & I. detector is desired is known as the G.P.O. Detector No. 2. It combines the functions of both a voltmeter and a milliampèremeter and is fitted with necessary terminals on the top of the case and a switch, by means of which both E.M.F. and current can be measured on two scales (four scales in all), the two for the former reading 0 to 5 and 0 to 50 volts, and the two for the latter 0 to 50 and 0 to 500 milliampères. Safeguards are provided for the protection of the coils in the event of the instrument being connected up for milliampère readings with the switch inadvertently in the voltage testing position. Where portability is required a leather case with shoulder strap is supplied with the instrument.

The galvanometers used in practical telegraphy indicate

the presence rather than the strength of working currents, so that no very special attempts need be made to secure extreme sensitiveness and freedom from friction upon the pivots. These conditions, however, are essential to a galvanometer which is to be used for testing purposes. One form of such an instrument, called the *Astatic* galvanometer, is shown in general arrangement by fig. 215A. It consists essentially of a divided coil of wire, with a vertical central axle fitted with two magnetic needles so pivotted that the needles move in the horizontal plane, one, *n s*, within and the other, *s' n'*, immediately above the coil, the opposite poles being in the same direction. By a consideration of the theory explained at p. 36, it will be seen that a current passing through the coil will tend to have the same effect upon both needles, and, therefore, the addition of the outer needle is advantageous from that point of view; but, further, it must be borne in mind that a magnetic needle properly balanced and pivotted to lie horizontally, points in a certain direction (north and south), in virtue of the directive force of the earth's magnetism, and, other conditions being constant, tends to remain in that position with a force dependent upon the magnetic strength of the needle. But in the astatic needle the *n'* pole of the upper magnet is placed over the *s* pole of the lower, and *vice versa*, so that if the two magnets were absolutely alike the needle would not be at all affected by the earth's directive force, but would stand in any position and would yet be quite free to be acted upon by the directive force of a current traversing the coil. In practice the two magnets are made slightly dissimilar in strength and the directive tendency resulting from this difference is under control. Sometimes the compound needle instead of being pivotted is suspended from a long silk fibre—an arrangement which eliminates the friction at the pivots and so increases its delicacy. The astatic galvanometer is a very useful form, but its sluggishness in coming back to zero is its weak point.

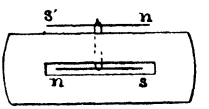


Fig 215A

A more generally useful galvanometer is that known as the *Horizontal*. In this case a small magnet, cup-pivotted like a compass needle, and fitted at right angles with an extremely light ebonite pointer, is made to slide into a simple flat coil,

and the pointer projects over a scale, just below which is a small reflector, to prevent parallax error.[1]

This instrument when properly constructed is as sensitive[2] as the astatic, and has not the defect of being sluggish. It is very largely used for ordinary circuit testing in connection with the Wheatstone Bridge.

One of the most useful galvanometers for general testing purposes is the *Tangent*. It consists of a circular coil of wire with a very short magnet pivotted in its centre. Theoretically this magnet should be of such dimensions that the influence of the magnetic field of the coil upon it should not vary with its position, but this is impossible, and practically it is found that with a simple ring coil, as shown in fig. 216, a needle whose length is from one-eighth to one-tenth the diameter of the

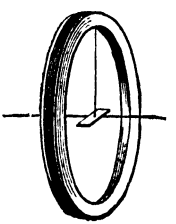


Fig 216

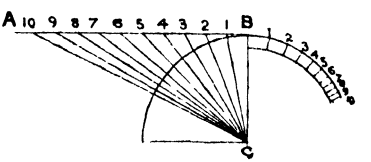


Fig. 217

coil gives sufficiently accurate results. The tangent galvanometer is so called because with the needle and ring arranged to fulfil the conditions just described, the *strength of the currents* which, in passing through the coil, will produce the various deflections are directly proportional to the *tangents of the angles of deflection* of the needle. Thus, if two different currents produce deflections of 30° and 45° respectively, the relative strengths of the two currents are as tan 30° to tan 45°, and these are respectively $\frac{1}{\sqrt{3}}$ and 1, so that a current which gives a

[1] As the pointer is necessarily elevated slightly above the scale, if the observer reads the deflection from a point not perpendicularly over the pointer, the reading is more or less inaccurate, but by the use of the mirror beneath, if the pointer and its reflection coincide when the reading is taken, no such error can arise, as the point of observation is then correct.

[2] The *sensitiveness* of a galvanometer is judged not necessarily by the extent to which the needle will deflect with a certain current, but rather by the amount of variation in current strength that must be made in order to affect the deflection.

deflection of 45° is $\sqrt{3}$ times the strength of one which gives a deflection of 30°.

If a line A B (fig. 217) be drawn at right angles to the radius C B of a circle, then the proportion $\frac{B\,1}{B\,C}$ is said to be the tangent of the angle B C 1; and $\frac{B\,2}{B\,C}$ is similarly the tangent of the angle

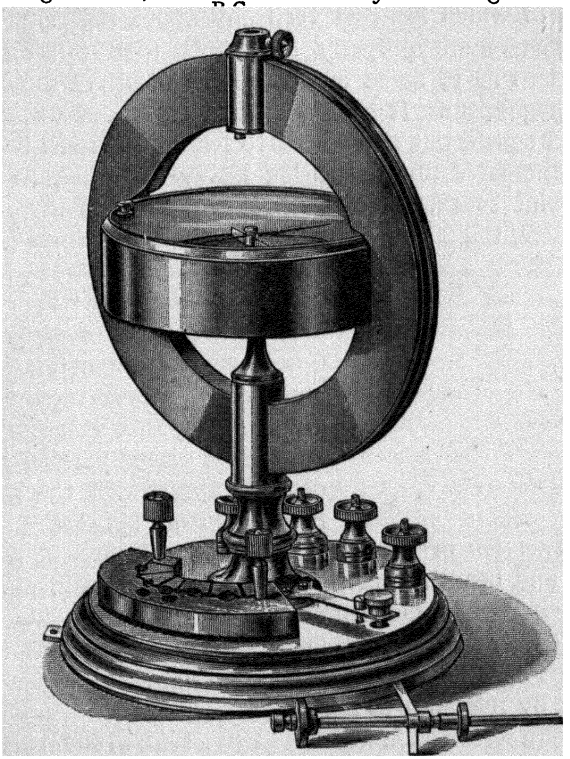


Fig. 218

B C 2, and so on. The tangents then are proportional to the lengths B 1, B 2, &c. Thus, if the pointer of a tangent galvanometer were long enough to reach the tangential line A B, deflections of the needle over the equal divisions 1, 2, 3, 4, &c., would represent proportional current strengths; but as it would be inconvenient to read from this straight line, the tangent scale is formed where lines drawn from the centre C to the various tangential divisions cut the circle described from the centre. This is clearly shown to the right in the figure.

The latest pattern of the Post Office form of the instrument is shown by fig. 218. This provides a series of shunt coils beneath the base which can be brought into use by means of the switch on the base, so that this instrument can be used for measuring a very considerable range of currents (Appendix, Section D).

At the front of the figure is shown the directing magnet, the stem of which is fitted vertically above the ring, so that the magnet—more properly *controlling* than *directing*—may be placed so as to assist or oppose the directive force of the earth's magnetism. It should always be placed magnetically north and south, but if required to reduce the sensitiveness of the galvanometer (for measuring heavy currents), its N pole should point south, whereas if it is desired to increase the sensitiveness, the N pole should point north. In these positions either effect is increased by lowering the magnet on its stem.

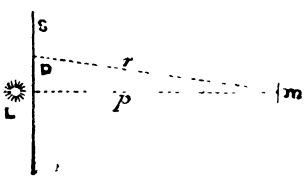


Fig. 219

Another form of tangent, the *Gaugain* Galvanometer, which, however, is never used for telegraphic purposes, consists of two large rings placed parallel at some distance apart, with the magnetic needle midway between.

The *Thomson* or *Kelvin* Galvanometer is among the most sensitive and beautiful instruments known to practical science. The principle of its construction is that of employing a very light, delicately suspended magnet, so arranged as to indicate its movements by a long beam of reflected light. This can be best explained by reference to fig. 219.

Let S be a screen upon which is fitted a scale of equal divisions; L, a lamp behind the screen, from which a beam of light is projected through a lens to fall upon a small mirror *m*, placed about three feet distant from S. This beam will be reflected on to the scale fixed at S. So long as the plane of the mirror is at right angles to the beam of light, the reflected beam will be in the same line (except that, as the reflected beam is required to be upon the scale above the lamp, the projected beam is directed slightly upward towards the mirror); but if the mirror be turned through a small angle as shown, the beam will be reflected upon the scale at D, and this distance will represent

double the actual angular deflection of *m*. For it is clear that when the projected and reflected beams coincide, they each are at right angles with the plane of the mirror, and, if the angle to which the mirror turns is *a*, the projected beam *p* will fall upon it at that angle from the perpendicular, but it is a fundamental law of reflection that the reflected beam makes the same angle with the mirror as the incident beam, and in the opposite direction; hence *r* will make the same angle with the perpendicular as *p* makes, and therefore the angle between *p* and *r* will be equal to twice the angular movement of the mirror. In this way the beam of light becomes equivalent to a fixed pointer about six feet long, and absolutely without weight. In applying this to the Kelvin galvanometer, upon the back of the small mirror (which is about three-eighths of an inch in diameter) several small magnets formed of highly magnetised watch-spring are fixed; and the mirror is suspended upon a single fibre of silk without torsion, in the centre of a large divided coil of wire, which so completely surrounds it that the influence of the coil is the same in any position of the needle. Very frequently this arrangement is doubled, a second coil being placed beneath, and the second series of magnets is connected to the first by a piece of aluminium wire, so as to form an astatic pair of needles. The arrangement of the parts furnishes all the conditions required for a tangent galvanometer, but as the range of deflection is always very small, it is permissible to assume that the strengths of current are practically proportional to the deflections of the spot of light on the scale. Only for tests where extreme accuracy is required is it necessary to reduce to tangents. The reading is taken from a black line across the reflected spot of light, which is caused by a wire placed across the lens through which the projected beam passes.

The sensitiveness of the instrument can be regulated by a directing magnet, as described in connection with the tangent galvanometer (p. 318). A high resistance galvanometer of this form is so sensitive as to be capable of giving a fair deflection with a current from one Daniell cell through 100 megohms,[1] and it is therefore necessary for many tests to be able to reduce the amount of current actually flowing through the coils of the galvanometer. This is done by means of *shunts*,[2] whereby only a certain definite proportion of the total current ($\frac{1}{10}$, $\frac{1}{100}$ or $\frac{1}{1000}$)

[1] A *megohm* is one million ohms.

[2] See Appendix, Section D.

is allowed to pass through the coils of the galvanometer. This shunt is connected across the terminals of the galvanometer.

The D'Arsonval is another type of reflecting galvanometer now much used in place of the one just described. It is not so sensitive as the better forms of Kelvin galvanometer, but it has the great advantage of a dead-beat action, and it is not affected by external magnetic influences. A coil of insulated wire, wound on a light copper frame with a mirror attached, is suspended between the poles of a powerful permanent compound horse-shoe magnet by a fine silver wire. This wire is attached to an adjusting screw at the top, and from the bottom of the coil there is another piece of similar wire connected to a light spring also fitted with an adjusting screw. These adjusting screws free the suspender wire from torsion and produce the tension on the wire required to keep the coil in position. The two pieces of wire also connect the coil with the external circuit. The magnetic field of the permanent magnet is augmented by a piece of soft iron placed adjacent to its poles. When the coil is in its normal position the lines of force generated in it by the current are at right angles to the field of the permanent magnet and the coil therefore tends to turn to one side or the other and to bring its lines of force into line with those of the permanent magnet, and against the torsion of the suspender wire.

All tests for resistance depend upon a comparison between the resistance to be tested and some standard resistance, hence various arrangements of *resistance coils* for testing purposes are made. Usually a series of resistances is so arranged that the resistance actually in circuit can be varied at will by the insertion or withdrawal of a brass plug between two brass blocks. The coils themselves consist of silk-covered platinoid, manganin, or eureka wire wound upon bobbins, and in order to avoid the effects of extra currents from self-induction, the wire is double-wound upon the bobbins, the inner ends being connected together, and the outer ends treated as the two ends of the coil: by this means the induced current from one half is neutralised by that from the other, because they are in contrary directions.

One of the most useful forms of resistance coils is shown in fig. 220. It represents a very generally used form of *Wheatstone Bridge*. The numbers indicate the resistance in ohms of the various coils, which are short-circuited by the insertion

of the plugs between the blocks, and brought into circuit when the plugs are withdrawn.

The principle of the Wheatstone Bridge can be best understood from an examination of the following diagram (fig. 221). Assume a, b, d, and x to be resistances, some of which are adjustable.

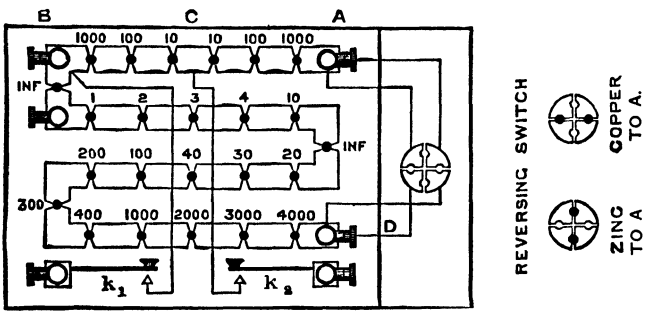


Fig. 220

If the battery circuit be completed by depressing the key k_2, the point D will be raised to a higher potential than the point C, but the difference, or fall, of potential between these two points along the path $(x + a)$ will be the same as that along the path $(d + b)$.

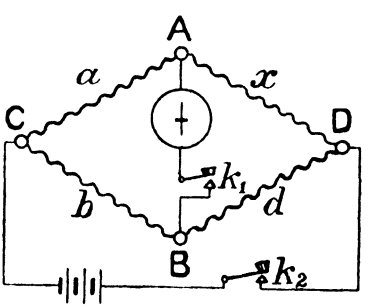


Fig. 221

Consider the potential at the point A; it lies between that at D and that at C, and since the fall of potential along each path is the same, it follows that there must be a point in $d + b$ at the same potential as A. Assume B to be this point. Then, clearly the fall of potential along D A is equal to that along D B; and that along A C to that along B C. Now since the fall of potential in any part of a circuit is proportional to the resistance of that part, the difference of potential between D and A is to that between D and C as the resistance x is to the resistance $x + a$. If the potential difference between D and C be V volts, then that between

D and A will be $V \frac{x}{x+a}$ volts; similarly, the potential difference between D and B will be $V \frac{d}{d+b}$, and since these potential differences are equal, we have—

$$V \frac{x}{x+a} = V \frac{d}{d+b} \quad . \quad . \quad . \quad (1)$$

For similar reasons—

$$V \frac{a}{x+a} = V \frac{b}{d+b} \quad . \quad . \quad . \quad (2)$$

Dividing equation (1) throughout by V we get—

$$\frac{x}{x+a} = \frac{d}{d+b}$$

that is, $xd + xb = xd + ad$

therefore $xb = ad,$

or $x = \frac{ad}{b}.$

This, then, is the relation which exists between the resistance a, b, d, and x, when A and B are at the same potential. In practice these two points are fixed and a sensitive galvanometer G may be connected between them by depressing the key k_1. The unknown resistance occupies the position denoted by x and convenient known resistances are placed in the arms a and b. The arm d is then adjusted until B arrives at the potential of A. This equality of potentials is indicated by the absence of any deflection when the galvanometer circuit is completed; for if there be the slightest difference of potential between the two points a current will flow through the galvanometer coil and produce a deflection of the needle.

Now, by referring to fig. 220, where the lettering corresponds with that of fig. 221, the resistances a and b will be seen to be adjustable coils, each arm consisting of 10ω, 100ω, and 1000ω. Between B and D is a series of coils, giving a range of adjustment from 1 up to 11,110. The two former series a and b are known as the *ratios*, while the larger series (represented by d in the above equation) is generally called the *rheostat*.

The equation $x = \frac{ad}{b}$ may be written $x = \frac{a}{b} d$, and then it

is evident that if the ratios a and b are equal, x, the unknown resistance, is equal to d, but if a is made 1,000ω, while b is only 100ω or 10ω (so that $\frac{a}{b}$ is 10 or 100), then x is 10 or 100 times the resistance of d; if, on the other hand, b is 10 or 100 times a, then x must be $\frac{1}{10}d$ or $\frac{1}{100}d$. This latter arrangement is the most accurate where practicable, as by this means it is possible to determine the value of x within $\frac{1}{10}\omega$ and $\frac{1}{100}\omega$ respectively. For measuring small resistances, therefore, it is advisable to have b larger than a.

It is necessary to observe that in order to make a test with the Bridge, the insertion of resistance in each ratio is essential—otherwise, as will be seen by a consideration of the formula, if in the equation $x = \frac{a}{b}d$ either a or b have no numerical value (that is if one ratio be either zero or infinite) the value of x cannot be determined.

If the ratios are equal, they can be either 10 and 10, 100 and 100, or 1000 and 1000, and the best value to employ may be determined by experiment. The condition required is that the relative values of a, b, d, and x shall be such that the galvanometer G is in its best position (that is, where the deflection will be greatest if the balance is nearly, but not quite, perfect). For instance, with the ratios 10ω and 10ω, and an approximate balance, note the deflection; change the ratios to 100ω and 100ω, or 1000ω and 1000ω, and that ratio which gives the greatest deflection is the best to employ. In the same way when unequal ratios are used, 10ω and 100ω may in some cases be better than 100ω and 1000ω, and *vice versa*. As a general rule, the higher the resistance to be measured (x), the higher should be the values of a and b.

A and D are the two points between which the ends of the unknown resistance are joined, and in practice there is a reversing switch connected between these points (fig. 220). A is really a double terminal, the lower part of which is connected to the ratio a and to one of the lower segments of the switch, while the upper part is connected to one of the upper segments of the switch. Similarly, with the terminal marked D, the lower part of which is connected to one end of the coils d and to the upper left-hand segment of the switch, while the upper part is connected to the lower left-hand segment. By this means the ends of the resist-

ance under test, which are joined to the upper part of A and D respectively, may through the switch be electrically connected either to A and D (if the switch connections are as shown by the figure at the side marked 'zinc to A'), or to D and A (if the switch connections are reversed, as shown by 'copper to A'). The direction of the battery current through the resistance can thus be readily reversed, a requirement that often presents itself.

One galvanometer terminal, instead of being actually connected to B, is joined to k_1, and the negative pole of the battery is joined to C through k_2. This provides means of breaking or closing the galvanometer and battery circuits independently and at will. In all tests the battery (right-hand) key should be first closed, and not released until after the galvanometer key, as otherwise the inductive effect of the wire under test may act upon the needle. The galvanometer key should at first be momentarily depressed, since if the resistance in *d* is not right, a lengthened depression of k_1, by giving a full deflection, will lead to much loss of time in making a test. When, however, the adjustment appears nearly perfect, that is, when only a very slight deflection is given, then the key may be held down, and the final adjustment made. It should be noted that too much resistance in B D will cause a deflection of the galvanometer needle in one direction, and too little resistance a deflection in the reverse direction.

The two plug-holes marked INF (Infinity) serve to disconnect the series at those points if required.

For the accurate measurement of small resistances, the ratios of the Wheatstone Bridge are sometimes formed of a straight German silver wire one metre long (the instrument hence being called the '*Metre Bridge*') stretched upon an oblong board parallel to a metre scale divided throughout in millimetres. The junction C (fig. 221) of the two ratios depends simply upon the position of the slider along the slide wire; the positions of the battery and galvanometer are also reversed. This instrument, however, is not used for ordinary telegraphic testing.

A useful instrument for testing the insulation resistance of lines is the *Megger*, which consists of an ohmmeter of the moving-coil type, combined with a commutated hand magneto generator, which produces the continuous current required for the tests.

The generator can be made to give either a constant or a variable pressure. In the latter the volts vary with the speed at which the generator handle is turned, whilst with the constant-pressure instrument the driving gear is so arranged that it slips when the generator handle is turned at a speed in excess of that required to produce the rated pressure of the instrument, so that the speed of the generator, and therefore the pressure at the terminals, remains constant. The advantages of this instrument are that it is light, portable, and simple to operate:



FIG. 222A

it dispenses with the use of a battery, it measures insulation resistance under high pressure, and its readings are indicated instantaneously by direct deflection on a dial. It is made to give a wide range of both pressures and readings, and any instrument can be fitted with a switch which divides the scale readings by 10. A convenient instrument for general purposes is one which reads from 10,000 ohms to 100 megohms with a pressure of 500 volts.

The *Evershed Bridge Megger* is an instrument which combines the functions of the plain megger with that of the Wheatstone Bridge.

The set consists of two parts—namely, the megger and a direct-reading resistance-box. The latter (fig. 222A) is fitted with four or more sets of resistances, each set being connected to a rotary

multiple-point switch, carrying a figure-dial arranged to show a digit representing the position of the switch. The total resistance of the box is thus indicated in a row of figures, and the value of the conductor-resistance measured can be read directly, or the reading may be divided by 10 or 100 according to the position of the ratio switch on the Megger. The Megger (fig. 222B) is of the constant-pressure type, wound to produce a pressure of 500 or 250 volts at its terminals, and with scale-readings for insulation

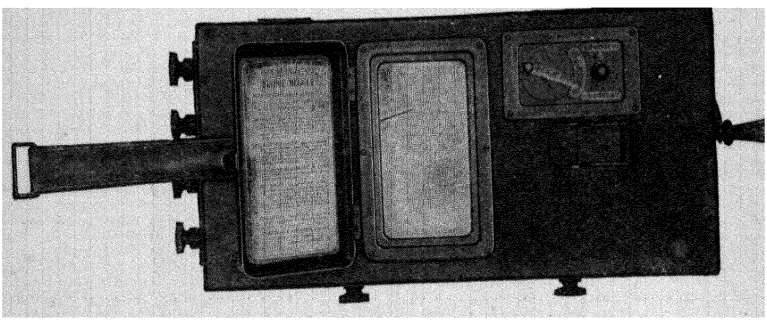


FIG. 222B

resistance measurements of from 1000 ohms to 20 megohms. It is fitted with two switches, one a 'change over' which joins the internal connections for either 'megger' or 'bridge' as may be required, and the other is the 'ratio' switch referred to above. When the change-over switch is turned to 'bridge,' the connections are so altered as to convert the ohmmeter into a galvanometer for the bridge, and it also connects the windings of the generator in parallel, and so increases the current from the machine. The 'ratio' switch alters the proportion of the ratio arms of the bridge, so as to make the value of the conductor-resistance under test either equal to that of the resistance-box or one-tenth, or one-hundredth of that amount. With this testing set there are no plugs to withdraw, no calculations are necessary, all readings are indicated directly and quickly, and the set is simple and easy to operate.

CHAPTER XIX

TESTING

Testing Circuits.—The subject of testing ordinary telegraph circuits may be conveniently considered in three parts, namely:—

(*a*) Testing wires during erection.
(*b*) Daily and other periodical tests to ascertain the condition of the circuits for the purpose of preserving a record and to anticipate as far as possible the occurrence of faults.
(*c*) Testing to determine the locality of a fault when its existence is known.

(*a*) During the erection of a new line, if of considerable length, conductor and insulation resistance tests should be carried out as each section of say ten miles is completed, in order that any defects that may have crept in during construction may be put right. On the completion of the line, final tests should be taken, and these should be recorded in a permanent manner, as the standards with which all subsequent tests should be compared. The most useful instrument for these tests is the Evershed *Bridge Megger* (see p. 325), with a 500 volts megger of the pressure type having a suitable range of readings for the insulation tests, and also with the bridge, which is a direct-reading instrument, for the conductivity tests.

(*b*) Under this head it was the practice for many years in the British Post Office to carry out daily tests of all lines, and these varied according to the length and importance of the circuits. On minor circuits it was considered sufficient for the head office to exchange signals with all sub-offices at the hour of opening, and ascertain whether the signals were 'good' or 'weak,' and the head office was also able to judge of the state of the signals

received from each sub-office. If the attention of any or all of them could not be gained, it was assumed that there was a fault on the circuit, and the responsible officer was informed accordingly. This system of morning tests is still carried out. By its means the working condition of all lines is ascertained, and minor faults are detected, and frequently removed, before the real work of the day commences.

With the same object, all important circuits were tested in a special manner every morning between 7.30 and 7.45, and a remarkably ingenious, although somewhat elaborate, method of carrying out this 'morning test,' devised by Mr. A. Eden, was employed. This system may still be favoured by some administrations, and as, apart from this, it possesses technical features of a highly interesting character, a full description of it is given hereafter (see p. 331).

With the expansion of the department's network of wires, and especially with the erection of trunk telephone circuits in all directions, on which the system employed constitutes a permanent test in itself, it was decided to abolish the special daily tests, and substitute monthly, and in some cases weekly, tests, and to introduce a system of testing which would admit of the tests being carried out more expeditiously. Under this system, the more important circuits only are tested for insulation and conductivity; the telephone circuits being tested once a month for both tests, and the telegraph lines once a week for insulation, and once a month for conductivity. Underground cables are similarly tested once a month, but one wire only, which is regarded as typical of all the wires in the cable, is subjected to the tests. The instrument used for carrying out these tests is either the Wheatstone Bridge or the Evershed Bridge Megger, which for this purpose gives 250 volts.

These periodical tests should be sufficient for all practical purposes under any climatic conditions. In a country having a dry, clear atmosphere, the tests might be carried out less frequently, and in this respect local conditions and experience are the best guide as to the intervals at which the tests should be taken. The results of all periodical tests should be carefully recorded, as by comparing these with previous tests, incipient faults can be readily detected, and measures taken for their removal before they become serious enough to interfere with the ordinary working.

Insulation Tests.—The necessary connections required when testing with the Wheatstone Bridge are indicated by fig. 223 and little further need be added respecting them. For the insulation test the line is attached to terminal A, and an earth-wire is connected to terminal D, to which the positive pole of the battery is also brought. The negative pole of the battery is joined to the k_2 terminal. The negative current is invariably employed for insulation testing, so the reversing switch should be arranged as shown in fig. 220 ' zinc to A.' If the test be within the total of the resistance coils, viz. 11,110ω, the whole of the resistance in each arm, viz. 1110ω, should be unplugged. As a general rule the resistance in each arm while a wire is being tested should approximate as closely as possible to the expected result of the test. If the test be over 11,110ω and under 111,100ω, then the resistance in *b* should be made to bear to that in *a* the ratio of 1 to 10, by inserting only 100ω in the former, while the 1000ω coil is inserted in the latter. Again, if the test be over 111,100ω and under 1,111,000ω, the resistance in *b* should bear to that in *a* the ratio of 1 to 100, and this can be effected by inserting 10ω in the former and 1000ω in the latter. The highest resistance which can be measured by this form of bridge is 1,111,000ω or $11{,}110\omega \times \frac{1000}{10}$, the latter factor being the highest ratio which can be obtained from the resistances in *a* and *b*. The total insulation resistance being thus found, the insulation per mile is obtained by *multiplying* this result by the number of miles of wire tested.

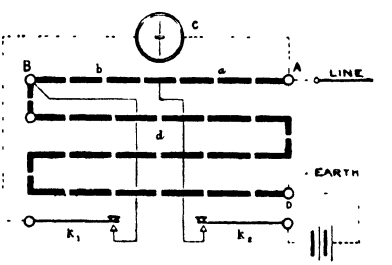


Fig. 223

Conductivity Test.—In taking the conductivity or wire resistance test the connections are the same as in the previous case; the only difference in the arrangement is that the distant station now puts the wire to earth, instead of leaving it disconnected. The same remarks as have been made about the resistance which should be inserted in the arms of the bridge when taking the insulation test apply equally to this test. But as the wire-resistance never exceeds 11,110ω, the test obtained

when 1,110ω is inserted in each of the branches can be verified by varying the ratio of a to b, making it either 1 to 10 or 1 to 100, and altering the resistance coils accordingly.

In making this test it has been assumed that the distant end of the line has been put to earth, and that earth has been joined to terminal D. Considering the difficulty, however, which frequently exists in the way of obtaining good earth (p. 250), and the danger which is thus incurred of additional resistance being thereby inserted in the circuit, it is advisable if a second wire is available to dispense altogether with the earth and to use the second wire as a return, so as to obtain a metallic circuit. The end of this wire should then be joined on to terminal D in place of the earth-wire, and the distant station should be instructed to loop the two together. If the wires are of the same gauge and traverse the same route, the resistance of each will be half of the total resistance. But supposing that they are not of the same gauge or go by different routes, and that a *third* wire is available, the resistance of each wire can then be found as follows—

Let Resistance of No 1 wire $= x$
,, ,, 2 ,, $= y$
,, ,, 3 ,, $= z$

Take three tests of these, having two of the wires looped for each test, so that the resistance of—

$$x + y = a$$
$$x + z = b$$
$$y + z = c$$

Then

$$x = \frac{a + b - c}{2}$$

$$y = \frac{a + c - b}{2}$$

$$z = \frac{b + c - a}{2}$$

The resistance test should invariably be taken with both the negative and positive current; for, although the result obtained would be the same with each supposing the wire to be quite clear throughout, in actual practice it is seldom, if ever, the case. Earth currents are always more or less present, and defective joints in the wires, as well as hidden flaws that may

exist in them, introduce a disturbing element on account of the different effects produced by the negative and positive currents at these points. The mean of both tests should then be calculated, *i.e.* calling x_1 the test obtained by the negative current, and x_2 that obtained by the positive current, the real conductivity resistance of the line may be taken as $= \frac{x_1 + x_2}{2}$.

The conductivity resistance *per mile* is this total resistance *divided* by the number of miles of line tested.

The 'Eden' Morning Test.—In the first place, as far as possible the wires are tested in pairs by 'looping' at one end, thus reducing the actual number of tests required by half. In the second place, the observations are made with one instrument only at one end of the looped wires, thus eliminating the

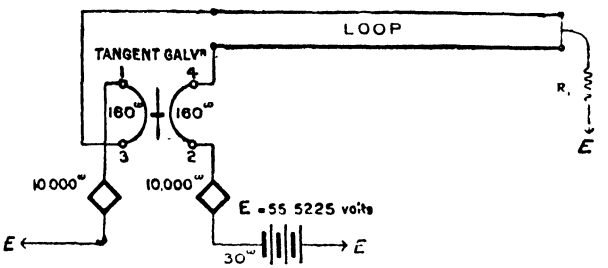


Fig. 224

errors due to differing 'constants' which are apt to follow when the results depend upon testing instruments at both ends.

The theoretical connections of the system are shown by fig. 224, from which it will be seen that the lines to be tested, which are looped at the distant end, are connected at the Testing Office with a double-wound tangent galvanometer (fig. 218), two 10,000ω resistance coils, and a testing battery, E. Under these circumstances, if the lines, both as regards insulation and continuity, were perfect, the whole of the current sent from the battery through coil 2–4 of the galvanometer would be received in the reverse direction through coil 3–1, and the galvanometer needle would be unaffected. The less perfect the insulation of the line the greater will be the current sent out and the less will be the current received, and the resulting deflection of the galvanometer needle will become a measure of the actual loss at the insulators. Now, as the actual resistance

of any sections of line ordinarily tested is small compared with the resistance coils of 10,000ω inserted at the end of each line, no material error will arise if the total amount of leakage that takes place upon the whole loop be treated as a single fault in the middle of the circuit having a definite resistance.

This, then, is the plan adopted. The leakage, which is really due to faults of high resistance distributed (chiefly at every insulator) along the entire length of line, is, under the conditions described, properly represented by an assumed resultant fault in the middle of the loop of such resistance that, with the same electromotive force, it will take off a current equal to the total leakage at all the insulators, &c. This resultant fault (shown as R_1 in fig. 224) represents the *total insulation resistance* of the line under test.

The relative values of the insulation resistance of various lines, however, must evidently largely depend upon their length; and, for purposes of comparison, it is therefore customary to reduce the *total* insulation resistance to the *insulation resistance per mile*. This is done by *multiplying* the total insulation resistance by the length of the circuit in miles. That this multiplication is correct will be clear when it is considered that if the leakage along the line be supposed to be uniform, and that there is no specific fault, the leakage along n miles will be n times greater, and the insulation resistance consequently n times less than for *one* mile of the same circuit. Now, the insulation resistance per mile which is found in England to be capable of being maintained upon open lines under the worst ordinary wet weather conditions is 200,000ω; and this is accordingly adopted as the minimum maintenance standard for engineering purposes.

Turning now to the actual conditions of the insulation test:

First, the tangent galvanometer is adjusted to give a 'constant' deflection of 80 divisions on the outer tangent scale[1] with one milliampère of current, so that any given deflection of D divisions represents a definite strength of current C. That is—

$$C = \frac{D}{80} \text{ milliampères};$$

[1] The outer tangent scale has a double range, the zero being at the left-hand end of the scale instead of, as on the inner scale, in the centre.

or conversely, the current in milliampères may be represented in divisions on the tangent scale, thus—

$$D = C \times 80 \quad . \quad . \quad . \quad . \quad . \quad (1)$$

when the current passes through both coils of the galvanometer.

This 'constant' of the galvanometer having been obtained, the connections of the looped section that is to be tested are made as shown theoretically by fig. 224. Now, with these conditions, and with a leakage fault (representing the total insulation resistance of the loop) of resistance R_1, in the centre of the total resistance (R), the current passing from the battery (E) through coil 2–4 of the galvanometer to line, divides at the fault, part going back through the second coil 3–1 of the galvanometer, and the other part going to earth at the 'fault.'

It is, therefore, required to determine (1) the strength of the current 'sent,' (2) the strength of the current 'received,' and (3) the strength of the current which passes to earth through the leakage. As regards (1) and (2), it has already been stated that the 'received' current passes through the second coil of the galvanometer in a direction which tends to neutralise (or at least reduce) the effect of the 'sent' current; hence the deflection observed will indicate the difference in effect between the two when acting through one coil of the galvanometer.

Now, taking R to represent the total resistance of the circuit, including 10,000ω coils, battery, galvanometer, and loop, the total resistance (including the leakage fault) from the battery (of electromotive force E), is made up of $\frac{R}{2}$ and the combined resistance of $\frac{R}{2}$ and R_1—which is (*see* Appendix, Section C),

$$\frac{\frac{R}{2} \times R_1}{\frac{R}{2} + R_1} \quad \text{or} \quad \frac{R \times R_1}{R + 2R_1} \quad . \quad . \quad . \quad (2)$$

therefore, the total, including leakage resistance, is—

$$\frac{R}{2} + \frac{R \times R_1}{R + 2R_1} = \frac{R(R + 4R_1)}{2(R + 2R_1)}$$

The total current sent to line C_S (in milliampères, if E be taken in millivolts[1]) is therefore—

$$C_S = \frac{E}{\frac{R\,(R + 4\,R_1)}{2\,(R + 2\,R_1)}} = \frac{2\,E\,(R + 2\,R_1)}{R\,(R + 4\,R_1)} \quad . \quad . \quad (3)$$

This represents the 'sent' current.

Again, the proportions in which this 'sent' current divides into the 'received' current C_R, and the 'leakage' current C_L, is determined by the law of shunted circuits,[2] to be respectively for C_R—

$$\frac{R_1}{\frac{R}{2} + R_1} \quad \text{or} \quad \frac{2\,R_1}{R + 2\,R_1} \quad . \quad . \quad . \quad (4)$$

and for C_L,

$$\frac{\frac{R}{2}}{\frac{R}{2} + R_1} \quad \text{or} \quad \frac{R}{R + 2\,R_1} \quad . \quad . \quad . \quad (5)$$

The 'received' current will therefore be found by multiplying equations (3) and (4) together, thus—

$$C_R = \frac{2\,E\,(R + 2\,R_1)}{R\,(R + 4\,R_1)} \times \frac{2\,R_1}{R + 2\,R_1} = \frac{4\,E \times R_1}{R\,(R + 4\,R_1)} \quad . \quad (6)$$

and the current $(C_S - C_R)$ actually measured will be the difference between equations (3) and (6), or—

$$C_S - C_R = \frac{2\,E\,R + 4\,E\,R_1 - 4\,E\,R_1}{R\,(R + 4\,R_1)} = \frac{2\,E}{R + 4\,R_1} \quad . \quad (7)$$

Further, the 'leakage' current will be (equations (3) and (5) multiplied together)—

$$C_L = \frac{2\,E\,(R + 2\,R_1)}{R\,(R + 4\,R_1)} \times \frac{R}{R + 2\,R_1} = \frac{2\,E}{R + 4\,R_1} \quad . \quad (7a)$$

[1] A millivolt is $\frac{1}{1000}$ of a volt.

[2] See Appendix, Section D, where it is shown that the proportion of current which will pass in the sections of a shunted circuit is in *inverse* proportion to the resistance of the sections.

But equations (7) and (7*a*) are identical, which shows that the current actually observed on the galvanometer represents the ' leakage ' current.

It must be noted that the deflective effect of the received current is practically equivalent to that of a current $(C_s - C_R)$ passing through *one coil* only (2–4) of the galvanometer. As already explained, the tangent galvanometer is adjusted to give a deflection of eighty divisions on the outer scale with one milliampère of current passing through *both* coils, which is equivalent to forty divisions if the current pass through only *one* coil. If, therefore, the right-hand side of equation (7) be multiplied by 40, it will represent in divisions, D, the actual equivalent of the ' leakage ' current.

Thus
$$D = \frac{80\,E}{R + 4R_1} \quad . \quad . \quad . \quad . \quad (8)$$

In the above equation (8) all the factors are known or can be derived from calculation ; and the object of the foregoing explanation has really been the determination of this equation. All the essentials of the looping-test system are dependent upon it.

The insulation resistance, R_1, is the only factor in the equation that is not actually known, and that is determined as follows :—

(1) Assuming the *total* insulation resistance of a circuit which is L_1 miles long to be R'_1, the insulation resistance *per mile* will be $L_1 \times R'_1$, and the total insulation resistance, R_1, of the length (in miles) under test L will be—

$$R_1 = \frac{L_1 \times R'_1}{L} \quad . \quad . \quad . \quad (9)$$

Now, by a series of careful experiments it has been shown that for any circuit that is wanted to meet the most exacting of telegraphic requirements (namely, automatic working) the total insulation resistance must not fall below the actual conductor resistance of the same circuit. This, therefore, gives a standard for insulation resistance which will meet the highest working conditions. This may be called the ' working standard.' In equation (9), taking R'_C, the total conductor resistance of the

circuit, to be the total insulation resistance for this standard, the insulation resistance of the section evidently will be—

$$R_1 = \frac{L_1 \times R'_c}{L} \quad . \quad . \quad . \quad (10)$$

(2) Further, at p. 332 it was explained that the average climatic conditions in England are such that it is not ordinarily possible in unfavourable weather to maintain a mileage insulation much above 200,000ω; and this accordingly determines another standard of insulation, which may be designated the 'maintenance standard.' Under this standard the total insulation resistance, R_1, of any section L miles long will evidently be—

$$R_1 = \frac{200{,}000}{L} \quad . \quad . \quad . \quad (11)$$

Equations (10) and (11) therefore give two values for R_1 which may be inserted in equation (8).

The further development of the explanation can be most conveniently proceeded with by help of a specimen weekly report of 'Morning Tests' (p. 337).

The particulars given in columns 1 to 10 are in the nature of fixed records; and for offices where a considerable number of tests have to be made, the forms are printed with those columns filled in.

Columns 1 to 3 need no comment.

Columns 4 to 8 are obtained from engineering records, checked by actual tests made when opportunities occur.

Columns 9 and 10 are obtained by calculation in the manner which will now be explained.

First, as to column 9—'Working Standard Deflection.' This is simply a calculated deflection obtained by giving to R_1 in equation (8) the value deduced from equation (10).

(1) Thus, for example, in order that the LV.EH 1[1] circuit may have its maximum efficiency, the total insulation resistance, R_1, of the (double) section between EH and the office at which the wires are looped (CE)[2] must not be less than—

$$R_1 = \frac{217{\cdot}75 \text{ (column 7)} \times 3160 \text{ (column 8)}}{198{\cdot}31 \text{ (column 5)}} = 3469{\cdot}78\omega;$$

[1] Liverpool-Edinburgh. [2] Carlisle.

POST OFFICE TELEGRAPHS.

MORNING TESTS.

Edinburgh Office.

Engineers' Department, East. Scot. Dist.
Week ending Saturday ———

1 Circuit	2 Office at which the wires are looped or earthed	3 Route	Looped section: 4 Conductor resistance	Looped section: Mileage. 5 Open	Looped section: Mileage. 6 Covered	Circuit: 7 Mileage (open)	Circuit: 8 Total conductor resistance	Standard deflections: 9 Working	Standard deflections: 10 Maintenance	11 Leakage in tangent divisions: Mon.	Tues.	Wed.	Thur.	Fri.	Sat.	12 Insulation resistance per mile if below maintenance standard	Remarks
LV.EH 1	CE	Rail	3110	101·	1 06	217·75	3160	119	162	105	66	108	70	100	83	—	—
CE.EH	,,	,,		97·31	0·51	97·31	1560	167									
LV.EH 2	,,	,,	2410	,,	,,	228·	2040	138	165	100	10	110	55	62	22	—	—
MR.EH 2	,,	,,		,,	,,	220	2800	125									
100	,,	,,	2330	,,	,,	180·5	2470	139	165	101	12	28	42	55	25	—	—
136	,,	,,		,,	,,	192·	2360	139									
MR.EH 3	,,	,,	1150	,,	,,	210·5	2600	101	150	72	6	28	4	34	28	—	—
ANGLO	DE	Road & rail	1130	60 06	5 28	104·38	1460	167	158	15	INF.	40	10	27	35	—	—
102	,,	,,		,,	,,	251·	2900	97									
										W	Calm	W	SE	SE	S	—	—
								State of weather		Fine	Dry	Fine	Fine	Fine	Dull	—	—

3160ω, in accordance with the rule just explained, representing the 'working standard' of insulation resistance for the whole circuit. This calculation explains the need for columns 5, 7, and 8 upon the Test Sheet. If the total insulation resistance fall below the total conductor resistance, loss of speed in automatic working will immediately result.

The value of R_1 in equation (8) for this example is thus found to be 3469·78ω.

(2) The value of R in the same example is 20000ω + 30ω + 320ω + 3110ω (column 4)—

$$\begin{aligned} R &= 20000_\omega + 30^\omega + 320^\omega + 3110^\omega \text{ (column 4)} \\ &= 20350^\omega + 3110^\omega = 23460^\omega. \end{aligned}$$

(3) Further, as regards E. When the galvanometer has been adjusted to give a deflection of 80 divisions with one milliampère, the 'constant' of the testing battery is taken. This is made as nearly as possible 110 divisions, or 2½ milliampères. With the resistance which is in circuit when this constant is taken, the electromotive force, E, that would give exactly 110 divisions would be 55·5225 volts or 55522·5 millivolts; and E for all purposes of calculation is therefore assumed to be of that value.

To continue, then, the example of the LV.EH 1 circuit: E is 55522·5, R is 23460, and R_1 is 3469·78; therefore (equation 8)—

$$D = \frac{55522{\cdot}5 \times 80}{23460 + 4\ (3469{\cdot}78)} = \frac{4441800}{37339{\cdot}12} = 118{\cdot}95$$

or practically 119, which is accordingly entered in column 9 as the working standard deflection. If the observed deflection does not exceed this, the section, so far as insulation is concerned, is good enough for the maximum high speed which can be maintained upon the whole circuit.

A similar calculation for circuit CE.EH[1] shows the Working Standard Deflection in that case to be 167.

Column 10. By the insertion in equation (8) of the value of R_1 obtained for the Maintenance Insulation Standard of 200,000ω per mile from equation (11), namely—

[1] Carlisle-Edinburgh.

$$R_1 = \frac{200000\omega}{198{\cdot}31} = 1008{\cdot}52\omega$$

the value which represents the 'Maintenance Standard Deflection' is found.

Thus $$D = \frac{4441800}{23460 + 4034} = 161{\cdot}55$$

which is entered on the Test Sheet as 162 divisions.

Similar calculations for the next two pairs of wires in the Test Sheet give the results indicated.

The *observed* deflections are entered in column 11 for each day of the week which is embraced by the Report.

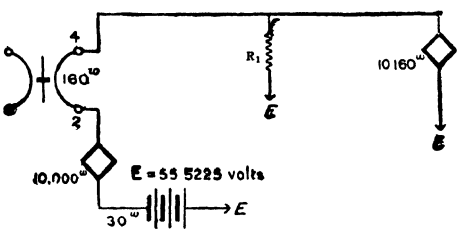


Fig. 225

The foregoing test as described is, however, applicable only in cases where two wires can be paired in a section; but it is sometimes impracticable to obtain two such wires. When this is so, the sections which cannot be paired are put to earth at the distant end through a resistance of 10,160ω. The conditions are then as represented by fig. 225. By comparison of this with fig. 224, it will be seen that the general conditions in the two cases are precisely similar, except that the 'received' current does not pass through the second coil of the galvanometer.

For purposes of comparison the Standard Deflections for single-wire tests are therefore calculated in precisely the same way as for looped wires—that is, by means of equation (8). In this way the Standard Deflections for the MR.EH [1] 3 circuit are found to be 101 and 150.

The actual deflection observed in the application of the

[1] Manchester-Edinburgh.

test, however, is determined by very different conditions. The deflection is really a measure of the 'sent' current, which is represented by equation (3).

But if the insulation of the line were perfect the current sent, c'_s, would of course be—

$$c' = \frac{E}{R} \quad . \quad . \quad . \quad . \quad (12)$$

In each of these cases the current circulates in only one coil of the tangent galvanometer, so that its deflective power is 40 divisions per milliampère. Converting the currents represented by these two equations, (3) and (12), to their equivalents in tangent divisions, they become respectively—

$$D_s = \frac{40\,E}{R}\left(\frac{2R + 4R_1}{R + 4R_1}\right) \quad . \quad . \quad . \quad (13)$$

and

$$D'_s = \frac{40\,E}{R} \quad . \quad . \quad . \quad . \quad (14)$$

and if (14) be deducted from (13), then—

$$D_s - D'_s = \frac{40\,E\,(2R + 4R_1 - R - 4R_1)}{R\,(R + 4R_1)} = \frac{40\,E}{R + 4R_1} \quad (15)$$

Comparing this with equation (8), it will be seen that the difference between the sent current reading upon the galvanometer and the theoretical sent current for a perfect line (equation 15) is exactly half the deflection which is the equivalent of the actual leakage current. Therefore, in order that the entries in the 'Daily Test' spaces of the Test Sheet (column 11) may be comparable with the standard deflections, for single wires the actual galvanometer reading is reduced by the theoretical 'perfect insulation' reading and the result multiplied by 2.

For example, the MR.EH 3 circuit on the Test Sheet (p. 337) is tested as a single wire. Equation (14) shows that the deflection with perfect insulation would be—

$$D'_s = \frac{40 \times 55522{\cdot}5}{20350 + 1150} = \frac{2220900}{21500} = 103{\cdot}3$$

or practically 103 divisions; but the deflection actually observed on Monday was 139 divisions; the entry made was, therefore—

$$(139 - 103) \times 2 = 72 \text{ divisions.}$$

It should be observed that if on a looped circuit there be no deflection, or if on a single-wire circuit the deflection be equal to the perfect insulation deflection, then it is a sign that the insulation is 'perfect'—that is, good beyond the measuring power of the galvanometer.

Again, if on a single-wire circuit the deflection be *less* than the 'perfect insulation' standard, it evidently indicates that the proper current does not pass to earth at the earthing office—that is, that the line is either fully or partially disconnected. If, on the other hand, the deflection be about *double* the 'perfect insulation' standard, it is evident that the resistance has been reduced by half—that is, that the circuit is direct to earth, so cutting out the 10,160ω coil at the distant end. The range of deflection, therefore, for single-wire tests is between that for 'perfect insulation,' which is entered as 'Inf.' (infinite), and double that deflection. This range is noted against the circuit as a fraction, thus: $\frac{103}{206}$, in the Test Record Book (p. 343).

Hitherto, in the examples taken, the underground section of the wires, both as regards the section under test and the two circuits of which that section forms part, has been so inconsiderable as compared with the whole length involved that it could be ignored without materially affecting the accuracy of the test. This, however, is not the case if for either condition (the section or the whole circuit) the underground portion reaches (say) five per cent. of the whole. It must then be properly allowed for.

Now the proper minimum standard of insulation for covered work is one megohm per mile, and the total insulation resistance, R_1^u, of any length in miles, L, is therefore—

$$R_1^u = \frac{1000000}{L} \text{ ohms.}$$

It will be at once understood that this R_1^u, which is virtually a covered work leakage fault, is practically a shunt upon the open leakage fault R_1^o; and that consequently the total

insulation resistance, R'_1, of the whole circuit will be (Appendix, Section C, 2)—

$$R'_1 = \frac{R_1^u \times R_1^o}{R_1^u + R_1^o}$$

From this the insulation resistance, R_1^o, of the open work is seen to be—

$$R_1^o = \frac{R_1^u \times R'_1}{R_1^u - R'_1} \quad . \quad . \quad . \quad (16)$$

which value must be used instead of the total insulation resistance of the circuit which is obtained by reference to column 8 in the Test Sheet.

If a considerable length of covered work exist also in the section under test a similar modification of the value of R_1 obtained from equation (9) must be used for insertion in equation (8).

Taking, for example, the entry of the 'Anglo' wire on the Test Sheet (p. 337), other records show that the total length of underground work on this circuit is 16·48 miles. The insulation resistance of the covered length is therefore taken as $1{,}000{,}000/16{\cdot}48 = 60{,}679\omega$; and (equation 16) the insulation resistance, R_1^o, of the open work of the circuit, instead of being taken as 1460ω, must be—

$$R_1^o = \frac{60679 \times 1460}{60679 - 1460} = 1495{\cdot}9\omega$$

From this the total insulation resistance of the section under test (equation 9) would therefore be—

$$\frac{104{\cdot}38 \text{ (column 7)} \times 1495{\cdot}9}{120{\cdot}12 \text{ (column 5)}} = 1299{\cdot}8$$

if there were no considerable amount of covered work in the section; but there being 10·56 miles (with an insulation resistance of $\frac{1000000}{10{\cdot}56} = 94696\omega$), the actual total insulation resistance, R_1, must be—

$$R_1 = \frac{94696 \times 1299{\cdot}8}{94696 + 1299{\cdot}8} = 1282\omega;$$

which value, being inserted in equation (8), gives the standard working deflection as 166·9 divisions, and this is entered in column 9 as 167.

It will be observed that the insulation standard for the whole circuit is fixed upon the basis of the open work (equation 16), but that for the section under test the total insulation, including the covered work in the section, is recorded.

It may be as well also to follow this example by the corresponding calculation for the maintenance standard (column 10).

If in this case there were no considerable amount of covered work in the section, the insulation resistance would be taken as

$$\frac{200000}{120{\cdot}12} = 1665^{\omega}$$

but as it was just found that the insulation resistance of the 10·56 miles of covered work is 94,696$^{\omega}$, the maintenance insulation standard, R_1, of the section must be—

$$R_1 = \frac{94696 \times 1665}{94696 + 1665} = 1636^{\omega}$$

and by the insertion of this value in equation (8) the maintenance standard deflection (column 10) is found to be practically 158 divisions

Similar calculations might be made for circuit 102, on which the total length of covered work is 23·86 miles.

In the first instance, the results of the tests are entered in the Test Record Book and copied on to the Test Sheets weekly. This book differs in some details from the Test Sheet: for instance, besides the entry of the range of deflection for single wires (p. 341), correction of the actual to the leakage deflection is not made at the time of testing, because the testing officer often has a great many observations to make in a very limited time, and must therefore not be troubled with unnecessary details.

The testing officer, however, is expected while entering the observed deflection in the Record Book to note, by comparison with the Standard Deflections (or with the range for single wires), whether the condition of the section is such as to necessitate the localisation of a fault. Thus, the reading on

Wednesday for the second loop on the sheet (p. 337) is noticed to be 110, although on the two previous days the deflections were less than those for the third (and practically similar) loop. Immediately, by turning the lever of his testing switch, he alters the connections to those shown by fig. 226, so that the current from the testing battery divides in opposite directions through the galvanometer coils, and so to earth through the fault. According as the resistance between 1 and the fault and 4 and the fault is the less, the deflection will be to the left or right. If the records (as in this case) show that the two wires of the loop have approximately the same resistance, the direction of the deflection will indicate whether the fault is on A or on B. If the wires are unequal in conductor resistance, the

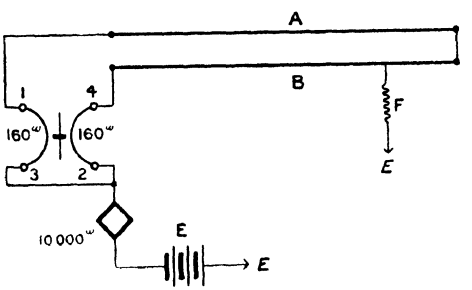


Fig. 226

rule is that the wire of higher resistance shall in all cases be connected to 1, and then that wire may be assumed to be the faulty wire if there be either no deflection or if the deflection be to the left. If the deflection be to the right, then the test does not show for certain on which wire the fault exists. This rough trial affords a basis for subsequent localisation.

If time permits, when all the other tests are completed, the distance of the fault may be localised thus: Connecting the two wires so that a deflection to the right is obtained with the connections as in fig. 226, this deflection, *d*, is noted. Turning the lever of the testing switch, the officer secures the connections shown in fig. 227, and again notes the deflection, D.

In both instances currents of same strength pass to the A and B lines; but *d* represents in divisions the difference between the two currents, while D represents the (greater) current passing through B. The two currents are, therefore, in the proportion

of D (through B) and D − *d* (through A); and accordingly the resistance, R_B between 4 and the fault is—

$$R_B = \frac{D - d}{2D - d} \times R - 160\omega \quad . \quad . \quad (17)$$

where R represents the total resistance of the loop (column 4) + the resistance of the galvanometer coils (320ω).

For example, in the case just referred to, *d* was found to be (say) 36 divisions, while D was (say) 149 divisions. Then the resistance from 4 to the fault was—

$$R_B = \frac{149 - 36}{298 - 36} \times (2410 + 320) - 160 = 1017\omega$$

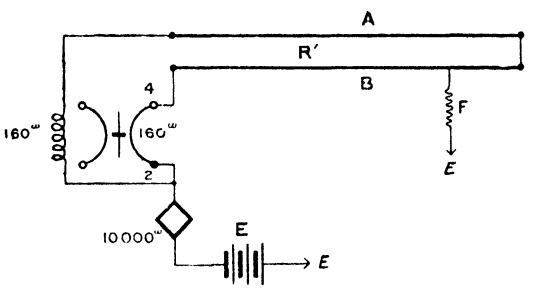


Fig. 227

This information, namely, that the MR.EH 2 circuit is faulty at a distance of 1017ω from EH, is accordingly supplied to the sectional engineer; and on reference to his records it appears that the actual conductor of this wire is 1150ω (LV.EH 2 being 1260ω); so that (as the line is of same gauge throughout) the distance of the fault from CE is evidently about—

$$97{\cdot}31 \times \frac{1150 - 1017}{1150} = 11{\cdot}16 \text{ miles.}$$

In taking the readings the testing officer should be careful not to read D too high, or *d* too low. The error in the estimation of the distance in ohms need not exceed 2 per cent. if the observations be accurately taken and the loop resistance correctly stated, even allowing for the unavoidable range of variation permitted in the electromotive force of the testing battery.

It will be observed that a ' fault ' is localised in the instanc just cited, although the deflection given by the test is below eve the standard working deflection. In fact, the testing offic should know by experience when the observed deflection higher than it would be if there were no specific fault, and shoul ' localise ' accordingly.

Still considering the specimen Test Sheet (p. 337), it will b noticed that the first loop, although its ' maintenance standard is lower than that of either of the next two loops, giv generally a higher leakage deflection. As the three loops a very similar, and for the most part go by the same route, th testing officer should proceed to test the first, with a view t ascertaining whether there is any particular sub-section whos insulation is below the average for the whole section.

To make this comparison it is necessary that he shall be ab to determine what actual total insulation the whole section has that is, what the observed ' leakage deflection ' represents a regards insulation resistance. This could, of course, be calcu lated from equation (8) ; but, in order to save such calculatio the officer is provided with a series of tables giving the require information as accurately as is necessary for the purpose.

A portion of such a table is shown on p. 347.

Assuming a fixed series of conductor resistances for loops b stages of 500ω, the insulation resistances that would give th various deflections from 1 to 198 divisions on the tangent sca are calculated on the basis of equation (8). For this purpo the equation needs to be re-stated thus —

$$D\,(R + 4\,R_1) = 80\,E$$

that is

$$R_1 = \frac{80\,E - D\,R}{4\,D}$$

and the most convenient form for the purposes of the calcul tion is—

$$R_1 = \frac{80\,E}{4D} - \frac{R}{4} = \frac{1110450}{D} - \frac{R}{4} . \quad . \quad (1$$

R in this formula is, of course, the sum of the conductor resistan of the loop, R_L, the two 10,000ω coils, the galvanometer co (320ω), and the nominal resistance of the battery (30ω),

TABLE OF INSULATION RESISTANCES

Leakage in tangent divisions	Insulation Resistance of Loops											Leakage in tangent divisions
	500ω Loop	1000ω Loop	1500ω Loop	2000ω Loop	2500ω Loop	3000ω Loop	3500ω Loop	4000ω Loop	4500ω Loop	5000ω Loop	5500ω Loop	
100	5892	5767	5642	5517	5392	5267	5142	5017	4892	4767	4642	**100**
101	5782	5657	5532	5407	5282	5157	5032	4907	4782	4657	4532	**101**
102	5675	5550	5425	5300	5175	5050	4925	4800	4675	4550	4425	**102**
103	5569	5444	5319	5194	5069	4944	4819	4694	4569	4444	4319	**103**
104	5465	5340	5215	5090	4965	4840	4715	4590	4465	4340	4215	**104**
105	5364	5239	5114	4989	4864	4739	4614	4489	4364	4239	4114	**105**
106	5264	5139	5014	4889	4764	4639	4514	4389	4264	4139	4014	**106**
107	5166	5041	4916	4791	4666	4541	4416	4291	4166	4041	3916	**107**
108	5070	4945	4820	4695	4570	4445	4320	4195	4070	3945	3820	**108**
109	4976	4851	4726	4601	4476	4351	4226	4101	3976	3851	3726	**109**
110	4884	4759	4634	4509	4384	4259	4134	4009	3884	3759	3634	**110**

$R_L + 20{,}350\omega$. The calculation then becomes very simple. Taking 100 divisions deflection, for a 500ω loop—

$$R_1 = \frac{1110450}{100} - \frac{20350 + 500}{4} = 11104{\cdot}5 - 5212{\cdot}5 = 5892$$

which is entered opposite 100 divisions in the 500ω loop column. But the calculation for the second column differs from the first only in that R_L is 1000ω instead of 500ω. This only necessitates that $\frac{500}{4}$ be subtracted from the previous figure. This is entered in the second column; and so on, deducting 125 from each column to determine the value of the next following.

By means of these tables the total insulation resistance of any loop can be approximately determined without calculation. For instance, the insulation resistance of the second loop in the report on p. 337 for Wednesday, when the deflection was 110 divisions, is found to be 4384ω from the 2500ω loop column. Actual calculation for the loop of 2410ω would have given a result of 4400ω.

Reverting again to the disparity between the deflections from the first loop in the report and those from the other similar loops, let it be supposed that on Friday, when the deflection was 100 divisions, the testing officer determined to see whether the high deflection was due to a specific fault or not. By reference to the tables he finds that for a 3000ω loop (that in question being 3110ω) a deflection of 100 divisions represents a total insulation resistance of 5267ω, or $1{,}044{,}499\omega$ that is, ($5267\omega \times 198{\cdot}31$) per mile. He then proceeds to test the lines to localise the fault by deflection *d* and D or by Wheatstone Bridge before the wires are unlooped at the distant office; or, if necessary after 'Morning Test' by testing the faulty wires singly to avoid stopping two wires at once, or it may be done by getting the wires looped at various points between EH and CE. If it be found that the presence of any particular section tends to reduce the insulation below the average of $1{,}044{,}500\omega$ per mile for the whole loop, that section is reported as requiring attention.

The tables are calculated only for loops ranging up to 5500ω, but occasionally this resistance is exceeded. When this is so the insulation can still be read from the tables, thus: Take the insulation resistance for the observed reading from the column which is nearly 4000ω less than the actual loop resistance, and reduce that by 1000ω, which will represent the insulation

resistance for the higher loop. The accuracy of this procedure will be easily seen from an inspection of equation (18). It is evident that by whatever amount R is decreased, if the equation is to be true R_1 must be increased by one-quarter the same amount. Hence, when R is taken as 4000ω below its actual value, the insulation must clearly be shown as 1000ω above, and the reading must accordingly be reduced to that extent. The tables themselves indicate this; for instance, the values in the 5500ω loop column are in all cases exactly 1000ω less than those in the 1500ω loop column.

(*c*) *Localising Faults.*—When a test shows the existence of a fault, the first step to be taken is to ascertain as nearly as possible

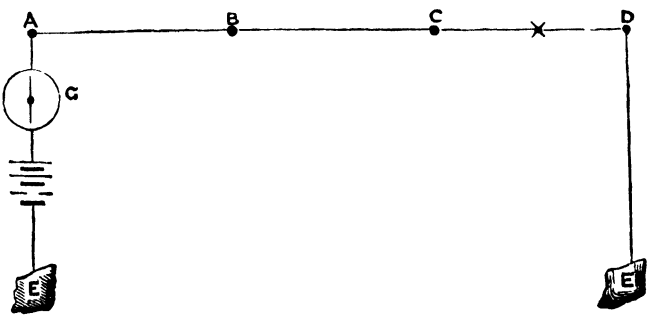


Fig. 228

its locality. Practically, on over-ground wires, a fault is localised by simply disconnecting or putting the wire to earth at successive stations until it is localised between two stations. At certain stations along the line the wires are led into test-boxes for the purpose of affording facilities for crossing, disconnecting, and putting to earth. Previously to communicating with any of these offices, however, it ought to be ascertained whether or not the fault may not be in the apparatus at the station itself. This is done by short-circuiting the apparatus or, if there be a line-box in the office, putting the wire to earth, to see if that removes the fault.

Taking first of all the case of a *disconnection*. Let A D (fig. 228) be a circuit between A and D led into line-boxes at B and C, and suppose that a disconnection has appeared upon it. Then, if A is the testing station, the wire is first of all put to earth at the test-box there, and a galvanometer inserted between it and

the instrument. As soon as it is ascertained that the fault is outside the office by the galvanometer being deflected when the instrument key is depressed, A advises B to put the wire to earth for one or two minutes. If, when this is done, the indication of the current is still obtained on the galvanometer, the fault is beyond B, and C is next advised to treat the wire in the same way, B having of course restored it at the expiration of the time named. If the line be through to C, D is advised, and if the galvanometer be now unaffected (or affected but very slightly that is, simply through the normal leakage between A and the locality of the disconnection) the fault is between C and D, and the lineman is at once advised of its nature and locality.

With an *earth* fault a similar course is pursued, differing only

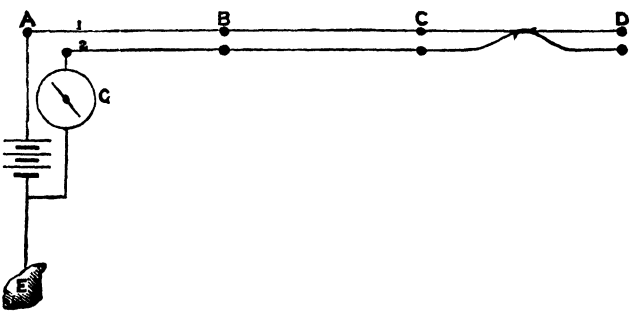


Fig. 229

in the fact that at the various test-boxes the wire is disconnected instead of being put to earth.

When two wires are in *contact* they are both put to earth at the testing station, and disconnected at the others. Thus (fig. 229) the indication at A of the two wires Nos. 1 and 2 being in contact would be that the current sent along one would be received on the other. To No. 1, therefore, the current is applied and in circuit with No. 2, which is put to earth direct at the test-box, a galvanometer is inserted; B is then asked to disconnect both wires, and if when this is done no indication is observed on the galvanometer the contact is beyond B. The same is done at C. If there is then no deflection, although when C restores the wires the current sent along No. 1 is received on No. 2, the fault must be between C and D. Upon no account whatever should B, C, or D put either wire to earth; no reliable test for a contact could be made if this were done, for if earth be put on near the

contact the greater portion of the current would go to earth and not along No. 2 wire to A. The test box detector (see p. 314) is a convenient form of apparatus for testing disconnection, earth and contact faults on open lines.

Crossing Wires.—The speedy restoration of communication upon busy circuits is a matter of such importance that immediately a fault upon such a circuit is localised every effort should be made to cut it out of the circuit, and so restore communication at once. This can be done only by crossing the wire with any other of less importance which may happen to exist between the two stations where the fault has been localised. Suppose that A E (fig. 230), an important through circuit between A and E, becomes faulty between C and D, and that there is between the same points a less important circuit picking up the stations B, C, and D. At C and D the faulty section of the through wire is thrown out until the fault is removed. In its place is substituted the section C D of the 'pick-up' circuit,

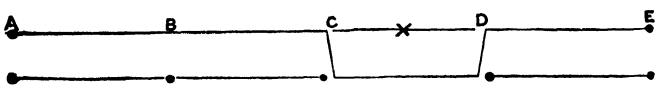


Fig. 230

the instruments of which C and D are joined to earth. Communication is thus preserved between A and E, the former of which can transmit the work of B and C, and the latter that of D. In this way the inconvenience felt from faults is, in a well-organised system, reduced to a minimum, and frequently four or five wires between two important centres may have faults upon them, and yet only one of them be really broken down, provided the faults are not in the same sections. Upon trunk lines of telegraph which are traversed by important wires it becomes a question for grave consideration whether it would not be advisable to erect a spare wire for the sole purpose of restoring the normal communication as far as possible when a fault occurs upon one or more of the working circuits.

Every important office should have one or more alternative routes by means of which, in the event of its main line of communication being broken down, an outlet may be found for the traffic. Thus (fig. 231), supposing all the direct wires between Brighton and London to be broken down, Brighton has cross country circuits to Portsmouth, Southampton, Eastbourne,

Hastings, and various other towns which are themselves in direct communication with London, so that any one of them can, by simply removing the earth and crossing the wires in their line-box, restore communication between London and Brighton.

Intermittent faults are by far the most difficult to deal with; and it is often impossible, on account of their short duration at one time, to localise them at once by crossing in the usual way. Where a wire subjected to an intermittent fault can be crossed with another, the fault can be traced thus:

Suppose that on the wire A E (fig. 230) an intermittent fault makes its appearance, the wire should be crossed with the section A B of the other wire, and kept so until the fault reappears;

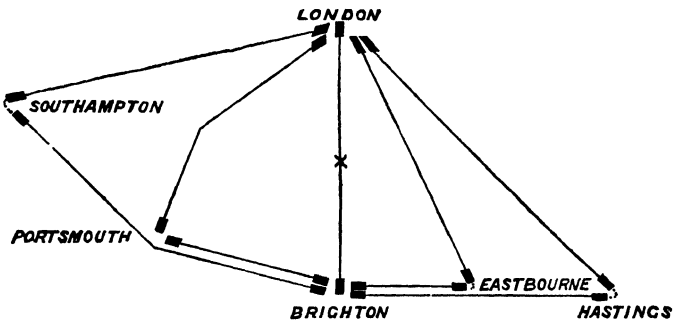


Fig. 231

and then in succession the other sections B C, C D, &c., are crossed until the fault is found to be upon the wire A B C D E. Only in this way can it be ascertained in what section the fault exists.

The testing at an intermediate station is exactly the same as that described for a terminal station. By putting earth on either side, and thus ascertaining on which side the fault exists, the station does really become terminal for the time for all practical purposes.

The method generally adopted for ascertaining the locality of faults upon the over-ground lines in England is that which has been described above. The testing stations are comparatively close to each other, and a fault being known to exist between two of them, can generally be removed an hour or two after the lineman has started in search of it. But upon covered wires this cannot be done, for, although the fault can be localised in the same way, the same facilities for examination do not exist

as in the case ot an over-ground line. If no other steps are taken for ascertaining the locality of a fault upon a covered wire beyond the disconnecting or putting it to earth at the testing stations, then the wire has to be cut and tested at each successive flush-box until the defective section is found. The inconvenience and delay attending this may be overcome in many instances by employing what is known as the *loop test*, provided there is available another wire in good condition between the testing points. (But see p. 309, *Wire-Finder*.)

The Loop Test.—If the insulation of a line were perfect, a condition which is never practically attained, the localisation of earth faults would become a very simple matter. Thus, for instance, let the wire A D (fig. 228) find earth at a point between C and D, and suppose that the fault is a perfect earth, that is

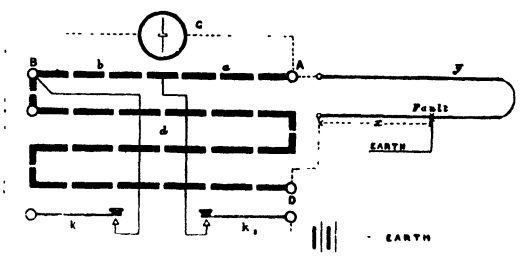


Fig. 232

to say, offers no resistance. If A is the testing station, and the wire when tested in this condition gives a resistance of 140ω, then, allowing 14ω as the resistance per mile, the distance of the fault from A is $\frac{140}{14} = 10$ miles. But the majority of faults of this kind do offer a greater or less resistance, and the insulation of the line is always more or less defective, so that theoretical calculations of this nature cannot be carried out in practice.

The advantage of the loop test consists in its being independent, within certain limits, of the resistance of the fault.

First Method.—A reference to fig. 232 will show the connections which have to be made in one method of taking this test with the Wheatstone Bridge. The negative pole of the battery is brought to the key k_2, the positive being put to earth. The galvanometer is inserted in the usual way, the good and bad wires are joined together at the line-box of the

distant station, and the end of the former is connected to terminal A and of the latter to terminal D. The resistances in the bridge should then be adjusted until equilibrium is obtained. Calling x the resistance between the fault and terminal D, and y the resistance from terminal A, according to the principle of the bridge—

$$a : y :: b : d + x$$

or

$$a\,(d + x) = b \times y.$$

But L, the total wire resistance of the whole loop (which can be ascertained on reference to the record of periodical

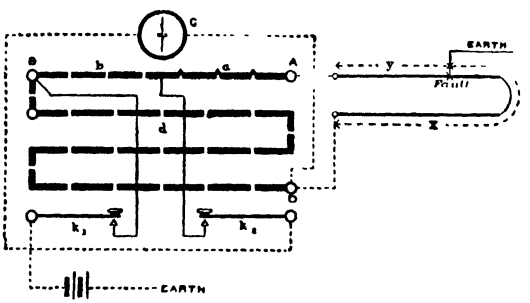


Fig. 233

tests), is $x + y$. Therefore $y = \text{L} - x$, and, substituting this value of y in the former equation—

$$a\,(d + x) = b\,(\text{L} - x)$$

$$\therefore x = \frac{b \times \text{L} - a \times d}{a + b} \quad . \quad . \quad . \quad (1)$$

And the values of a, b, d, and L being known, the resistance of x is obtained: this divided by the resistance per mile of the wires gives the distance in miles of the fault from the testing station.

If the two arms of the bridge a and b be made equal to each other, the above equation becomes—

$$x = \frac{\text{L} - d}{2} \quad . \quad . \quad . \quad . \quad (2)$$

Second Method.—A second method of taking the loop test is shown by fig. 233. In this the resistance in the arm a should

be plugged up, and b, d then becomes the two arms of the bridge. The connections being made as shown in the figure, and b, d adjusted until equilibrium is obtained (x and y being the resistances between the fault and terminals D and A respectively), it follows that—

$$b \times x = d \times y$$

but

$$x = \text{L} - y$$

$$\therefore b\,(\text{L} - y) = d \times y$$

that is

$$y = \text{L}\,\frac{b}{b + d}$$

and this, divided by the wire-resistance per mile, gives the distance in miles of the fault from the testing station.

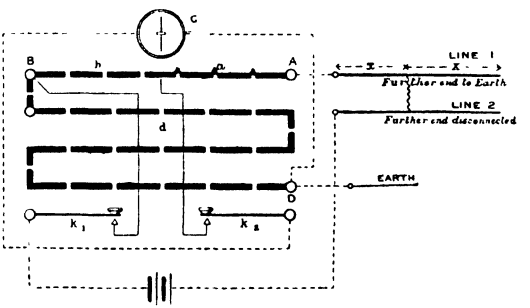


Fig. 234

If the two wires employed have not the same resistance per mile, then the value of y must, of course, be divided by the resistance per mile of the faulty wire.

And if the total resistance of the two wires be not known, it must be found by making the connections as shown in fig. 232, except that the earth connection should be removed and the positive pole of the battery taken to terminal D.

If two wires are in contact, the distance of contact from the testing station can be readily found, provided that the fault itself offers no resistance. The two wires form a loop whose resistance can be measured by means of the bridge, and half of this divided by the resistance per mile of the wires, will give the distance from the testing station.

If, however, the contact does offer a certain resistance, the locality can be ascertained by connecting the bridge in

much the same way as was done in the second method of taking the loop test described above. The connections required for this are shown in fig. 234. The resistance in a is plugged up as before, and b, d become the arms of the bridge. One of the two wires is disconnected at the distant station, while the other is put to earth there. The former is connected to the positive pole, and being thus made practically only a battery wire, does not enter into the calculation. The resistances in b and d being now adjusted until equilibrium is obtained, it follows that—

$$b \times \text{X} = d \times x$$

but X + x is known, let it be L.

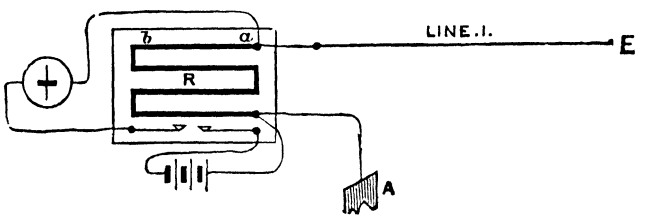


Fig. 235

Then $$\text{X} = \text{L} - x$$

therefore $$b\,(\text{L} - x) = d \times x$$

that is $$x = \text{L}\,\frac{b}{b+d}$$

the distance of the fault from the testing station can thus be ascertained.

Unless the circumstances are very exceptional, the resistance of an 'earth' should not be permitted to exceed 10^{ω}. Ordinarily it is by no means a simple matter to make a reliable test of the resistance of an 'earth,' but, where facilities exist, the following method of testing, devised by Mr. F. H. Pomeroy, is satisfactory and simple. The Wheatstone Bridge is connected up as shown in fig. 235, where LINE 1 is any line-wire put to earth at the further end, and A is the 'earth' which is to be tested. Balance is obtained on the bridge in the usual way. Let the resistance required to balance be R.

The battery is now reversed and the other connections are altered as shown in fig. 236. The negative pole of the

battery, instead of going direct to earth at A, is connected with a second circuit (LINE 2), which runs in a different direction to LINE 1 (preferably at about right angles to it), and which is put to earth at the further end. A second balance is then obtained on the bridge. Let the resistance required to obtain this be r. Then the resistance of the earth at A is—

$$\frac{a\,(R - r)}{a + b} \qquad \text{(General Case)}$$

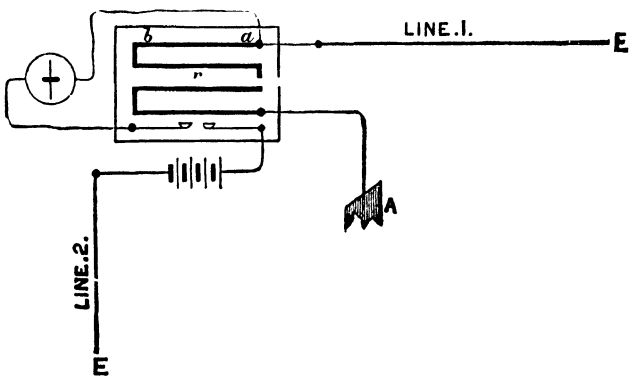


Fig. 236

Or if the two arms a and b of the bridge are equal, then the resistance of the earth is—

$$\frac{R - r}{2} \qquad \text{(Special Case)}$$

that is, *half the difference between the two resistances.*

As it is desirable in making the two tests that the current passing at the earth-plate in both cases should be approximately equal, the battery power for taking the second test should be rather greater than that used in taking the first. If a galvanometer be kept in circuit with the battery, and the battery be so adjusted that the deflections of the galvanometer are about the same in both tests, then the current passing at the earth A will be about the same in both cases.

The object of reversing the battery for the second test is to arrange that the current flowing out at the earth-plate under test (A) may be in the same direction as it is in the first test.[1]

[1] For the Theory of this Test, see Appendix, Section G.

The loop test can also be carried out by means of the Bridge Megger.

Test-Boxes.—If an office contains but a few instruments, and is not a testing station, each wire is led direct to the instrument which it is intended to work. But if the number of instruments be considerable, each wire is first led to a *test-box* and brought thence to its instrument. Test-boxes are likewise fixed at offices situated on a trunk line, and into them are led all the wires which pass, for the purpose of giving facilities for testing. It is, however, not desirable to have these intermediate test-boxes at too frequent intervals, as by multiplying them, the insulated leading-in wires become of considerable lengths and they, with the numerous connections, affect seriously the resistance

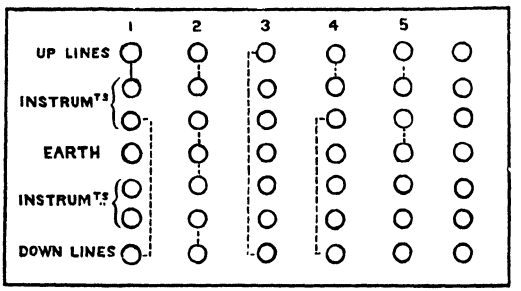


Fig. 237

and capacity of the line. A good rule to follow is to have these boxes so far apart that a lineman can comfortably traverse half the distance between two boxes in one day.

The plan usually adopted in fitting up line-boxes is shown in fig. 237, but this is frequently departed from to meet local requirements.

On a wooden frame, generally formed of mahogany, and varying in size according to the number of wires which are to be led up to it, seven rows of brass terminals are symmetrically fixed. The upper and lower rows of terminals are used for the 'Up' and 'Down' line wires respectively: the two rows below and above them are 'Instrument' terminals, and the centre row are 'Earth' terminals. The number of earth terminals varies according to the number of line-wires, but, as a general rule, for every two of the latter there should be one earth terminal. The line terminals are numbered consecutively from left to

right. Various systems have been adopted in assigning the numbers to the wires in a test-box; that which has been found to answer best is to assimilate the test-box in this respect to the terminal pole outside the office, where such exists, and so arrange the numbers upon both as to coincide with each other.

In addition to marking the numbers, it is advisable to attach bone labels to the terminals, and indicate upon these the names of the various circuits. The labels can be changed according to any alteration rendered necessary by a rearrangement of the wires. In fig. 237 the wires going to terminals 1 and 4 have intermediate instruments joined up on them; at 2, two circuits, one 'Up' and one 'Down,' are connected, and at 5 only the 'Up' side is in use, while at 3 the wire is brought in simply for testing purposes. It is always advisable to leave a few spare terminals, in order to provide for the normal increase of wires.

The wires are connected to the terminals at the back of the box; these connections should invariably be soldered. The earth-wires running along the back of the box should be carefully soldered to each of the terminals marked earth. The terminals themselves should be kept bright and clean, and ought always to be well screwed down, so as to prevent disconnections. To guard still further against this, the wire employed in the connections for a test-box should be of a stouter description than the No. 20 india-rubber-covered wire which is frequently used.

At large offices where there are a great many circuits it is found convenient to have a battery-box fitted upon the same principle as the line-box, and in close proximity to it. In these boxes the terminals are arranged in sets of four, forming the corners of a square, the left and right-hand top corners being used respectively for connecting the negative and positive poles of the battery, and the two lower terminals being for the instrument. The battery can by this means be easily disconnected from the instrument for testing, changing, or increasing power. All the batteries in the battery-room are connected to the battery-box.

Another form of test-box in which the screw terminals are replaced with test-holes and U-links is now much used. It is much more compact than the older type, and the connections are of a more reliable character. The test-holes are usually fitted

in sets of four, and they are so centred that the links fit into any pairs either vertically or obliquely as may be required to connect the wires either 'through' or to instrument-leads. The links do away entirely with loose wires on the front of the box, and good contact is ensured between the links and the test-holes by the arms of the links being so split that they normally press against the insides of the test-holes. A number of 'earthed' holes is usually provided, and the earthing and crossing of wires is effected by means of pairs of plugs and cords, the ends of the plugs being split similarly to the links. Test-boxes of this description can be made up in convenient form to take any number of line and battery-leads, and the line test-holes are frequently fitted with carbon disc lightning-arresters. The test-holes taking the battery-leads should be far enough apart to prevent the possibility of their being short-circuited by a link being inadvertently inserted into them.

In very large offices where secondary cells are employed, the *switch-spring type of test-board* is now installed.

This is about the same height as, and of similar appearance and construction to, a floor pattern 100-line telephone switchboard. The line wires are taken, in the first place, to a set of cross-connecting strips fitted with soldering tags placed in the lower part of the board, where access to them is got from the rear of the board. The switch-springs are laid up in sets in similar form to the jack of a telephone switch board. Each set of springs consists of four single springs, the two outer (longer) being connected together, the two inner springs are also connected together, and normally each of these two springs is in contact with one of the outer springs. For each line and instrument connection, two sets of springs are used one above the other, the line being connected to the outer pair of springs of the upper set and the instrument-lead to the outer springs of the lower set. The inner pairs are connected together so that when a line is connected through to its instrument, direct connection, without the aid of pegs or loose wires, is given through the two sets of springs. There is no return wire from the instrument to the test-board, as in the case of the old type of test-box, all instruments, with the exception of those required for 'intermediate' working, being earthed at the instrument-table. The cost of the return leads which, in the case of a large office, would be considerable, is thus saved. The springs

are mounted in strips of ebonite, each carrying twenty of these double sets, and a standard single-panel board, as used by the British Post Office, will accommodate up to 120 lines and instruments, the number of strips fitted depending upon the number of lines running into the office. Where one strip of twenty sets only is used, blank strips are fitted in the remaining spaces, and these can be replaced with strips of switch-springs as further lines are brought in. For the earthing, grouping, and crossing of wires, in the front of the board, pairs of pegs with cords are provided. Special strips of springs are provided for earthing, and forking or grouping the lines, and also for looping where this is required to be done for testing purposes. A special strip is also fitted with single sets of springs for 'intermediate returns,' that is, for the return wires from instruments which are required to be connected up for 'intermediate' working. In this case a special set of apparatus is provided, and even where the traffic requirements do not call for any of these sets, one at least should be provided for testing purposes. This set includes an ordinary double current key, instead of the 'single current key with switch' (fig. 102, p. 113) which is used on the terminal instruments, a line and earth reversing-switch, and an adjustable resistance. For the latter, a standard 'condenser coil' (p. 110) with a range of from 0 to 4050 ohms by steps of 50 ohms is suitable, and it spurpose is to balance as nearly as possible the resistance of the two lines connected to the set. The line normally connected to this set passes through its line and instrument switch-springs on the test-board to the instrument, and a return lead is taken to a set of springs on the 'intermediate returns' strip where it is 'earthed' through the top outer and top inner springs. Connected in this manner the instrument set is ready for terminal working, and all that is necessary to bring it 'intermediate' is to connect the second line with the 'return' set of springs by means of a cord and pair of pegs. The test-board is fitted with a suitable testing galvanometer, the connections to which are made through a seven-hole test tablet by means of pegs and cords.

The single-panel board is about 7 ft. in height by 2 ft. 8 in. in width by 1 ft. 6 in. in depth. A two-panel board, which would accommodate 240 lines, is the same height and depth and 4 ft. 9½ in. in width. Where a two-panel board is installed, 'transfer' strips are provided on each panel for the cross

connecting of wires between the two sections, and in order to obviate the use of exceptionally long cords.

Battery Testing.—There are two requirements with regard to which batteries need to be tested—*resistance* and *electromotive force*, and the different methods by which each of these may be determined are very numerous. It is proposed to describe only the simplest of these.

Resistance Test.—Half Deflection Method.—First, to find the internal resistance (r) of a battery, having given a galvanometer of a known resistance G, and of which the relative values of the different deflections are known (for example, a tangent galvanometer), and a set of resistance coils. Join the galvanometer and the coils in circuit with the battery as shown in fig. 238 and adjust the resistance so as to get a convenient deflection, D. Suppose the resistance to be R_1. After noting the deflection, increase R_1 to R_2 until the value of the deflection is reduced to $\frac{1}{2}$ D.

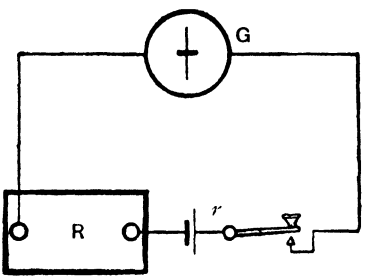


Fig. 238

In the first case we have in circuit $r + G + R_1$ and in the second case $r + G + R_2$, but the current in the second case is only half that in the first, which shows that by increasing R_1 to R_2 the *total* resistance was doubled; therefore the difference between R_1 and R_2 is equal to the total resistance in the first test, that is—

$$R_2 - R_1 = r + G + R_1$$

or

$$r = R_2 - (G + 2R_1) \quad . \quad . \quad . \quad (1)$$

As all the quantities on the right of the equation are known, the resistance (r) of the battery can be easily deduced.

Very frequently this test is made with a galvanometer of practically no resistance, and then the first reading is taken with no resistance in circuit except that of the battery itself. In that case—

$$r = R_2 \, . \quad . \quad . \quad . \quad . \quad (2)$$

or the resistance of the battery is *equal to the added resistance.*

Electromotive Force Test.—The value of the electromotive force of a battery requires to be compared with the unit (the *volt*) ; but as there is no actual practical standard it is usual to compare the electromotive force with that of a recognised standard cell or with a special form of Daniell cell, the electromotive force of which is fairly constant and is assumed to be equal to 1·079 volt.

Equal Resistance Method.—If now it be required to find the electromotive force of a battery, join up the standard cell whose force (E_1) is known to be 1·079 volt in circuit with a tangent galvanometer and a set of resistance coils, as shown in fig. 238, and insert a sufficient resistance to obtain a convenient deflection on, say, the tangent scale; let this deflection be d_1 divisions Note the total resistance in circuit (R). Now remove the standard cell and insert the battery whose electromotive force (E_2) is to be ascertained, and, if this has a different resistance (which must be ascertained by previous test), readjust the resistance in B D so that the total resistance may be the same as in the former test. Again note the deflection, d_2.

Now, by Ohm's law, the current C_1 producing the deflection d_1 is—

$$C_1 = \frac{E_1}{R}$$

and the current C_2, producing the deflection d_2, is—

$$C_2 = \frac{E_2}{R}$$

And, dividing the latter by the former we obtain—

$$\frac{C_2}{C_1} = \frac{E_2}{E_1}$$

but, as the relative values of the deflections are directly proportional to the current strength, they may be substituted thus—

$$\frac{d_2}{d_1} = \frac{E_2}{E_1} \qquad \text{or} \qquad \frac{d_2}{d_1} = \frac{E_2}{1{\cdot}079} \text{ volts.}$$

Since 1·079 is the assumed electromotive force of the standard cell, and as d_1 and d_2 are known, the actual electromotive force of the battery can be easily calculated.

With the tangent galvanometer shown in fig. 218, if the deflection given by the battery under test be inconveniently great as compared with that given by the standard cell, one of the 'shunts' may be inserted, in which case E_2 must be multiplied by the reciprocal of the shunt; for instance, if the shunt be $\frac{1}{8}$, multiply by ten, and so on.

Equal Deflection Method.—This is another simple way of testing for electromotive force. Join up as in fig. 238, and having inserted a convenient resistance note the deflection D and the total resistance (R_1) in the circuit when E_2 is in circuit. Remove E_1 and insert E_2, adjusting the resistance until the previous deflection is reproduced. Now again note the total resistance R_2 in the circuit.

In this case, by Ohm's law the current in each case being equal (since the deflections are so)—

$$C = \frac{E_1}{R_1} \quad \text{and} \quad C = \frac{E_2}{R_2} \quad \text{therefore} \quad \frac{E_1}{R_1} = \frac{E_2}{R_2}$$

that is to say, the electromotive forces of the batteries are directly proportional to the total resistances in circuit, and

$$E_2 = E_1 \frac{R_2}{R_1}$$

E_1 (1·079 volt), R_1 and R_2 being known.

CHAPTER XX

WIRELESS TELEGRAPHY

WIRELESS TELEGRAPHY—or Radiotelegraphy as it is officially termed—is a method of transmitting signals between two distant stations not linked together by a metallic conductor. The actual medium used is the ether that fills all space, in which waves, generated at the transmitting station by extremely rapid electrical oscillations amounting to hundreds of thousands per second, flow out in all directions and create in turn similar, but weak, electric oscillations at any suitably arranged station, past which these waves flow.

In an ordinary telegraphic circuit, we have the source of electrical energy—usually a battery—a transmitting key for making and breaking the circuit, the line wire stretching across the country on insulators fixed to poles, a receiving instrument at the distant point, and the earth which acts as the return conductor.

In Wireless Telegraphy there is also a source of energy, a transmitting key, a receiving apparatus and the earth, but the line is replaced by an 'aerial' or antenna at each station, which are systems of insulated wires supported on high masts.

The scope of this book will not allow us to deal with the actual form of these etheric waves, which give rise to electric phenomena, or their mode of progression, but it is desirable to give some idea as to how electric oscillations succeed in disturbing the ether so that such waves are generated.

It is well known that if two insulated bodies are oppositely electrified, these two bodies are presumed to be joined together by a number of Faradian or electrostatic lines of force, the ends of each line terminating on the two bodies, and that these lines

being mutually repulsive spread out over the whole surface of the two bodies in the same way as pure magnetic lines of force, springing from one pole and ending in the other, spread out in the space surrounding a magnet. If, therefore, an insulated wire is suspended in the air and that wire and the earth underneath are charged electrically, the space between the wire and the ground is filled with these electrostatic lines of force all having one of their ends on the wire and the other ends being spread over a considerable area of the ground underneath. This group of lines would have a shape somewhat similar to a tent, the wire being the ridge of the tent roof.

It is also well known that if the two charged bodies are connected by a low resistance link, the two charges do not immediately coalesce, but oscillate backwards and forwards between the two bodies, the lines of force continually reversing in direction. It is easy to realise that these rapid reversals which take place hundreds of thousands of times per second are able to disturb the ether so that waves flow out in all directions in much the same way as the dropping of a series of stones into a pond causes a flow of waves to spread out over the surface of that pond.[1] These waves, flowing past two insulated bodies, or a suitably connected insulated wire and earth, set up similar electrical oscillations in that circuit.

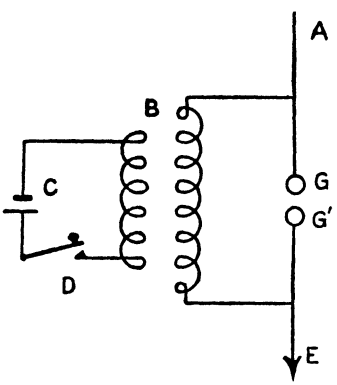


Fig. 239

In order therefore to generate such waves, it is necessary to set up electrical oscillations between an insulated wire and earth. *Hertz* demonstrated in 1886 that electric oscillations between two insulated bodies set up waves in the ether, but it was *Marconi*, who, in 1896, first introduced the method of transmitting signals for commercial purposes by means of these

[1] It is generally assumed that the lines of force themselves become detached from the aerial and travel outwards with one end clinging to the earth, the wave form being due to the varying number of lines and their different polarities.

waves. He connected the two balls of a spark gap, supplied with energy from an induction coil, one to an elevated capacity (which afterwards became a number of insulated wires suspended from a tall mast), the other to the earth. When a spark connected the two balls, the charges on the wires and earth oscillated to and fro and thus set up the waves. Fig. 239 shows the original connections—B is the induction coil, the primary of which is connected with a battery C and a transmitting key D, the secondary to the two electrodes of the spark gap G G′, and G is further coupled to the aerial or antenna, A, while G′ is connected to earth.

Lord Kelvin had proved that the discharge of a Leyden jar was oscillatory, and that the number of complete oscillations per second (N) during a discharge $= \frac{1}{2\pi\sqrt{KL}}$; or $\frac{160,000}{\sqrt{KL}}$ approximately, where K is the total capacity of the circuit in microfarads and L the total inductance or self-induction in microhenrys. Hertz had demonstrated that the electric waves generated by this discharge travelled at the rate of 300,000,000 metres per second, like light waves.

As each complete oscillation gives rise to one wave, the length of a wave is—

$$\frac{300,000,000 \text{ metres}}{N} \text{ or } 1885\sqrt{KL} \text{ metres, approximately.}$$

The drawback to Marconi's original arrangement was that the waves were highly damped, that is they rapidly diminished in amplitude, so that in practice if the sending key was held down for an appreciable time the waves were really a series of 'kicks' spaced irregularly—

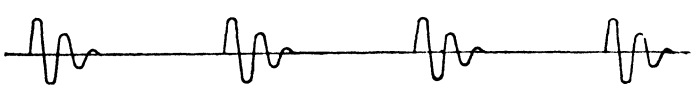


Fig. 240

and their range was very limited.

The first advance on this primitive circuit was made by *Sir Oliver Lodge*, who, in 1897, realising that it would be advantageous to separate to some extent the circuit containing

the charged bodies from the charging circuit, introduced this arrangement—

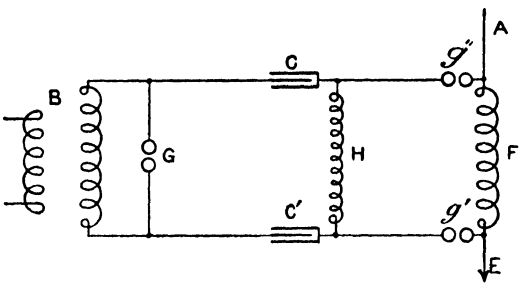


Fig 241

The charging or exciting circuit, connected to the secondary of an induction coil, B, consisted of two condensers C C′, one plate of each being attached to one of the spark balls G, the other plates being connected together through a high inductance[1] H, but each also connected through a very small spark gap g' g'' to the aerial and ground circuit, which included a small inductance F inserted between the auxiliary gaps. Each time a spark passed across the main gap G the two condensers C C′ discharged, not through the high inductance, but through the small spark gaps g' g'' and the small inductance F in the aerial circuit. Oscillations therefore flowed through the main spark gap circuit C, G, C′, g' F, g'' and set up similar oscillations in the aerial circuit E, F, A. The former were quickly damped, as in the earlier primitive arrangement, but the latter, having but little inductance, were free to oscillate after the spark had ceased to pass. Each train of etheric waves was by this means considerably lengthened and might be represented thus (fig. 242)—



Fig. 242

In 1900 Marconi introduced his method of producing less

[1] An inductance is a coil specially designed to have a predetermined self-induction. When a current in a coil is varying, an E.M.F. is set up in that coil in consequence of that variation, which tends to prevent that variation. This E.M.F. generating action of the current is called self-induction (see also p. 150).

damped waves, also by separating the exciting from the aerial circuit. But instead of using small spark gaps he linked the two circuits together by means of a specially designed transformer, which he termed a jigger (K, fig. 243).

Marconi also found that by making the primary oscillating circuit a persistent oscillator, it steadily and continuously assisted the oscillations in the aerial circuit. As the oscillations in the aerial circuit were employed in generating waves in the ether, that is in doing material work, these oscillations lost their energy fairly quickly, and would thus be materially assisted

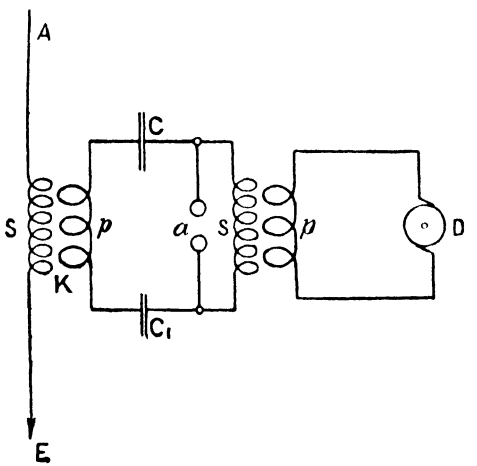


Fig. 243

if the spark gap circuit were made a persistent oscillator so as steadily to feed the aerial circuit with energy.

This was assisted by the introduction of an alternator and transformer in place of a battery and induction coil. But the main factor in this improved system was the introduction of carefully tuned circuits, that is the aerial circuit A E and the oscillating circuit s, c, p, c_1 were adjusted for definite identical rates of oscillations—in other words, were in tune.

The importance of *tuning* must never be lost sight of in wireless telegraphy. These oscillations and waves are closely analogous to material vibrations and sound waves, or with the swinging of a pendulum. It is a well-known fact that if it be desired to keep a pendulum swinging it is essential that each push or stroke must be given at a time when this push will

be in the same direction as that in which the pendulum is then moving. If the push acts even slightly against the actual movement of the pendulum, it does more harm than good and tends to stop the pendulum. Similarly, if you have two oscillating electrical circuits interlinked at one point, unless the natural vibration of the two circuits are in tune,[1] interference and not assistance will result.

Since we know that $N = \frac{160000}{\sqrt{K L}}$, and that it is an easy matter to arrange for any capacity K, and any inductance L, in any circuit, this tuning is easily effected.

This circuit, introduced by Marconi in 1900, is almost universally employed, though, as we shall see shortly, some modifications introduced do affect appreciably the mode of working laid down by Marconi.

So far as the Marconi system is concerned, the only later important improvement introduced is the apparatus known as the rotary discharger, which has largely displaced the ordinary spark gap (fig. 244). This apparatus consists of a metal disc, mounted on, but insulated from, the alternator shaft, which carries 8, 10, 12 or more studs standing out from the periphery of the disc. On a fixed ring encircling the disc are carried two rods, so arranged that the studs on the disc periphery pass their ends every revolution, within a distance of one or two millimetres. These rods are electrically connected to the secondary of the main transformer; therefore each time a pair of studs is opposite these two rods, which is arranged to occur only at the maximum amplitude of the periods, a spark passes. By this means, the frequency of the alternator and the frequency of the sparks are in tune, and these again are in unison with the natural frequency of the alternating circuit, the spark circuit, and the aerial circuit. The result is that, so long as the sending key is depressed, an almost continuous flow of waves is set up of nearly constant amplitude—an extremely close approximation to the ideal requirements of a transmitting Wireless station. Another advantage in the use of an alternator is that its periodicity is impressed on the trains of waves and governs the

[1] 'In tune' does not necessarily mean that each oscillation in the one set must coincide with each oscillation in the other set; it need only coincide with every 2nd or 10th or 100th or 1000th, but it must be arranged that the slower oscillation reaches its full amplitude at the moment an oscillation of the other set also reaches its full amplitude.

pitch of the note heard in the receiving telephone. This note has a vibration double that of the frequency of the alternator.

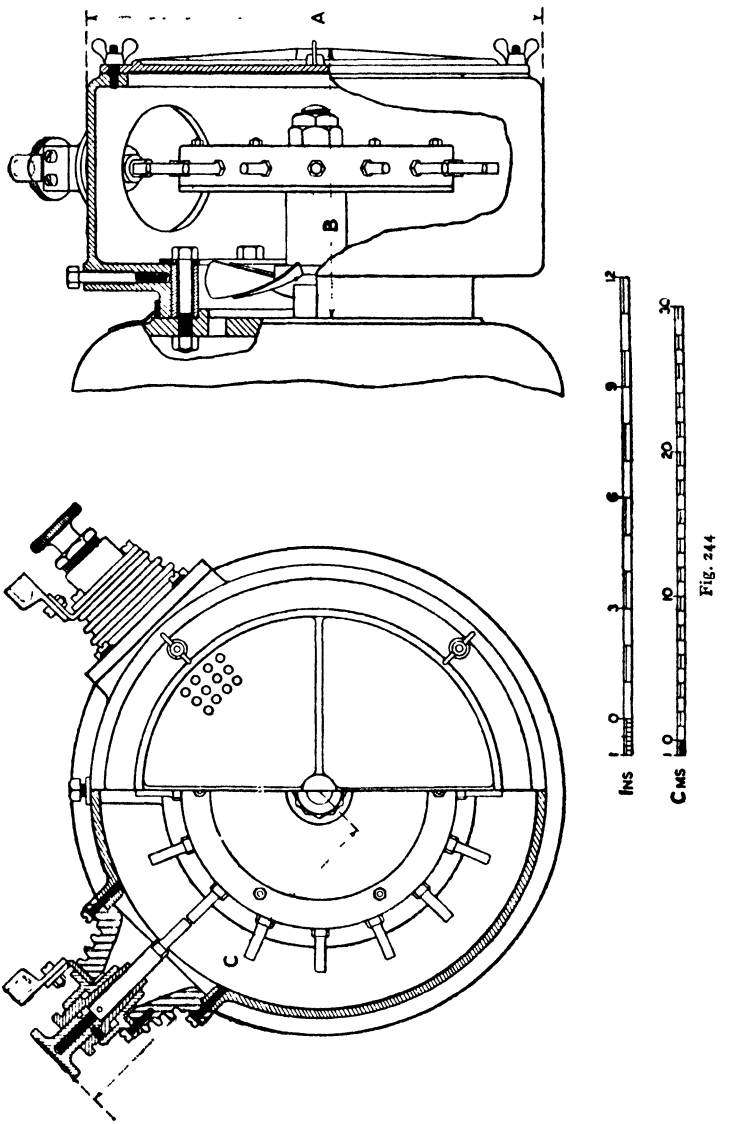


Fig. 244

It is thus easy to arrange for any special note, whereby the various stations can be distinguished.

Fig. 245 shows the connections of a Marconi station. The alternator 5, driven by a motor 4, served from a secondary battery 3, usually has a frequency of 300–500 periods, a voltage of 300, and is connected with the primary of the transformer 29, through the transmitting keys 27, 28. Four choke coils 30,

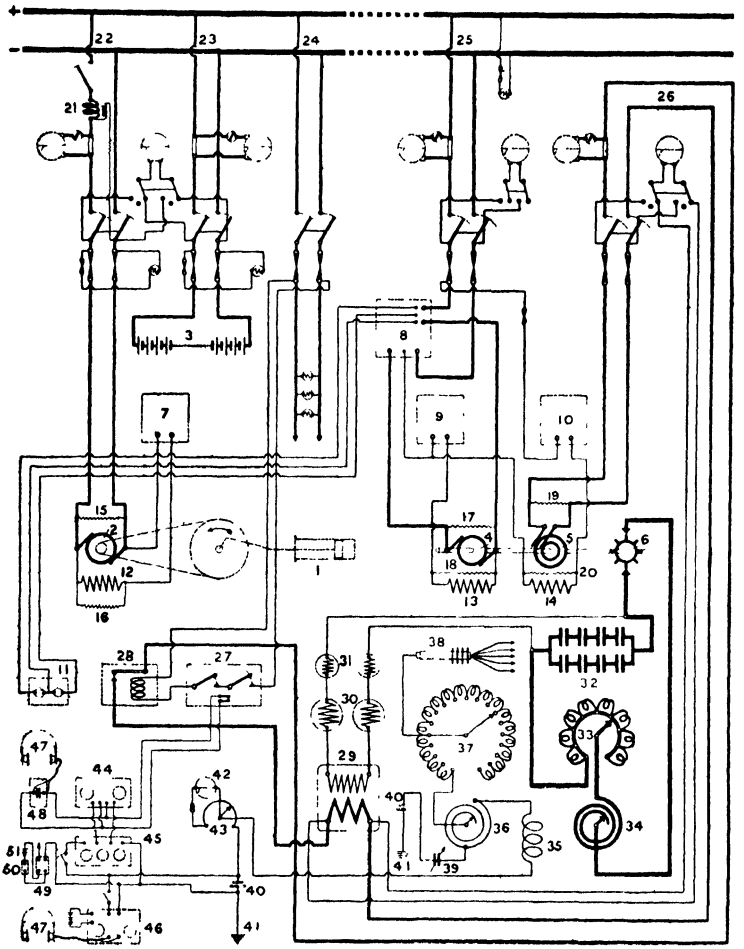


Fig. 245

31 are inserted in the two connections between the secondary of the transformer and the oscillating circuit 32, 33, 34, 6, mainly for the purpose of preventing the high frequency currents generated in this circuit from affecting the transformer and

alternator. This oscillating circuit contains a variable condenser 32, the rotary discharger 6, and variable inductances 33, 34—both variable for the purpose of altering the length of wave generated—the inductance 33 acts as the primary of the aerial transformer or jigger.[1] The condensers usually have zinc plates separated by glass plates and contained in wooden boxes filled with insulating oil. The capacity of the condensers depends on the power of the station and the type of aerial and the wave length required. The inductance is a large coil of stranded wire wound spirally on a frame from which tappings are taken off at various points to enable the total inductance of the circuit to be varied. The jigger consists of two separate windings 33, 37 mounted on separate frames adjustable in their mutual positions for the purpose of varying the 'closeness' of the coupling.

The coupling, i.e. the strength of the mutual induction between the two windings of the oscillating transformer or jigger, is of great importance in the arrangement of a Wireless station. In an ordinary transformer this coupling is unity, but if such a transformer were used as a jigger, the reaction of the inductance of the secondary on the primary would be sufficiently powerful to set up two distinct and different waves. As the coupling is reduced (below 0·5 it is called 'loose' in contradistinction to 'tight') the second and shorter wave increases in length, and the first or longer one decreases, the waves tending to coincide. To obtain oscillations of one single wave length only the coupling should be 0, but then there would be no link between the two circuits. As a rule the coupling is about 0·1 or 10 per cent., which gives a single wave at a few hundred yards from the station. These coils of the jigger are tapped at various points so as to adjust the inductance in the two circuits. One end of the secondary of the jigger is connected to the aerial 38, the other end is connected to the earth system 40, 41. The transmitting keys 27, 28 are inserted in the circuit containing the primary of the main transformer. The actual make-and-break key 28 is actuated magnetically by means of a relay controlled by the hand key. This arrangement only permits the circuit to be broken when the potential is at zero, thus preventing heavy sparks passing at the contacts.

[1] Sometimes the secondary of the main transformer is connected to the two fixed rods of the discharger; the condenser, inductance, and jigger primary 'being in bridge' across the same terminals.

Before dealing with the aerial and earth systems we will shortly describe other transmitting systems.

By far the greatest number of stations equipped throughout the world use the Marconi system, but the two systems which also have considerable use are the German one known as the *Telefunken quenched spark* and the French one known as the *S.F.R.* or *Radio-Electrique.* The essential difference between the quenched spark and the Marconi systems lies in the primary spark circuit. The Marconi principle is to arrange this circuit so that the oscillations set up therein shall continue for

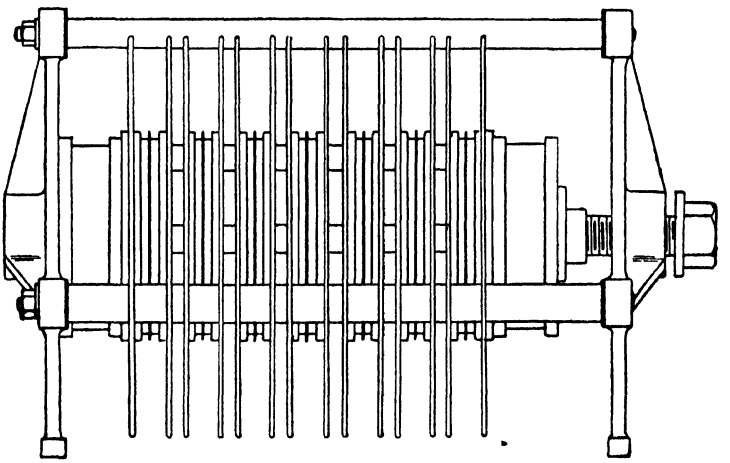


Fig. 246

as long a period as possible, that is that it shall be a persistent oscillator, and by this means to feed the aerial circuit steadily with energy in order that the oscillations in this aerial circuit may be kept going.

With a quenched spark system the aim is the exact opposite so far as the exciting circuit is concerned. This circuit is made as damped as possible, and generates a series of independent short oscillations of a powerful nature which transmit a sequence of independent kicks or shocks to the aerial circuit. This is attained by using a number of very small spark gaps in series, each electrode being cooled by rapid radiation from large copper flanges, which radiation is assisted with larger powers by an air blast. In the Telefunken system these spark gaps consist of a series of circular electrodes (fig. 246) separated by rings of mica,

0·1 mm. in thickness. The number of gaps varies from six to a hundred according to the power of the station. Fig. 247 gives the connections of a 5 kw. Telefunken station. As a rule the condensers in this system take the form of large Leyden jars of glass covered outside and inside for a certain distance with lead foil.

Another quenched spark system is that invented by *Baron von Lepel.* The peculiar feature of this system is also the form of spark gap, which consists of some ten or twenty copper tubes in series, each ½ in. in diameter and 6 in. long, held in an adjustable frame with parallel motion normally separated

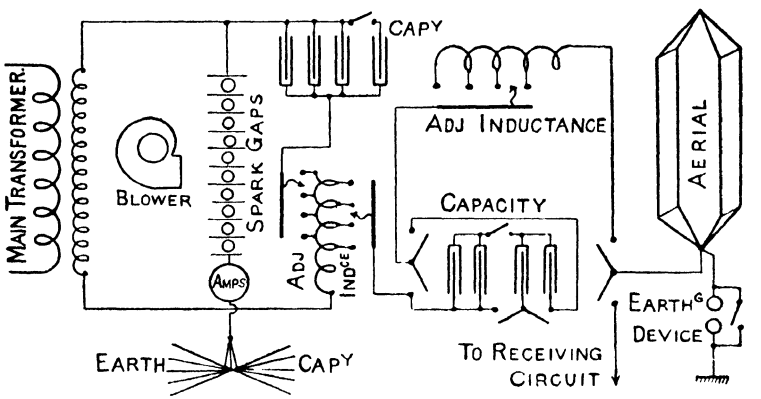


Fig. 247

by 0·1 mm., but which can be altered by an adjusting screw. Figs. 248 and 248A show the arrangement of a Lepel 5 kw. station.

The principal French system, known as the S.F.R. or System ' Radio-Electrique ' uses neither a quenched spark nor a persistent primary oscillating circuit. The electrodes of the spark gap are a tube—usually of brass—and a copper plate, the spark passing between the edge of one end of the tube and the flat surface of the plate. A current of air is blown through the tube, thus cooling the electrodes, and helping to extinguish the spark. The energy is supplied by a specially designed alternator for giving a musical note, which has a frequency of 500 or more—sometimes 2000. In one connection between this alternator and the primary of a transformer is inserted an adjustable inductance choke coil. The secondary of the transformer is coupled to the spark gap as in other systems.

The primary oscillating circuit consists of the spark gap E, which bridges the secondary windings of the H.T. trans-

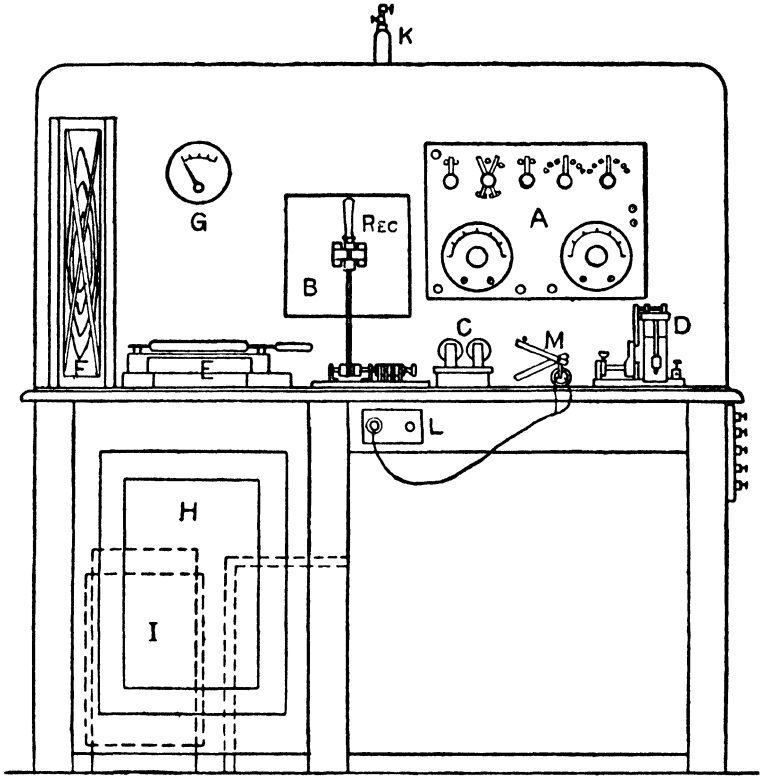


Fig. 248

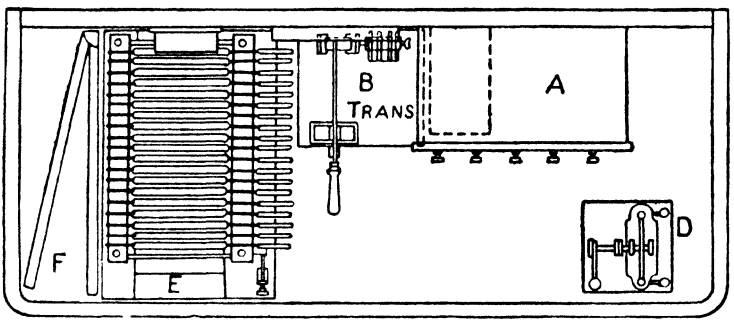


Fig. 248A

former, a condenser c, and an inductance L_1; the secondary oscillating circuit consists of the aerial, an inductance L_2 and earth.

The primary and secondary inductances are fixed almost at right angles to one another, and the links between the two coils consist of metallic connections F G and B C (see fig. 249). It is claimed that this arrangement gives rise to a pure wave, and a mechanical analogy to this method of coupling the two circuits is furnished by two equal pendulums which are connected together by a stiff rod, so that the whole system swings as one pendulum.

The *Poulsen system* is based on an entirely different principle, and grew out of a discovery published by Mr. Duddell in 1900. Mr. Duddell found that if the carbons of an arc lamp formed part of a circuit containing inductance and capacity, the arc when burning could be made to give out musical notes. The passage of the continuous current through the arc set up oscillations in the auxiliary circuit bridging the arc. Poulsen, the Danish engineer, took up the study of these oscillations, and was able, by placing the arc in a chamber filled with hydrogen or other gas, to obtain oscillations giving rise to a continuous flow of ether waves.

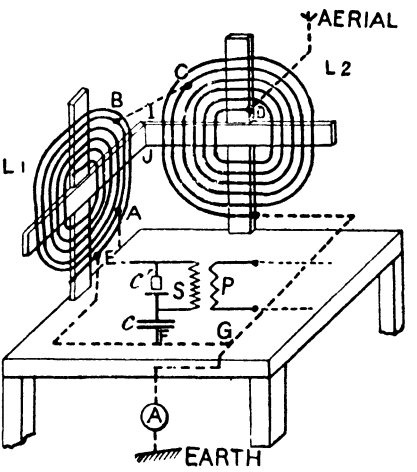


Fig. 249

The drawback in this system so far as concerns ship and shore communication is that either a special form of receiver must be used in order to receive signals, or an interrupter must be included in the transmitting circuit, to cut up the flow of continuous waves into discontinuous waves, thus enabling the signals to affect the normal type of detector. This, however, involves a serious loss of efficiency.

A still newer method of obtaining continuous waves is by a generating machine. Many attempts to do this have been tried during the past few years. *Fessenden*, an American Wireless inventor, designed such a machine which, within certain limits, has given good results. Unfortunately the speed required

is very high, and so far the maximum size yet attempted is one generating 2 kw., which is hardly sufficient.

The most successful machine constructed up to the present is that designed by *Dr. Rudolph Goldschmidt*, and one of this design constructed by Messrs. Bergmann has successfully delivered over 150 kw. into the aerial, and transmitted signals clearly over a distance of nearly 4000 miles.

Aerial

A most important factor in the design of a Wireless station is the shape and dimensions of the aerial. The company exploiting each system is rather wedded to one or two of its own designs, and unfortunately no reliable figures have yet been published or even obtained regarding the actual efficiencies of the various forms of aerial.

The most common are the umbrella and the T forms of aerial. For small stations up to 5 kw. the umbrella form has usually four arms, each suspended from the central mast, 180 ft. high, the lower end of each wire being supported in position by a 60 ft. mast or by a stay. The connections from the station are joined at the central mast-head (fig. 250). T aerials are supported from two masts, 180, 200, or occasionally 250 ft. or more high. Some twelve to sixteen wires are used and they are 400–500 ft. long and about 10 ft. apart, being held in position by wooden spreaders on the two masts. Fig. 251 shows a Marconi T aerial with the Admiralty type antennae. In this case two groups of wires are used ; each group containing eight wires being carried on circular spreaders, forming what is usually termed a sausage. The two sausages are some 20 ft. apart. The connections from the station are brought up to the centre of the wires.

These aerial wires require to be well insulated, and the leading-in wires must also be well insulated where they pass into the station building.

For communication between two fixed stations, the most satisfactory aerial is the Marconi directional aerial (fig. 252). With this aerial, longer waves can be employed than with T or umbrella forms, and the directive effect is unquestionably beneficial.

In order to get the best effect out of the aerial, it is essential that the capacity and inductance of each wire shall be exactly

the same, as an unbalanced aerial has a most deleterious effect on the range of the station.

Every aerial has one natural period of oscillation without the addition of extra capacity and inductance. This period

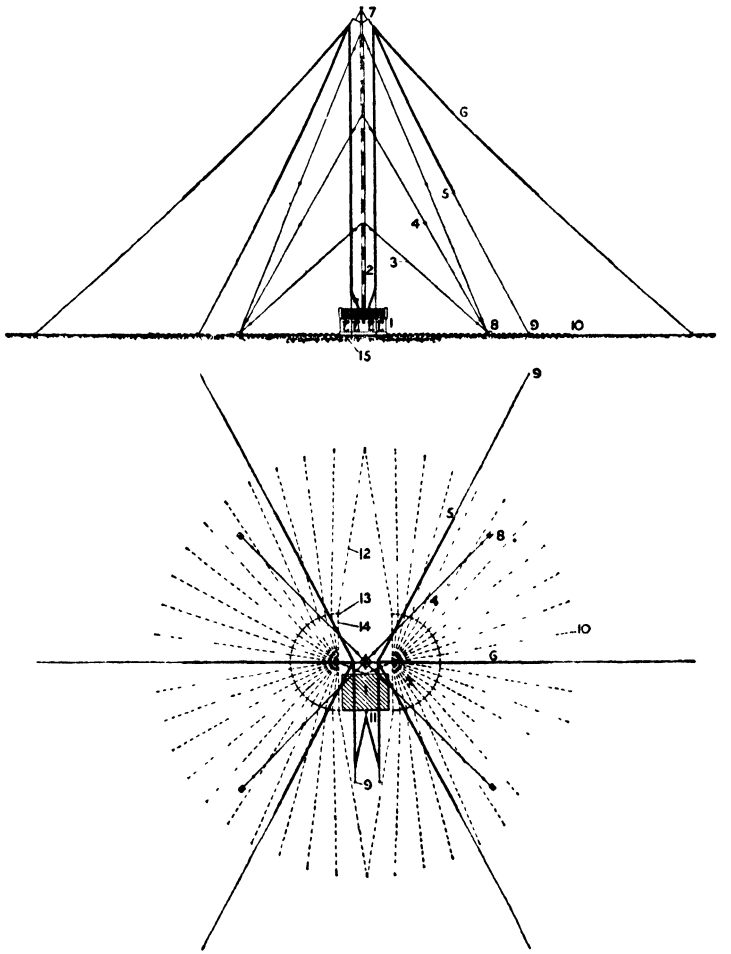


Fig. 250

gives rise to a certain wave length. To decrease the length of this wave a condenser must be inserted in series with the aerial; to increase the length a condenser in parallel and inductance must be added.

A good earth connection is essential. The Marconi Company's

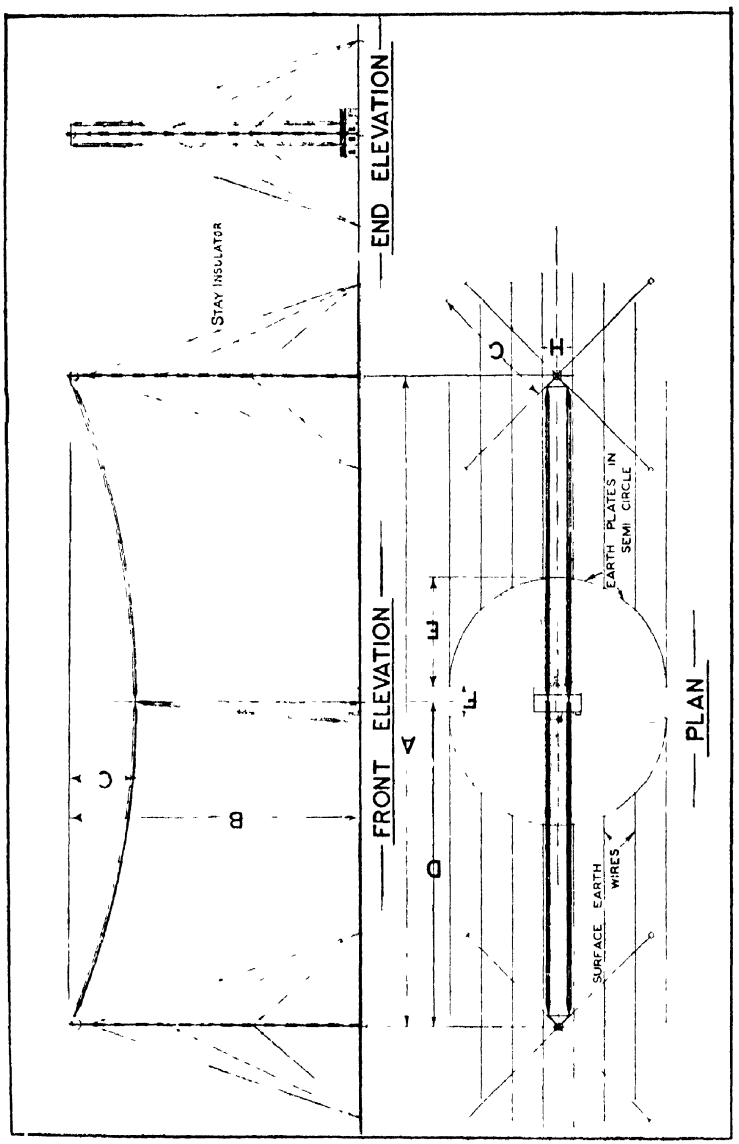

END ELEVATION
STAY INSULATOR
FRONT ELEVATION
PLAN
EARTH PLATES IN SEMI CIRCLE
SURFACE EARTH WIRES
A
B
C
D
E
F
G
H

Fig 251

practice is to bury a ring of earth plates, about 100 ft. diameter surrounding the building, and to connect each plate with a radial wire from the building. The building is always erected as near the centre of the aerial as possible to make the whole system symmetrical, and in order that the connections between aerial and station may be as short and direct as possible.

Reception.—In all small stations the one aerial does service for both duties, transmitting and receiving. The oscillations set up by the flowing past of electric waves are extremely minute, and very delicate apparatus is required to detect their presence. During the first few years of Wireless Telegraphy the only detector known was the 'coherer,' a glass tube containing, between two electrodes, a mixture of metal filings, which cohered and thus completed a metallic circuit when oscillations were set up in the circuit. This primitive receiver soon gave way to

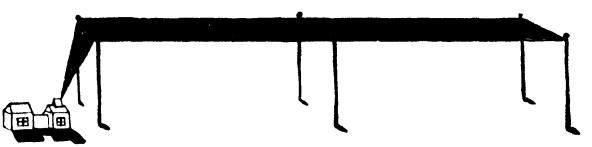


Fig. 252

electrolytic detectors and to the magnetic detector of Marconi. This latter is still largely in use, as though not very sensitive it is wonderfully trustworthy, and rarely gives trouble. Fig. 253 shows this detector. The band of fine insulated soft iron wires w is driven by clockwork, and forms a path for the magnetic lines of force emerging from the two magnets M M′ placed over it. The band travels through the centre of two concentric coils c and c′. The inner coil c′ is connected to the aerial and earth, the outer one c to a telephone receiver. When oscillations flow through the inner coil they vary the state of the magnetic field passing through the telephone coil, and this causes clicks in the telephone.

Another detector largely used by the Marconi stations is the Fleming Valve. This consists of a small incandescent lamp served by an accumulator. A circular metal sheet or gauze is fitted inside the lamp round the glowing filament. When this metal electrode is attached to the positive pole of a battery, which has its negative pole attached to the filament, a current passes; but if the connections are reversed, no current flows.

If the filament and sheet are included in the circuit in which oscillations are flowing, this 'Valve' acts as a rectifier and all the positive impulses flow through and affect a telephone receiver.

The most sensitive detector in use at present is that known as the Crystal, introduced first in the United States. This consists of a piece of crystal—carborundum, silicon, zincite, molybdenite, or other material—which is held between two metal plates or pressed on by a pointed conductor, and inserted in the secondary of the receiving jigger; these also rectify the oscillations, and the current affects a telephone receiver. These detectors are far more sensitive than any other form and rather liable to get out of adjustment.

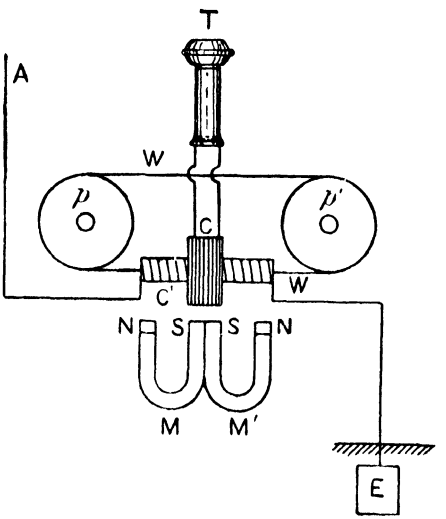


Fig. 253

It is in connection with receiving that tuning becomes so important. Any circuit containing inductance and capacity has, by reason of these factors, a natural period of oscillation. If this natural period of oscillation be identical with the oscillations set up in that circuit by a flow of electric waves, there would obviously be a tendency for the circuit to assist the oscillations, to swing with them and enlarge their amplitude, just as a piano wire, though not touched, will respond to its own note if the identical sound waves be set going anywhere within the vicinity. Also, if the aerial were subjected to the flow of two or more different waves at one moment, it is obvious that, if that circuit is specially adjusted to oscillate on one particular frequency, it would strengthen the oscillations set up by those waves whose period corresponded to the frequency of the circuit, and damp out any other waves.

The receiving circuit on a properly tuned system consists of an oscillation transformer or jigger, with the primary inserted

between the aerial and earth, and the secondary winding included in the circuit containing the detector. A telephone receiver is attached to the terminals of the detector and is usually bridged by a condenser.

The two main troubles experienced in Wireless stations are: (1) *Atmospherics*; (2) *Screening*. Atmospherics are due to the electrified state of the atmosphere, and cause disconcerting clicks in the receiver; they vary largely at different times of the year and in different parts of the globe. The most efficient method of minimising these effects is the use of a musical note in the transmitted signals. This note results from the frequency of the alternator which supplies the energy, but to obtain this it must be arranged that sparks pass at about the maximum amplitudes of the alternating current, so that fresh energy is imparted to the aerial with each pulse. By this means the frequency of the alternator is superimposed on the oscillations and on the corresponding ether waves. If the alternator has a frequency of 500 and the spark passes at each point of maximum amplitude, this will mean 1000 sparks per second, and the sound wave produced in a receiving telephone will have a frequency of 1000 per second. This is a high note, but it can be heard distinctly, although atmospherics—which invariably cause a low sound (a sort of scratch)—may be fairly persistent and frequent. The reading of wireless signals is largely a matter of practice. A good operator can distinguish and read signals clearly through considerable atmospheric disturbances, whereas a poor operator loses the signals entirely.

The effect of atmospherics varies considerably with the height of the masts. It is found that when signals are unreadable from an aerial 180 ft. high, they may be read if a lower aerial (60–100 ft. high) be used.

Screening is mostly caused by hills intervening between the transmitting and receiving stations. These act as shields to the waves, preventing their further flow in that direction. It often happens, however, that a ship close under a hill will be entirely cut off from the transmitting station, but that it can pick up the signals again when at a greater distance.

Forests seriously absorb the energy transmitted, but the longer the wave the less is this effect. It has been demonstrated that a 5 kw. station having masts 150 ft. high cannot transmit 80 miles over a forest in daytime if the wave length be less than

2000 metres, but if the wave length be 3000 metres or more the distance bridged exceeds 200 miles with the same energy.

It is becoming the practice to equip all Wireless stations with small sets of apparatus for short distance work and for emergencies. This is undoubtedly a wise proceeding. A 10 in. coil served by a few dry cells is sufficient for communication over 30–50 miles of sea. In this case, one spark electrode is connected direct to the aerial, and the other to earth, a transmitting key being inserted between the primary of the coil and the battery.

A very efficient form of coil introduced by *Mr. W. H. Wilson* and *Prof. E. Wilson* of King's College has been found to be a distinct advance on the ordinary 10 in. induction coil for this purpose.

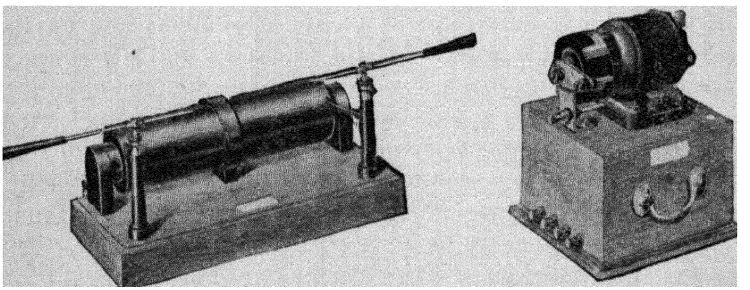


Fig. 254

This Wilson coil, which is specially designed to give heavy discharges, is used in conjunction with a condenser, which supplies the primary winding with an oscillating current. The interrupter used consists of a contact wheel, on which bear brushes driven by a small electric motor. The arrangement is shown in fig. 254 and the connections in fig. 255. 2 and 3 are the primary and secondary of the induction coil, 4 is a condenser, 5 the motor-driven contact wheel, 6 the leads from the direct current source of supply, in one of which the sending key is inserted when used for Wireless Telegraphy.

The operation is as follows :—

When brush *a* touches the contact segment the supply is connected *via* brush *b* across the inductance 1, or some portion of it according to the power required. Energy is stored in the magnetic field built up in the inductance coil. The condenser

4 is also charged in parallel with the inductance, through the primary of the induction coil. The segment then passes from under brush *a* and the supply is disconnected. The condenser immediately discharges its energy into the inductance and begins to charge in the reverse direction owing to the collapse of the magnetic field in the inductance. Owing to the large inductance of the circuit the transfer of energy is relatively slow. The brush *c* is adjusted to make contact with the segment at the moment when the whole of the energy is stored in the condenser. Its effect is to short-circuit the inductance 1, and thereby to reduce the time period of the circuit very greatly. The energy from the condenser discharges with great rapidity through the primary of the coil, producing a high E.M.F. in the secondary.

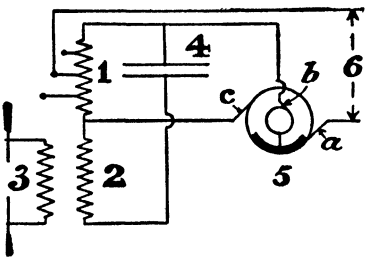


Fig. 255

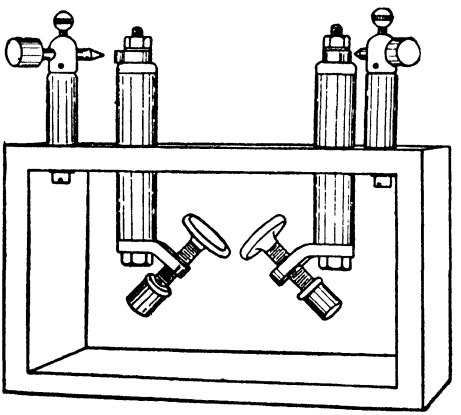


Fig. 256

The method of operating lends itself to a construction with a closed, or nearly closed, magnetic circuit, so that the magnetic leakage is small, and practically the whole of the energy is transferred to the secondary in the first swing.

These coils are being constructed up to half a kilowatt. They have the great advantages of small bulk, lightness and efficiency. The coil also gives a clear musical note. Fig. 256 shows the discharger, used with the coil, placed in a silencing box.

Within the eighteen years since the first introduction of radio-telegraphy, this method of transmitting signals has become indispensable for ships, and is in use all over the world. So far

it has not displaced the use of land or submarine telegraphy, but the experience gained in French and Belgian Congo and on the Amazon shows that this means of signalling is undoubtedly practical for bridging dense forests, and the Marconi trans-atlantic station demonstrates the possibility of competition with submarine cables. It remains, however, for the future to show to how great an extent continuous metallic circuits can be efficiently replaced by this form of Telegraphy.

APPENDIX

SECTION A.—OHM'S LAW

(References, pp. 5, 363)

THE flow of electricity between any two points is regulated by the *electromotive force* of the generator, and the *resistance* of the conductor between them. It is therefore necessary to know the relations which exist between these, and this Law of the Current was determined by the great physicist Ohm early in the nineteenth century. He found that the strength of current which flows in a circuit varies *directly* as the electromotive force and *inversely* as the total resistance. The law thus expressed is called, after the discoverer, 'Ohm's Law.' It may be shown thus:

$$\text{Current varies as } \frac{\text{Electromotive Force}}{\text{Resistance}}$$

Thus, if the electromotive force be doubled, the current will also be doubled; but if the resistance be doubled, the current will then be halved.

Now, when the standard units of these functions are applied to the above expression, it may be stated as an equation, thus:

$$\text{Current in ampères} = \frac{\text{Electromotive force in volts}}{\text{Resistance in ohms}}$$; and this may be shortened to

$$C = \frac{E}{R} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Giving numerical values to these letters (Ex. 1), if the electromotive force (E) be 10 volts and the total resistance of the circuit (R) be 25 ohms

Here, $C = \frac{10}{25} = 0{\cdot}4$ ampères

or this may be stated in the sub-unit milliampères—

$$C = 0{\cdot}4 \times 1000 = 400 \text{ milliampères.}$$

But formula (1) $C = \frac{E}{R}$ may be rewritten—

$$CR = E \quad . \quad . \quad . \quad . \quad . \quad (2)$$

which shows that the electromotive force (E) in a circuit is proportionate to the product of the current strength and the resistance.

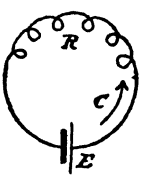


Fig. 1

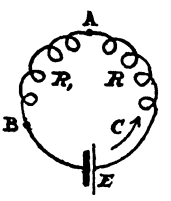


Fig. 2

Thus (Ex. 2) if the strength of current in a circuit of 1079 ohms resistance (including resistance of the battery) is 20 milliampères, what is the electromotive force ?

$$E = 1079 \times \frac{20}{1000} = 1{\cdot}079 \times 20 = 21{\cdot}58 \text{ volts.}$$

As 1·079 volt represents the highest electromotive force of a Daniell cell, the above conditions would result from a battery consisting of 20 Daniell cells, presuming the total resistance in circuit, 1079ω, included that of the battery.

Equation (2) also indicates, what is the fact, that the electromotive force for *part* of a circuit may be calculated. Thus (fig. 2) the current strength C is due to $\frac{E}{R + R_1}$, that is to say, the strength of current throughout the circuit is C, and therefore E_1, the electromotive force, or, as it is more usually expressed, the *difference of potential* between A and B through R_1 will be—

$$CR_1 = E_1 \quad . \quad . \quad . \quad . \quad (3)$$

NOTE.—This equation is not correct when there is a source of electromotive force in the section of circuit dealt with ; for instance, it would not apply to the difference of potential between A and B if the resistance between those points through R were substituted for R_1.

Again, $C = \frac{E}{R}$ may be written $R = \frac{E}{C}$ . . . . (4)

from which it is clear that, having given a fixed electromotive force, the resistance through which it is made to act will be indicated by the reciprocal of the currents $\left(\frac{1}{C}\right)$.

SECTION B.—CALCULATION OF STRENTH OF CURRENT

(References, pp. 5, 10, 92, 97)

As seen in the previous section, the strength of an electric current flowing in a circuit depends upon the electromotive force of the generator (whether that be a voltaic battery, a magneto machine, a dynamo, or a secondary battery) and upon the resistance through which the electromotive force is applied. In calculating the strength of current it is necessary that the *total* resistance included in the circuit be taken. For example (fig. 3), with a battery of electromotive force E and resistance *r*, joined in circuit with resistance coils R and galvanometer of resistance G, what is the strength of the current (C) ?

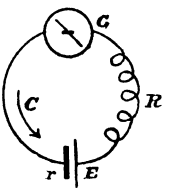


Fig. 3

Here, $C = \frac{E}{R + G + r}$

and if E = 21 volts, R = 1416 ohms, G = 250 ohms, and *r* = 84 ohms, then—

$$C = \frac{21 \times 1000 \text{ (millivolts)}}{1416 + 250 + 84} = \frac{21000}{1750} \text{ milliampères}$$
$$= 12 \text{ milliampères.}$$

SECTION C.—COMBINED RESISTANCES

(References, pp. 91, 151, 301, 318, 320)

For any given conductor of uniform section the electrical conductivity varies directly in proportion to the transverse sectional area, and inversely in proportion to the length ; that is to say—

$$\text{Conductivity varies as } \frac{\text{Sectional area}}{\text{Length of conductor}}$$

Now resistance is the converse of conductivity, so that—

$$\text{Resistance varies as } \frac{\text{Length of conductor}}{\text{Sectional area}}$$

For instance, a piece of copper wire of certain sectional area and ten yards long will give double the resistance of five yards of similar wire, and the resistance of equal lengths of wire whose sectional areas are in the proportion of 1 to 3 will be respectively as 3 to 1.

It is clear that if a series of resistances be joined up successively as R_1, R_2, R_3, R_4 (fig. 4), the total resistance between A and B will be $R_1 + R_2 + R_3 + R_4$; that is, the total resistance of a series of resistances joined successively is the sum of the separate resistances.

But if the same four resistances be joined as shown in fig. 5, what will be the resistance? These are said to be joined

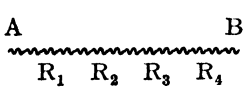


Fig. 4

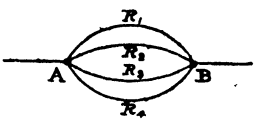


Fig. 5

'in multiple,' or 'for quantity.' It will be at once seen that there are here four ways for the current between A and B, and the resultant resistance must therefore be reduced. Now we may assume that each wire, R_1, R_2, R_3, R_4 is equal in length, and that if they vary in resistance (or conductivity) it is owing to their varying sectional areas. The relative conductivities of these wires are $\frac{1}{R_1}$, $\frac{1}{R_2}$, $\frac{1}{R_3}$, and $\frac{1}{R_4}$; so that, relatively, the total conductivity between A and B is $\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}$; and the total resistance (R) is the reciprocal of this, namely—

$$R = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}} \quad . \quad . \quad . \quad (1)$$

that is, *the joint resistance of two or more resistances joined for quantity is the reciprocal of the sum of the reciprocals of the several resistances.*

The case where there are only two resistances, R_1 and R_2, may be reduced to simpler form, for—

$$R = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}} = \frac{1}{\frac{R_2 + R_1}{R_1 R_2}} = \frac{R_1 R_2}{R_1 + R_2} \quad . \quad (2)$$

that is, *the joint resistance of two resistances joined for quantity is the product of the two divided by their sum.*

(Ex. 1) (*a*) Four resistances, respectively 40ω, 60ω, 80ω, 100ω, are joined in series; what is the total resistance?

$$R = 40 + 60 + 80 + 100 = 280\omega.$$

(*b*) What is the joint resistance when joined in multiple?

$$R = \frac{1}{\frac{1}{40} + \frac{1}{60} + \frac{1}{80} + \frac{1}{100}} = \frac{1}{\frac{30 + 20 + 15 + 12}{1200}} = \frac{1}{\frac{77}{1200}}$$

$$= \frac{1200}{77} \text{ ohms} = 15{\cdot}58\omega.$$

(Ex. 2.) What is the joint resistance of two resistances respectively 40ω and 60ω?

$$R = \frac{40 \times 60}{40 + 60} = \frac{2400}{100} = 24\omega.$$

It should be observed that the sectional areas of circular or square conductors vary as the square of their diameters or sides respectively, and that, consequently, *resistances of equal lengths vary inversely as the squares of their diameters*; thus the relative resistances of equal lengths of circular wires whose diameters are d_1 and d_2 will be inversely proportional to $(d_1)^2$ and $(d_2)^2$ respectively. [The actual areas would of course be $(d_1)^2 \times 0{\cdot}7854$ and $(d_2)^2 \times 0{\cdot}7854$.]

Suppose now that there are two wires of equal length whose areas are as 2 to 1; their weights will of course be in the same proportion, and their resistances as 1 to 2. If the length of the thinner wire be doubled the resistance will also be doubled, and will hence be *four* times that of the thicker wire, while their weights will be equal. Again, suppose the area to be as 3 to 1 and the lengths 1 to 3, then the resistance of these equal weights will be as 1 to 9; hence, *for equal weights of similar uniform conductors, the resistance varies directly as the square of the length and inversely as the square of the area or as the fourth power of the diameter.*

(Ex. 3.) Two wires of equal weight are respectively 10 yards and 15 yards in length; what are their relative resistances?

As $10^2 : 15^2$, or $100 : 225 = 4$ to 9

(Ex. 4.) The respective diameters of two circular wires of equal weight are 4 and 5; what are their relative resistances?

$$\text{As } \frac{1}{4^4} : \frac{1}{5^4} \text{ or } \frac{1}{256} : \frac{1}{625} = 625 : 256,$$

that is, the resistance of the wire of diameter 4 is 625 if that of the wire of diameter 5 be taken as 256.

SECTION D.—SHUNTS

(References, pp. 151, 301, 318, 319)

It sometimes happens in measuring a current by means of a galvanometer that the deflection which the current would give is too great to be conveniently measured, and in such case recourse is had to the use of a *shunt*. The application of the term is not strictly limited to galvanometers, but to any form of resistance which is arranged to divert or take off part of a current flowing in a section of a circuit. In dealing, however, with the more restricted case, the general principle will be also explained.

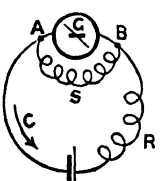


Fig. 6

If the needle of the galvanometer G when placed in circuit with the battery E be deflected to an inconvenient extent, a second way for the current may be made by joining the resistance S in multiple with the coil of the galvanometer. As indicated by the previous section (C) this will reduce the resistance between A and B (fig. 6) to $\frac{G \times S}{G + S}$. Incidentally this will have the effect of increasing the actual current flowing from the battery, but this may either be compensated for by correspondingly increasing the resistance of the other part of the circuit, or it may be ignored. Now, the *conductivity* of these two paths between A and B are as $\frac{1}{G}$ to $\frac{1}{S}$ or as $\frac{S}{G \times S}$ to $\frac{G}{G \times S}$; that is to say, the proportion of current which will flow in the two sections, the galvanometer and the 'shunt' will be respectively as S is to G; so that, if the current be supposed to be subdivided into S + G parts, S parts will pass through the galvanometer and G parts through the shunt. It will now be evident that, by giving S certain definite values as compared with G the resistance of the galvanometer, and then measuring the current passing in G, the total current of the undivided circuit may be

calculated. Suppose, for instance, that S be equal to G, then $S + G = 2S$, and it is clear that the current flowing through G is only $\frac{S}{S+G}$ or $\frac{S}{2S}$ that is, one half of that flowing in the undivided circuit. Again, if $S + G$ be made equal to 10 S, 100 S, or 1000 S, then the current flowing through G will be $\frac{1}{10}$, $\frac{1}{100}$, or $\frac{1}{1000}$ of that flowing from the battery, and the *multiplying power of the shunt* in these cases will be respectively 10, 100, and 1000. But it is clear that these proportions may be obtained by giving S a value equal to $\frac{1}{9}$, $\frac{1}{99}$ or $\frac{1}{999}$ G, from which may be deduced the general rule that, calling the multiplying power of the shunt m,

$$S = \frac{G}{m-1} \quad . \quad . \quad . \quad . \quad (1)$$

(Ex. 1.) A $\frac{1}{100}$ shunt is to be applied to a galvanometer of 320ω resistance; what must be the value of the shunt?

Here, $$S = \frac{320^{\omega}}{99} = 3{\cdot}232^{\omega}.$$

It was remarked above that the introduction of a shunt has the effect of reducing the total resistance of the circuit, and reference was made to compensating for this decrease. This compensation (R) must be equal to G less the combined resistance of G and S, that is,

$$R = G - \frac{G \times S}{G+S} = \frac{G(G+S) - G \times S}{G+S} = \frac{G \times G}{G+S}$$

but, as was seen in (1), $S = \frac{G}{m-1}$, m being the multiplying power of the shunt; therefore—

$$R = \frac{G \times G}{G + \frac{G}{m-1}} = \frac{G}{\frac{(m-1)+1}{m-1}} = \frac{G(m-1)}{m} \quad . \quad (2)$$

(Ex. 2.) In Ex. 1 what compensation resistance (R) should be inserted?

$$R = \frac{32^{\omega}(99)}{100} = 316{\cdot}8^{\omega}.$$

SECTION E.—THE WINDING OF ELECTRO-MAGNETS

(References, pp. 35, 36, 44, 45, 46)

For telegraphic purposes the (copper) wire used on electro-magnets is invariably covered with silk.

As a general rule it may be taken that the diameter of the bobbins should not exceed $\frac{1}{8}$ of the length of the electro-magnet core.

It is usual to specify the *resistance* to which electro-magnets are wound, as this is important for purposes of calculating strength of current, &c.; but this must not be taken absolutely as indicating the efficiency of the electro-magnet. It has been pointed out (p. 46) that the efficiency depends upon the number of convolutions around the core; that is, virtually, upon the actual *length* of wire used, and for a given resistance the length of wire will vary directly as the square of the diameter; hence the larger the wire the more convolutions there will be and the greater the efficiency of the electro-magnet. Therefore the largest possible wire which the bobbin will take for the specified resistance should be used in winding electro-magnets. Incidentally it may be noted that the larger the wire the less likely it is to be fused by currents of unusual strength; for this reason the rule applies also to ordinary resistance coils.

SECTION F.—CONDENSER

(Reference, p. 107)

The principle of the Leyden jar was discovered in 1746, probably by Von Kleist, although the discovery is more commonly associated with the name of Muschenbroek, or of Cuneus of Leyden. It consists of a wide-mouthed bottle coated inside and out with tinfoil to about three-fourths its height. Connection with the inside coat is generally obtained by means of a chain attached to a metal rod which terminates in a knob (see fig. 214); The two coats of the jar thus separated by the glass have a power of retaining a certain quantity of electricity in the form of a charge, and the amount held depends upon the surface of the coatings, and the thickness of the glass. When, however, we come to deal with the more convenient method of obtaining capacity—the condenser—where the customary glass of the Leyden jar is abandoned in favour of some more convenient dielectric, the electrostatic capacity is found to vary in conformity with three conditions, namely: (1) Directly, as the surfaces of the opposing conducting plates; (2) inversely, as the distance between the opposing conducting plates; and (3) directly, as the *specific inductive capacity* of the dielectric. This last is a property inherent to all non-conducting substances, in

[1] The use however of enamel, especially in the tropics, is largely coming into force.

virtue of which they have the power of effecting induction to a specific extent. Comparatively, if air be taken to have a specific inductive capacity of 100, then that of glass is 190, that of paraffin 198, of gutta-percha 420, and of mica 500. For use in making condensers glass is inadmissible, except for very small capacities, on account of its fragility; gutta-percha cannot be relied upon because in thin sheets it soon becomes brittle; and, in fact, the only dielectrics ever used for condensers under ordinary conditions are mica and paraffined paper. Mica, from the fact that it can be so readily split into very thin sheets and that its specific inductive capacity is very high, is most suitable, but its high price



Fig. 7

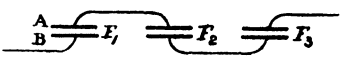


Fig. 8

prevents its use except for special purposes, such as standard condensers. All ordinary condensers, therefore, are constructed with paraffined paper.

As stated above, the capacity varies directly as the surfaces of the opposing plates. If now three condensers, F_1, F_2, F_3, be joined up as shown in fig. 7, the effect is clearly to connect all the A plates together, so that, practically, they become one plate of large area, and so also with the B plates; hence, by such an arrangement, the total capacity (F) becomes—

$$F = F_1 + F_2 + F_3 \quad . \quad . \quad . \quad . \quad (1)$$

Again, the capacity varies inversely as the distance between the plates. Assume the distances in fig. 8 are $\frac{1}{F_1}$, $\frac{1}{F_2}$, $\frac{1}{F_3}$; then, if the three condensers be joined as shown, the B plate of F_1 is practically brought opposite that of F_2 by the connection of the A plates of F_1 and F_2, but at distance $\frac{1}{F_1} + \frac{1}{F_2}$, and similarly with F_2 and F_3, so that the distance between plate B of F_1 and plate A of F_3 is $\frac{1}{F_1} + \frac{1}{F_2} + \frac{1}{F_3}$, and the capacity (F) is therefore

$$F = \frac{1}{\frac{1}{F_1} + \frac{1}{F_2} + \frac{1}{F_3}} \quad . \quad . \quad . \quad . \quad (2)$$

The special case of two capacities works out similarly to that of the law of combined resistances (section C), and becomes—

$$F = \frac{F_1 F_2}{F_1 + F_2} \quad . \quad . \quad . \quad . \quad (3)$$

SECTION G.—TESTING 'EARTHS'

The theory of the method of finding the actual resistance of an 'earth,' which is described at p. 355, may be explained thus:

First Test

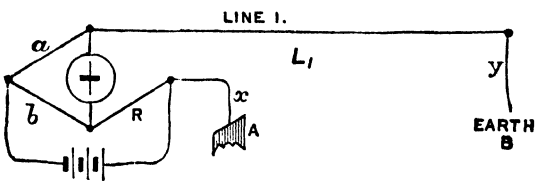


Fig. 9

Let x be the resistance of the earth A (the resistance required)
" y " " " " B (not known),
and L_1 " " " line 1.
Then, when balance is obtained—

$$a\,R = b\,(L_1 + y + x)$$

or

$$a\,R = b\,(L_1 + y) + bx \quad . \quad . \quad . \quad (1)$$

Second Test

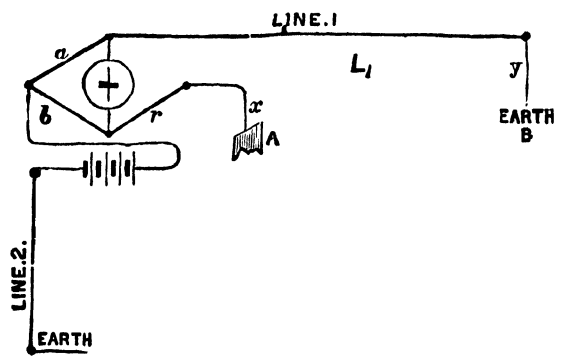


Fig. 10

In this case, when balance is obtained,

$$a\,(x + r) = b\,(L_1 + y)$$

that is,

$$ax + ar = b\,(L_1 + y) \quad . \quad . \quad . \quad (2)$$

Then, by subtracting (2) from (1)

$$a\,\mathrm{R} - ax - ar = bx,$$

or

$$x\,(a + b) = a\,(\mathrm{R} - r)$$

that is,

$$x = \frac{a\,(\mathrm{R} - r)}{a + b} \quad . \quad . \quad \textit{(General Case)}$$

and, if a and b are equal,

$$x = \frac{\mathrm{R} - r}{2} \quad . \quad . \quad . \quad \textit{(Special Case)}$$

Note to Section H

(*See pp.* 398, 399)

Area in square inches	×	6·452	=	area in square centimeters
Ohms per foot	×	3·281	=	ohms per metre
Feet per ohm	×	0·305	=	metres per ohm
Pounds per foot	×	1488·	=	grammes per metre
Ounces ,, ,,	×	93·0	=	,, ,, ,,
Grains ,, ,,	×	0·213	=	,, ,, ,,
Length in inches	×	25·40	=	length in millimetres
,, ,, ,,	×	2·540	=	,, ,, centimetres
,, ,, feet	×	0·305	=	,, ,, metres
,, ,, yards	×	0·914	=	,, ,, ,,
,, ,, miles	×	1·609	=	,, ,, kilometres
Weight in grains	×	0·065	=	weight in grammes
,, ,, pounds avoirdupois	×	0·453	=	,, ,, kilogrammes

SECTION H.—STANDARD SIZES OF COMMERCIAL ANNEALED COPPER CONDUCTORS

(Weights and Resistances per Statute Mile)

Legal Standard Gauge	Diameter in inches			Weight per mile in lbs.			Resistance per mile at 60° F. (15·6° C.) in ohms		Sectional area, in sq. inches of Standard size
	Standard	Minimum allowable	Maximum allowable	Standard	Minimum allowable	Maximum allowable	Standard	Maximum allowable	
[1 sq. in.]	1·128379	1 1170	1 1396	20350·0	19943·0	20757·0	0·04231	0 04316	1 00000
7/0	0·5000	0·4950	0·5050	3996·	3916·	4076·	0·2155	0 2198	0·1963
6/0	0·4640	0·4593	0·4686	3441·	3372·	3510·	0·2502	0 2552	0·1691
5/0	0·4320	0·4277	0·4363	2983·	2923·	3042·	0·2887	0·2944	0·1466
4/0	0·4000	0·3960	0 4040	2557·	2506·	2608·	0·3367	0·3434	0·1257
3/0	0·3720	0·3683	0·3757	2212·	2168·	2256·	0 3893	0 3971	0·1087
2/0	0·3480	0·3445	0·3515	1936·	1897·	1974·	0·4448	0·4537	0·09511
1/0	0·3240	0·3207	0 3272	1678·	1644·	1711·	0 5132	0·5234	0·08245
1	0·3000	0·2970	0·3030	1438·	1410·	1467·	0·5986	0·6105	0·07069
2	0·2760	0·2732	0·2787	1218·	1193·	1242·	0·7072	0·7213	0·05983
3	0·2520	0·2495	0 2545	1015·	994·7	1035·	0·8483	0·8653	0·04988
4	0·2320	0·2297	0·2343	860·3	843 1	877·5	1·001	1·021	0·04227
5	0·2120	0·2099	0·2141	718·3	704·0	732·7	1·199	1·223	0·03530
6	0·1920	0·1901	0·1939	589·2	577·4	601·0	1·461	1·491	0·02895
7	0·1760	0·1742	0·1778	495·1	485·2	505·0	1·739	1·774	0·02433
8	0·1600	0·1584	0·1616	409·2	401·0	417·3	2·104	2 146	0 02011
9	0·1440	0·1426	0·1454	331·4	324·8	338·0	2·598	2·650	0·01629
10	0·1280	0·1267	0·1293	261·9	256·6	267·1	3 288	3·354	0·01287
11	0·1160	0·1148	0·1172	215·1	210 8	219·4	4·004	4·084	0·01057
12	0·1040	0·1030	0·1050	172·9	169·4	176·3	4·981	5 080	0·008495
13	0·0920	0·09108	0·09292	135·3	132·6	138·0	6·365	6·492	0·006648
14	0·0800	0·07920	0·08080	102·3	100·2	104·3	8·418	8·586	0·005027
15	0·0720	0·07128	0·07272	82·86	81·20	84·51	10·39	10·60	0·004072
16	0·0640	0·06336	0·06464	65·47	64·16	66·78	13·15	13·42	0·003217
17	0·0560	0·05544	0·05656	50·12	49·12	51·12	17·18	17·52	0·002463

18	0·0480	0·04752	0 04848	36·82	36·09	37·56	23·38	23·85	0·001810
19	0·0400	0·03960	0·04040	25·57	25·06	26·08	33·67	34·34	0·001257
20	0·0360	0·03564	0·03636	20·71	20·30	21·13	41·57	42·40	0·001018
21	0·0320	0·03168	0·03232	16 37	16·04	16·69	52·61	53·66	0·0008042
22	0·0280	0·02772	0·02828	12 53	12·28	12·78	68·71	70·09	0 0006158
23	0·0240	0·02376	0 02424	9 206	9·022	9·390	93·53	95 40	0·0004524
24	0·0220	0·02178	0·02222	7 736	7·581	7·890	111·3	113·5	0 0003801
25	0·0200	0·01980	0·02020	6 393	6·265	6·521	134·7	137·4	0 0003142
26	0·0180	0·01782	0·01818	5 178	5·075	5·282	166·3	169·6	0·0002545
27	0·0164	0·01624	0 01656	4 299	4·213	4·385	200·3	204·3	0·0002112
28	0·0148	0 01465	0 01495	3·501	3·431	3 571	245·9	250 9	0 0001720
29	0·0136	0·01346	0·01374	2·956	2·897	3 015	291·3	297·1	0·0001453
30	0·0124	0·01228	0·01252	2 458	2·408	2 507	350·4	357 4	0·0001208
31	0·0116	0·01148	0·01172	2 151	2 108	2·194	400·4	408·4	0·0001057
32	0·0108	0·0169	0·01091	1 864	1 827	1·902	461·9	471·1	0·00009161
33	0·0100	0·009899	0·01010	1·598	1·566	1·630	538·7	549·5	0·00007854
34	0·0092	0·009108	0·009292	1 353	1·326	1 380	636 5	649 2	0 00006648
35	0·0084	0·008316	0 008484	1 128	1·105	1·150	763 5	778·8	0·00005542
36	0·0076	0 007524	0 007676	0 9232	0 9047	0·9416	932·7	951·3	0·00004536
37	0·0068	0·006732	0·006868	0 7390	0·7243	0·7538	1165	1188	0 00003632
38	0·0060	0·005940	0 006060	0 5754	0 5639	0 5869	1496	1526·	0 00002827
39	0·0052	0·005148	0·005252	0 4322	0 4235	0 4408	1992	2032·	0·00002124
40	0·0048	0·004752	0·004848	0·3682	0·3609	0 3756	2338·	2385·	0·00001810
41	0·0044	0·004356	0 004444	0 3094	0 3032	0 3156	2783·	2838·	0 00001521
42	0·0040	0 003960	0 004040	0·2557	0·2506	0·2608	3367	3434·	0·00001257
43	0·0036	0 003564	0·003636	0·2071	0·2030	0 2113	4157	4240·	0 00001018
44	0·0032	0 003168	0 003232	0·1637	0·1604	0·1669	5261	5366·	0·000008042
45	0·0028	0·002772	0 002828	0·1253	0 1228	0·1278	6871·	7009·	0·000006158
46	0·0024	0 002376	0 002424	0 09206	0·09022	0 09390	9353·	9540·	0 000004524
47	0·0020	0·001980	0·002020	0·06393	0 06265	0 06521	13468·	13737·	0·000003142
48	0·0016	0·001584	0·001616	0·04092	0·04010	0·04173	21044·	21465·	0·000002011
49	0·0012	0·001188	0·001212	0·02302	0·02256	0 02348	37411·	38159·	0·000001131
50	0·0010	0·0009899	0·001010	0·01598	0·01566	0·01630	53872·	54949·	0·0000007854

SECTION I.—COPPER CONDUCTORS

The following standards for copper conductors have been agreed upon by the Engineering Standards Committee in London as from August 1904.

(1) A wire one metre long, weighing one gramme, and having a resistance of 0·1539 standard ohm at 60° Fahr. (15·6° C.) is taken as the standard for hard-drawn high-conductivity commercial copper.

(2) Hard-drawn copper is defined as that which will not elongate more than 1 per cent. without fracture.

(3) A wire one metre long, weighing one gramme, and having a resistance of 0·1508 standard ohm at 60° Fahr. (15·6° C.), is taken as the standard for annealed high-conductivity commercial copper.

(4) Copper is taken as weighing 555 lbs. per cubic foot (8·89 grammes per cubic centimetre) at 60° F. (15·6° C.) which gives a specific gravity of 8·90.

(5) The average temperature coefficient of 0·00238 per degree Fahr. (0·00428 per degree C.) is adopted for commercial purposes.

(6) A variation of 2 per cent. from the adopted standard of resistance is allowed in all conductors.

(7) A variation of 2 per cent. from the adopted standard of weight is allowed in all conductors.

(8) An allowance of 1 per cent. increased resistance, as calculated from the diameter, is allowed on all tinned copper conductors between diameters 0·106 and 0·028 (Nos. 12 and 22 S.W.G.) inclusive.

(9) In cables, for the purpose of calculation of tables, a lay, involving an increase of 2 per cent. in each wire, except the centre wire, for the total length of the cable is taken as the standard.

(10) The legal standard wire gauge is adopted as the standard for all wires.

SECTION J.—(I) ELECTROMOTIVE FORCE OF BATTERIES

Bichromate Battery (p. 22)	.	2·14 volts	(approximate).
Leclanché (pp. 17) . .	.	1·60 ,,	,,
Daniell (p. 11) . . .	.	1·07 ,,	,,
Secondary (p. 25) . .	.	2·00 ,,	,,

The electromotive force of a cell depends solely upon the chemical action which takes place, and is quite independent of the internal resistance between the poles.

(II) RESISTANCE OF BATTERIES

The resistance of a cell depends upon its chemical constituents and their density, and the construction, shape and size of the cell.

the thickness and density of porous pot (if one is used), &c. Hence it is difficult to indicate any standard, but the following gives the range of resistance permitted for Post Office Batteries :—

	Standard. Ohms	Highest allowed. Ohms
Bichromate, Fuller's quart size (p. 21) . . .	2	3
Daniell (p. 11)	4	6
Leclanché, Porous Pot (p. 17)	2	3
,, Agglomerate (p. 17)	0·5	—

So-called *Dry* Leclanché cells are made which possess lower internal resistance than the Wet cells with porous pots.

SECTION K.—SAGS FOR COPPER AND IRON WIRES

At various temperatures which provide for a factor of safety of 4 at 22° Fahr.

Temperature in degrees F.	Sags for various Spans									
	Copper Wire					Iron Wire				
	50 yds.	60 yds.	70 yds.	80 yds	90 yds.	50 yds.	60 yds.	70 yds.	80 yds.	90 yds.
	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.
22	0 8	0 11⅛	1 3⅜	1 8⅛	2 1⅞	0 9¼	1 1⅛	1 6½	2 0¼	2 6⅛
25	0 9⅛	1 2⅛	1 5⅛	1 10¼	2 4	0 10⅜	1 2¼	1 7⅛	2 1½	2 8
30	1 0¼	1 4¼	1 8½	2 1⅛	2 7½	1 0⅛	1 4¾	1 9⅞	2 3½	2 10
35	1 2⅜	1 6⅛	1 11¼	2 4⅜	2 10	1 2	1 6½	1 11⅛	2 5⅞	2 11⅞
40	1 4⅜	1 8¾	2 1⅜	2 6⅞	3 0⅛	1 3½	1 8	2 1½	2 7½	3 1⅜
45	1 6¼	1 10¾	2 3¾	2 9½	3 3¼	1 4⅝	1 9⅛	2 2⅞	2 8¼	3 3⅛
50	1 7⅝	2 0⅛	2 5⅞	2 11⅝	3 5⅛	1 6	1 10½	2 4¼	2 10⅛	3 5⅛
55	1 9⅛	2 2⅛	2 7⅞	3 1⅝	3 7⅛	1 7	2 0½	2 5⅛	2 11½	3 6⅞
60	1 10⅝	2 3⅝	2 9⅛	3 3½	3 10	1 8⅛	2 1½	2 7	3 1⅛	3 8½
65	1 11⅞	2 5½	2 11	3 5½	3 11⅞	1 9⅛	2 2½	2 8⅛	3 2⅝	3 9⅞
70	2 0⅛	2 6⅞	3 0⅛	3 7	4 1⅜	1 10⅛	2 3⅜	2 9⅛	3 4⅛	3 11⅛
75	2 2	2 8	3 2⅛	3 8⅝	4 3⅝	1 11	2 4⅝	2 10⅛	3 5⅝	4 0⅛
80	2 3⅛	2 9½	3 3⅞	3 10¼	4 5⅞	1 11⅞	2 5⅞	2 11⅛	3 6⅞	4 2
85	2 4½	2 10⅝	3 5	3 11⅞	4 7⅞	2 0⅛	2 6⅞	3 1	3 7⅞	4 3½
90	2 5⅞	2 11⅝	3 6½	4 1⅝	4 8½	2 1⅛	2 7⅞	3 2⅛	3 9¼	4 4⅞
95	2 6⅞	3 0⅛	3 7⅝	4 3⅜	4 10⅝	2 2⅛	2 8⅝	3 3⅛	3 10¼	4 5⅞
100	2 7⅞	3 1⅝	3 9	4 4⅞	5 0	2 3⅛	2 9⅜	3 4⅛	3 11⅝	4 7⅛

The sag varies with the material and not with the gauge.

SECTION L.—STRESSES (COPPER WIRES)

Temperature in degrees Fahr.	Stresses in lbs. for various Spans in yards																				Temperature in degrees Fahr.
	150 lbs. per mile (97 mils diameter, No. 12½ S.W.G.)					200 lbs. per mile (112 mils diameter, No. 11½ S.W.G.)					400 lbs. per mile (138 mils diameter, No. 8 S.W.G.)					600 lbs. per mile (193 mils diameter, No. 6 S.W.G.)					
	50 yds.	60 yds.	70 yds.	80 yds.	90 yds.	50 yds.	60 yds.	70 yds.	80 yds.	90 yds.	50 yds.	60 yds.	70 yds.	80 yds.	90 yds.	50 yds.	60 yds.	70 yds.	80 yds.	90 yds.	
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
22	120	120	120	120	120	160	160	160	160	160	320	320	320	320	320	480	480	480	480	480	22
25	96	102	106	109	111	129	136	142	145	148	258	272	284	290	296	386	409	425	436	444	25
30	76	84	91	96	99	102	113	121	128	133	204	226	242	256	266	306	338	364	383	399	30
35	65	74	81	86	91	87	98	108	115	122	174	196	216	230	244	262	295	323	346	365	35
40	58	66	73	79	84	77	88	96	106	113	154	176	192	212	226	232	265	294	318	338	40
45	52	61	68	74	79	70	81	90	98	105	140	162	180	196	210	211	243	271	296	317	45
50	48	56	63	69	75	65	74	84	92	100	130	148	168	184	200	194	223	253	277	299	50
55	45	53	59	65	71	60	70	79	87	94	120	140	158	174	188	182	211	238	262	284	55
60	42	50	56	62	67	57	66	75	83	90	114	132	150	166	180	171	200	226	250	270	60
65	40	47	53	59	65	54	63	71	79	86	108	126	142	158	172	162	189	214	238	260	65
70	38	45	51	57	62	51	60	68	76	83	102	120	136	152	166	153	181	205	229	249	70
75	37	43	49	55	60	49	58	66	73	80	98	116	132	146	160	147	173	197	220	240	75
80	35	41	47	53	58	47	55	63	71	77	94	110	126	142	154	141	166	190	212	232	80
85	34	40	46	51	56	45	53	61	68	75	90	106	122	136	150	136	160	183	205	225	85
90	33	39	44	49	54	44	52	59	66	73	88	104	118	132	146	131	155	177	199	218	90
95	32	37	43	48	53	42	50	57	64	71	84	100	114	128	142	127	150	172	191	212	95
100	31	36	42	47	52	41	48	56	62	69	82	96	112	124	138	123	146	167	188	207	100
Poles per mile	35	29	25	22	19½	35	29	25	22	19½	35	29	25	22	19½	35	29	25	22	19½	Poles per mile

SECTION M.—STRESSES (IRON WIRES)

Temperature in Degrees F.	Stresses in lbs. for various Spans in yards									
	200 lbs. per mile (121 mils diameter, No 10½ S.W G.)					400 lbs. per mile (171 mils diameter, No. 7½ S W.G)				
	50 yds.	60 yds.	70 yds.	80 yds.	90 yds.	50 yds.	60 yds.	70 yds.	80 yds.	90 yds.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
22	135	135	135	135	135	270	270	270	270	270
25	120	124	127	128	130	239	247	253	256	259
30	103	110	115	119	122	205	219	230	238	243
35	91	100	107	112	115	182	199	213	223	230
40	83	92	99	105	110	165	184	198	210	219
45	77	86	94	99	105	153	172	187	199	210
50	72	81	89	95	101	143	161	177	190	201
55	67	77	85	91	95	134	153	169	182	194
60	64	73	81	88	94	127	146	162	175	187
65	61	70	78	85	91	121	139	155	169	181
70	58	67	75	82	88	116	134	149	163	175
75	56	64	72	79	85	111	129	144	158	170
80	54	62	70	77	83	107	124	140	153	165
85	52	60	68	75	81	103	120	135	149	161
90	50	58	66	73	79	100	117	132	145	157
95	48	56	64	71	77	97	113	128	142	154
100	47	55	63	69	75	94	110	125	138	150
Poles per mile.	35	29	25	22	19½	35	29	25	22	19½

Factor of safety of 4 at 22° Fahr. for all wires.

The stress varies with both the gauge and the material.

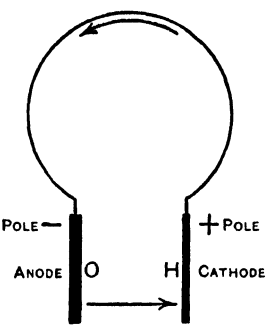
The stress for 100 lbs. (No. 14) copper wire is half that for 200 lbs. and the stress for 800 lbs. (No. 4½) copper wire is double that for 400 lbs.

SECTION N.—NOMENCLATURE OF POLES AND PLATES

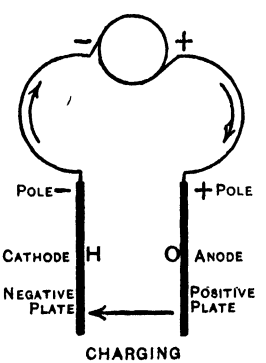
So many mistakes are made in naming the poles, plates of cells, and electrodes, from which currents start and towards which they flow, that the following figures have been drawn, which give at a glance the correct information, as used in this text-book.

Diagrams illustrative of the Nomenclature conventionally applied to the Poles and Plates of Cells, &c.

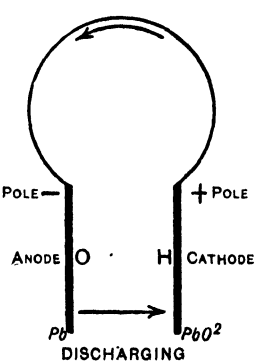
VOLTAIC CELL



ACCUMULATOR

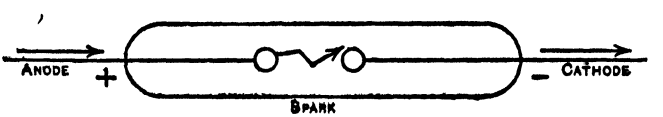


CHARGING



DISCHARGING

VACUUM TUBE



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