

ELECTRIFICATION OF SYDNEY AND SUBURBAN RAILWAYS.

II.—THE SIGNALLING SYSTEM.

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Introduction.

In attempting to describe the signalling system as a part of the work involved in the electrification of the suburban railways, one is faced by the purely academic question of the extent to which the signalling system, as carried out, is actually contingent on electrification. Strictly speaking, the conversion of a section of line from steam to electric traction with overhead structures involves very little beyond the modification of the signal structures so as to maintain a good view of the signals by the drivers. Instances may be quoted where the electrification of a railway has involved nothing more than this in respect of the signalling system.

In practice, however, the electrification of a suburban railway involves, from a signalling point of view, a great deal more. Electrification is usually associated with rapid

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acceleration, fairly high speed, and above all things close train headway. It has become an axiom in electrification practice that these conditions can be satisfactorily fulfilled only by the aid of an efficient signalling system, and it is indeed recognised that, without such a system, the requirements could not be met and many of the advantages looked for in electrification could not be obtained. A further necessity arising out of electrification is due to the fact that one man only is employed in the driving compartment of electric trains, and hence means must be provided to make up for the factor of safety associated with the presence of the second man on the footplate of a locomotive. In working out the problems arising from these conditions, it is obvious that, while the necessity for a high degree of safety is the paramount consideration, the need for providing for the maximum possible train movements comes next and that the latter is actually dependent on the former.

In dealing with the subject of this paper, it is, therefore, intended to review the principal features of the New South Wales suburban signalling system as a whole without special reference to such portion of it as is actually the result of electric traction, and in so doing the author may anticipate criticism by acknowledging that in some of the work that is being done there is little of originality, and that the accepted practice under similar conditions elsewhere has been followed. For this reason, also, many of the better-known features, which are common to all signalling systems, will be but lightly touched on so as to avoid unduly extending the scope of the paper.

It has been said that the mere fact of electrification does not in itself call for a reconstruction of an existing signalling system and that, in fact, instances could be quoted where a line has been electrified and the signalling has been practically undisturbed. Under such conditions, with the growth of the traffic, modern methods of signalling would, however, inevitably have to be introduced sooner or later, and this work would then have to be done under the unfavourable conditions of rapid and growing traffic.

Upon the suburban area of the New South Wales Railways, due to the policy of the Commissioners extending now over a number of years, the installation of modern signalling equipment has largely preceded the work of electrification, so that, when electrification was finally decided upon, a very large amount of the necessary signalling had already been done. The approximate route mileage in the suburban

area covered by the Commissioners' present electrification scheme (apart from the City Railway) is 102 miles of double track, and of this mileage 66 miles are already equipped, or are in process of being equipped, with automatic signals, thus leaving a balance of 36 miles to be dealt with as the electrification work proceeds.

The features of the system to be described may be grouped broadly under three heads, viz. :—

- (i) The power supply ;
- (ii) The signals themselves ; and
- (iii) The interlockings.

These will be referred to in the above order and some description will then be given of certain of the more important ancillary parts of the system and equipment.

Power Supply for the Signalling System.

(a) *Electrical.*—It is hardly necessary to say that in an extensive and concentrated signalling system the use of primary batteries is out of the question and, this being the case, the system must be dependent on an electrical power supply. In this matter, like a celebrated character in fiction, the Signal Engineer, although his requirements as to quantity are extremely modest, requires his supply to be “both regular and constant.” With an intensive traffic, the temporary stoppage of power brings about immediate delay, and this being cumulative in its effects, disorganisation quickly results. This is bad enough when only the signals are affected, but the difficulties which the failure of power supply brings about in interlocking areas are for various reasons still more serious. It is thus necessary to provide a complete and comprehensive system of generating plant and a transmission system which is to be used for signalling purposes alone.

The power supply for the Sydney suburban signalling is provided for by three-phase, fifty-cycle generators in the main power house, with three-phase transmission at high voltage to the sub-stations. From the sub-stations along the various routes there are cables carrying 2,200 volts, single-phase, and these are laid out so as to form a complete ring system with switching at the sub-stations and at signal boxes for the purpose of isolating sections in an emergency. The power house plant is in duplicate, and the ring system of feeders makes the system continuous. The

signalling supply at 2,200 volts is distributed along the railway route in armoured concentric cables laid in treated wooden troughing, supported on concrete pegs. Upon the City sections, and in other special cases, a concrete trough is used. At each transformer location, Reyrolle interlocked switch-gear, fuses, and a transformer are provided on the 2,200-volt mains, current being stepped down at the location to 120 volts for signal and point operation. The switches are of the oil-immersed enclosed interlocking type, and are so arranged in groups to provide for isolating the section of cable between the transformer locations on either side. There are three of these enclosed switches at each location; the centre switch is automatic and connects to the transformer, and in the event of over-load will immediately open off the line.

At the principal interlockings, see Fig. 1, sub-mains are provided between each transformer location with complete switching arrangements in order that service from an adjacent location can be obtained in the event of a transformer breaking down or being taken out of service from any cause. These sub-mains, carrying current at 120 volts, can also be used to provide for intermediate supply at any points between the main locations. The interlocking of the Reyrolle switches renders them fool-proof. The circuit arrangement provides for transformers in duplicate, but only in the more important locations are these installed.

From the 120-volt signalling side of the transformer location, current is taken to the signalling busbars and then transformed by separate transformers to the voltages necessary for operation of the various functions as under :—

For signal and point operation and electrical detection—
120 volts from the main transformer.

For signal lighting—12 volts.

For track circuits—4, 6, 8 and 10 volts.

For track diagrams—12 to 24 volts.

For electric lever locks—14, 25 and 120 volts.

Air-cooled transformers, made to the requirements of the British Standards Specification, are used for these operating circuits. Separate transformer secondary windings are used for each track circuit. In all cases these track windings are kept distinct from all other operating circuits.

(b) *Electro-Pneumatic*.—Compressed air, at a pressure of from 65 lbs. to 75 lbs. per square inch, is being used for

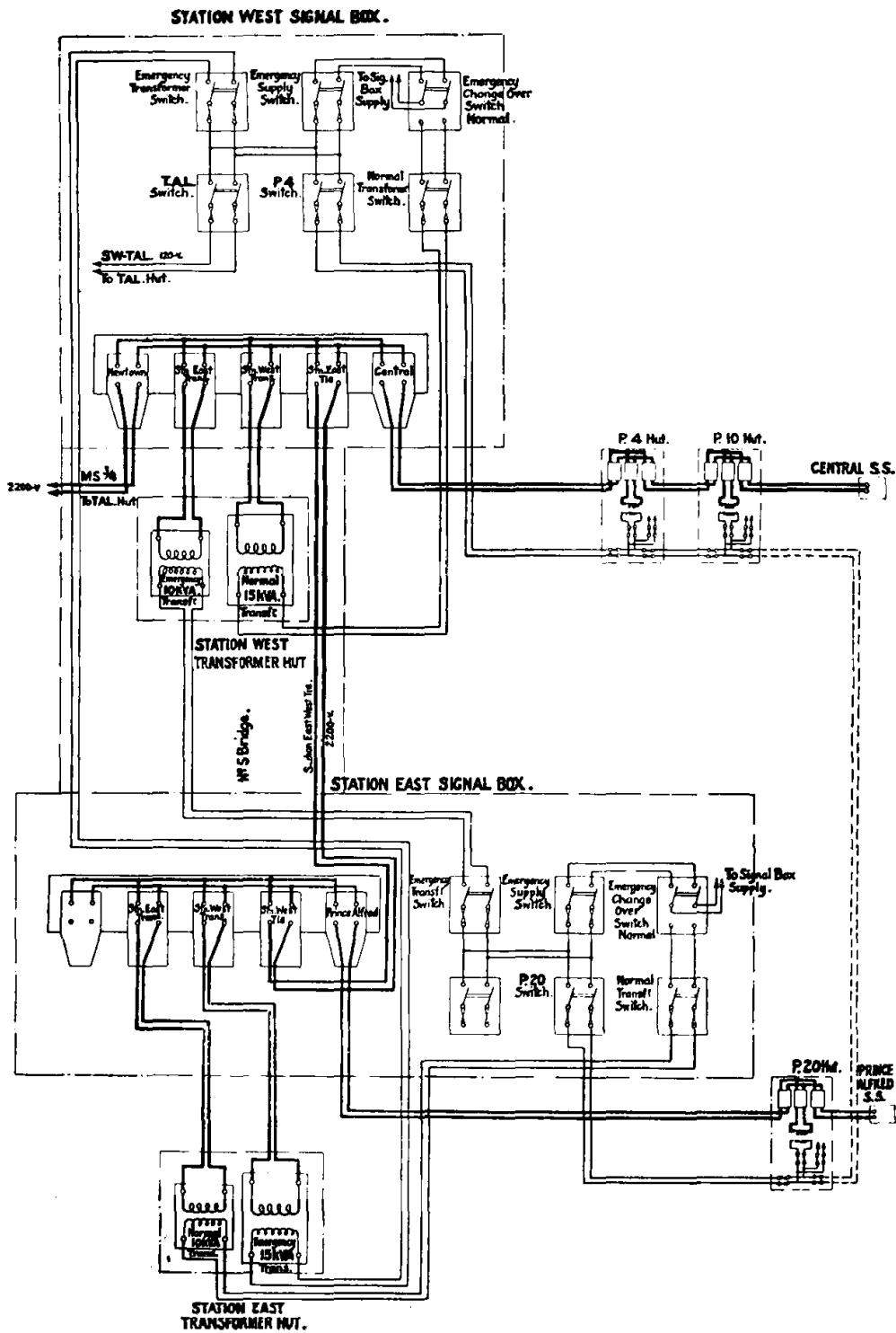


Fig. 1.—Power Distribution at Interlockings.

the operation of electro-pneumatically worked points, signals, and train stops, in the area St. James Station to Homebush Junction and to Sydenham Junction. This air is furnished by a duplicate set of Ingersoll-Rand electrically-driven air compressors, located in the Signalling sub-station at the southern end of Redfern Station. Each compressor is capable of compressing 930 cubic feet of free air per minute up to a pressure of 90 lbs. per square inch, and ordinarily one compressor is capable of supplying the present requirements, working about 50 per cent. of the time. The compressors cut in and cut out automatically on a pressure range of 65 lbs. to 75 lbs., the operation being entirely automatic through a set of contactors mounted on the switchboard.

The air is transmitted along the railway route in 2-inch galvanised steam piping, from which it is distributed to the various functions in $\frac{1}{2}$ inch branch pipes. Reservoirs and isolating air valves are located at frequent intervals along the route. The main reservoirs assist in maintaining a uniform supply of air, and small auxiliary reservoirs of two cubic feet capacity are located at each function to provide for the collection of water formed by the condensation due to the gradual cooling of the compressed air. All these auxiliary reservoirs are provided with outlet valves which are opened periodically when the compressed air effectually ejects the water.

The main compressors at Redfern will, for some time to come, be capable of carrying the load for the entire system, but as a precaution against failure, there are being provided at the principal power interlockings outside the Sydney Station area, viz., at St. James Station, Sydenham Junction, Ashfield and Strathfield Junction, auxiliary air compressors equipped with automatic cut-in and cut-out relays, and these will operate on a reduction of air in the main pipe line. The practice is to set the control relay to cut in at 60-lbs. air pressure, and to cut out at 75-lbs. In addition, an emergency air service is provided from the steam-driven air compressing plant at the Eveleigh Workshops, but such is the efficiency of the electric power supply that this emergency service, although it has been available for many years, has never yet been made use of.

Signals and Signal Aspects.

The automatic signals employed on the New South Wales Railways have been evolved in three distinct stages. The automatic signals, which were first installed, are lower-quadrant

and show two arms (a "Home" and a "Distant") at each location. Then followed upper-quadrant signals in which, by means of the upper inclination of the arm at 45 and 90 degrees, it is possible to give the same three indications ("Stop," "Caution" and "Clear") as by the two-arm signals. Finally came the color-light signals whereby these three indications

INDICATION	STOP	PROCEED Next signal at "Stop"	PROCEED Next signal at Caution, but signal within braking distance at "Stop" or next signal at "Medium" for turnout junction.	PROCEED Next signal at "Caution" or "Clear"
NAME	STOP	CAUTION	MEDIUM	CLEAR
Automatic Signals.				
Signals at Interlockings.		 Straight Turnout	 Straight Turnout	 Straight

Fig. 2.—Color-Light Signal Aspects.

are given, both by day and by night, by colored lights in the same combinations as are displayed in the semaphores. In the case of the color-light signals, it is, however, possible to give a fourth indication by the use of a yellow lens. The meaning of the yellow light is "Proceed at medium speed" and thus in the color-light signals the four indications are:—"Stop," "Caution," "Medium," and "Clear." (See Fig. 2.)

It is not proposed to give any detailed description of the upper or lower quadrant signal mechanisms, except to say that these are operated either by electricity or compressed air as may be convenient according to situation. Reference may, however, be made to the electro-pneumatic upper quadrant signal mechanism which has been developed on these railways and an illustration of which is given. (See Fig. 3.)

The color-light signals employed have also been developed in the Department, and comprise a lamp case fitted with light units made up of clear dioptric lenses, $8\frac{3}{8}$ inches in diameter. Behind each lens is a colored roundel of the same diameter, and the centre of the clear lens is frosted over a circular area of about 2 inches diameter. Both these pre-

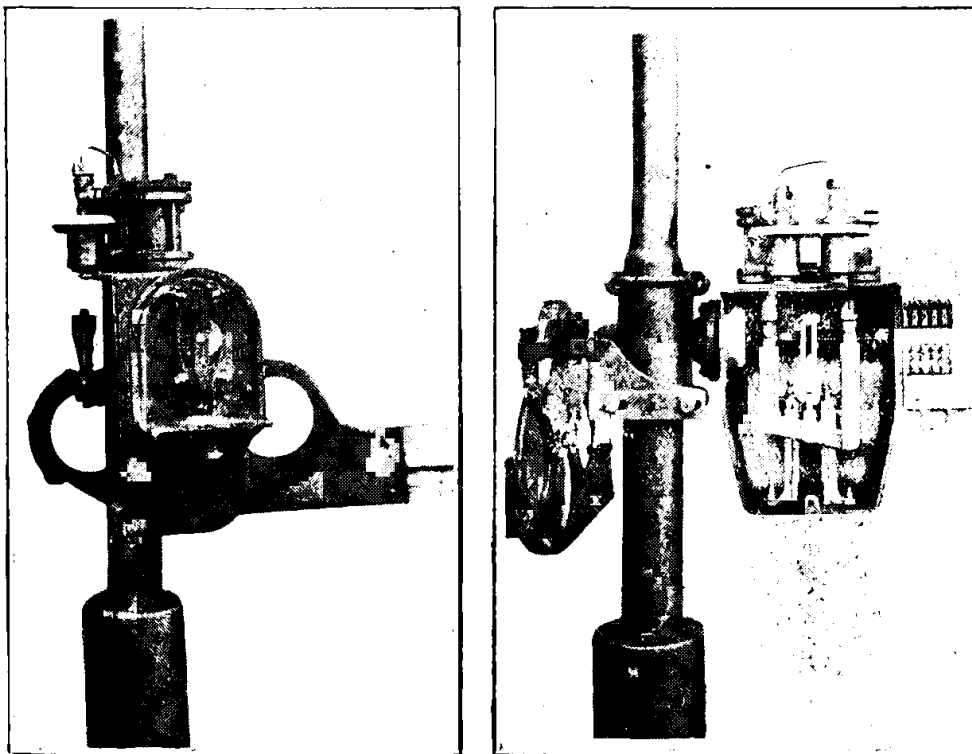


Fig. 3.—Side and Back Views of Electro-Pneumatic Upper Quadrant Signal.

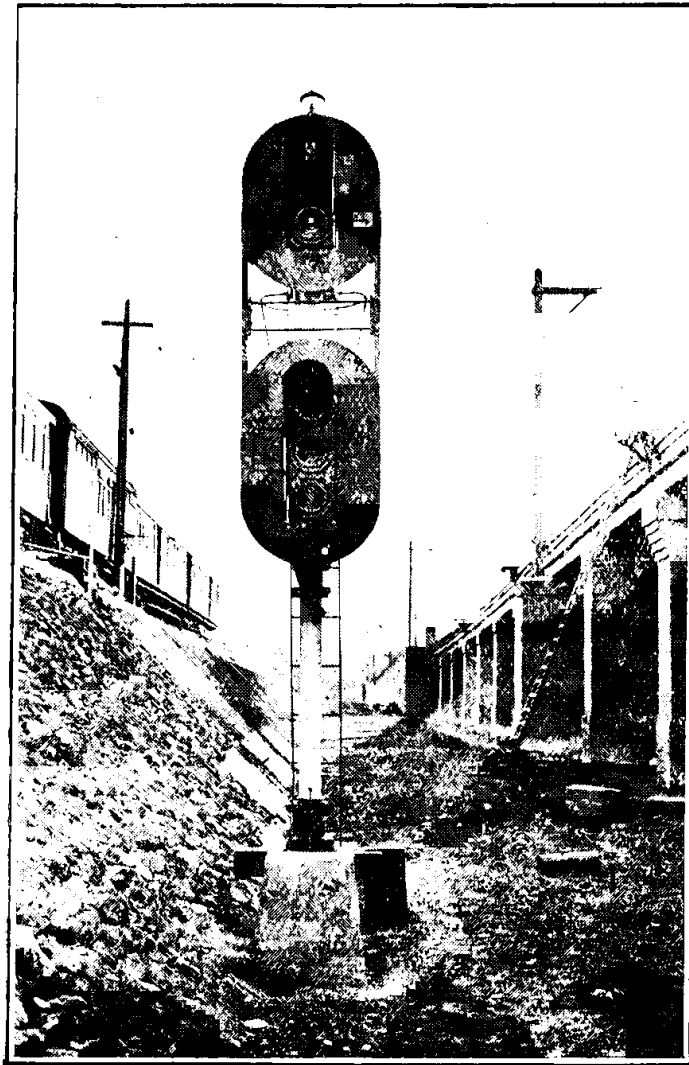


Fig. 4.—Color-Light Signal.

cautions have been taken with a view to avoiding phantom lights when the sun is shining in a position almost horizontal to the signal lens. The light signals are suitably hooded and provided with a background. (See Fig. 4.) The lamps employed have semi-concentrated double filaments, one at the exact focal point of the lens and the other slightly out of focus. Thus, if one filament fails this becomes apparent by the diminution of the light. The lamps are 36-watt and are under-run at about 12 volts.

From what has been said, it will be seen that the indications of the color-light signals now being employed are merely a development of the night indications of the original semaphores, with the addition of the fourth indication made

possible by the use of the yellow light. It should also be explained that these signals always display two lights, the upper indicating the state of the section immediately in advance, and the lower affording an advance indication of the signal or signals next in advance. The upper yellow light is made use of to show a driver that he is about to be turned through a junction which calls for a reduced speed, and the lower yellow light indicates that, although the next signal ahead is not at "Stop" there is a signal at "Stop" within braking distance and that, therefore, on that account he must reduce speed. This method of light display has the supreme advantage of being in conformity with the system in use throughout the whole of the railways of the State, and a driver is thus never under the disadvantage of having to accustom himself to a different series of indications on entering automatic territory. Throughout the whole of the New South Wales Railways, the signal light indications always have the same significance. The system has the further advantage of obviating the necessity for the use of what is known as the "Red Marker Light" which is used elsewhere to distinguish automatic signals from interlocked signals, and thus a driver, if he sees a red light, can never fail to realise that he must

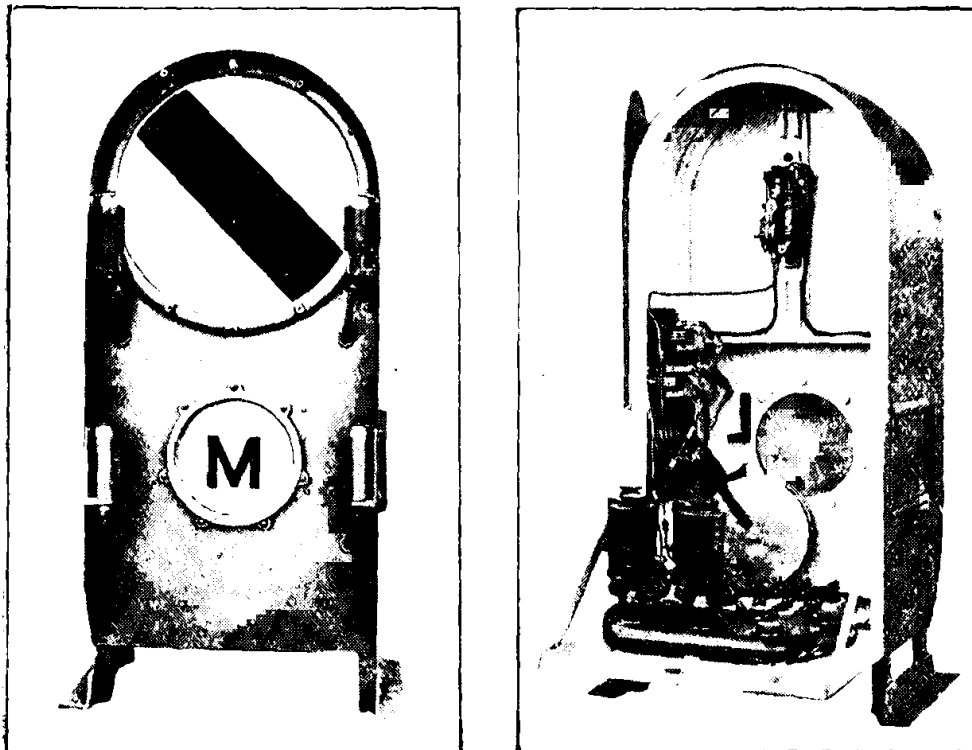


Fig. 5.—Electro-Pneumatic Ground Signal.

take immediate action. Where it is necessary in busy areas to provide for low-speed signals, indicating a restricted clearance, this indication is displayed by means of a small green light both by day and by night, fixed considerably lower than the ordinary arm or lights, and visible only at short range.

The color light signals are particularly well suited to the conditions on electrified lines where the overhead structures make it extremely difficult to maintain a good sight for semaphores of the arm type.

For shunting movements and other subsidiary purposes, an electro-pneumatic type of ground signal is employed and, to avoid a multiplicity of arms when several routes are concerned, this signal shows a route indication in a lower aperture. (See Fig. 5.)

Power Signal Interlockings.

The term "Interlocking" is usually employed to mean the area in which groups of points, junctions and the relevant signals are worked from a particular signal box. Relatively small interlocking groups may be conveniently handled from a signal box worked manually; that is, without the aid of power for working the points. An example of this is the interlocking at Hurstville, of which the illustration shows the exterior and interior. (See Fig. 6.) When such plants occur in automatic signal territory, it is necessary to control the automatic power-worked signals by means of contact makers attached to the manual interlocking machine, and signals so controlled are known as semi-automatic signals. It is also usual, and, in the case of busy lines, essential to add to the manual plant such electric interlocking as may be required to provide for securing the routes by means of track circuits.

When, however, the grouping of points and junctions becomes more elaborate and particularly if the area is extensive, it is almost always necessary to install a power interlocking plant. By this means it is often possible for one signal box to do the work for which, if manual plants were employed, several would be necessary, thereby making possible a saving in signalling staff. Moreover, a power interlocking is much more readily adapted to the control of automatic signals and for the addition of electric interlocking and other safeguards.

The introduction of electric traction and intensive traffic movements involves, as has already been explained, the provision of a more complete signalling and interlocking system,

while the widening of the lines and the additional junctions are involving much more extensive interlocking group areas. The installation of many power interlocking plants thus became inevitable from both causes, and as a result a considerable number of new power installations are now in use or in process of construction.

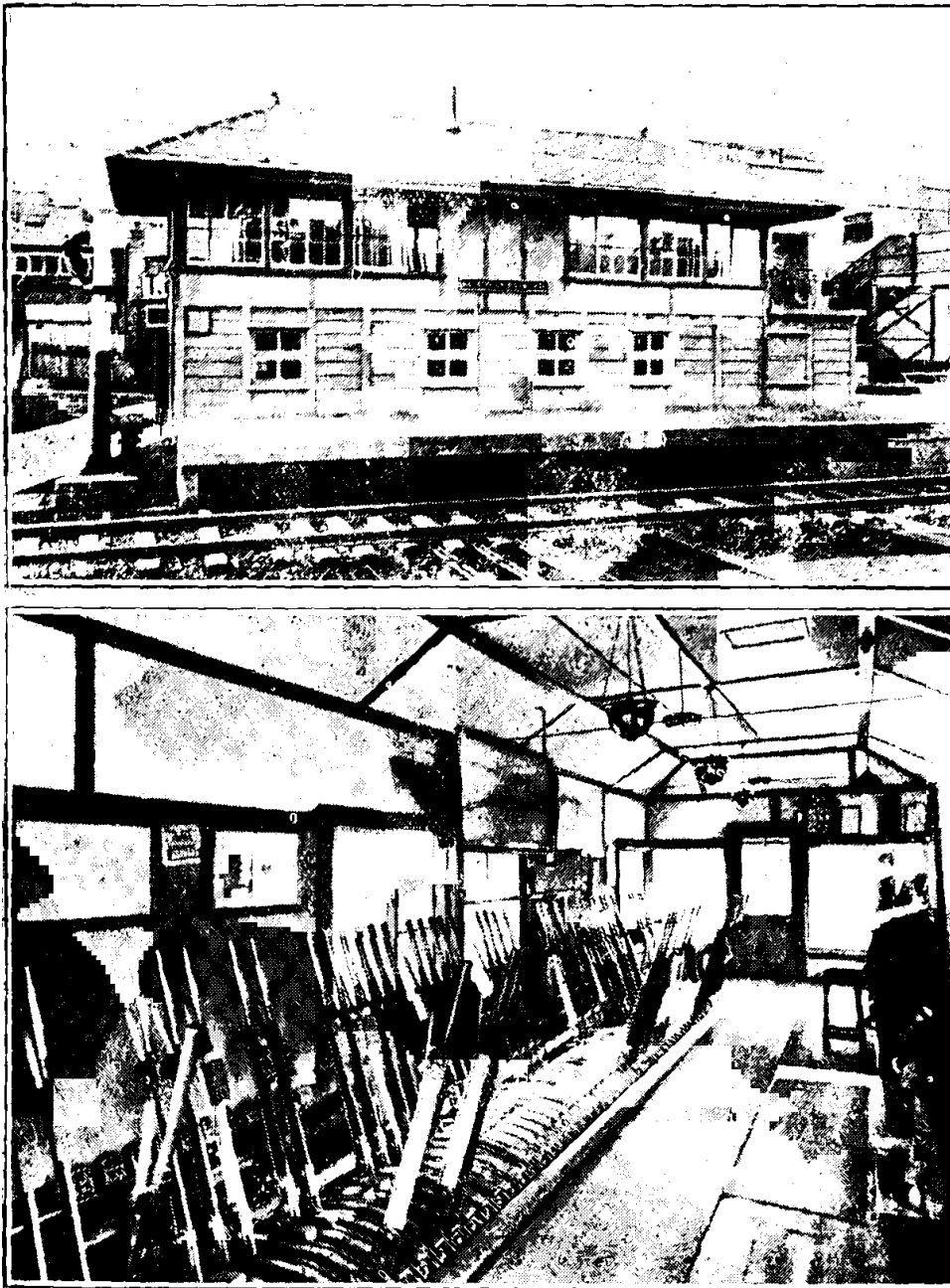


Fig. 6.—Hurstville Signal-Box.

The electrification work and the extensive widening works in connection have thus brought about the necessity for several large new power interlocking plants beyond those already in existence. When the work is completed, all the principal junctions will be handled from power interlockings from Sydney outwards to Sydenham on the Illawarra Line, and to Lidcombe on the Main Line. Example of power inter-

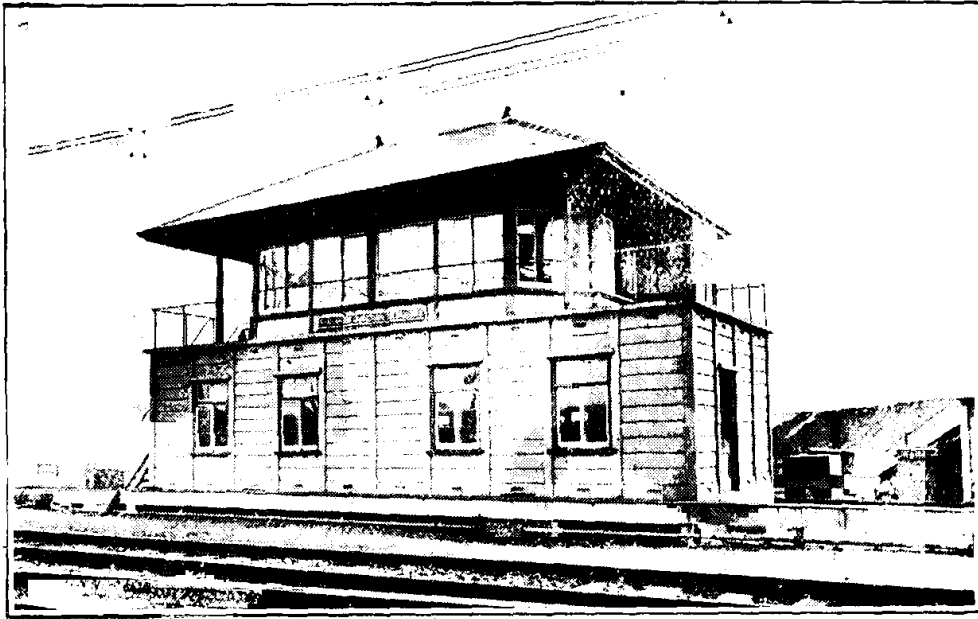


Fig. 7.—Sydenham Electro-Pneumatic Interlocking.

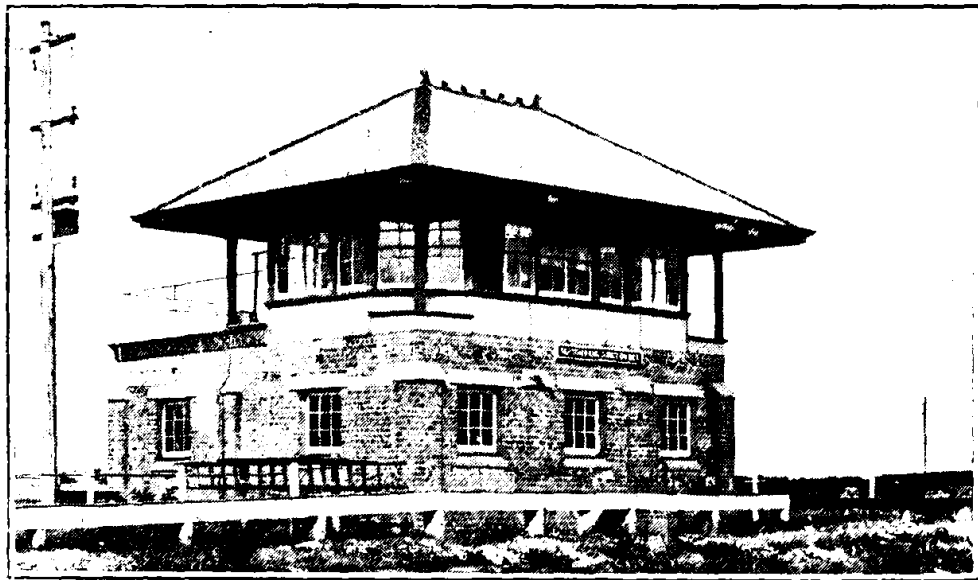


Fig. 8.—Sefton Park Junction All-Electric Interlocking.

lockings at Sydenham and Sefton Junction are illustrated. (See Figs. 7 and 8.) There will also be a large power interlocking at Hornsby. All of these will be operated electro-pneumatically. Smaller power plants will be installed at the various junctions on the City Railway.

Power plants operated wholly electrically already exist at several important junctions outside the area mentioned above, at Flemington, Sefton Park, Lidcombe and Meek's Road. All these power interlockings are interlinked with the adjacent automatic signalling, and there is thus provided a continuous system of automatic and semi-automatic signalling throughout the area concerned. Outside this area, within the limits of the electrification, the original manual interlockings have for the most part been retained but in order to provide the safeguards already referred to as essential where there are intensive traffic conditions, a complete system of electric track locking is being added to the manual plants, which, as in the case of the power interlockings, is interlinked with the adjacent automatic signalling.

The earliest power interlocking machine on these railways was that in Sydney Yard, installed in 1910. This was

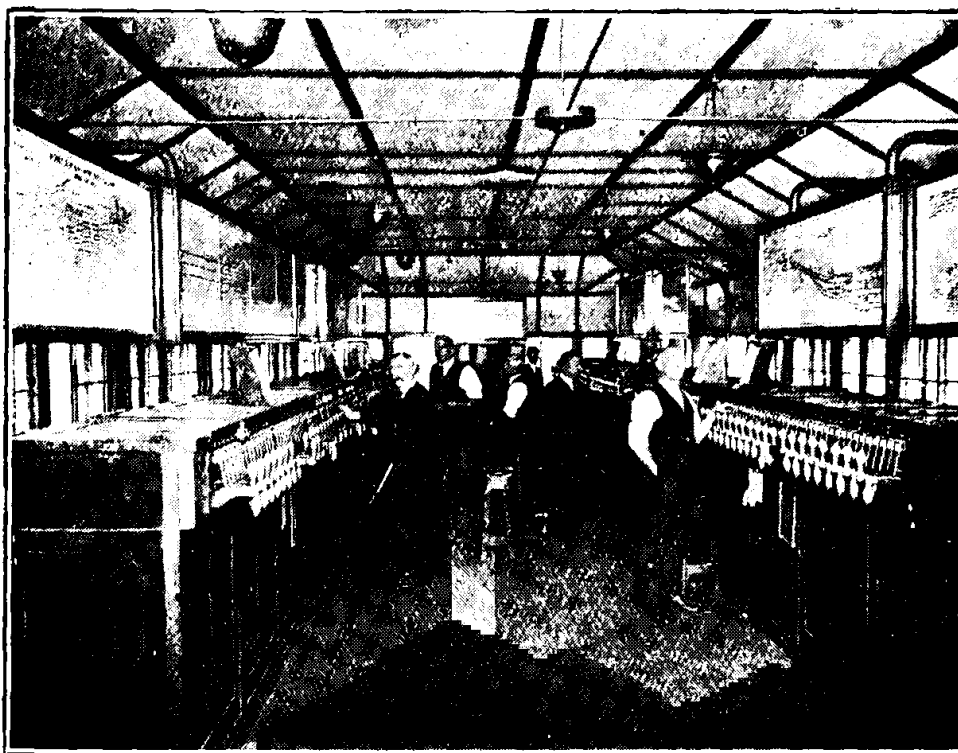


Fig. 9.—Electro-Pneumatic Interlocking Machine, Station West Signal Box, Sydney Yard.

supplied by the Westinghouse Power Signal Company, and did good service for many years. It has since been superseded by a larger machine constructed in the Railway Workshops (see Fig. 9), and the original machine, which was in

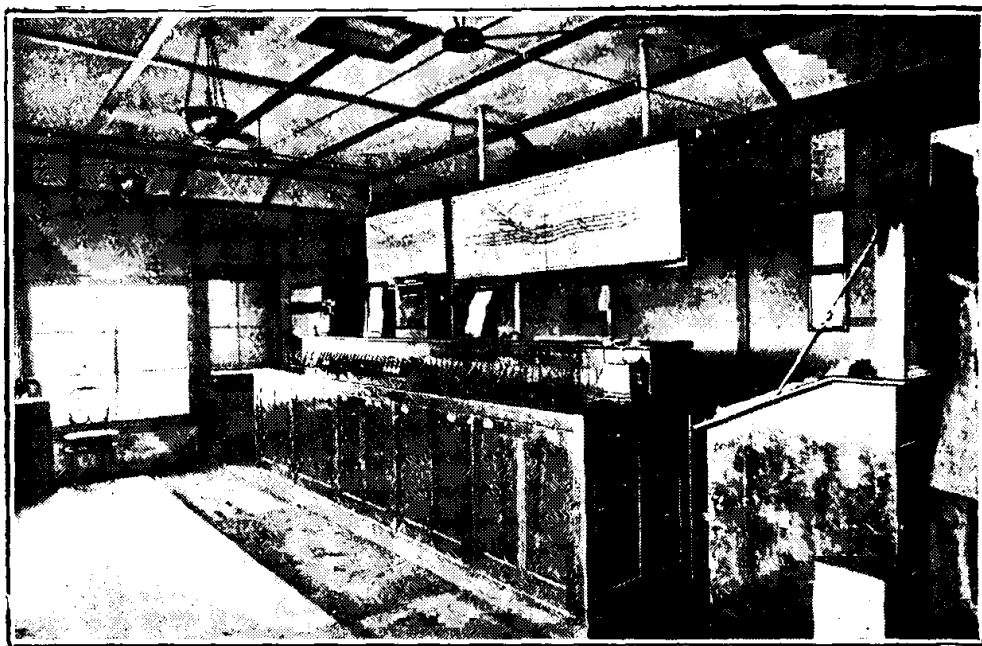


Fig. 10.—Sydenham Electro-Pneumatic Interlocking Machine.

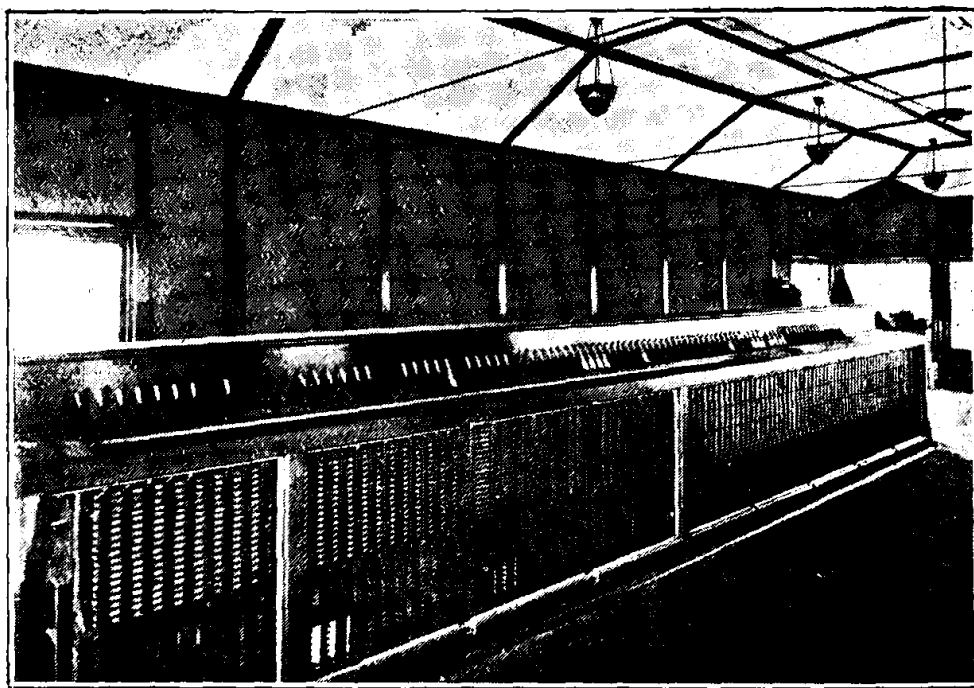


Fig. 11.—Wells Street Electro-Pneumatic Interlocking Machine.

excellent condition notwithstanding its very heavy service, is being re-assembled to form smaller machines for some of the new interlockings referred to above. Examples of this occur at Sydenham and Wells Street interlockings, of which results are given. (See Figs. 10 and 11.) Outside the electro-pneumatic area, there are two all-electric machines supplied by the General Railway Signal Company of Rochester, New York, and a small machine made by Messrs. McKenzie & Holland Pty., Ltd., at their Melbourne works. All the power machines, other than those mentioned, are of Departmental design and construction.

Train Headway.

It has been pointed out above how essential is a Signalling System in the maintenance of an intensive traffic, and it may be found interesting to indicate some of the principles which have to be followed in providing for the required train headway.

The expression "Train Headway" is usually employed to indicate the interval between following trains. The interval must first be expressed in terms of distance, and show the space to be maintained between the tail of one train and the head of a following train, and in order to calculate the possible number of trains per hour which can be accommodated on a line, this space interval must be translated into terms of time. Thus, if the time taken for the head of a following train to occupy the position of the head of a preceding train, on the basis of the space interval required, is, for example, 100 seconds, this would be expressed as a headway of 100 seconds and would give a maximum number of trains per hour of 36.

The well-known principle of the block system is the maintaining of an interval of space between following trains for purposes of safety. Upon lines of comparatively light traffic, this space interval need not be very precisely defined so long as it is reasonably sufficient to ensure safety and to provide headway for the traffic. Upon lines of intensive traffic, however, the necessity is, while maintaining the factor of safety, to obtain the utmost possible track capacity and, therefore, the space interval must be exactly balanced between the necessity for safety on the one hand and the necessity for close train headway on the other.

In making calculations to ascertain this, it is found that the space interval between following trains is made up of three parts :

- (a) The length of the train ;
- (b) The margin of safety known as the “ Overlap ” ; and
- (c) The sighting time of the signal.

Taking these three in order, the length of the train must be taken as a constant, as the system must necessarily be laid out to provide for the longest trains which will ordinarily be run. If shorter trains are occasionally run, there would, of course, be a slight decrease in the train headway, due to the fact that the tail of the shorter train would pass the clearing point sooner than the tail of the longer train but, as the use of the shorter trains would necessarily occur in the slack hours when close headway is of less moment, this is a variation which it is not necessary to take into consideration. For this reason, therefore, in making a calculation, the train length may be taken as constant.

The second component part is the “ overlap.” This is the margin ahead of a signal, which must be clear before a train is allowed to approach that signal. The length of the overlap is calculated on the maximum train speed and grade, and is based on a service braking deceleration rate of 1 $\frac{1}{4}$ miles per hour per second, with an addition of 30 per cent. margin and adjusted for grade. Thus, should a train pass a signal in the “ Stop ” position, the application of the train stop would automatically bring the train to a stand with a margin well clear of any possible preceding train. Under favorable conditions, this margin would be the 30 per cent. allowed for, plus the difference between a service and an emergency brake application.

The sighting distance is the distance in the rear of a signal at which a motorman, finding a signal ahead of him in the “ Stop ” position, must proceed to decelerate. This, in practice, is taken as a distance equivalent to the overlap. It is, of course, obvious that in order to maintain undiminished speed and, therefore, uniform headway, a motorman must sight a clear signal at such distance as to avoid the necessity for reducing speed.

These three component parts, namely, the train length, the overlap and the sighting distance, make up the space headway which must be maintained between following trains for purposes of safety on the one hand, and to maintain uni-

form running on the other. If trains ran without stopping through a series of sections, it would merely be necessary to translate this distance into terms of time on the basis of the maximum speed permitted. Upon railways such as those under discussion, however, an important and very disturbing factor is introduced by the station stop, and it is found in practice that this is the factor which ultimately governs the carrying capacity of the tracks.

The station stop calculated for on the City Railway sections is 30 seconds. The station stop involves not only the actual standing time but also the time occupied in deceleration and acceleration, and these have to be very carefully calculated in ascertaining the time headway required. Upon the City Railway sections, the train running has been carefully calculated on the basis of the grades and with a maximum of 35 miles per hour and, taking all the factors into considera-

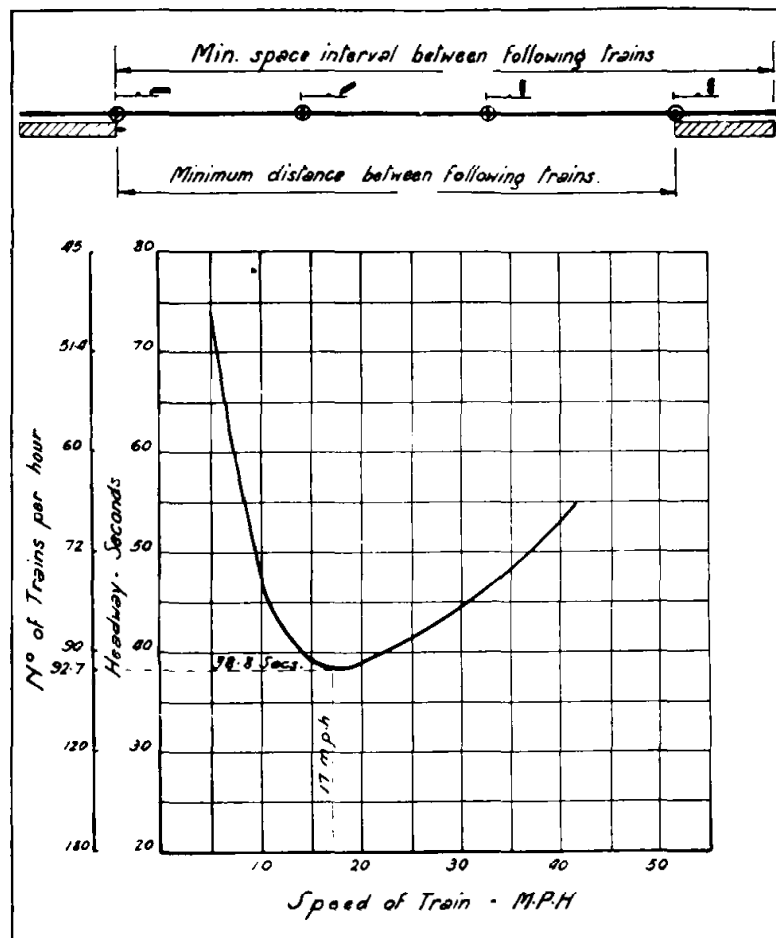


Fig. 12.—Train Headway Chart.

tion, the minimum headway has been worked out at 99.6 seconds, giving a maximum number of 36.14 trains per hour.

In arriving at train headway, it is obvious that the greater the speed the greater will be the headway required, and the fewer the possible number of trains per hour. In plotting a curve, however, showing the headway there comes a point at which the reduction of speed does not lead to a shorter headway. (See Fig. 12.) This is due to the fact that the length of the train is a constant, and when the overlap permissible (which, of course, decreases as the speed decreases) becomes less than the length of a train, the headway time increases, thus decreasing the possible number of trains per hour. The figures quoted as the minimum headway and the maximum number of trains arrived at for the City Railway have been taken as a reasonable mean.

In discussing the considerations which govern train headway, it may be conceded that, for the reason mentioned below, the method adopted for arriving at the overlap is not absolutely ideal, as an overlap should vary not only with the local conditions, but with the actual speed of each train as it passes over the section. Moreover, an ideal overlap would not be given from a fixed signalling point, but would be given invariably from the head of each train as it passed over the section. To express the idea in another form, each train should, so to speak, push its overlap in front of it, and the length of that overlap should vary every moment with the speed of the train. Upon the City sections of the Sydney Electric Railways, a system of time-limit relays is in use. These time-limit relays function on the approach of a train to a signalling point and, provided the time occupied in travelling over the section in the rear of a signal represents a pre-determined reduction in speed below the normal, the overlaps are automatically shortened. Thus, the space interval between following trains is automatically decreased provided the speed of the trains is reduced to a point which renders this safe.

Traction Bonding.

From the point of view of the signalling, the efficiency of the traction bonding is a matter of great concern. Should there be partial or complete failure of the traction bonds, this will affect the operation of the track circuits and it might, under certain circumstances, lead to damage to the track relays. Hence, it is usual in electrification work for the traction bonding to be installed and maintained by the Branch responsible for the signalling.

To provide a path for the traction return circuit, the whole of the running rails and siding rails in the area electrified is bonded with flexible copper bonds of sufficient capacity to prevent undue heating of the bond with the maximum load it is anticipated will be carried. The bond used is constructed of two stranded copper cables $91/.052$ inches or $94/.044$ inches, 16 inches long. The ends of the bonds are crimped into a steel ferrule which effectually holds the strands in position and provides a solid end terminal for welding to the rail. The welding is done by means of the oxy-acetylene



Fig. 13.—Rail Bonding.

process to the outside head of the rail in the case of fishplate joints, (see Fig. 13), and to the flange of the rail at frogs and crossings. A bonded joint should have a resistance equivalent to not more than 6 feet of rail, and should the periodical test disclose any higher resistance than 9 feet of rail, the bond is replaced. The average resistance of bonded joints installed approximates the equivalent of 5 ft. 6 inches of rail.

In addition to the traction bonding across the rail joints, cross bonds to adjacent tracks are provided at certain impedance bond locations in order to obtain the best possible return for the propulsion current. These are provided by connecting a bare copper cable, the cross section of which is determined by the amount of return current to the neutral point of the

impedance bond. This neutral point is the place between the two impedance bonds where the copper turns are connected together, forming a common connection.

Track Circuits.

(a) *Track Equipment.*—The principle of the track circuit has been so frequently explained that it is hardly necessary to say more than that it consists of a current flowing through the rails, which when shunted by the wheels of a passing train de-energises a relay placed in series with the circuit through the rails.

On general principles, track circuits on electric roads are identical with those on steam roads. The first requirement in connection with the former is, of course, to ensure that the track circuit shall not suffer any interference from the presence of the return propulsion current. It has now become the general practice on electrified roads to provide against this by using alternating currents for track circuit work. This has brought about the development of an entirely different type

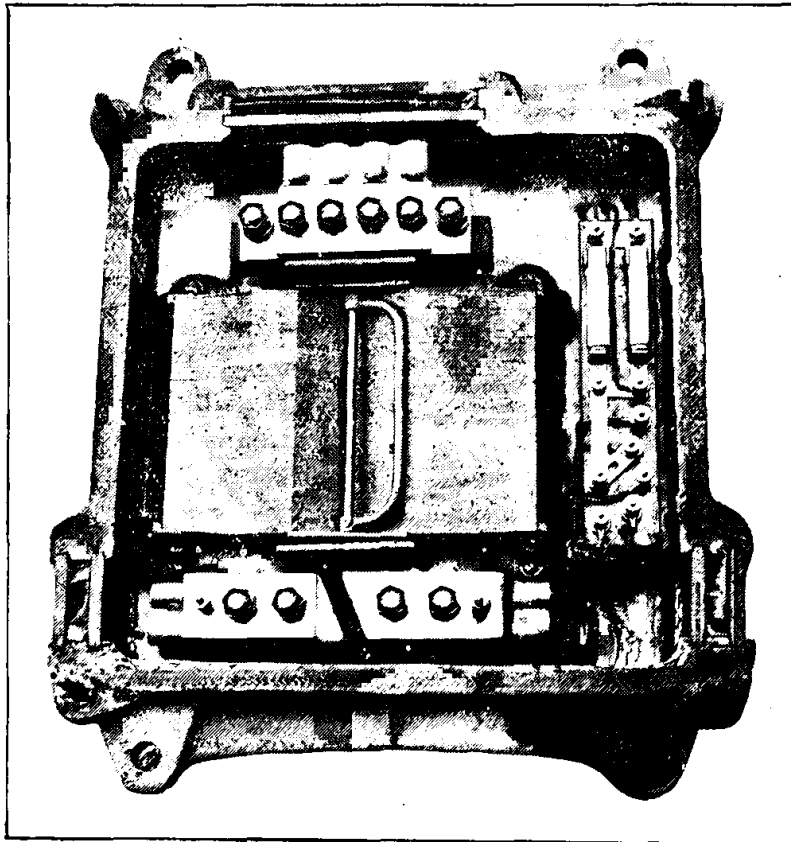


Fig. 14.—Resonated Impedance Bond.

of track relay which, as will be explained later, is fed in a different manner to the direct current relays used on steam roads. But further, the track circuit depends on the use of the running rails which have to be definitely isolated in many separate sections by insulating section from section. When, therefore, as in the case of the Sydney suburban railways, the rails are employed also as a return path for the propulsion current, the two requirements have to be reconciled by the provision of impedance bonds at the insulated rail joints. (See Fig. 14.)

In laying out track circuits on electrified roads, two courses are open. Either one rail is definitely isolated for signalling purposes and is, therefore, unavailable for the traction return current, or both rails are used in common for both traction return current and signalling purposes. The former is usually known as "Single rail track circuit," and the other as "Double rail track circuit." In practice, single line track circuits are confined to interlocking areas where the tracks are short and numerous and where, therefore, the employment of impedance bonds would be almost out of the question, both on the score of expense and owing to the difficulty of fixing them in an area with points and crossings. Outside interlocking areas, where the track circuits are relatively long, the double rail track circuits are employed.

In the single rail track circuits, as has been explained, the signalling rail is definitely isolated at the required points by means of insulated joints. The opposite rail is then a common rail from a track circuit point of view, and is also available for the traction return current. In double rail track circuits, both rails are isolated by means of insulated joints, as on steam roads, but, in order to afford a path for the traction return current, the impedance bonds, already referred to, connected between the rails at the end of each track circuit, are provided. The impedance bonds comprise a very heavy copper strip, which passes a number of times around a laminated soft iron core, and they are provided with a centre tap to connect with a like tap on the bond of the adjoining track circuit. These impedance bonds offer practically no resistance to direct current, and thus provide a path of negligible resistance for carrying the return propulsion current around the insulated joints used for the signalling track circuits. A small amount of alternating current from the signalling track circuit passes from rail to rail through the bond, setting up on the well-known principle of impedance a difference of alternating current potential across the bond terminals sufficient

to operate the track circuit relay which is connected to the rails at the impedance bond connections. (See Fig. 15.)

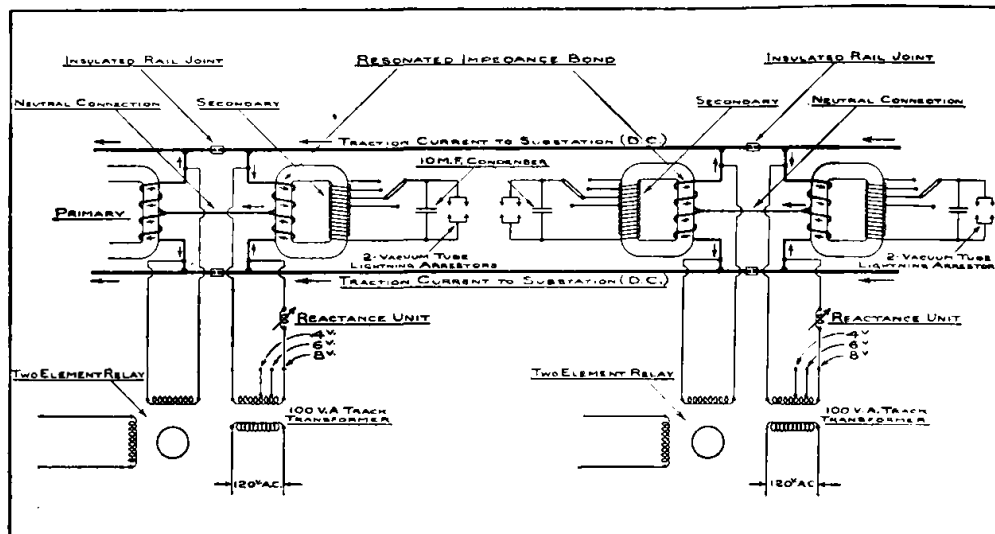


Fig. 15.—Double Rail Track Circuit Connection.

Satisfactory shunting of the track circuits by a train is to a large extent dependent upon variations in ballast resistance. With good ballast, which means small variation between wet and dry weather conditions, it is possible to adjust track circuits for much higher shunting than in the case of bad ballast. With the object of getting the most favorable conditions of train shunt, irrespective of weather conditions, the whole of the ballast in the area to be electrified was removed, and new coarse ballast of $1\frac{1}{2}$ -inch bluestone metal substituted. In addition, the track drainage was improved where necessary. The effect of these improvements has been to raise the insulation ballast resistance, rail to rail, for an average track circuit from 5 ohms, to approximately 50 ohms.

(b) *Track Relays*.—Two types of alternating current track relays are in general use on track circuits, the Vane and the Polyphase type. Both types are double element, and are provided with two separate and distinct windings, one of which—the track winding—is connected to and receives power over the rails, and the local winding receives power direct from a transformer. (See Fig. 16.) In the track winding, operation in the case of the Vane relay is at 0.75 volts, and the Polyphase at 0.25 volts. The local winding takes 110 volts direct from the transformer. The operation of these two-element relays is such that both the track and the local windings must be simultaneously energised before any operation of the relay

can take place. The local winding is permanently energised regardless of whether there is a train on the track circuit or not. The track winding is energised only when the track circuit is unoccupied.

Where single rail track circuits are used, an impedance coil is placed in parallel across the relay track winding in order to prevent the possible passage of heavy direct current through the relay. This impedance has a low ohmic resistance, and a high impedance. Being in parallel with the relay and having a low ohmic resistance as compared with that of the relay, it is obvious that most of the direct current will be shunted around the relay. The relays used are immune from risk of operation from direct current, but without the impedance shunt enough direct current might pass through the relay to burn the winding. A resistance is also used between the track connections and the relay to cut down the propulsion drop across the relay.

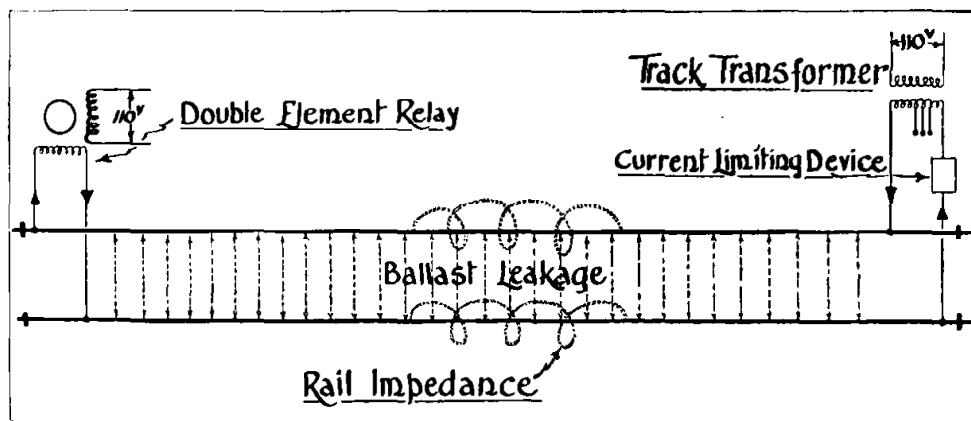


Fig. 16.—A.C. Track Circuit—Method of Feeding.

Automatic Train Stops.

It was mentioned in the introduction that it is usual on electrified lines equipped with automatic signalling to provide certain safeguards in place of the factor of safety associated with the presence of a second man on the footplate of the engines of steam trains. Partly on this account, but still more to meet the conditions arising out of a close headway and rapid acceleration, it is usual on electrified lines to provide means whereby, should a driver attempt to pass a signal set against him, his train would automatically be brought to a stand. This is being accomplished on the City Railway, and later, on the Suburban Railways, by means of automatic train stops, which, when in position, engage a dependent

member on the train which opens the brake system to atmosphere and thus gives an emergency application of the brakes.

In the electro-pneumatic area these train stops consist of a pneumatic cylinder, the piston of which operates a crank attached to a square shaft, on which is mounted the train stop arm for engaging with the trip cock on the train. (See Fig. 17.) The cylinder is contained in a cast iron box mounted outside the running rails and fixed below rail level. The piston operates the arm and in addition, a circuit controller, and pushes against a strong spring, the latter being compressed when the piston is forced out of the cylinder by the admission of compressed air, and its pressure is used to force the piston back to its normal

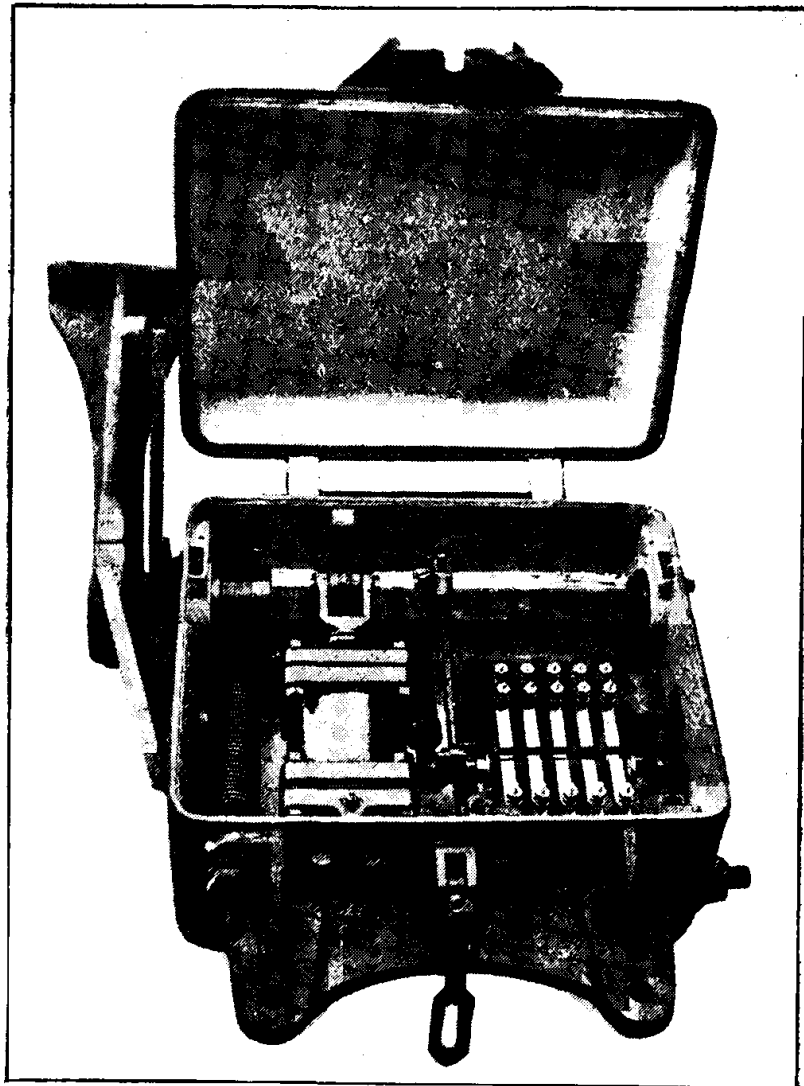


Fig. 17.—Electro-Pneumatic Train Stop.

position when the compressed air is released. The movement of the compressed air to and from the cylinder is controlled by a pin valve and electro-magnet of the same type as used on the electro-pneumatic points and signals. The train stop magnet is energised when the signal is in the "Clear" position, see Fig. 18, and remains energised until the last vehicle of a train entering the section has cleared the stop. The magnet being energised permits the compressed air to enter the cylinder and force the piston out, and lowers the engaging arm to a position $\frac{1}{4}$ inch below rail level and clear of the train trip. When the train stop magnet is de-energised, due to the control circuit being

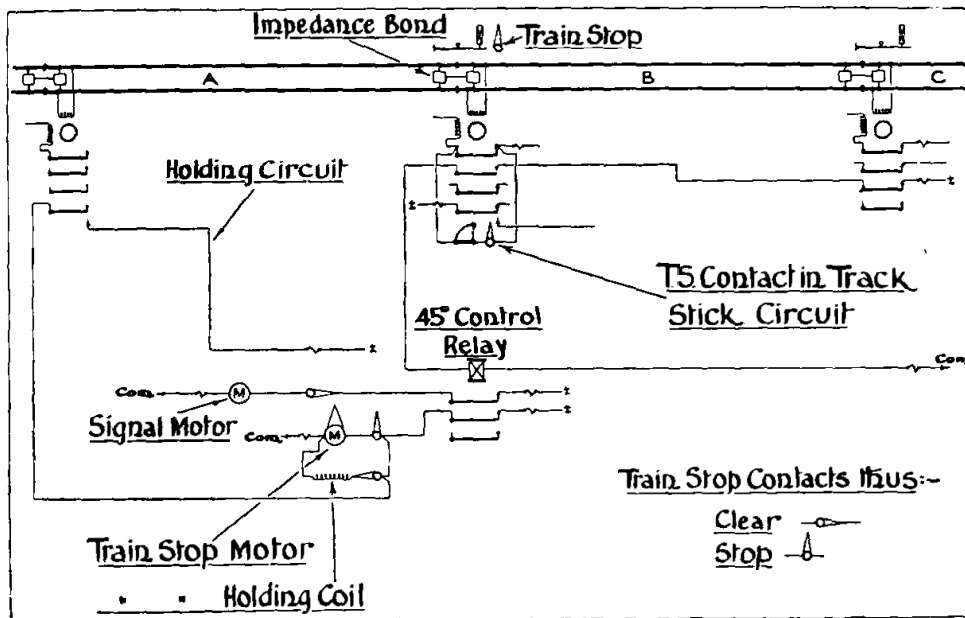


Fig. 18.—Train Stop Circuit, showing Holding and Clearing Circuits.

opened, air is permitted to escape from the cylinder and the engaging arm is raised to a position 5 inches above rail level, ready for engaging with the train trip. The head of this engaging arm is 6 inches wide. (See also Fig. 23.)

The train valves are of the automatic re-setting type, and after the expiration of a certain time interval re-set themselves without the necessity for the motorman to leave his cab for the purpose. The time interval is, of course, set sufficiently long to ensure that, under all circumstances, the train must have been brought to a stand. It should be understood that in ordinary working, the automatic train stop should never operate, and hence the train valve should never be tripped, but should a driver in mistake pass a signal in the "Stop" position, he would, after

being brought to a stand by the train stop, be able to regain control of his train after the interval referred to had expired.

Each motor car unit on a train is equipped with a trip arm, mounted on the left hand leading axle box, at a proper height to come in contact with the train stop arm when the latter is in the raised, or open circuit, position.

Motormen are provided with a special key with which they can operate the automatic train stop by hand should it be necessary to move a train past an automatic signal at which the automatic train stop is in the raised position. The circuit of the stop is so arranged that after the motorman has operated it with his key the stop will remain in the lowered position until the whole of the train has passed the signal. At interlockings, in addition to the use of the key, a special "Calling-on" signal, controlled from the locking machine, is provided for the purpose of "calling on" a motorman past the train stop and signal. This is for the purpose of ensuring the correct position of the points, in the event of failure of the signal.

Outside the electro-pneumatic area, 110 volt alternating current induction motor-operated train stops are being installed. Except in respect of the engaging arm and its train of driving gears, these motor mechanisms are in all respects similar to the all-electric signal mechanisms.

As an additional safeguard, a means of detecting the condition of the train stop arm is provided. This consists of a driving rod in engagement with the head of the train stop arm and attached to the spindle of a rotary contact. Should the head of the train stop arm become detached or broken off, the driving rod is released, and its tension spring causes it to drive open the circuits in the rotary contacts, and the signal for entering the section goes to "Stop" and remains so.

Signalling Telephone System.

A very complete system is in use in connection with the signalling and train working. This falls under three heads, namely :—

- (a) The train control telephone system ;
- (b) The signalling telephone system ; and
- (c) The maintenance telephone system.

The City area is being equipped with a separate train control telephone system in which selective telephones are employed.

These telephones are placed adjacent to the signal locations, on the station platforms, in booking offices and at other necessary points. The system is controlled from the train control room in Sydney Yard, and by its means the operator can speak to, or can be spoken to from, any of the locations covered by the system.

Outside the City Railway, an independent selective telephone system is in operation between the train control room and the various signal boxes and other necessary points. The train controllers are thus in constant touch with every operation in the city and suburban area, and can be spoken to from any of the telephone locations by the person desiring communication merely speaking into the transmitter. Outside the City area, where for the present train stops are not being provided, each signal is in direct telephone communication with the interlocking signal box next in advance on the line to which it applies. When a train is brought to a stand at a signal, the driver or motorman makes use of the telephone to obtain a direction from the signalman.

In addition to these telephones, a complete system of maintenance telephone circuits is provided throughout the whole of the City and Suburban area. These are in direct communication with the officer on duty connected with the signalling maintenance, who is thus able to keep in constant touch with the staff throughout the line. These telephones have been gradually extended with the signalling system, and have proved absolutely invaluable in enabling prompt attention to be given in case of trouble.

Point Operation.

It is not within the scope of this paper to give any detailed description of the mechanism employed in the working of points. This is one of the most critical features in any signalling plant, and of supreme importance under electrification conditions. Whether the points be manually worked or power worked, the principles to be observed are identical, and the difference occurs only in the method by which they are applied.

It has already been said that the electrification work in the suburban area has brought about the installation of a number of power interlocking plants at various places in the area. In the wholly-electric plants, the points are worked by means of motors connected to the point switches by trains of gears and fitted with various devices to secure the correct movement and secure locking of the points. In the electro-pneu-

matic plants, the points are moved by pistons of air motors, the admission of the air being controlled by electrically operated pin valves. In the manual plants, the points are worked by levers in the signal box, the movement being transmitted by lengths of rodding to the points. In each case, as has been observed, the objects to be attained are identical, viz., to ensure that the points respond to the movement of the controlling medium (lever or switch as the case may be); that before a signal can be given for the route concerned, the points shall lie in their correct position and that, finally having been so placed, the clearing of the signal and the presence of the train on the route affected shall hold the points securely until the train has safely passed over them.

The accomplishment of these results involves the provision of a large amount of equipment, both electrical and mechanical, and complicated circuits which have to be worked out in separate detail for every individual combination. It is in the circuit combinations indeed that there lies the secret of providing an installation which, while meeting the requirements of safety, will at the same time allow the utmost permissible freedom in traffic movement. The broad features of the apparatus which is used to give the results mentioned and which have to be co-ordinated by the circuit combinations referred to may be given.

In the first place, it is necessary that the levers from which the signals and points are controlled shall be interlocked with one another so that confliction of functions shall not be possible. This is accomplished by some form of mechanical interlocking, and in itself forms a very important and intricate part of the work.

Secondly, means must be taken to ensure that the points respond properly to the lever movement. In manual plants the rigidity of the rod connection is usually relied upon for this, but, in power plants, electric locks on the levers are used and are controlled by contact makers on the points in such a manner that the lever movement is checked in mid-stroke until the return of current through the circuit breaker at the points gives assurance that the points are home and properly secured.

The holding of the points in the desired position during the passage of a train is effected by a separate series of electric locks on the levers, such locks being controlled by the relevant track circuits. This portion of the circuit combinations calls for very considerable ingenuity in devising circuits which will

meet all possible traffic combinations, particularly where the routes concerned are used in both directions.

These three features are essential in interlocking plants which handle rapid and intense traffic, and they are invariably applied throughout the electrified area of the Sydney suburban system. There is, however, one more safeguard, the necessity for which arises from the use of power working. In manual working, as has been said, the transmission of the power exerted by the signalman's muscle is by means of rigid rods to the points. Assuming proper interlocking of the levers, it is reasonable to suppose that short of some serious damage (which would at once become apparent), the points cannot be moved without the movement of the lever and, therefore, cannot be in conflict with the lever combinations. It is otherwise, however, in the case of power working. Here the power (electric or air) is applied at the actual point of movement, and the risk has to be guarded against of the introduction of the power independently of the controlling circuit. This might take place as the result of crosses or grounds in the connections. Every possible precaution is taken in the arrangement of the circuits to guard against such possibilities, but in spite of these, some combination might conceivably occur which would apply power improperly, and thus move the points when they should not be moved. As the elimination of even the remotest element of risk is the aim of the New South Wales Railways, an appliance to remove this has been introduced on these Railways by the author. In electro-pneumatic plants, this consists of an actual lock applied to the point movement and lock on the ground, see Figs. 19a and b, and so wired that (quite independently of the controls and locks in the locking machine) the point movement and lock themselves are held locked from the time the relevant signal is cleared until the train has actually passed over the points and has cleared the fouling point. In electric plants, instead of the lock on the point movement, an isolating relay is employed at the points, and cuts off power from the motor under the same conditions. Thus, it will be seen that in both cases no possible application of power to the motors from any source could bring about improper movement of the points.

A novel feature in point operation which has very seldom before been used has been introduced at St. James' Station. Here, until the complete circle is ready, the trains terminate, and for this purpose, after discharging their passengers, are run into a dead end at the northern end of the Station, and there reversed to return to the Station on the outward-bound track. The points leading to this siding are

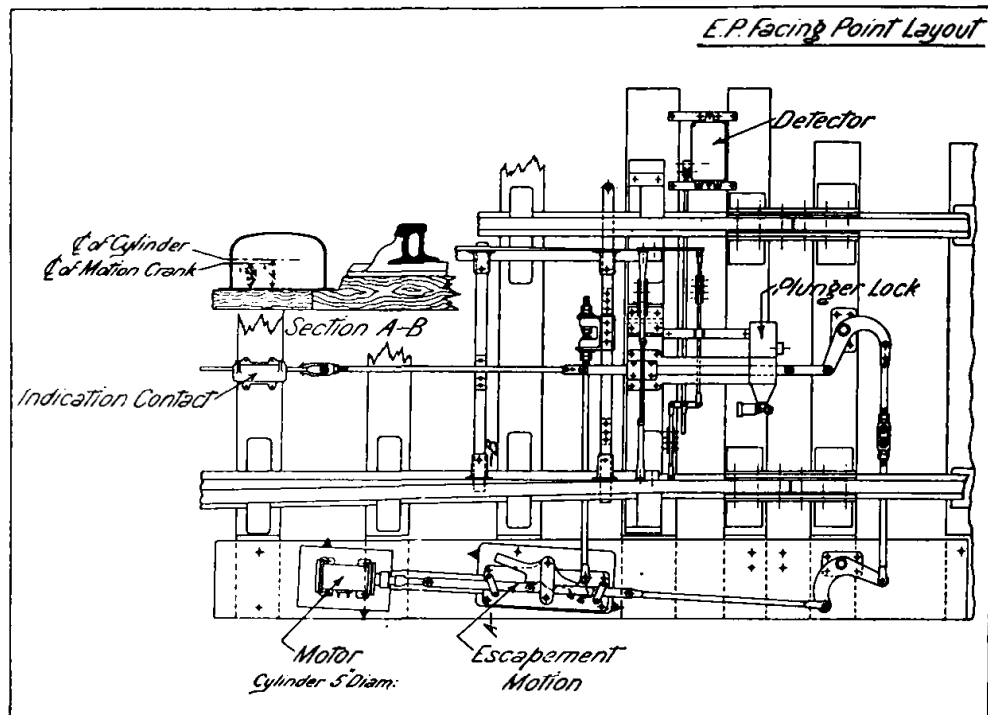


Fig. 19a.—Electro-Pneumatic Facing Point Layout, showing Electro-Pneumatic Plunger Lock.

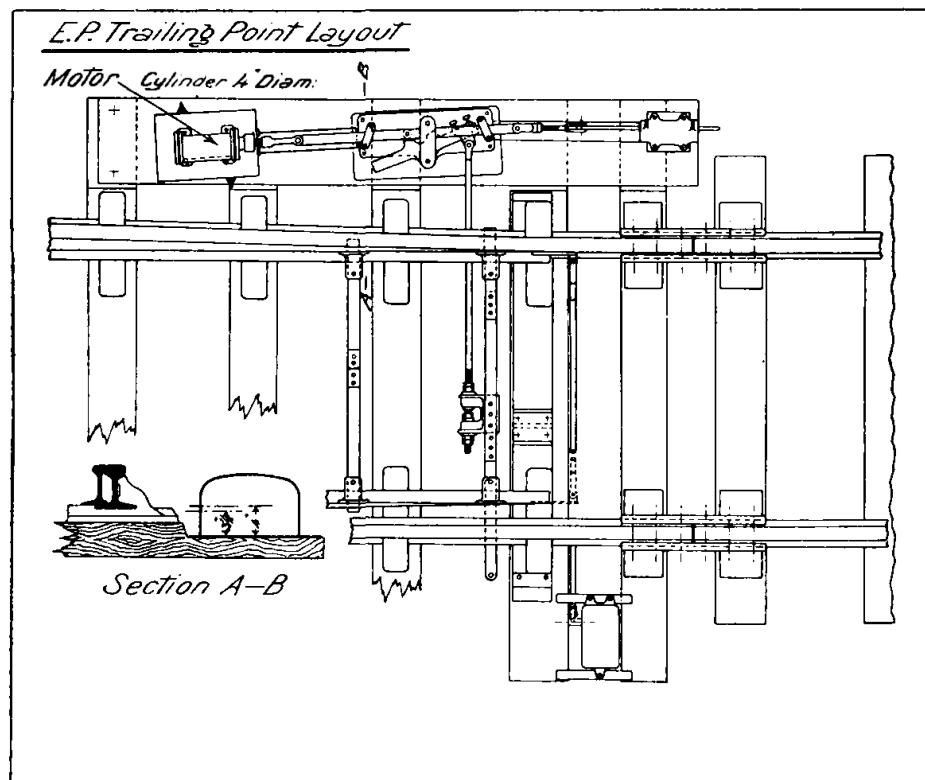


Fig. 19b.—Electro-Pneumatic Trailing Point Layout.

turned automatically on the approach of the train, and are restored immediately the train is within the siding. The whole of the movement thus takes place without the intervention of a signalman. It has been in operation since the opening of the City Railway in December, 1926, and has worked practically without a hitch. The whole of the movement is governed by signals in exactly the same way as if the junction were worked from a signal box, and is protected by the safeguards of which mention has already been made.

The Housing of the Controlling Equipment.

It will have become apparent from what has been said that the working of an automatic or a power signalling installation involves a very large amount of various kinds of apparatus which has to be distributed at locations from one end of the territory to the other. Such equipment comprises, at any given location, the transformers, switches, fuses, relays, terminals and many other details which make up the complete lay-out there. In earlier installations, it was the practice to place this apparatus in cupboards distributed about the plant. In New South Wales, however, the practice was adopted some years ago of grouping the whole of the apparatus at a given location and housing it in small huts (see Fig. 20). In interlocking areas the equipment is in like manner brought to-

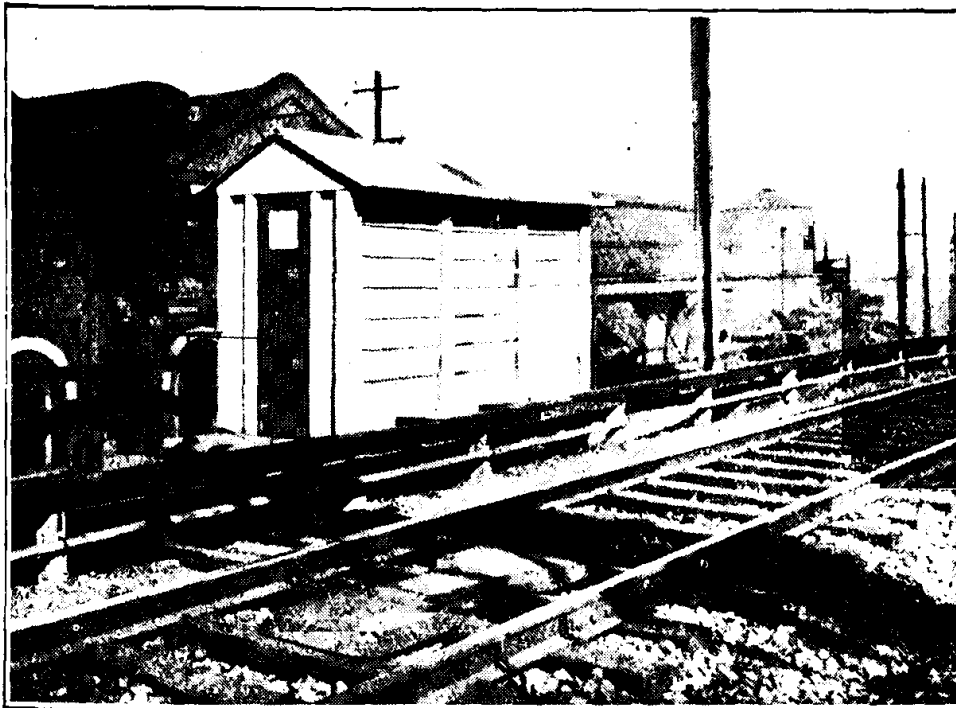


Fig. 20,—Hut used for Housing the Signalling Equipment.

gether in a specially designed space in the under portion of the signal box.

By grouping in this manner, many advantages arise ; the wiring is more concentrated, and more accessible, and work on the apparatus is done under cover. The maintenance telephones referred to elsewhere are in these huts, and the maintainer can thus be kept in constant touch with headquarters. The huts are now built of reinforced concrete, and are fitted with standard arrangement of terminal boards and shelving. The doors are locked by a key, which is one of the series used for buildings belonging to the Signalling Branch and supplied to all responsible officers so that they can always gain immediate access. In the tunnel sections of the City Railway, similar accommodation is given in specially constructed recesses

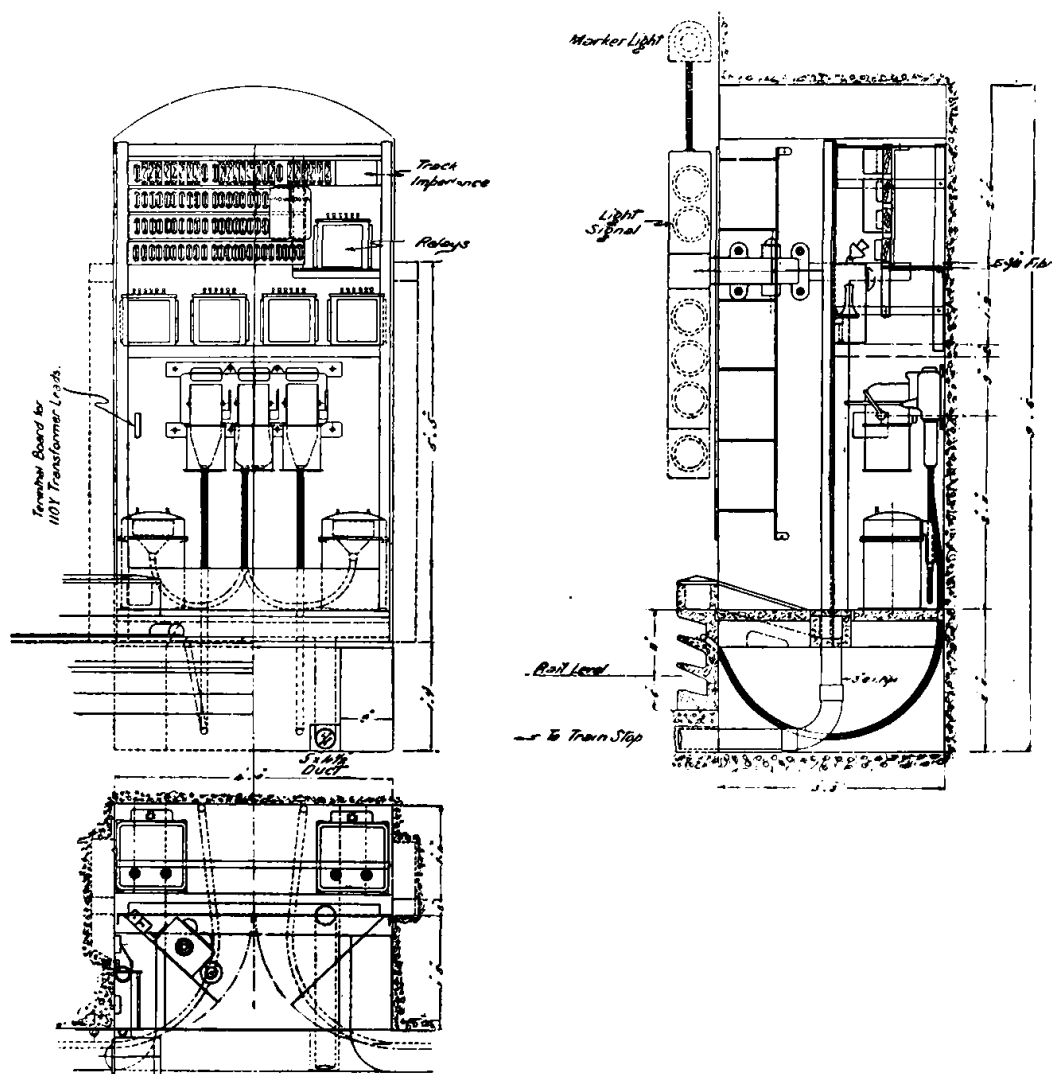


Fig. 21.—City Railway Signalling Recess.

in the tunnel wall and fitted with steel doors and shelving, see Fig. 21. A special layout is adopted on the flyover junctions where the space is limited.

Troughing for Conductor Wires.

Nothing is more essential to the satisfactory working of a signalling plant than a reliable system of conductors, and nothing is more liable to give trouble if not properly installed and maintained. None but the highest grade of insulated wire can safely be used for signalling purposes, and the thickness and quality of the dielectric must be such as to give the greatest possible security against the baring of the conductor wire. The greatest enemy which has to be contended with is moisture. Rats have also done damage, but it is usually found that if their way is not barred, they will not attack the insulation. To accommodate both the rats and the moisture, it is found useful in large troughs to provide a grating under the wires. Every effort is made to avoid underground wiring, as neither solid laying or conduit wiring has been found satisfactory for signal conditions. Where it is necessary to cross the tracks and a bridge is not available, wooden surface troughing is used with a cover which can be readily removed for inspection. The main lines of wiring are, however, whenever possible provided for in troughing carried well above the ground.

Outside the City Railway area, wooden troughing with weathered coverboard supported on concrete pegs is used. When supported well off the ground, the wooden trough has an indefinite life and it is much more adaptable to the purposes of signalling wiring than a concrete trough, and of course lends itself much more readily to alterations. It is formed in lengths and dipped in creosote in the workshops, and tarred after fixing. The cover is secured with galvanised iron clips held on by split pins, and can thus be easily removed.

Upon the City Railway sections and also outside in special cases where the wiring is heavy, concrete troughing is used. (See Fig. 22). This is pre-cast in various sizes to suit the local requirements, and covered either by a weathered concrete slab in the tunnel sections or by a pressed sheet steel cover with a cambered top to throw off the wet, in the outside sections. The sections are grouted together at the joints and treated inside with bitumastic solution to prevent injury to the wires.

The cables carrying the power mains are carried in smaller troughs secured on the sides of the concrete pegs in the outer

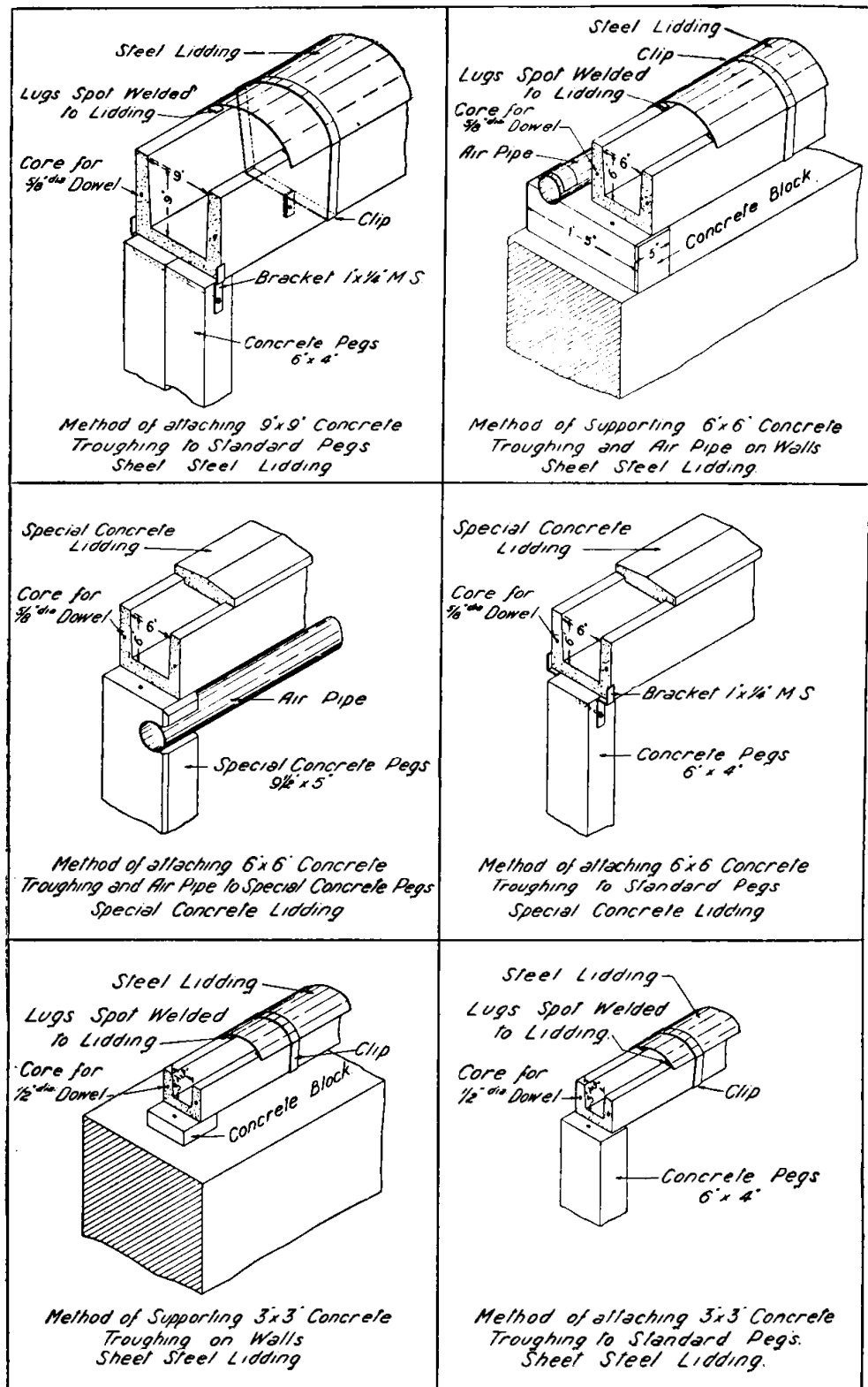


Fig. 22.—Troughing for Wiring.

areas, and on concrete shelving or cast iron brackets on the City Railway area. (See Fig. 23.)

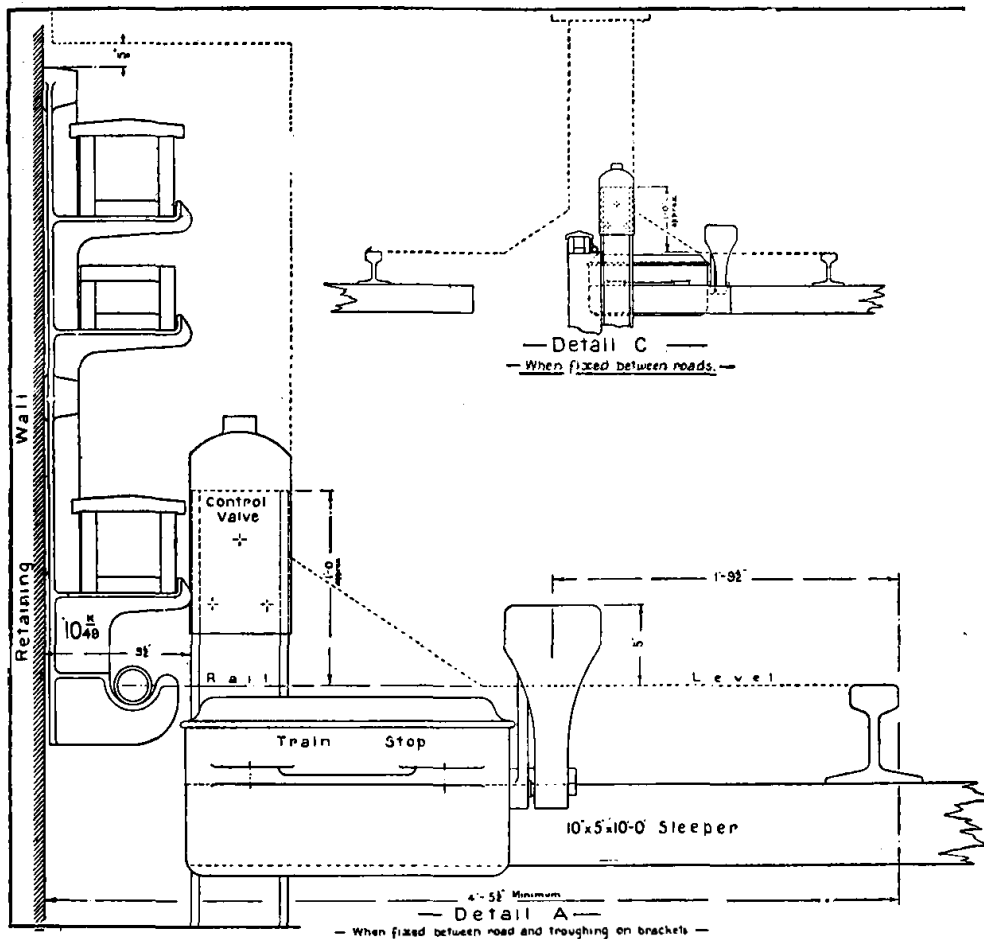


Fig. 23.—Method of Carrying Troughing and Air Piping along Retaining Walls where the Clearance is limited. Also showing Arrangement of Automatic Train Stop.

Platform Train Indicators at Stations.

For a frequent suburban service with numerous different destination points, an adequate system of station and platform indicators for the guidance of the public is an important adjunct. By their means, not only is annoyance to passengers avoided, but they exercise a definite influence in reducing the time of the station stops, a matter which, as has been pointed out in this paper, is a very important bearing on train headway. Considerable attention has, therefore, been devoted to elaborating a system of indicators to give the results aimed at.

No more effective type of indicator for an assembly platform has been produced than that seen in the large indicator which has been in use for many years on the Sydney station. By it the passenger is informed of the time, platform number, and stopping places of the next trains on the various lines, and it is intended to provide an indicator similar in effect but entirely different in the method of operation on the assembly of the new electric stations. In the new indicator the names will be exhibited electrically, the combinations being controlled by barrel contact springs operated by contact studs which can quickly be changed if required. The time clocks will also be modified so as to suit train services which are run at a few minute intervals and where, therefore, indication of the actual time is not needed.

Upon arriving on the platform which has been indicated to him upon the assembly, the passenger will find another indicator which will tell him the destination of the next three trains to arrive. Even if his own train does not at that moment appear on the platform indicator, he will, by watching it, always know within three trains ahead of its arrival, the order in which it will come, and thus he will not be taken unawares. This indicator, which is in use on the London underground railways, is known as the Magazine Train Describer.

At some common point on the route of the trains in the direction from which they are travelling, a description of each train as it passes is fed into a transmitter and received in the apparatus at the various stations in advance. Up to fifteen of such descriptions can be fed into the apparatus and the first three of these at once appear in the platform indicators in a form showing the destinations of the first, second and third trains to arrive at that station. The remaining descriptions are stored in the station receiving apparatus. Immediately the first of the three trains has passed, the second description automatically takes its place and becomes the first. The third becomes the second, and the next in order then appears as the third. The process is repeated, and the indications are thus automatically stepped up as each train passes. The actual indications are afforded by illuminated letters in a metal case, the destination names being permanently alight and the indications of first, second and third lighting up opposite the names as required. The information transmitted by the Magazine Train Describers will not only be exhibited on the station platforms but will also be transmitted to the signal boxes at the junctions in advance in order to give the signalman notice of the direction of trains coming towards him. By this means he

will have a constant indication before him of which trains are approaching, and can thus route them without loss of time even should the scheduled order have been departed from.

Signalling Workshops at Chullora.

The carrying out of the work to which reference has been made in this paper has necessarily involved a very large amount of material. Some small portion of the apparatus employed, such as train stops and alternating current relays, is obtained from outside contractors, but by far the largest portion of the apparatus is manufactured in the Departmental workshops.

These shops occupy a site upon the area at Chullora which, under the Commissioners' scheme for workshops generally, will ultimately be occupied by the whole of the plant now at Eveleigh and elsewhere. The Signalling workshops have been erected in place of the original workshops which for many years past were situated in Sydney and Redfern Yards and which, owing to the extensions necessitated by the City Railway works, were displaced from their original sites. Advantage has been taken of the opportunity to instal an up-to-date plant for the manufacture of the multifarious equipment necessary in connection with a modern signalling system.

When the workshops were removed, a considerable quantity of improved machinery was installed, and the shops have been laid out generally so as to ensure the most rapid and economical production. It is not too much to say that but for the increased facilities afforded by the new shops, it would have been quite out of the question to cope with the very large requirements consequent on the City Railway and Suburban Electrification work. The workshops occupy a site of about 29 acres in extent adjacent to the Liverpool Road, about one mile beyond the point at which the road crosses the goods lines at Enfield North. The erection was commenced on July, 1924, and the removal of the whole of the shops was completed by December, 1925. During the time the removal was in hand, demands for materials were constantly increasing, but, owing to the increased facilities which became available with the new shops, very little delay resulted to the work in the field as a result of the removal.

In concluding this paper, the author desires to express his appreciation of the work of those members of his staff who have been and are still engaged on the various parts of the very complicated work involved in the undertakings described

in this paper. In perhaps no work more than in signalling is there such constant demand for conscientious attention to detail, and in this respect the necessities of the situation have been amply met by those engaged upon it. In this connection it is proper to refer in particular to the assistance rendered by the Chief Assistant Signal Engineer, Mr. W. F. Barton, A.M.I.E. Aust., and to the Field Engineer, Mr. J. P. Fahey.

[The paper is illustrated by Figs. 1-23 in the letterpress and Appendices A-C are appended.]

APPENDIX A.

Particulars of Signalling Equipment now in service or which will be Installed in connection with the Electrification of the Suburban Railways and City Railway Section to St. James.

POWER INTERLOCKINGS.

Place	System	Make of Machine	Total Levers	Signals worked	Points worked	Track Circuits	Relays
St. James†	110v. A.C. E.P.	N.S.W. ...	10	7	2	13	45
Station East	18v. D.C. E.P.	Westinghouse	83	48	26	73	350
Station West	18v. D.C. E.P.	N.S.W. ...	432	414	130	164	700
Wells Street	18v. D.C. E.P.	*Westinghouse	107	58	20	50	366
Illawarra Junction	18v. D.C. E.P.	*Westinghouse	131	41	20	85	312
Sydenham	18v. D.C. E.P.	*Westinghouse	59	30	22	42	180
Meeks Road	110v. D.C. Elec.	G.R.S. ...	80	61	25	57	200
Rockdale	110v. A.C. Elec.	N.S.W. ...	74	37	22	37	135
Petersham†	110v. A.C. E.P.	McK. & H.	20	14	6	12	63
Ashfield†	110v. A.C. E.P.	N.S.W. ...	100	50	31	59	380
Strathfield†	18v. D.C. E.P.	*Westinghouse	95	46	16	56	340
Homebusht	110v. A.C. E.P.	N.S.W. ...	90	35	19	53	220
Lidcombe	110v. D.C. Elec.	N.S.W. ...	70	42	24	42	200
Flemington Goods Junctions	110v. D.C. Elec.	G.R.S. ...	88	65	32	76	155
Sefton Park Jns.	110v. A.C. Elec.	N.S.W. ...	48	22	15	32	120
Hornsby†	110v. A.C. E.P.	N.S.W. ...	140	59	53	50	200
Abattoirs†	110v. A.C. E.P.	N.S.W. ...	100	57	23	50	160

NOTE.— E.P. — Electro-pneumatic.
 G.R.S. — General Railway Signal Company (Rochester, N.Y.)
 McK. & H. — McKenzie and Holland Pty. Ltd. (Melbourne).
 * — Portion of original machine from Sydney Yard re-conditioned and re-built.
 † — Under construction.

APPENDIX B.

MANUAL INTERLOCKINGS.

Place	Total levers	Signals worked		Points worked		Track circuits	Relays
		Power	Manual	Power	Manual		
Erskineville ...	52	30	7	3	23	35	120
Hurstville ...	72	23	21	1	21	29	120
Mortdale ...	20	5	7	—	9	11	30
Oatley ...	20	8	4	—	6	8	26
Como ...	20	11	1	—	5	7	36
Sutherland ...	36	7	13	—	12	14	60
Loftus Jn. ...	20	1	6	—	6	2	4
Canterbury ...	68	20	21	—	15	36	150
Lakemba ...	16	6	6	—	6	10	31
Punchbowl Car Siding	24	6	12	—	9	13	40
Bankstown ...	28	2	10	—	6	8	14
Flemington ...	40	7	13	—	10	20	60
Abattoirs Jn. ...	36	12	10	—	13	23	85
Auburn ...	56	7	21	—	23	20	60
Clyde Jn. ...	48	6	14	—	13	13	40
Granville ...	36	9	14	—	22	16	60
Parramatta ...	48	7	26	—	22	10	50
Dog Trap ...	18	5	3	—	6	8	20
Merrylands ...	21	4	7	—	7	5	20
Guildford ...	12	—	7	—	4	2	2
Fairfield ...	16	—	8	—	10	2	2
Cabramatta Junction	24	8	1	—	8	16	60
Liverpool ...	32	4	12	—	29	7	20
Milson's Pt. ...	48	22	5	—	22	21	120
Bay Road ...	12	4	2	—	5	9	25
Chatswood* ...	28	21	—	—	19	20	105
Lindfield* ...	24	12	—	—	11	15	110
Gordon* ...	24	12	—	—	7	15	80
North Strathfield ...	76	6	35	—	25	8	40
Ryde ...	32	—	16	—	10	1	1
Eastwood ...	20	—	10	—	8	4	4

*Not yet installed.

APPENDIX C.

AUTOMATIC SIGNALS (OTHER THAN THOSE IN INTERLOCKING AREAS.)

Line	Section	No. of signals	Track circuits	Relays	Impedance bonds
City Railway ...	St. James to Central ...	17	27	80	60
Illawarra ...	Sydney to National Pk.	97	134	330	500
Illawarra ...	Sydenham to Bankstown ...	37	60	150	200
Main Suburban ...	Sydney to Parramatta*	196	411	1000	700
South ...	Lidcombe to Liverpool	19	39	100	220
South ...	Granville to Cabramatta ...	20	40	100	140
Milson's Point ...	Milson's Point to Hornsby†	65	117	320	200
North ...	Strathfield to Hornsby	72	130	350	300

*Additions under construction.

† Under construction.