THE

ELECTRIC TRAMWAYS OF SYDNEY, NEW SOUTH WALES.

I.—Distribution.

The distribution has been placed first; in order that the general features of the Sydney lines may be considered. Unfortunately, Sydney and its suburbs, abounding in winding roads and heavy grades, present very great difficulties to the Tramway Engineer.

There are very few straight roads, and all the lines terminating at the harbour or ocean foreshores rise very rapidly, with grades from ten per cent. or less. A glance at the plan of Sydney shows the straggling nature of the suburban lines, all of which are very long and difficult to operate.

The total length of track consists at present of thirty-nine miles twenty-eight chains of double track, and seventeen miles sixty-five chains of single track. Of these, ten miles fifty-four chains double track, and nine miles fifteen chains of single track are now working electrically, and by the end of the year it is anticipated that there will be a further addition of six miles fifty-six chains of double track, and four miles sixty-one chains of single track.

In many cases the long lines have very heavy grades at the distant end, such as Coogee, Bondi, etc., and it is necessary to move very heavy loads from these pleasure resorts at times, and on the North Shore lines all the heavy business and holiday traffic is delivered by ferry at the water's level, and has to be lifted in all cases up to the high levels on to tracks abounding in curves and grades. For example, the Mosman line rises two hundred and ninety feet in four thousand six hundred and twenty feet, *i.e.*, 6·2% average grade for that distance. Neutral Bay rises from the water's edge with a grade of 9·5% for half-a-mile.

It can readily be conceived therefore, that the consumption of energy is much above the average per car-mile of the average city with easy grades and straight tracks. I suppose there are few cities in the world with so many difficulties for traction work as Sydney. It is, of course, common knowledge that the Railway Commissioners propose to convert the whole of the system to electricity, and the work is being rapidily pushed on. Already, the whole of the North Shore lines are being operated by electricity, generated mostly at Ultimo. The George and Harris Street line, Dulwich Hill and St. Peter's, and Rose Bay lines are now working electrically, and in a few weeks, the Public Works Department expect to be able to hand over the Cook's River Extension (two miles fourteen chains), to be followed by the Spit Road Extension (one mile forty-two chains), and Dover Road Extension of the Rose Bay line (one mile five chains). These are new roads, and are an addition to the mileage of four miles sixty-one chains of single track. The Commissioners have stated that they anticipate the conversion of the whole of the Western Suburbs to be ready by the end of this year.

The overhead construction of the tramways has been very carefully carried out, all the fittings and material having been selected with a view to strength and reliability after experiments on various types. In a paper, read by the author before the Electrical Association of New South Wales last year, the details of the overhead wiring were set out at length, and it will be sufficient therefore, if the general nature of the work is described.

Poles.—The George and Harris Street line was equipped by the Public Works Department with Mannesman steel poles, with iron brackets, and cast-iron ornamental bases and fittings. The poles are mostly set in the centre of the street, the track being spread to seven feet centres to allow sufficient room. There is a protective trachyte kerb around them, and now that the increased tram traffic practically occupies the whole of the centre of George Street, there seems to be little objection to them on the ground of interfering with vehicular traffic.

Poles are in all cases set in concrete, the holes being excavated about six feet deep.

In the conversion of the existing lines, the side pole system has been adopted with span wires across the streets, and in some cases these poles are of steel, but without any ornamental base. The cost of the base was not considered to be justified on the grounds of its decorative value. In most cases the poles are of ironbark, twenty-nine feet six inches long, and as best shown on the drawings, they vary in size according to the nature of the stress they have to withstand, It is not unusual to apply a horizontal stress of one thousand five hundred to two thousand pounds, to a pole at about twenty feet from ground level, the pole being set six feet in the ground.

It is considered by the author, that the design of wooden poles used is an handsome one, and the advantage of the insulation provided by the wood, give less liability of an interruption to the service by short circuits at the pole, due to the breaking down of the insulation of hangers, etc., and the fact that about ten shilling's worth of fittings per pole are saved, all confirm the opinion that wooden poles should be used wherever possible. Another valuable feature of the wood pole, is that it can be obtained locally, whereas the steel poles are imported. The prices of steel poles delivered in Sydney vary from three pounds to twelve pounds each; and wooden poles cost, from thirty-three shillings to forty-five shillings each. The cost of setting the poles varies according to the nature of the ground, etc., and may vary from seventeen shillings and sixpence to three pounds.

The trolley wire which is used on the city side of the harbour is figure 8 section, area one hundred and sixty-eight thousand circular mils (0·13 square inches) held in a special clip by the top rib, thus presenting a clear under surface for the trolley wheel and avoiding any bumping or shock as the wheel passes the fitting. The trolley wire is insulated from the cross spans by a Billings and Spencer hanger, a sample of which is shown. The span wires are of galvanised steel rope, and at each end are attached to insulators, and an adjusting screw or turn-buckle is provided at one end of each span, so that they may be tightened up and the sag adjusted. In all cases where steel poles are used, this double insulation is provided; but in the case of wooden poles, only the insulation in the hangers is used, the pole itself being relied upon for the second insulation.

On curves, the trolley wiring is pulled into shape by pull-off wires and suitable fittings, and the proper arrangements of these is one of the nice problems in electric traction work requiring an expert knowledge.

On the part of the North Sydney and at Rose Bay, the trolley wires are supported by side brackets in wood poles, and in all cases two trolley wires are provided on single tracks, one for the up and the other for down traffic. The number of feeders required is therefore reduced. At North Shore the trolley wires are circular (No. O.B. and S. gauge) and are not suspended over the centre of the track as on the City side of the harbour. This arrangement permits of the use of a shorter bracket for the single lines, and the trolley base and board are mounted on a stanchion at the side of the car, instead of over the centre of the car as usual.

The trolley wires are divided into sections by fittings known as section insulators, a sample of which is shown. These were specially designed locally, after many experiments, with a view to sustaining the necessary stress required in the use of a figure 8 trolley wire. The position of these section insulators is determined with a view to meeting traffic requirements in case of emergencies. The connection between the successive sections of trolley wire is made by means of cables and switches similar to those used for the feeders. By means of these section insulators, therefore, it is possible to operate certain sections of the line independently of the others; a very necessary provision in case of fires or injury to the overhead construction, etc. As the position of such insulators is a matter of purely departmental interest, no further reference is made to the matter; but the determination of the position of such insulators is, together with that of the most suitable feeding points, a highly technical matter. In many cases section insulators are provided, but are fitted with metal bridges, so that while under ordinary circumstances they do not act as section insulators, they may however be so utilised in cases of emergency with the minimum loss of time, by merely replacing the metal bridge by an insulating wooden one.

The feeder cables are of two types, viz., underground and overhead. The former start at the switch-board at Ultimo, and pass along Liverpool Street to George Street in Callender-Webber bitumen casing, laid under the footpath, except in George Street, where it is laid in the concrete foundation of the track in the seven feet space between the tracks. The conduit is of a bituminous nature, moulded in lengths of a few feet and provided with a number of circular ducts, two and three-eight inches in diameter, running from end to end, and each length is jointed to the next as laid in the trench. The whole of the route is divided into sections, varying in length from one hundred and fifty feet to five hundred and twenty feet, and at the end of each section is built a brick pit or junction box. The pits are about four feet by three feet, and five feet deep with nine inch walls, cement mortar being used. They are drained to the sewer. The length between pits is again divided up by draw boxes, which are in some cases cast iron boxes, forty-two inches by thirty inches by fifteen inches deep, and in others brick pits, one being no less than ten feet deep to allow of cables passing under pipes, &c. The conduit ends abut into the brick pit, and the lengths of conduit being jointed together form a series of tubes from junction pit to draw box, and so on to the next box. It was found necessary to provide many more draw boxes than was anticipated by the contractor, owing to the up and down nature of the route and the difficulty of drawing in the cables.

The cables themselves are of Messrs. Callender & Co.'s manufacture, provided with their patent vulcanised bitumen insulation. They are not lead sheathed or armoured, and are supposed to be sufficiently protected from mechanical injury by the bitumen casing. The system was installed as a drawing-in one, so that a fault in or break down of any cable might be quickly remedied by removing the cable and replacing it by a good one. Fortunately, so far, there has been no necessity to attempt this. The ends of the sections of cable are provided with brass thimbles, and are connected together in the pits, being hung free in the air. Surface leakage from the thimbles is guarded against by specially insulating the ends. The original system as installed did not prove satisfactory. The junction boxes were of cast iron with an inner lid, as provided in the case of draw boxes, and the connections were made on a marble terminal or junction block. The inner lid was supposed to be sealed by bitumen run in hot, but experience has shown that this protection is of little value, as, owing probably to the different rate of expansion between the iron and bitumen, cracks occur which admit water. In addition, it was found that the clearance between the live conductor and the box was insufficient, especially as the latter was practically at the same potential as the rail. There seems to be no doubt that the only successful method of jointing the ends of cables in a drawing-in system such as is installed in Sydney, is by the use of commodious brick pits, well-drained, and with a proper system of insulation for the ends of the cables. Fortunately, in the case of Callender's cables this is easily obtained, but if these cables had been insulated with paper, as is the case in very many modern installations, the insulation of the ends would have been a much more difficult matter. Another great feature in connection with this system is the question as to whether the bituminous material used for the conduit will maintain its shape, subject as it is to certain temperature effects, and heavy street traffic.

The area of each cable is 0·45 square inches, and the overall diameter, one and five-eighth inches.

Seven cables run from the Power House to Liverpool Street, and from there along George Street towards Dawes Point. These cables terminate at various points, such as Liverpool Street, the Markets, Hunter Street, etc., where they are connected to the trolley wires by a feeder switch on the poles. Some of the cables go as far as Dawes Point, where they continue to Milson's Point by the submarine cables, and thence to Ridge Street, North Shore, by overhead cables, delivering the necessary energy for the North Shore system. In addition to the above, an underground feeder is run from the Power House in conduit, to a position midway between Gipp Street and the intersection of Pitt and George Streets.

Overhead Feeders.—Wherever possible, the feeders have been run overhead on wooden and steel poles. In this case, the type of feeder used is very different to that for the underground system. It consists of hard drawn high conductivity copper in the form of cables, rope laid, five hundred thousand circular mils area, insulated with treble braiding, and a bituminous compound (so-called weather-proof cable). The insulating value of the covering is not relied upon. Cables of this nature have been run from the Power House at Ultimo to the Rushcutter's

Bay Power House, Cook's River, Dulwich Hill, Codrington Street Newtown, Leichhardt and Balmain, and have also been used at North Sydney. The necessary insulation is obtained by the use of the John's toggle clamp feeder insulator, of which samples are shown. This, by experience, has been found to be the most satisfactory form of insulator for this purpose. Owing to the great weight of this cable (approximately two lbs. per foot) it is necessary, in order to keep the sag within reasonable limits, to apply considerable tensile stress amounting to as much as two thousand five hundred lbs., and when it is necessary to go round a corner, special precautions have to be taken to relieve the insulator pins of the strain. Hardwood (Ironbark or Locust wood) pins are used on the straight, and steel pins at the angles. At all angles the cable is placed in the neck of the insulator and not in the toggle clamp, in order to deliver the strain on to the pin closer to the cross-arm. The cross-arms used for this work on wooden poles are made specially heavy, and those on the steel poles are made of cast-iron. All such cables should be built rope laid and not cable laid, in order to facilitate splicing, as it is impossible to rely upon a cable joint, all joints are spliced and sweated. Connections to the trolley wire are made at predetermined points by a well insulated 19/12 cable through feeder switches, which are in boxes attached to the poles; the cables being led to the switches through wrought iron piping. It is very necessary in these switch boxes to ensure that they are water tight, also that in all cases they are protected by a special lock.

In all instances the shortest possible routes are naturally chosen for feeders, but unfortunately, Sydney suffers from such an excess of telegraph and telephone wires erected overhead, that it is extremely difficult to run a feeder in any direction, without incurring considerable expense in alterations to telephone lines, etc.

PERMANENT WAY.—The permanent way of the Sydney Tramways has been very considerably improved of late, following the universal tendency to increase the weight of rails. Many of the original lines laid were rails of forty-two pounds, and these have given place to sixty, seventy and eighty-three pounds, and sundry other sizes as traffic is increased. Most of the new lines, as constructed by the Public Works Department, are laid with a standard eighty-three pounds grooved rail, of which a sample is shown. In all cases the rails are of the Vignoles' pattern, laid on hardwood sleepers to the standard gauge of four feet eight-and-a-half inches. In the suburbs they are laid in macadam with blue-stone ballast, but on most of the city lines, as laid by the Railway Commissioners, the rails are carried by hardwood sleepers in concrete. In some cases, such as the George and Harris Streets Line, the roads are merely laid upon concrete. This however, has not been found successful, particularly when used, as it is, in conjunction with wood blocks. The almost universal practice of laying the rails butt jointed is now followed. A special type of construction has been laid from Bridge Street to the Redfern Station, with rigid joints and machined fishplates, the rails being electrically connected by strips of thin copper squeezed between the fishplate and the web and flange of rail. The important feature of the permanent way from the Electrical Engineer's point of view is, of course, its electrical resistance made up of the resistance of the rail, and which is much more important, the resistance between successive rails. The latter has to be reduced to a minimum by a suitable class of bond. The Author ventures to think that no bond has yet been proved perfect. Many experiments have been carried out locally, with a view to testing the efficiency of the different ways of electrically connecting successive rails. The greater part of the track has so far been bonded with what is known as the Harold P. Browne plastic bond, consisting of a plastic mercury and tin amalgam which is applied between the web of the rail and the fishplate on each rail. The web of the rail and a corresponding spot on each fishplate are faced to a bright surface, then amalgamated with a mercury-sodium alloy and water. Between the brightened faces thus obtained a plastic amalgam is squeezed, by the fishplate being retained in position by a cork case, samples of which are shown. The whole efficiency of this bond (which, while making good contact, is as good as could be desired), depends upon the maintenance of the intimate contact between the amalgam, the fishplate, and the web of the rail. Unfortunately, no system of rail joint has yet been proved by experience to be free from a certain amount of working or movement. It is only by maintaining this intimate contact, and by the exclusion of all moisture, chemical salts, etc., that this bond can hope to be successful. Some of the other systems of bonding tried, consist in carefully drilling holes through the web of the rail, then expanding in them a soft copper thimble by means of a steel drift. This is done in each rail, the copper thimbles of course, being connected by a flexible cable or solid copper bar. Samples are shown of the various types of bond that have been used. The only reliable test of a bond is time, and although much experience has been gained here and elsewhere on various types of bond, the Author does not feel disposed to give any definite opinion upon the merits of the various types, whose virtues are so loudly acclaimed by their manufacturers. A few trial samples of sixty feet rails have been put in position for testing purposes, but there are not sufficient data at present to justify any expression of opinion upon the merits of the system. The proper bonding of the track, and the reduction of its resistance to a minimum, is one of the most important matters with which the Electrical Engineer has to deal, inasmuch as the safety of all underground metallic systems, such as water pipes, gas pipes, pneumatic tubes, etc., depends upon the reduction of the resistance to a minimum, in order to keep down leakage of current from the track to such systems. And in a city like Sydney, where all the telephones are worked on an obsolete system of single lines and earth returns, the importance of a well bonded track is much accentuated.

The question of distribution therefore, resolves itself into laying out to suitable points along the route, feeder cables which will deliver the necessary current to the trolley wire with only such a loss of pressure as will permit of the efficient working of the motors, and suitably bonding the rails. In all cases it has been the endeavor to utilise a standard size of cable and a standard form of construction. The trolley wiring which distributes the power from the feeders to the cars has in all cases been erected with a similar view to standardisation, and all the materials and fittings used have been evolved after an impartial consideration of the value of the various patterns upon the market.

II.—Generation.

The electrical energy for the Sydney Tramways is mostly generated at the Power House, situated in William Henry Street, Ultimo, on a site which is fairly well situated for the obtaining of coal and water for condensing purposes. The Power House which the members will have an opportunity of visiting on Friday night, contains at present four sets of direct coupled compound engines and generators. Each set comprises an Allis Corliss type of cross-compound condensing engine of the following appoximate dimensions :—

High press cylinder, twenty-six inches diameter.
Low press cylinder, forty-eight inches diameter.
Stroke, forty-eight inches.
Horse-power, one thousand two hundred, and capable of withstanding a temporary overload of fifty per cent.

Each engine is fitted with Reynolds-Corliss valve gear, E. P. Allis & Co.'s manufacture, with an ordinary Porter governor actuating the cut-off of high and low press cylinders. In addition to this governor there is an overload one, which actuates the special stop valve, closing it when the speed rises five per cent. above or below the normal of one hundred revolutions per minute. The fly-wheel, which is built up of cast-iron arms and segments, is reinforced by a system of steel plates forming the rim, which are held in position by steel rivets and turned up in situ. The crank shaft is twenty inches in diameter, the high and low press crank shaft bearings are thirty-six inches in length. The armature is directly coupled to the main crank shaft. The crank shaft fly-wheel and armature weigh seventy tons. The diameter of the fly-wheel is twenty feet, with a speed of one hundred revolutions per minute. The dynamo, which was manufactured by the General Electric Company, is of eight hundred and fifty kilowatts capacity, capable of sustaining a temporary overload of fifty per cent. The field is of cast steel provided with twelve poles, each wound with a shunt and a series winding, the generators being wound for ten per cent. over compounding, that is to say, a rise of ten per cent. in the potential between no load and full load. There are twelve sets of brush holders arranged alternately, positive and negative, and connected alternately to the + and − rings. The construction of these generators and engines has been so well described in the technical journals, being a standard pattern, that there is no need for further discussion of them. To each pair of engines is fitted a Wheeler surface condenser, the vacuum being provided by a Blake steam air pump. The boilers consist of two batteries of seven boilers each of two hundred and fifty horse power capacity nominally, designed by the Tramway Construction Branch, Public Works Department. They are of the under-fired return tube type, and are fitted with Alva's patent hot draft, that is to say, the furnace is fed with air heated in flues surrounding boilers. The flues terminate in a stack two hundred feet high, ten feet internal diameter at the base—forming one of the most imposing stacks in the city. The batteries are arranged in groups of four with a system of steam piping, such that any one boiler may be cut out of action without interfering with the operation of the others. The steam piping from the boiler room to the engine room has been