PART II.

PAPERS.

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UNDERGROUND ELECTRIC LIGHT MAINS.

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The question of Underground Electric Light Mains is entirely one of recent years, but it is one to which a large amount of attention has been devoted, and is, without doubt, one of the most important branches of electrical engineering. The subject has received very close attention from electrical engineers, and may now be said to have passed the region of experiment and entered on that of practical engineering. It will be interesting to trace the early attempts to lay electric conductors underground, and note the gradual developments of the systems at present in use. The first experiments at subterranean lines are due to the enterprise of the men who made the electric telegraph a possibility, and who seem to have realised, much more vividly than some of their successors have done, how great a nuisance and eyesore would be caused by a large group of overhead conductors. In fact, the pioneers in telegraphy at first contemplated *only* the use of underground wires; it was only when the great difficulty of insulating the conductors was discovered in practice that overhead wires were substituted. The earliest record of a subterranean wire is that of a Mr. Renals, of Hammersmith, in 1823. This gentleman was conducting a series of experiments in telegraphy by means of frictional electricity, and he made use of a conductor enclosed in a glass tube, and laid in a wooden trough, and surrounded with pitch. This, it is hardly necessary to say, was not found effective, and was not proceeded with. The first real success was reached when the discovery of the insulating properties of gutta percha was made, and, although this material was at first used only for submarine work, it was soon seen that all the qualities that made gutta percha suitable for submarine work would also make it, to a great extent, suitable for subterranean work.

In America, Professor Morse was working on the same lines, and it is recorded that, as far back as 1832, he designed and layed a length of underground conduit for telegraph purposes in Baltimore. The length of this line was seven miles, and it consisted of copper wires insulated with shellac, and enclosed in a split lead tube, as shown in Plate I, Fig. 1. Needless to say this line was not a success, and its failure did much to retard the development of underground wires in the United States.

As far as telegraph work is concerned, it may be said that no advance of any importance in this line has been made since the introduction of gutta percha. It is true that the methods of preparing the gutta percha, and of covering wires with it, have been much improved, with the result of greatly higher insulation, but in all essential principles the underground telegraph wires of to-day, as laid in Great Britain and elsewhere, are the same as they were thirty years ago.

In 1860, underground cables were in use in Paris; and, in Mr. Sabine's book on "The Electric Telegraph," published in 1867, we find the following remarkable description of these cables:—

"The underground cables in Paris are composed of seven conductors, each consisting of a strand of seven copper wires, insulated with several thicknesses of gutta percha. They are placed in the sewers, in the catacombs, and under the streets. . . . . For the lines under the streets iron tubes are employed to protect the cables from mechanical injury, and also to prevent the free circulation of air and consequent oxidation of the gutta percha. The tubes are of cast iron, and are of the length of eight feet, and the lengths are connected by lead joints."

This is really a very remarkable description, as, although written in 1867, it would, with very slight and entirely unimportant alterations, be a correct description of the system so successfully adopted in the English telegraph service by Mr. Preece, and which has been found equal to all the requirements at the present day.

At the same time, viz.: about 1860, the great expense of gutta percha, and its companion India rubber, induced many experimentors to look about for a substitute, and nearly all looked to asphalt and bitumen to supply this. We find recorded in Sabine's book, already referred to, that three methods of insulating conductors by means of asphalt had been prominently brought forward at that time.

Viz.: First, a system, invented by Mr. Nicolle, of rigid sections consisting of copper wire covered with hemp, impregnated with bitumen, and then enclosed in a hollow cane also impregnated with bitumen. At the ends the wires protruded about four inches for the purpose of making a joint, and, when the wires were thus connected, a short tube was placed over the ends of the two sections, and then filled up with insulating compound. This is clearly the progenitor of both the Edison and Ferranti systems of mains.

The second system is described by Mr. Sabine as follows:—

"Cast iron troughs are first placed in a trench, the wires are then laid in them on glass supports, and then melted gas pitch is poured in and a lid wedged on."

This system clearly suggests the lines on which the Callender Solid System has since worked.

The third system was that of M. Jallourou, of Paris, who covered his wires with strips of brown paper impregnated with insulating compound; and it is specially interesting to note that at the present time several cable manufacturers are claiming to have attained high degrees of insulation by precisely similar means. We know that Mr. Ferranti has adopted the same material for his high tension mains at Deptford.

In connection with these early attempts it is of interest to note the prophetic remarks of Mr. Sabine. He says :—

"The idea of asphalt insulation is not new; it has been tried, and has repeatedly disappointed its advocates. Nevertheless, it has never been satisfactorily proved that the system is a bad one, but rather that some element to success was wanting. . . . . There are now (1868) reasonable hopes that with the benefit of all the experience and failures bequeathed to them by earlier workers in the field, the promoters of asphalt insulation may succeed in their endeavours to give us cheap underground lines."

How this prophecy has been realised we shall see when we come to consider in detail the modern systems of underground mains. In all these early experiments the conductors, being only for telegraph work, were of small size, and the author has shown how little advance has been made even now in insulating conductors for this class of work, but with the discovery by Edison and others of the practical subdivision and distribution of electric light, a demand was immediately created for a more effective and cheaper method of insulating the large conductors required. Gutta percha was out of the question, owing to its high cost and also to its extreme susceptibility to changes of temperature. Vulcanised India rubber was tried, and gave great hopes of success, but was too expensive; and, until recently, the process of vulcanising was not properly understood, and the consequent uncertainty as to the behaviour and durability of the material caused it to be looked on with suspicion. Innumerable patents were taken out, and almost every known substance has been in some form or other tried as an insulator, and it is fair to assume that the systems now in use fairly represent the survival of the fittest.

Mr. Edison, who was so largely instrumental in creating the demand for the new insulation, was also one of the first to bring forward a complete scheme of underground mains; and his arrangement of copper bars, insulated with bitumen and enclosed in an iron tube, was a departure from recognised principles, though we have shown that it had been clearly suggested by Mr. Nicolle previous to 1867. On the Continent, a very important step was made by M. M. Berthoud Borel, who were the first to introduce the use of a fibrous material impregnated with bituminous compound, and enclosed in a lead tube.

In England, attention was chiefly devoted to improving the manufacture of rubber cables, and the method of vulcanising bitumen so as to render it flexible and elastic was introduced by Mr. W. O. Callender. It was at first thought that a well-insulated cable could be laid in the ground without any protection at all, but a very short experience was sufficient to dispel the idea; and many methods of mechanically protecting the cables were introduced.

Mr. Brooks, an American, introduced a system of covering cables with cotton, and drawing the cable so made into an iron pipe, which was then kept filled with resin oil. This system appeared to promise well at first, but has not answered the expectations of its inventor, owing to the great difficulty of keeping the pipes tight.

Modern electric light mains divide themselves naturally into two classes. First, those in which the conductors are permanently fixed in position; and, secondly, those in which the conductors can be withdrawn and added to as required.

The first class, which may be called the Solid System, has many advantages, especially in the important point of first cost, and, where the supply and current can be accurately gauged once for all, is no doubt the most satisfactory method of laying mains. It is, however, rarely that the final output can be estimated sufficiently closely, and it must be remembered that the mains must be calculated for the greatest possible service required, and this means a large outlay of capital which will not be remunerative for years, that is until the maximum output of the station is reached. The Solid System has, however, a special field of application in large cities, where the consumption can be pretty accurately known.

The Drawing-in Systems, on the other hand, permit of a small conductor being laid at first, and replaced by a larger one as the current to be carried increases, and the first cost need only be the cost of laying a line of pipes or conduits into which the cables can be drawn as required. This is a very real and important advantage, and one that appeals directly to that most important body—the investing public.

The chief systems in use at present are—

SOLID SYSTEMS:

The Edison Tubes
The Ferranti Tubes
The Callender Solid Bitumen System.
Lead Covered Cables.

DRAWING-IN SYSTEMS:

Various systems of Iron Pipe Conduits.
Callender Webber Conduits.
Earthenware Conduits.
Wooden Conduits

BARE COPPER:

The Crompton System.
Kennedy System.
St. James' Co's System.

There are a number of other systems that have been more or less extensively used, but the above list includes all those that have achieved success in practical working. We will now consider these leading systems in detail and endeavour to point out the merits and advantages of each.

The Edison System was, as we have already said, one of the earliest in the field and in the hands of the Edison Co., achieved a considerable success in America. It consists essentially of rigid copper bars of a semi-circular form, enclosed in an iron tube of such size as to allow a space of about a quarter of an inch on all sides of the conductor. The method of manufacturing these tubes is as follows:—The copper bars are each wrapped spirally with a special jute cord, and then the two or more conductors are wrapped together with another spiral covering in an inverse direction. The conductors thus treated are then inserted in the iron tube, and the ends closed with a vulcanite plug. An insulating compound composed of bitumen and ozokerit is then forced into the tube, completely impregnating the jute and filling up all vacant spaces. The tubes are usually made in lengths of twenty feet, and the conductors project from two to four inches at each end. At first it was usual to place only two conductors in each tube, and these conductors were then of a semi-circular form. The semi-circular form has been abandoned, and round copper bars substituted. The joining of the tubes is done by means of special boxes, which fit into the ends of the tubes by means of clamp and ball and socket joint. The conductors are joined by a short piece of flexible cable, having a small brass socket at each end, into which the bars are soldered. Plate I, Figs. 2, 3, 4 and 5. The cover is then bolted on, and the whole box filled with the same composition as the tubes, through a small hole which is finally sealed. Branch joints to the houses are made in a precisely similar manner, by means of a T shaped box. The use of the flexible connecting pieces allows of expansion and contraction of the copper without putting any strain on the joint. A complete system of boxes for connecting feeders and mains, and also for testing purposes has been elaborated. Plate I, Figs. 6 and 7. A full description of all the details of this system would require a paper to itself, and the author has, therefore, contented himself with explaining its chief characteristics. The whole system in the hands of Mr. Edison has achieved a decided success, but although it has been tried in Europe it has not been found to meet the requirements of our moister climate. The chief drawback to the system is the difficulty of maintaining the insulation at a sufficiently high figure. The joints, however well made, are a constant source of trouble, and even if perfectly good when first laid, the insulation will in a short time be found to be very low, owing to the expansion and contraction of the tubes.

This fault is so serious as to prevent the adoption of the system in any country where a high degree of insulation is required by the authorities. The system has never been used by anyone but the Edison Companies, and it is very significant to note that the Parent Edison Company in America has found it necessary to commence the manufacture of the Siemen's lead covered cable (Plate I, Fig. 8), to use in connection with the tubes. The Edison system has only been used for low tension currents.

A system which has many points in common with the Edison, but which also presents radical differences in others, is that of Mr. Ferranti. The system was adopted by the London Electric Supply Company, and designed and manufactured under the direction of Mr. S. Z. de Ferranti. It consists of an arrangement of two concentric tubes forming the two conductors. Plate I, Fig. 9. The inner conductor is a tube of copper insulated by spiral wrappings of brown paper, saturated with a composition, the exact nature of which is kept secret, but the principal ingredient of which is known to be ozokerit. The tube thus insulated is then passed into another copper tube, which is then drawn down tightly on to the paper; a further layer of paper is then wound on, and the cable thus formed is passed into an iron tube, and the whole is then filled with insulating compound under high pressure. The tubes are twenty feet long each, as in the case of the Edison tubes, but the jointing is carried out in a totally different manner. The author is indebted to the "Electrician" for the following description of the method of jointing:—

"The 20 ft lengths are laid down underground with wooden boxes, afterwards to be filled in with pitch, and the mains are separated by means of wooden bearers. The lengths of main having been laid down in the proper direction, a copper and an iron sleeve are slipped over on one end of the main. The copper rod is then pushed into the open end of the inner tube, and the two inter-fitting ends of two lengths of the main are forced together by an hydraulic press, the copper rod is rammed half into one inner tube and half into the other, and forms a good electrical connection between the two inner copper tubes. The copper sleeve is then drawn over so as to connect together the two outer copper conductors, and is corrugated on to them by means of a peculiar tool, which compresses together the outer members of each 20 ft. length and the copper tubular sleeve which connects them together. The tubular sleeve is shown in Plate I, Fig. 9. In the same way the iron sleeve G is then drawn over and corrugated on, connecting together the iron tubes of two adjacent 20 ft. lengths, and the interspaces between the iron outer tubular sleeves and the inner copper sleeve is filled with melted wax forced through a screw-hole, which is afterwards closed. In this way a joint is made in which the insulation between the inner and outer copper tubes is perfectly continuous, because the wax paper cones weld together under the pressure in such a manner that they require very considerable force to pull them apart. In order to allow for expansion, bends are placed at intervals with a slight double curvature of an S shape. The wood troughing is then filled in with pitch and a wooden cover laid on. At intervals in the main, street boxes are inserted, which allow the mains to be disconnected for testing a section of these boxes is shown in Plate I, Fig. 10. T boxes for branches are also used and are shown in Plate I, Fig. 11. When the joints are completed both these boxes are pumped full of heated resin oil, and the cover bolted on."

It is very difficult to get any reliable data about these mains, but recent reports seem to show that they are successfully carrying a current of 5,000 volts potential. The first cost, however, is said to be very heavy, but no information has been made public on this point.

The Ferranti mains embody many points of great interest; the most notable of which is the tubular form of the conductor. While this form was adopted solely for electrical reasons, and based on the data and experiments of Sir William Thomson on self-induction, it has, at the same time, great mechanical advantages, and has also greatly simplified the question of jointing. It appears, however, that the weak point of this system, as with the Edison, is in the joints; and the author anticipates that considerable trouble will be experienced here. It is well to note, however, that the Ferranti joint is a distinct advance on the Edison, and there is less likelihood of faults occurring from the expansion of the tubes. The future of these mains is being watched with great interest by all electrical engineers.

Under this class we also must include all classes of lead-covered cables, of which there are many different makes, but the general features are the same in each case. These cables, as used for both high and low tension work, consist of a strand of copper wire of varying sizes, usually 37 or 61 wires are employed. The conductor thus formed is wrapped with a fibrous covering of jute cotton or similar material, which is saturated with some insulating compound; the thickness of this insulating sheath varies with different makers. The Siemen's Company use only about $\frac{1}{8}$in., whilst the Fowler-Waring, Callender, and others use nearly $\frac{1}{4}$ in. This insulating coating is then covered with a coating of lead pipe, usually put on cold by hydraulic pressure; the lead is then usually protected with an armour of either steel wires or steel ribbon, purely for mechanical protection, and is finally covered with a coating of jute and asphalt. In some cases a layer of jute is placed between the lead and the steel, and this is a decided advantage, as it prevents any chemical action between the two metals. The cable thus manufactured is laid directly in the ground without any further protection than a light plank laid over it simply to indicate its presence to any workmen who may happen to be excavating at a future date. The chief difference in the cables made by different firms consists in the different compositions used for impregnating the fibre, thus we find—

The Fowler-Waring Company	use	Petroleum Residuum.
The Berthoud Borel Company	,,	Oxydized Resin Oil.
The Siemens Company	,,	A composition of Gutta Percha, Resin Oil and Stockholm Tar,
The Callender Company	,,	Refined Bitumen.
The Patterson Company	,,	Paraffine and Resin Oil.

All these materials have been found thoroughly efficient, and there is little to choose between them. During the last twelve months the Norwich Wire Company of Brooklyn have introduced the use of paper in the place of a jute or cotton wrapping, and claim to have obtained a very high degree of insulation. The jointing and branch services are carried out by means of special forms of boxes, which vary with each manufacturer, but the general features are the same, and Plate I, Fig. 12 shows that used by the Siemens Company which may be taken as fairly representative. Figure 13 shows the system adopted by the Berthoud Borel Company. This type of cable has been very extensively used in Germany and on the Continent generally, and has been in the last two or three years largely used in England and the United States. Under certain conditions these cables have been found fairly serviceable. The chief advantage possessed by this system lies in the fact that the cables can be laid directly in the ground, without any other protection other than that afforded by the steel sheathing, and this greatly facilitates the work of laying, especially in crowded cities. The drawbacks are, first and most important, the very uncertain action of lead when laid underground. The whole success of this class of main depends on the lead being kept intact, and the smallest puncture of the lead sheathing is fatal to the cable. It has often been said that lead will last practically for ever, when laid in the ground, and the recent discovery of lead conduits for water supply at Pompeii, which were in perfect condition after being buried over a thousand years, is instanced as a proof of this. Against this we must put the fact that time after time lead covered cables and lead pipes have failed in modern cities, and the experience of gas engineers has all tended to show the unreliability of lead in the polluted soil of modern cities. The reason appears to be that the lead conduits of ancient times were made from lead bullion containing silver, and probably arsenic and other impurities, whilst the lead of to-day is practically pure. It is claimed that the addition of two to three per cent. of tin has the effect of greatly increasing the power of resisting the action of the soil, but this has not been authentically proved, and until it is beyond all doubt, manufacturers will not add even this small per centage of tin, as it adds enormously to the difficulties of manufacture. On the whole, while lead-covered cables will always be useful in certain cases, it is unlikely that they will ever be generally adopted, owing to the great uncertainty of their durability.

The only other solid system that has met with an extended application is the Callender Solid Bitumen System. In this system stranded copper wire cables form the conductor, and are insulated with a thick sheath of bitumen vulcanised by the Callender process, and then wrapped with two or three tapes impregnated with refined bitumen, and are finally braided and asphalted over all. The cables thus insulated are laid in rectangular cast iron troughs, and are carried on spacing bridges of asphalt or dry wood, impregnated with bitumen. Plate I, Fig. 14. The bridges are designed so as to allow a minimum distance of at least half an inch between the cables and the sides of the iron casing. Into this space refined bitumen is poured, and allowed to set, and a cast iron lid is then bolted on. The whole forming a solid mass, absolutely impervious to moisture, and having great mechanical strength. Joint boxes are placed at intervals as required, and are made water tight by sealing with bitumen as shown in Plate II, Fig. 15. Service boxes of various forms are used for from one to six house services, and the house wires are carried into the houses by means of either high insulation cables in iron pipes, or lead covered cables. The main troughs are usually of cast iron, about 3-16ths in. to 5-16ths in. thick, having socket pieces on one end, so that when fitted together the surface inside the trough is of one level. Plate II, Fig. 16. For carrying the mains round corners, and for changing levels, circular pieces and curved troughs are made, but considerable deviation from the straight line is possible with the ordinary type. Brick and cement trenches are sometimes used for special situations, but they are expensive and offer no advantages over those of cast iron. In connecting the mains together, two different methods have to be considered—(1) Those in which the joint is solid, permanent, and covered in with the insulation in the same manner as the rest of the cables, and (2) those which require to be occasionally disconnected, either for change of load or for testing purposes. In making the solid connection, the method shown in Plate II, Fig.