Technical Meeting of the Institution

held at

The Institution of Electrical Engineers

Wednesday, March 30th, 1955

The President (Mr. J. H. FRASER, O.B.E.) in the chair

The minutes of the Technical Meeting held on February 22nd, 1955, having been read and confirmed, the **President** introduced to the meeting Mr. J. C. Waterworth, Mr. P. J. Fisher, Mr. L. T. Eccles and Mr. N. E. Pick, present for the first time since their election to membership, also two overseas Members, Mr. F. Stewart, Chairman of the Australian Section, and Mr. H. L. M. Gasper, of the East Bengal Railway.

The **President** then called upon Mr. A. N. McKillop to read his paper " Rapid Transit Signalling in North America."

Rapid Transit Signalling in North America

By ALISTAIR N. McKILLOP (Associate Member)

Diagrams—Inset Sheets Nos. 11-16

1—Introduction

The purpose of this paper is to describe the nature and trend of development in Rapid Transit railway signalling in North America today.

Let us start by defining the term " Rapid Transit." This expression is common currency in America and is generally applied to describe a public city transport system operated electrically, with multiple-unit trains running on an exclusive right-of-way and operating at regular and frequent intervals. The right-of-way is usually either above or below street level ; in the case of modern installations it is always below street level and often in subway.

Although subways are not new in America—the first one was opened in New York City in 1906—the phenomenal growth in automobile registrations in the post-war era, and the resulting congestion in city streets, has led transport authorities more and more to look to subways as at least a partial solution to the problem of reducing saturation motor traffic in the streets of the larger cities, and of transporting the largest number of people in the shortest time between their homes and places of work. Some idea of the extent of the traffic problem may be gained from the fact that a recent survey of tramcar traffic in Montreal showed that the average speed of the trams in one main thoroughfare during rush hours varied from 4 to 6 miles per hour. So severe is the congestion that it is common to hear business men say to one another, " Shall we walk, or have we time to take a taxi ? "

Since the end of the recent war, therefore, those cities which already possessed rapid transit systems have been modernising and extending them, and a number of cities are either actively constructing subways or are engaged in detailed planning of them. In 1953, American rapid transit undertakings owned a total of 9,500 subway cars and carried 2,124 million passengers between them.

2—Historical

The history of rapid transit in America follows rather different lines from that of this country. The original tendency in America was to build railways over, rather than under, the streets of the cities, and the earliest undertakings were elevated railways, the first of these being built in New York in 1868—five years after the opening of the first section of the Metropolitan Railway in London. It was not until 30 years after the opening of the first " el " that the first subway was built in New York, by which time a measure of respect for the amenities of the city and public outcry against the ugly and noisy structures of the elevated had forced the authorities to consider other means of routing the rapid transit lines. In none of the other three cities which had acquired extensive rapid transit facilities by the beginning of 1940 had that goal been reached without prolonged argument. Boston started building a subway, changed its mind and organised the Boston Elevated Railway Company, and then proceeded to dig a subway before it built its elevated line. Chicago began quite early with elevated railways, but didn't get around to digging a subway till 1939. Philadelphia began operation of a combined subway-elevated system in 1908, to which additions were made in later years. In Cleveland, however, the pioneering town planning efforts of the Van Swerigen brothers in developing suburban Shaker Heights and providing a central right-of-way, broad enough to accommodate all main line railways into Cleveland and their own Shaker Heights Rapid Transit as well, gave Cleveland one of the best of the earlier rapid transit systems, and paved the way for the more extensive lines of the Cleveland Transit System undertaking, due to come into operation early this year.

At the present time six major North American cities possess rapid transit undertakings of note: in addition to the five mentioned above, Toronto was added to the list with a 4.6 mile subway opened in March 1954. At least three other cities—Montreal, Washington and Los Angeles—are engaged in detailed planning.

The latest trend in rapid transit construction is to have these facilities " built-in " when super-highways are being constructed. It has been reliably estimated that, with highway construction costs running at between two and five million pounds per mile, an additional £84,000 per mile will provide a transit right-of-way in the centre. Thus, a 60-ft. roadway will accommodate three lanes of motor cars carrying 3,700 people per hour in each direction. With buses using one lane the carrying capacity is increased to 11,130 people per hour in each direction. With trams the capacity becomes 15,630. One express/local subway will carry 100,000 passengers per hour in two tracks in one direction. Thus, in terms of mass transportation, an excellent return is available for the additional £84,000 invested per mile. This theory is being tried out now in Chicago, where the Chicago Transit Authority will operate rapid transit trains on the " median-strip " of the Congress Street Super-Highway now under construction.

3—Signal Equipment

Since in almost every case rapid transit lines have grown up as part of a more or less integrated network of surface transport, and are therefore seldom associated with the main line railways, their signal systems have developed independently. This process is, of course, stimulated by the fact that the requirements of a rapid transit railway in terms of signal aspects are much less onerous than those of the main lines, where the signal aspects are complicated by the necessity of providing for trains of widely varying speed and braking characteristics.

Although signal practice and the type of aspect used varies to some extent between the various undertakings, there are a number of common factors imposed by the similarity in the nature of the object to be achieved—that is, the necessity of ensuring that an extremely expensive right-of-way is used to the limits of its capacity.

Signals

Semaphore signals operated electrically or electro-pneumatically still remain in some of the elevated lines of the older undertakings, but all new construction for some time now has been with colour light signals. Due to the restricted clearances generally imposed on rapid transit subway systems, signals are as small as is consistent with reasonable aspects. A typical colour light signal is shown in fig.1. Where space considerations require the size of the signal head to be kept to a minimum, the lamps are fed from a transformer in an adjacent location. This transformer has a number of secondary windings feeding track and line circuits in addition to the lamps.

Train Stops

Train stops of both electro-pneumatic and all-electric design are used. Wherever possible these mechanisms are mounted in the four-foot space between rails, but where this is not possible—as when the rails are laid direct to the concrete tunnel invert—the stop mechanisms are fitted in a recess in the catwalk alongside the track. When such conditions prevail, the trip arm is mounted remotely and connected by shaft and coupling to the mechanism. A layout of this type on the Toronto subway is shown in fig. 2.

Point Operation

Point machines are of the same general design as those familiar in this country: a typical point layout is shown in fig. 3. It will be observed that permanent way layouts at switches are usually much heavier than those met with in this country, and that guard rails protect the open blade of a switch. It is claimed that this device prolongs considerably the life of switch blades at the " nose " in addition to making derailment less likely.

Point Heating

On the open sections of line, some form of point heater is essential in the severe conditions of the North American winter.

Many varieties of heater are in use, employing such diverse forms of energy as propane gas and electricity. All types operate by applying the heat to the stock rail from nose to heel of the blade. Fig. 4 shows one type of electric heater used in the Toronto subway. These electric heaters are usually wired in pairs in series across the traction supply and, as it would be possible under severe fault conditions on the heaters for traction voltage to leak on to the signal rail, special precautions are taken to protect track circuits where heaters are fitted. One form which such protection takes is the provision of an isolating transformer, and the wiring diagram of such a track circuit is illustrated in fig. 5.

Track Circuits

In considering track circuits, the diversity of rail fastenings met with in rapid transit practice is an important factor affecting performance and design. On open cut sections of line, standard sleeper and ballast construction is invariably employed. In tunnels, however, a number of different means of fastening the rails to the concrete invert or floor of the tunnel are employed. In one method the rails are mounted on short transverse timbers of the same cross-section as standard sleepers. In another the rails are spiked to a continuous longitudinal timber which in turn is fixed to the invert; in this form of construction a laminated bakelite insulating key is inserted between the spike and the rail. The system employed in Toronto is thought to be unique, and consists of first placing on the invert a rubber plate $\frac{3}{8}$-in. thick, on top of which the rail bearer plate or " chair " is placed. The rail is bolted to this plate with two bolts per chair. Two other fixing bolts are bedded direct into the invert and these are insulated from the chair by means of rubber sleeves and flat washers. The arrangement is shown in fig. 6. It has been found with this method of track construction that " ballast " resistance tends to fluctuate over very wide limits, and unless the tunnel is unusually dry it is difficult to maintain a satisfactory standard of insulation resistance in the rail plates and washers.

Although impedance bonds are used by some administrations where their cost can be justified, general practice in rapid transit service is to employ single rail track circuits. Such track circuits are usually resistance-fed, and fig. 7 shows a typical circuit as used by the New York City Board of Transportation. Usually the track relay is located at the entering end of the track circuit in the normal direction of traffic. An individual transformer is used for each track circuit. These transformers have three windings on the secondary side. One winding supplies energy in one volt steps from 1 to 12 volts to feed the track circuit. A second winding of a similar type is used to feed the local signal light circuits, and a third winding of 110 to 115 volts is employed to feed the track diagram lamps at signal boxes, in series with the front contact of the appropriate track relay. In New York, all track circuits are indicated in at least one signal box on the system. Limiting resistors and protective Fusetrons are placed in the signal rail lead at each end of every track circuit to protect against overloads and damage to the relay due to excessive traction return current flow. A Fusetron is a proprietary device combining the functions of fuse and heat coil. The fuse element provides short-circuit protection in the manner of a fuse, while the thermal element protects against overload without rupturing on momentary surges. The value used for track circuit work is 600 volt, 6·25 ampere rating. A diagrammatic view of a Fusetron is given on fig. 8, while some characteristic curves are illustrated on fig. 9.

The design and maintenance of track circuits in America is made considerably easier by the much lower value of train shunt which is considered acceptable by the Interstate Commerce Commission. This value of 0·06 ohm is less than one-eighth of the value of half-an-ohm usually regarded as the minimum acceptable in this country. This lower standard enables track circuits to be worked over wider limits than are generally possible here. However this facility is purchased at the price of some degree of safety, since there is a much greater chance of a relay failing to drop away to a poor train shunt. Many American properties employ trains of P.C.C. type cars equipped with resilient wheels which are bonded to the hubs, but are not equipped with rim brakes. This latter fact means that wheel rims tend to accumulate a film of grease and dirt which in extreme cases could very adversely affect the train shunt.

4—Signal Aspects and Controls

The differing character of rapid transit railway operation and its independence of main line working has already been mentioned. Due to this feature, there is no generally accepted standard of signal aspects. In practice, however, the relatively small number of rapid transit undertakings and the frequent interchange of information between their executive engineers through the medium of the American Transit Association has resulted in a large measure of agreement on the system of aspects most suited to the purpose, and the broad rules quoted below apply to almost every undertaking.

Signals are divided into two main types—interlocking and automatic. Taking the former first, interlocking signals can be further sub-divided into main and dwarf signals. A typical interlocking main signal is illustrated on fig. 10. Such signals consist of seven aspects mounted vertically in two units of three aspects and one single aspect at the bottom. In one aspect code the topmost unit reads to the most important line or track, where there is a junction in advance, while the lower three aspect unit reads to the secondary or divergent line. Thus an aspect of yellow-over-red would indicate " proceed with caution on main route, next signal indicates stop," while red-over-green would indicate " proceed at authorised speed on secondary or divergent route." This aspect code is in line with the A.A.R. standard code of aspects used on the main lines where the highest " arm " always governs the high speed route. An alternative code used by some rapid transit administrations, including the two latest, is for the topmost unit to indicate the state of the line ahead while the lower unit indicates whether the route is set for the principal or divergent route. On this code, yellow-over-green means " proceed with caution on principal route, next signal indicates stop," while green-over-yellow means " proceed at allowable speed over divergent route."

The lowest unit on an interlocking main signal is a single yellow aspect. This is the call-on aspect, used in combination with a red in each of the two upper units to indicate " proceed with caution, prepared to stop within vision." On modern installations, in order to ensure obedience to the low speed required by the display of the call-on aspect, a small hand-operated circuit controller accessible to the motorman on opening his cab window is attached to the signal post. Under such conditions, when controlled to display a call-on aspect, the signal will display red-over-red-over-yellow but the associated trip arm will remain in the tripping position until the motorman has operated the " key-by " unit, as it is called, upon which the trip arm will clear. This procedure ensures that, even if the aspect is displayed before the train reaches the signal, the train must come to a stand at the signal or be tripped.

Interlocking dwarf signals are short-range ground signals used mainly at yard and siding outlets to govern low-speed movements on to running lines. They are also used to govern set-back or reverse-traffic moves taking place against the normal current of traffic on running lines. Such signals display one of two aspects : red (sometimes red-over-red) meaning " stop and stay " or yellow, meaning " proceed with caution prepared to stop within vision."

Fig. 11 shows a general view of the Davisville Yard of the Toronto subway. A dwarf signal can be seen to the left of the picture, with an interlocking home signal and " key-by " unit in the foreground.

Automatic signals display aspects usually determined solely by the condition of the track sections ahead. A typical automatic signal is illustrated on fig. 12. Three aspects only are generally used on this type of signal :—

RED :	Stop : then proceed with caution prepared to stop within vision.
YELLOW :	Proceed with caution, prepared to stop at next signal.
GREEN :	Proceed at allowable speed.

The rolling stock used on American rapid transit systems is generally built up of two-car units, and trip cocks are provided at the end of each such unit. Facilities are not provided for the intermediate trip cocks on multi-unit trains to be made inoperative. Thus " tripping-past " a faulty signal may mean three or more stops for re-setting the trip cocks on each unit, and would therefore be a lengthy business. The practice is therefore to avoid such necessity by ensuring that the trip arm is in the non-tripping position on every occasion when it is necessary to pass a signal. If a signal fails to clear due to a circuit failure, the stop aspect will normally be exhibited, and since for automatic signals this is interpreted as " stop : then proceed at restricted speed prepared to stop within vision," the control circuits are arranged so that under these circumstances the stop arm can be cleared. In earlier installations this facility was applied by means of a " key-by " circuit controller mounted on the signal post, and the motorman was instructed that on coming to a stand at a red signal he was to operate the key-by unit and the stop arm would clear to allow him to proceed according to rule. In the latest installations however, the " key-by " feature has been provided automatically. The manner in which this is arranged can best be considered in relation to fig. 13, from which it will be seen that the block joint at each automatic signal location is situated 10-ft. 0-in. in approach to the signal, and that the trip arm is 4-ft. 0-in. beyond the signal. There are thus 14-ft. 0-in. between the block joint and the trip arm. In addition a delay period of two seconds is imposed on the operation of the train stop mechanism while the signal displays red. Thus a motorman approaching a danger signal will bring his train to a stand immediately in rear of the signal, and in this position his leading wheels will be occupying the track circuit beyond the signal. The drop away of this track relay will, after two seconds have elapsed, cause the trip arm to assume the non-tripping position. The delay period is chosen to ensure that it is impossible to pass the signal at danger, without being tripped, at speeds in excess of one or two miles per hour.

In cases where the signal is at red and the stop fails to clear when an approaching train passes over the block joint, the rules usually provide for the arm to be hooked down until the whole of the train has passed the signal, when the hook is removed and the arm resumes the tripping position.

Normally, full block overlap is provided in automatic working, and a diagram showing a section of track with automatic signals and control limits is shown on fig. 14. Normally all signals show green aspects with the trip arms in the non-tripping position. When a train passes and enters the track circuit beyond a signal, the aspect of that signal changes to red (a slight delay is imposed to cover the effect of the block joint position in approach to the signal). The trip arm, however, does not restore at this time. When the train has passed clear into the next block and the block track of the first signal is clear, the trip arm at that signal rises to the tripping position. When the train has passed into the second block ahead and two track circuits ahead of the signal are clear, the trip arm resumes the non-tripping position and the signal displays a yellow aspect. As soon as the third track circuit clears, the yellow aspect changes to green. Thus a train occupying a block is always protected by a trainstop in the tripping position at least at full braking distance behind it.

Fig. 15 shows some automatic block signal control circuits as used in New York. It is general practice for all signal circuits except track circuits to employ d.c. line controls. The circuits given are for successive automatic block signals.

It should be explained that, in New York, the 12-volt d.c. energy for the line controls, designated LB and LC, is derived from a rectifier at each location. The negative of each such rectifier is fed to a line common wire which extends throughout the area, and to which automatic earth detecting devices are connected. A separate rectifier at each location feeds the local 12-volt d.c. circuits, designated VB and VC, for that location only. This local energy alone is connected to the stop circuit controllers, so that in the event of earth faults occurring in these circuits the local equipment only is affected. The ingenious use of the DV relay as a normal stop repeater as well as a green aspect control relay will be noted. In the event of a train-stop failing to restore properly to the tripping position after a train has passed, the DV relay will be unable to pick up and the other relays at that location will therefore remain down, thus maintaining the red aspect at the signal concerned. The signal in rear, however, will display the yellow aspect.

A useful incidental facility of the circuits described is that, in the event of reverse traffic movements having to be made, the trip arms will clear automatically in sequence in advance of the movement due to the back contact of the track relay in the train-stop circuit, thus avoiding the necessity of tying down trip arms in such circumstances to avoid back-tripping.

It is not the practice in America to prove the integrity of the actual trip arm itself, even when remotely mounted, it being considered satisfactory to depend on the circuit controller in the mechanism itself.

5—Interlockings

A typical interlocking layout in approach to a facing junction is shown on fig. 16, together with the basic control table. The first signal in approach to the interlocking is X1, and this signal is designated an interlocking approach signal. It has a three aspect head like an automatic signal, from which it is distinguished only by the fact that it carries an interlocking number plate (preceded by X) in addition to the geographical number plate carried by all signals. This type of signal has the rail joint arrangement found at automatic signals, and can therefore be passed at red under the " stop and proceed " rule. It is controlled from the interlocking, however, but such control is usually non-stick, and the controlling key or lever is maintained in the proceed position unless it is necessary to change the route line-up of the facing points ahead. It will be noted that this signal does not directly lock the facing points ahead : this is to permit a train to approach signal X3 on a yellow aspect at X1 and permit the signalman more time to change the junction line-up at the last moment without delaying the train. Route locking would normally be imposed, however, to prevent the route being changed from a clear to a fouled overlap after a yellow has been displayed on X1. The home signal protecting the junction is X3, which is an interlocking home signal normally displaying a red-over-red " stop and stay " aspect. The aspects displayed by this signal under the various conditions of route setting and track occupancy ahead are shown on the table, which has been drawn up on the assumption that the aspect code used is that in which the centre unit is the " route " unit and the top unit the " track occupancy " unit. The call-on aspect, red-over-red-over-yellow, requires the approach track to be occupied and also, normally, the key-by contactor at the post to be operated before the signal can be passed. Call-on signals have no other track circuit control, but usually detect facing points in their route.

6—Interlocking Machines

In the older properties, many interlockings controlled by power lever frames are in use. However, modern practice in this as in other fields, is to provide route relay interlocking control, usually associated with plug-in relays. Control machines are of the desk type, either of the " unit lever " pattern where the keys and indicators for operating points and signals are mounted vertically above the desk, with the illuminated track diagram mounted above that again (see figs. 17 and 17A) ; or of the entrance-exit type, where all control keys and indications are mounted on the track diagram, as in fig. 18. Machines of a somewhat different design were furnished by the British signalling contractor for the Toronto subway : the two machines installed on this property utilise multi-way route keys mounted on the panel for route selection purposes, in the manner more familiar to British signal engineers. The larger of the two machines on the Toronto Subway is illustrated on fig. 19.

A feature of most rapid transit interlocking control panels is the facility provided of operating points if they should become locked by virtue of a failure of a point detector track circuit. A sealed push button is provided under each three-position emergency point operating key on the panel, and under detector track failure conditions the seal is broken and, after the expiry of a pre-determined time limit, and providing all signals reading over the route are at danger, the points concerned can be operated by means of the emergency key to the desired position. One operation only at a time is permitted in this manner, a separate operation of the push button and time relay being necessary for each movement of the points.

7—Special Features of Rapid Transit Signalling

Thus far, discussion has been confined to the general features of signalling used on rapid transit lines. In recent years, however, the necessity to utilise the maximum possible capacity of existing lines, and the desirability of keeping trains on the move at the closest possible headways, has resulted in the introduction of a number of special features into signal systems. Some of these special features are described below :—

(*a*)—*Grade Timing*

In America, steep gradients are encountered at certain locations, for instance when an elevated railway continues underground, or when cut-and-cover subways have to dip under a river. At such locations it is desirable to enforce speed limitation on the down grade, and this is done by the introduction of " grade timing " in the manner shown on fig. 20. Five successive automatic signals are shown, together with their control limits. Normal indications are : signal 1, green ; signal 3, yellow-over-lunar-white ; signal 5, red-over-lunar-white ; signal 7, red ; signal 9, green. A speed restriction sign is mounted alongside signal 1 indicating the allowable speed. When a train enters track 1 and traverses it at not exceeding the designated speed, signal 5 will change to yellow-over-lunar-white and 3 to green. If, however, the speed is too high on track 1, signal 3 will remain at yellow-over-lunar-white and 5 at red-over-lunar-white, and the speed restriction must be observed on 3T, otherwise the train will be tripped. If the restriction is observed on 3T, signals 7 and 5 will clear to green. The purpose of the lunar-white indication is to indicate that the control limits of the signal ahead are clear, and that signal displays red only to enforce the speed restriction. The reason for giving the motorman this information is to discourage him from being unduly cautious in passing a yellow-over-lunar-white signal : when he knows that the signal will clear on observance of designated speed, he can " ride the red " closer than he would dare in other circumstances. The system appears to suffer from some defects, however, and on the Toronto system where grade timing was required on one block only, to prevent excessive speed round a sharp curve, one timing section only was provided for the signal concerned, as shown on fig. 21.

(b)—Station Timing

If rapid transit trains are not to follow each other in a series of jerks under close headway working, arrangements must be made to permit closing up at stations to compensate for station stops. This is done by the provision of station timing in the manner illustrated (fig. 22). The signals in approach to a station, designated station time signals, are spaced closer together than normal and have their controls overlapped to govern over several blocks, so that a train standing at a station platform is protected by three or more red signals, the total distance providing safe braking distance at the maximum speed. An illuminated " T " sign informs motormen where the special timing controls start so that they can reduce the speed of their train accordingly. As a train enters each successive block, a time relay commences to operate. If the speed of the train is reduced so that the head end does not pass the next signal before the timing relay completes its operation, then that signal will have its extended overlap cut off, the train stop will be lowered to its non-tripping position and the signal aspect will change from red to yellow so that the train can continue without stopping. If the train continues at restricted speed, the next signal will have its extended control cut off by the second timing relay, and so on, thus bringing the train up closer to the station, so that as the leading train departs, the second one can pull up to the platform at approximately the same speed, thus increasing track capacity. When no train is occupying the station, the signals normally display green, and under these conditions a train approaches at normal speed.

8—Terminal Working

Special arrangements for ensuring close headway working through any particular subway route are useless if congestion occurs at the terminals of the line, and careful consideration has been given to layout of terminals in recent years in order to reduce turnround time at these points.

Probably the most efficient terminal arrangement for a double track line is the loop, where trains discharge at one platform, turn round the loop, and load up with passengers for the return journey at the adjacent platform. Signalling arrangements on such a layout are simple, and the loop itself can be divided into one or more blocks according to its size. It is not often, however, that the land available at terminals is sufficient for the installation of a loop, and this is particularly the case if the line is underground at the terminal point since the additional construction costs involved in excavating for the loop would hardly be justified. Where a loop is not possible, therefore, an arrangement such as that shown on the diagram (fig. 23) is adopted. The arrangement shown is that at the Eglinton terminal of the Yonge Street subway in Toronto. Incoming train movements are controlled by signals X40 and X42, while outgoing movements are controlled by signals X1 and X3 from platforms 2 and 1 respectively. Points 100 lie normally for platform 2, while 101 points lie normally for the route platform 2 to southbound main, and northbound main to platform 1. The interlocking at this place is controlled from a panel interlocking machine at Davisville, ¾-mile away, but facilities are provided on the control machine for the terminal to be switched to automatic working and this is the normal condition. Under automatic working, with no trains in the area, signal 40 shows G/G, 42 Y/Y and the route is set into platform 2. The first train to enter the area goes accordingly into platform 2, and once it is clear inside the platform 100 points reverse to set the incoming route for platform 1, and signals 40 and 42 clear for this route to G/G and Y/G respectively. It will be noticed that at this stage the train in platform 2 has a clear path to depart when necessary without fouling the path of an incoming train ; it is for this reason that the first train is always directed into platform 2. The second train now enters the area under clear signals and occupies platform 1. At this stage, both platforms are occupied, 101 points are normal, 100 points reverse, and 40 and 42 signals each display R/R. A third train entering the area at this time would receive a delayed call-on indication at 40 signal after being brought almost to a stand, and will proceed under caution to come to a stand at 42 signal. Immediately the first southbound train—that in platform 2—has departed and cleared the crossover, 100 points will normalise, 42 signal clear to Y/Y, and the third train will be admitted to the vacated platform. When the second train is ready to depart, both 101 and 100 points will reverse and signal 3 will clear.

Thus far in the description, the movements have been controlled solely through the medium of track circuit occupancy. However, complete control of the working cannot be effected in this manner without sacrificing efficiency, because of the inability of track circuit control alone to discriminate between outgoing and incoming movements when they mutually conflict. This condition occurs when platform 2 is vacant with platform 1 occupied. The southbound train cannot depart until both 100 and 101 points are reversed, and since reversal of 101 locks the incoming signals, it will be apparent that if the southbound route is lined up in advance of the actual departure time of the train, northbound trains may be held unnecessarily outside the station.

In order to ensure maximum efficiency of operation in the terminal area, therefore, the Toronto Transit Commission decided to supplement track circuit controlled automatic working by what is known as Automatic Dispatcher control. This method of control was first employed by the Philadelphia Transportation Company to control the Snyder Avenue terminal of their Broad Street subway thirteen years ago, and had been found so effective that its use was extended to eight further locations. The machine is shown on figs. 14A, B and C, and the principle of operation is this :—A continuous opaque strip of standard commercial cinematograph film is arranged to pass at a very slow rate between a light source and a photo-electric cell. The strip is endless and the speed of movement is arranged so that one complete cycle takes 24 hours. Holes are punched in the strip to correspond with the scheduled departure time of trains from the terminal, and these holes are arranged so that the beam from the light source can impinge on the photo-cell for a short time when one of them passes that point. When this occurs, a telephone-type relay is energised. Two multi-point telephone-type rotary impulse switches complete the basic equipment of the Automatic Dispatcher unit. The arrangement and basic circuits are shown on fig. 25. One of these switches is fed an impulse every time a hole on the film strip passes the photo-cell unit. A normally-energised relay is maintained by a circuit which extends from the wiper contact of the first selector (the S switch) through the first bank contact of that switch to the first bank contact of the second switch (the L switch), through the wipers of that switch to the relay coil and so to negative. Every bank contact of the S switch is strapped to the corresponding contact of the L switch, and therefore the relay referred to, known as ATD-PR, will be energised as long as the wipers of the two switches are in step. Thus when the S switch is stepped by an impulse derived from the passage of a punched hole in the film strip, the two switches are no longer in step, and the ATD-PR drops away. The drop-away of the ATD-PR initiates the clearance of one of the platform starting signals, provided conditions are safe for this to occur. An impulse is fed to the L switch whenever a southbound train accepts the platform starting signal. The stepping of the L switch in this manner places it once more in step with the S switch, and the ATD-PR is restored. If for any reason trains are not running to schedule there may be occasions when there is no train at the station at the time of a scheduled departure. Under such conditions the S switch will step, but the departure signal will not clear due to the fact that the appropriate berth is unoccupied. Should delay be prolonged, the S switch will continue to step once for each scheduled departure. When service is restored, the departure signal will clear immediately the first incoming train is clear inside the platform and the outgoing route has lined up, and subsequent trains will be given a clear signal in the same manner as soon as conditions are safe for this to be done. Every departing train will step the L switch, which will in the course of time come back into step with the S switch. Immediately this has occurred the ATD-PR will pick up once more and normal working is resumed. Thus the system is flexible enough to cater for minor variations in the service without the intervention of an operator.

In order to obviate the possibility of delays occurring due to an incoming train crossing the path of an outgoing train, special circuit arrangements are made to ensure priority for the outgoing movement. Operation takes place in this manner :—Assume a southbound train occupying platform 1, with platform 2 empty. The hole in the film representing the scheduled departure time of this train is arranged to pass in front of the light source some 90 seconds in advance of the actual booked departure time This period represents the run-in time of a northbound train from entry on to N316 track to a stand in platform 2. If a train enters N316 track just before the S switch is stepped by a hole in the strip passing in front of the light source, the incoming route through 100 points normal will be lined up for platform 2 and signals X40 and X42 will display " proceed." Meanwhile the ATD-PR will drop and a timing circuit will commence to time off 90 seconds. By the time the 90-second delay period has expired the incoming train will be clear inside platform 2, and the route will immediately reset and the appropriate departure signal will clear for the southbound train from platform 1 to the southbound track. Thus the outgoing train will depart exactly on schedule time. If, however, the S switch is stepped just before the northbound train enters N316 track, the outgoing route through 101 points reversed will be lined up, thus locking out northbound signal 42, and causing the incoming train to receive a delayed call-on aspect on signal 40 to permit it to proceed under caution up to 42 signal. The home signal 3 governing the southbound train, however, remains at danger until the expiry of the 90-seconds delay period, after which it will display " proceed " to permit the outgoing train to depart on schedule. The delay to the incoming train does not affect the overall schedule but merely reduces slightly the terminal lay-over time allocated to it.

In accordance with the rules of the Interstate Commerce Commission governing automatically operated points, a delay period is imposed before a route line-up can be changed. This is a safeguard against possible loss-of-shunt on the point detector track circuits.

Emergency push buttons are provided on the platforms to cover such eventualities as a train being unable to start, or a track circuit failure, and under these conditions the system will continue to function automatically with one platform only in use. Only in the case of serious disruption of service, or of signal system failure is it necessary for the signalman to take over control.

More recently the Chicago Transit Authority has applied the principles of Automatic Dispatcher control to 134 miles of their " L-subway " routes in that city. In this large scale application the system is termed " line supervision," and in addition to exercising automatic control of at least one terminal interlocking train starting lights at key stations throughout the system are controlled from the central office equipment, and trains are held to schedule time as these points, thus preventing cumulative delays. Visual supervisory lamps on the central equipment are illuminated if a train fails to leave a station within a minute after the starting lights have been lit, and if the delay is such that the train has not left before the booked time of the following train, a distinctive indication is given and a " late starting " alarm bell is rung.

9—Latest Developments

Among the latest developments in the field of rapid transit signalling in America is the electronic train identification system introduced by one of the American signal manufacturers. In one application of this system a transmitter-receiver pair of coils is mounted on top of a location case close to the right-hand side of trains. Identification of trains is effected for two different destinations on the section of track concerned. The leading car of all trains operating on one of the routes carries an inert tuned coil on the front right corner as shown on fig. 26. When such a coil enters the field of the wayside transmitter coil, momentary coupling is effected between that coil and the receiver coil associated with it through the medium of the coil on the train, and a pulse from the receiver is amplified and used to energise the appropriate route identification relay. When a train on the alternative route approaches the wayside coils, the transmitter is energised, but as no tuned coil is carried by those trains, no signal is sent into the receiver. This fact is detected by an identification relay for the alternate route.

In the particular case described, the system is employed to effect automatic operation of the diverging junction between the two routes. A system similar in principle is planned for operation on the Flushing line of the New York City Board of Transportation to enable express trains to be automatically routed on to the express track. In this installation, train describers at intermediate stations are also controlled, and advance warning of the train is forwarded to the signalman at key points (see fig. 27).

10—Conclusion

The author has attempted to give as comprehensive an outline as possible of present-day signalling practice in North America in the specialised field of Rapid Transit. In the larger field of main-line railways the differences which exist between practices in this country and America can reasonably be attributed largely to differing backgrounds and geographical and operating characteristics. In the signalling of urban electric railways, however, these factors do not apply to any extent. Here the problem is simply that of providing a signal system capable of enabling any section of line to handle the maximum number of trains—of standardised accelerating and braking characteristics—at the highest speeds consistent with safety, and that problem is the same whether the section of line traverses Fifth Avenue or Oxford Street. Thus in this limited field a direct comparison is possible between the solutions adopted by the engineers of the two countries, and it is hoped that the description given of recent progress and developments in North America will be of interest to signal engineers in this country.

DISCUSSION

Opening the discussion, **Mr. W. Owen,** said he noticed in the paper that the trip arm was often mounted remotely from its operating mechanism and this did not seem to be the best arrangement. Possibly there was some condition on the particular railway for the engineers to adopt the practice, but many things could happen between the actual machine and the trip arm itself, and no doubt it added to the complication of proving the trip arm in its correct location. He felt that the type of point heater employing electricity and connected in any way to the current rail left much to be desired, as any fault on the point heater would be conveyed to the rail and thus to the track circuit. It was surprising to see that the railways in America accepted a train shunt of a value as low as 0·06 ohm for a track circuits. He was doubtful of results with such a low train shunt when applied to interlocking such as was described at the end of the paper. Reliance was, perhaps, placed on the time device applied to the point operation, but if the track picked up under a train when the last bogie was some distance from the points, it would seem that the time would elapse and the points would move.

With regard to signal aspects in connection with close headway working, the best method was to tell a driver either to stop or to proceed and to give him no other instruction. For this a plain red and a plain green were all that was required, apart from some simple method of telling the driver in which direction he was going, either to the left or to the right. It was preferable to the system adopted on the Toronto Subway where the driver was permitted to pass a red light under some conditions. He did not favour the idea of the automatic clearing of a trainstop when a train approached, but would prefer something which meant stop and stay there, until the driver had clear instructions to go forward. It was stated in the paper that it was not the practice to prove the actual trainstop arm. He had known of cases where trains had equipment hanging from them which had damaged train stops and caused delays in traffic.

He asked what train intensity was possible with the signalling system described in the paper, and what speeds were attainable.

The **Author** said that the paper was written to describe a system, not to justify it and it was quite possible that it would not be to the satisfaction of London Transport.

The only case he had come across of the trip arm mounted remotely from the trainstop itself was on the Toronto Subway, which was owing to the peculiar type of construction. On almost any property in the United States or Canada, some sort of cavity was available between the rails in which the trainstop machine could be mounted, but on the Toronto Subway, one rail being fixed direct to the concrete, there was no alternative to mounting the trip arm remotely.

With regard to the point heaters, he thought that it really depended on how much confidence one was prepared to place in the design and manufacture of the heater equipment. If the type of heater used was well protected by some special means of insulation and also against mechanical damage, the chance of dangerous conditions arising was remote ; and if they did arise, they were guarded by some such circuit as he had described. In an all-electrified system, one invariably had 600 v. available, and it was very convenient to use it for such purpose as heating points.

He could not attempt to defend the low train shunt. He had addressed some remarks on the matter to the signal engineer on the New York system in the hope of receiving an answer before the meeting, but he had not yet received a reply. Although he felt that it was dangerous, he had not heard of any serious results due to it.

The complicated system of signal aspects was really a matter of opinion. The junction route indicator, which was regarded as a normal thing in the United Kingdom, had not been adopted in America. The 3-aspect signals, which were used in Toronto and most of the properties which he had seen, seemed to function really well. The drivers had no difficulty in interpreting them and they certainly expedited traffic.

The question of passing a red light was also a matter of opinion. He had held much the same opinions as Mr. Owen, but having seen it in practice, many objections appeared to be unfounded. Provided it was ensured that a driver could not pass any signal without being tripped, he did not see any great danger in putting the trip arm down once it was made sure that the driver had come almost to a stand. The real reason for that was the different make-up of American stock, where there were a number of tripcocks, and to ask a train to pass a signal with the trip arm up would be quite a lengthy procedure.

Regarding headways, those on the Toronto Subway were for a 2½ minutes service. The signalling system could do a good deal better than that, probably 1¾ minutes. Generally speaking, the headways on American rapid transit railways were in the region of 2 to 2½ minutes, with an average speed of 40 m.p.h. to 45 m.p.h. the conditions being much the same as in Britain.

Mr. B. Reynolds was particularly interested in the section dealing with the grade timing and said that London Transport had had grade timing arrangements in operation since about 1940, where the signals were cleared on a sharp down gradient only after the conditions of speed restriction had been met. The station timing described in the paper represented the practice adopted on the Underground to quite a close degree, as they, too, had their chain of home signals under speed control conditions, which had normal overlaps and a reduced overlap if the approach speed restriction was complied with by the driver. The additional white light mentioned by the author, which told the driver that the signal was at red because he had not complied with the speed restriction, was worthy of consideration.

Referring to the automatically operated points, he asked for details with regard to the delay period which was imposed before a route line-up could be changed, as a safeguard against possible loss of shunt on the point detector track circuits.

The **Author,** referring to grade timing, said that in his experience it was quite surprising how close experienced drivers could run the red light when the lunar was showing, in comparison with the condition that they knew the signal was red because the track ahead was occupied. The provision of a separate indication to tell the driver that he was merely on timing conditions probably saved a number of seconds on the overall schedule and enabled them to run the signals to an extent which seemed alarming. The lunar white light, in any case, was probably quite worth while.

The delay period used with automatically operated points on the Toronto installation was obtained by a time relay, When a train had gone through the route, before the track relay in effect had released the locking, the time relay was energised and a period had to expire before the relay came off. In the case of Toronto, the time was two seconds ; in some properties it was as much as five seconds. With a greater delay one might be holding up traffic.

Mr. W. Owen enquired if the speed restriction sign was continuously alight in the grade timing. Speed restriction signs associated with speed restriction for headway purposes only lighted up if the signalling was in a condition to clear as the speed restriction was obeyed.

The **Author** replied that it was misleading if a sign was illuminated at all times, as the driver got to know that if the signal showed yellow or green, the station was clear, and he would not obey it. In Toronto, it was left to the driver to realise that he had to come down before the signal cleared.

Mr. F. Stewart stated that America in general did not require such a high train shunt as in the United Kingdom. Although British signal engineers expected 0·5 ohm he did not think this value was always reached.

There were several installations on rapid railways in Melbourne and Sydney of a similar nature to those described in the paper and there had never been any trouble. It was to be remembered that the track circuits were short.

He thought that many signal engineers would like to go over to speed signalling, but it seemed that the traffic people did not like to change and therefore route signalling stayed in such places.

The " key-by " circuit controller had been tried out in Australia many years ago, but difficulty had been experienced by the train drivers in stopping at the appropriate place to make use of it. Similar timing circuits to those mentioned in the paper were installed on one section of the Sydney Underground Railway in 1926 and on a second section in 1932. The signal cleared but the trainstop did not unless the train reduced to the speed shown by the signal and maintained it up to the signal. If one of the lower speed aspects, the driver had to maintain that speed up to the next signal, when he could interpret the speed in relation to that aspect.

The **Author** said that with regard to the question of the signal clearing but not the trainstop, it seemed fundamental not to show a proceed aspect when there was an obstruction in the form of a trip arm ; and even displaying a red or yellow aspect to a motorman when the trip arm was not down, was not really good practice. But in actual operating experience it appeared to work reasonably satisfactorily. In Toronto, the drivers did not experience any difficulty in stopping their trains opposite the "key-by" post. The only difficulty they had was at the start of the installation, when they had several drivers who got down to re-set their trips and walked to them from their cabs.

Mr. C. C. Bennett asked if the lamps used in the signal head were of the double filament type, and if the author could give any more information regarding the fusetron, which seemed to be a very useful piece of apparatus.

The **Author** replied that the practice with regard to lamps varied to some extent. So far as he could recall, it was the general practice to provide in the tunnel signals where the brilliance was not so great, two lamps side by side ; and on the open sections a double filament lamp of the 11 v., 11 w. main line type.

He could not add a great deal of information with regard to the fusetron, but in the circumstances which existed at the opening of the Toronto Subway, where serious difficulties were caused by the prevalence of brake dust, the fusetrons saved a great amount of delay. He did not think they were available in the United Kingdom.

Mr. W. Owen, referring to Mr. Stewart's comment on train shunt, said that London Transport put in special track circuits to ensure a better train shunt than 0·5 ohm and that 2 ohms was quite common.

Mr. B. F. Wagenrieder said that it seemed that the train would have to stop in a convenient position for the motorman to use the circuit controller, otherwise he would have to get out of his cab and might not then be able to reach the handle.

The **Author** replied that on the Toronto installation they tried to provide as large a handle as they could in order to make sure that the driver had no difficulty in finding it in the dark. In the American unit, the " key-by " circuit controller was much smaller, but again, they found no difficulty in reaching it.

The **President,** referring to insulation of flat bottom rails, noticed that the rubber pads seemed to finish abruptly just at the end of the base plate. Brake dust could cause a lot of trouble and he suggested that the pad should be extended for ½-in. at the side or ½-in beyond the foot of the rail. He could not agree with the statement that wheels without rim brakes tended to accumulate grease which would affect the train shunt. A great portion of the freight stock of Great Britain was only hand-braked, and only occasionally was it pinned down in a siding to stop a truck from trickling back. Some stock was not braked for months and yet the wheels kept reasonably clean.

Regarding the low train shunt, he understood that rolling stock in America was much heavier than in Britain and, if that applied equally to rapid transit stock one could afford to let the train shunt down without running the risk that would be entailed with the British light tube stock. Recent developments in America included the conveying of messages from the train to the ground by a radio system, so that the train could set the junction in front of it. This was a sidelight on the A.T.C. working and raised the question as to the use of the same kind of thing for conveying messages from the train to the ground—in other words, an A.T.C. receiver on the ground at a certain point to set the points in front of the first train. That would seem much simpler than employing radio.

The **President** proposed a very cordial vote of thanks to Mr. McKillop for his very interesting paper, which was carried with acclamation.

Rapid Transit Signalling in North America (*McKillop*)

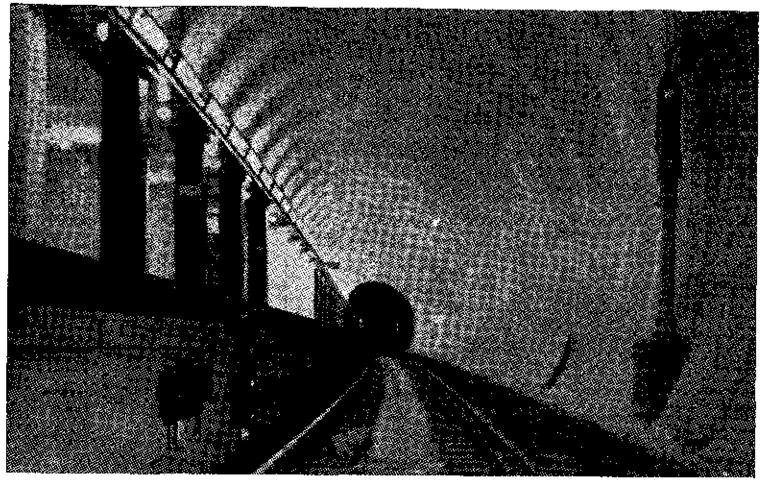


Fig. 1. Automatic signal at station on route No. 1, Chicago Subway

Fig. 2. Tunnel train stop layout. Toronto Subway

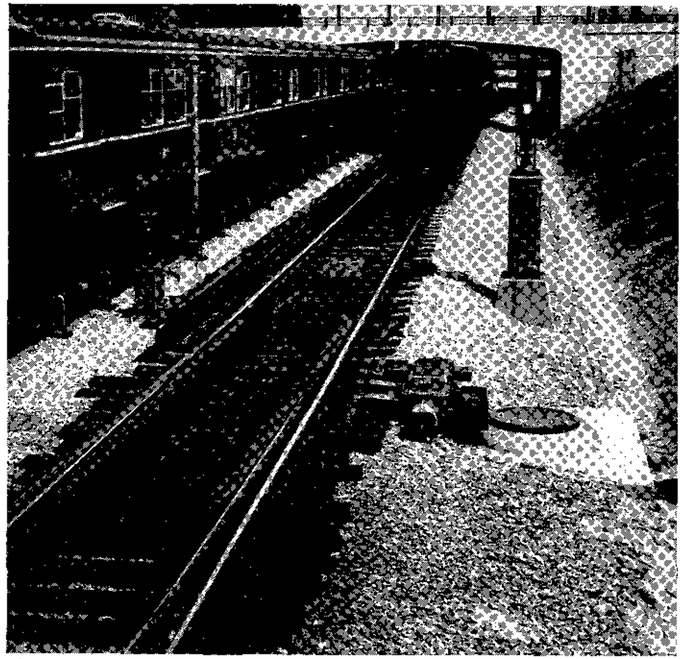


Fig. 3. Point layout at Davisville, Toronto Subway

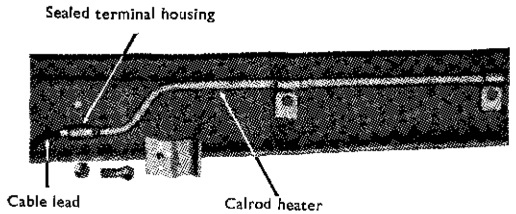


Fig. 4. " Calrod " point heater, showing method of connection to rail. (General Electric Co., U.S.A.)

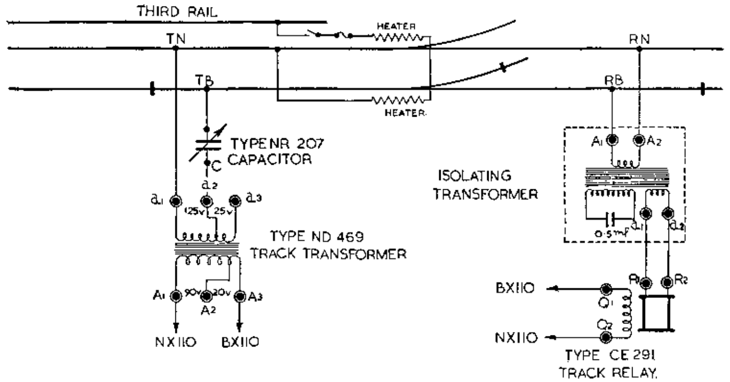


Fig. 5. Track circuit where electric point heaters are in use. Toronto Subway

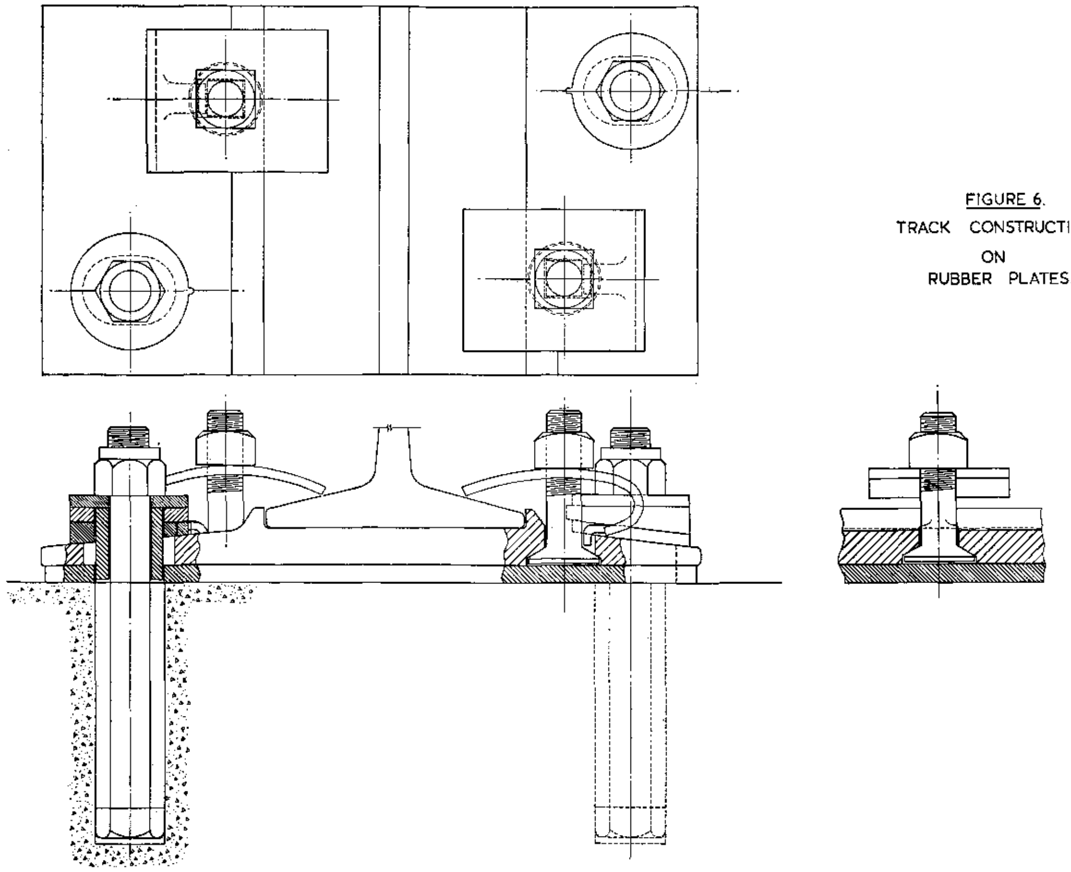
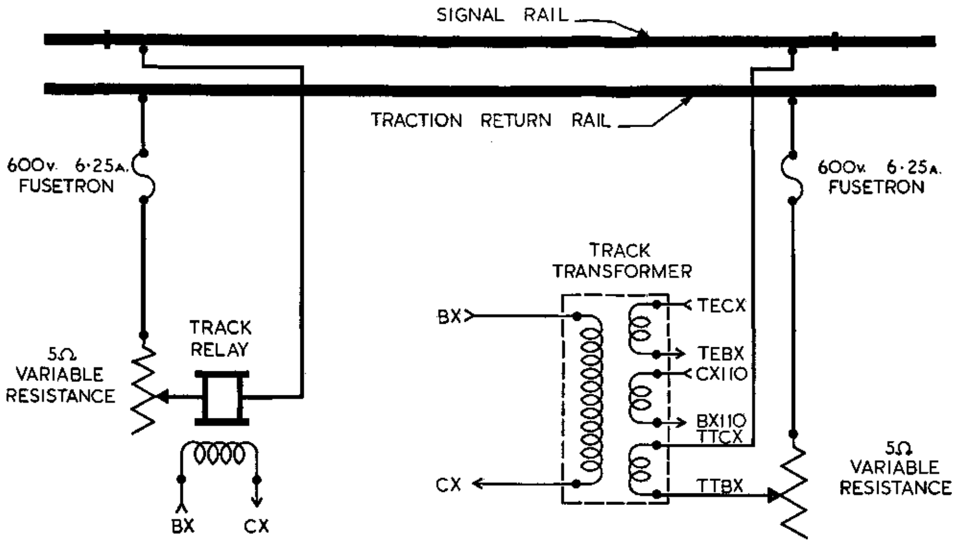


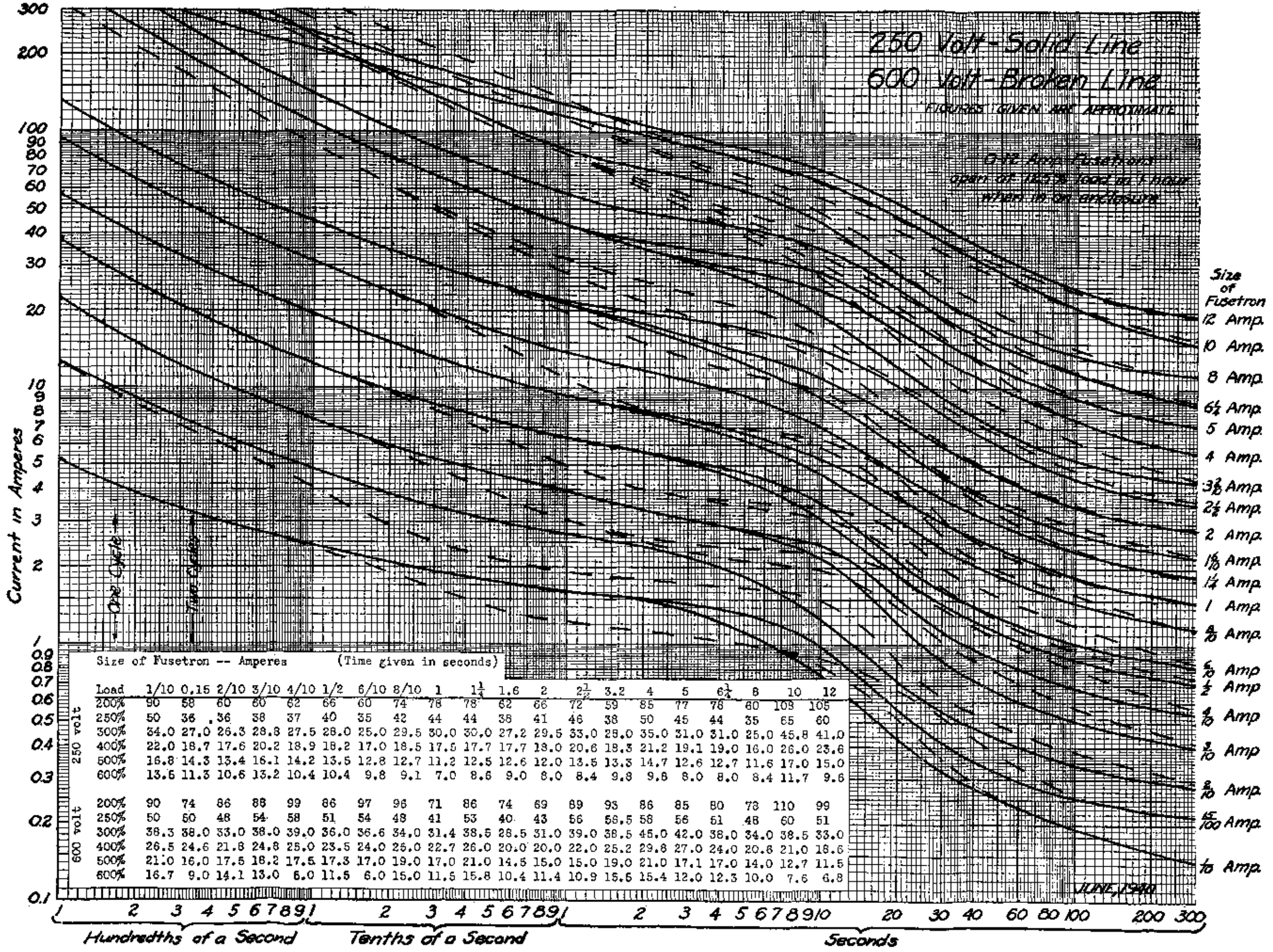
FIGURE 6.
TRACK CONSTRUCTION
ON
RUBBER PLATES.



TYPICAL SINGLE RAIL TRACK CIRCUIT AS USED IN NEW YORK SUBWAY.

Fig. 7. Diagram of typical track circuit. (New York City Board of Transportation)

Fig. 8. Sectional view of Fusetron. (Bussman Mfg. Co., St. Louis, Mo.)



Size of Fusetron -- Amperes (Time given in seconds)

	Load	1/10	0.15	2/10	3/10	4/10	1/2	6/10	8/10	1	1¼	1.6	2	2½	3.2	4	5	6¼	8	10	12
250 volt	200%	90	58	60	60	62	66	60	74	78	78	62	66	72	59	85	77	78	60	108	105
	250%	50	36	36	38	37	40	35	42	44	44	38	41	46	38	50	45	44	35	65	60
	300%	34.0	27.0	26.3	28.8	27.5	28.0	25.0	29.5	30.0	30.0	27.2	29.5	33.0	28.0	35.0	31.0	31.0	25.0	45.8	41.0
	400%	22.0	18.7	17.6	20.2	18.9	18.2	17.0	18.5	17.5	17.7	17.7	18.0	20.6	18.3	21.2	19.1	19.0	16.0	26.0	23.6
	500%	16.8	14.3	13.4	16.1	14.2	13.5	12.8	12.7	11.2	12.5	12.6	12.0	13.5	13.3	14.7	12.6	12.7	11.6	17.0	15.0
	600%	13.6	11.3	10.6	13.2	10.4	10.4	9.8	9.1	7.0	8.6	9.0	8.0	8.4	9.8	9.8	8.0	8.0	8.4	11.7	9.6
600 volt	200%	90	74	86	88	99	86	97	96	71	86	74	69	89	93	86	85	80	78	110	99
	250%	50	60	48	54	58	51	54	48	41	53	40	43	56	56.5	58	56	61	48	60	51
	300%	38.3	38.0	33.0	38.0	39.0	36.0	36.6	34.0	31.4	38.5	28.5	31.0	39.0	38.5	45.0	42.0	38.0	34.0	38.5	33.0
	400%	26.5	24.6	21.8	24.8	25.0	23.5	24.0	25.0	22.7	26.0	20.0	20.0	22.0	25.2	29.8	27.0	24.0	20.6	21.0	18.6
	500%	21.0	16.0	17.5	18.2	17.5	17.3	17.0	19.0	17.0	21.0	14.5	15.0	15.0	19.0	21.0	17.1	17.0	14.0	12.7	11.5
	600%	16.7	9.0	14.1	13.0	6.0	11.5	6.0	15.0	11.5	15.8	10.4	11.4	10.9	15.6	15.4	12.0	12.3	10.0	7.6	6.8

TIME OF OPENING — 0 to 12 amp. sizes

Fig. 9. Operating curves of Fusetrons. (Bussman Mfg. Co., St. Louis, Mo.)

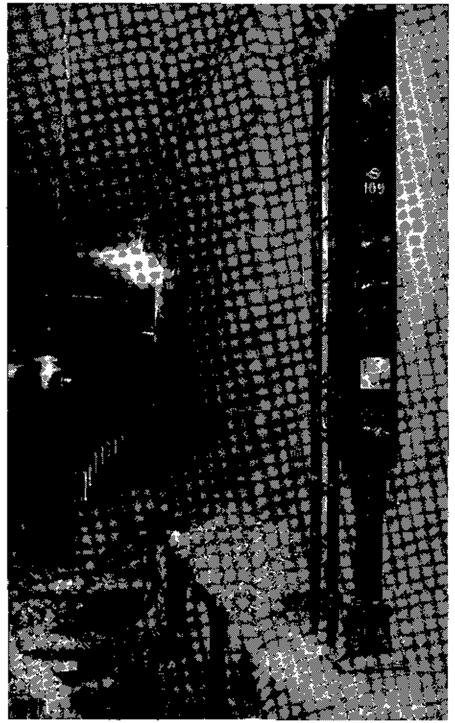


Fig. 10. Interlocking home signal, Union Station, Toronto Subway

Fig. 11. General view in Davisville Yard, Toronto Subway

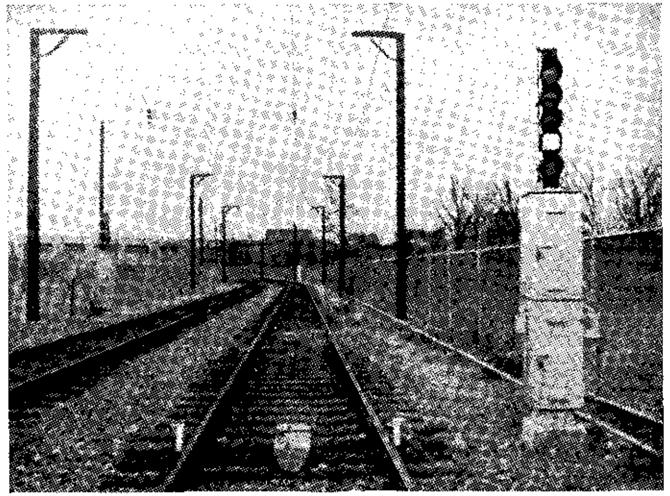


Fig. 12. Automatic signal in open cut. Metropolitan Transit Authority, Boston

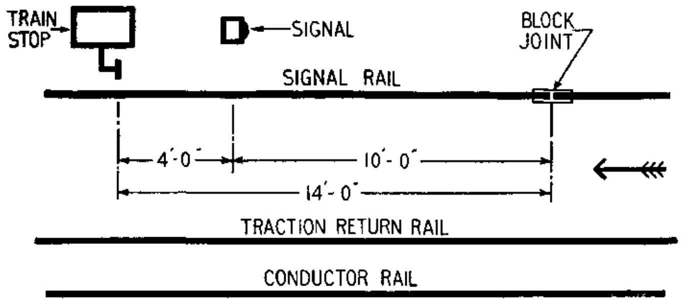
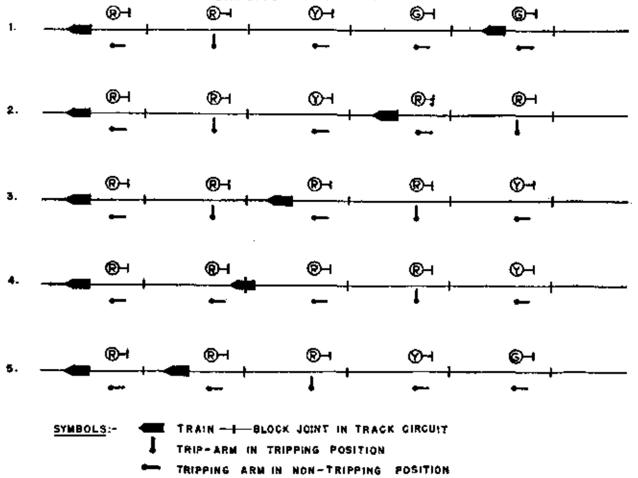


FIG. 13 RELATION BETWEEN SIGNAL, BLOCK JOINT AND TRAINSTOP.

FIG. 14 AUTOMATIC BLOCK SECTIONS STANDARD ARRANGEMENT



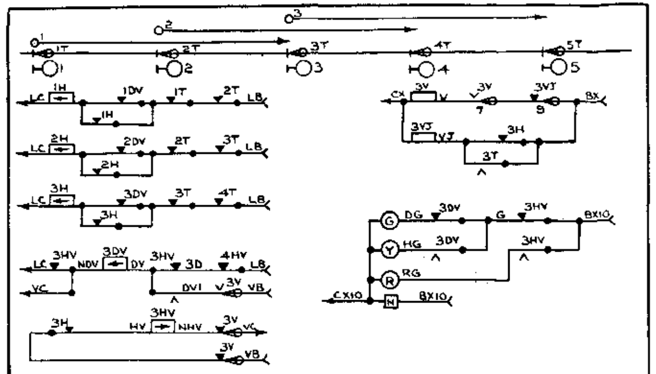
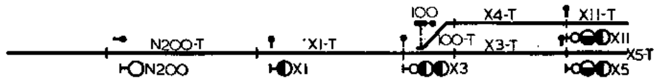


FIG 15
TYPICAL AUTOMATIC BLOCK SIGNAL CIRCUITS – D.C. CONTROLS

Automatic signal control circuits. (*Courtesy New York City Board of Transportation*)



SIGNAL	DESCN	LOCKS & DETECTS	ASPECT	CONTROLLED BY TRACKS CLEAR	AND SIGNAL	AT
N200	AUTO	–	Y G	N2OO-T, XI-T " "	XI	Y or G
XI	INT. APP.	–	Y G	XI-T, 100-T (X4-T or 100) (X3-T or 100R)	X3	Y/Y or Y/G or G/G
X3	INT HOME	100 " 100R	Y/G G/G Y/Y	100-T, X3-T, X5-T " " " 100-T, X4-T, XII-T	X5	Y/G or G/G
X3	CALL ON	(100 or 100R)	R/R/Y	(XI-T OCC.)	(REQUIRES KEY-BY OPERATION TO CLEAR STOP)	

FIG. 16 LAYOUT AT TYPICAL INTERLOCKING.

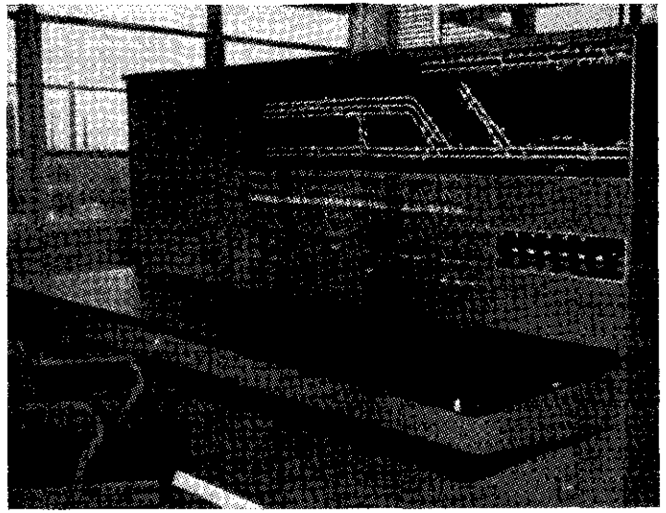


Fig. 17. "Unit lever" interlocking machine, Orient Heights, Boston

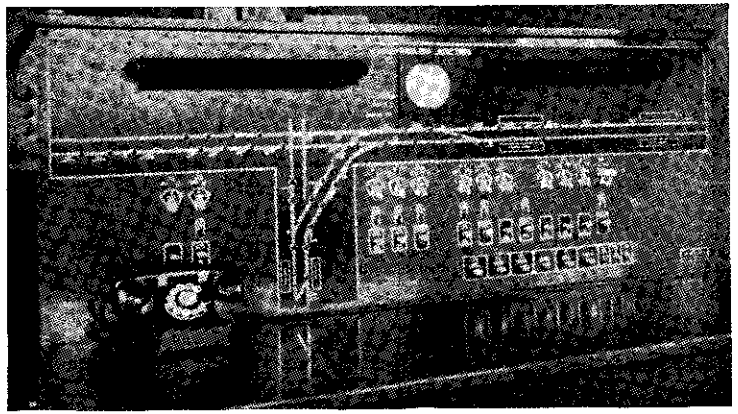


Fig. 17A. Lake Street, Chicago

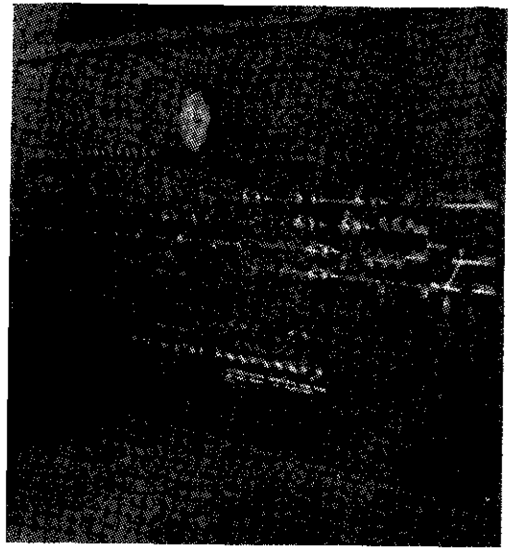


Fig. 18.

" UR " interlocking machine, South Portal, Chicago, (Chicago Transit Authority)

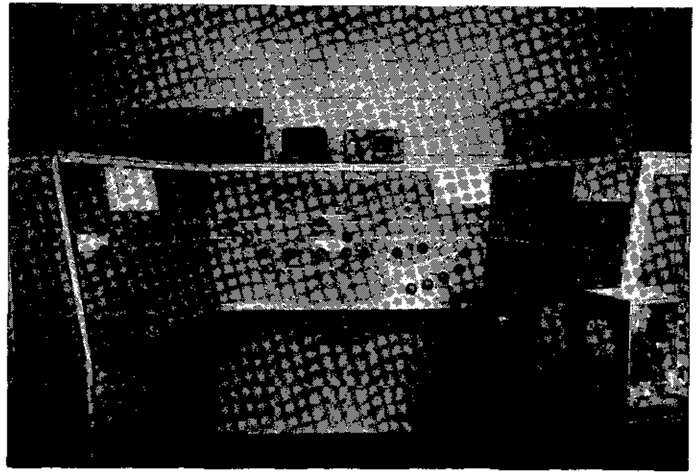


Fig. 19. " Multi-way-key " interlocking machine, Davisville. Toronto Subway

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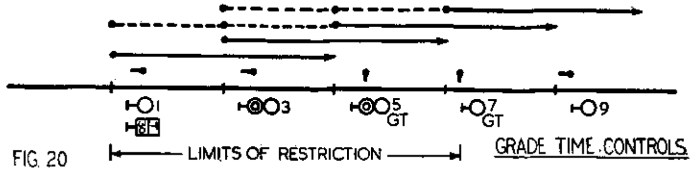


FIG. 20

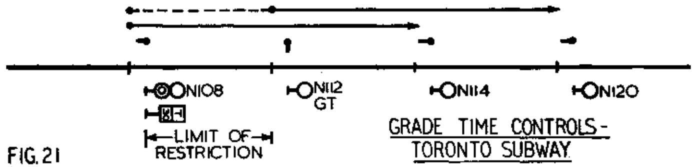


FIG. 21

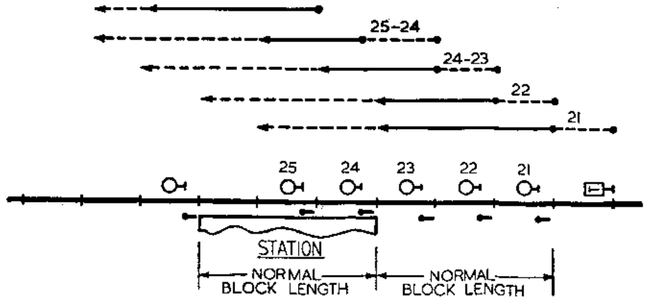


FIG. 22 TYPICAL STATION TIMING CONTROLS.

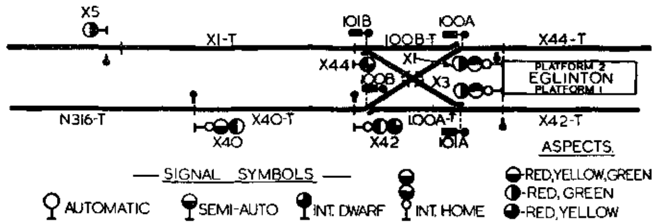


FIG. 23 LAYOUT AT EGLINTON STATION, TORONTO.

Fig. 24A. Automatic Dispatchers

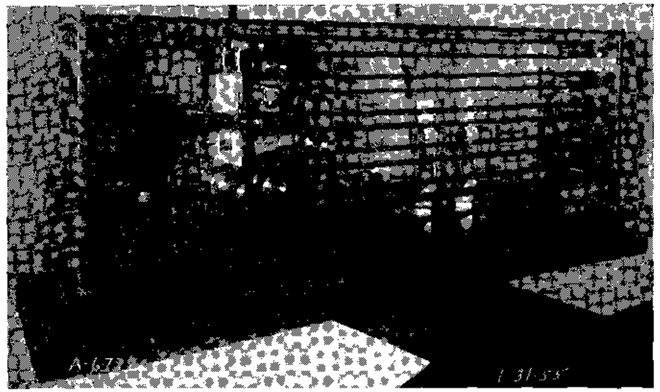
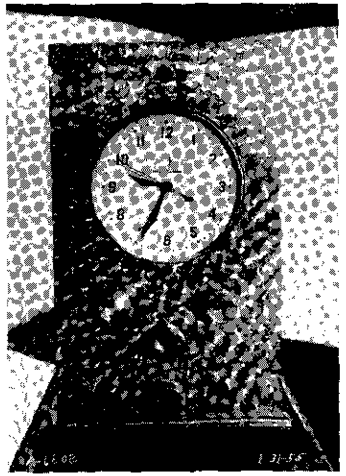


Fig. 24B. Automatic Dispatchers

Fig. 24C. Automatic Dispatchers



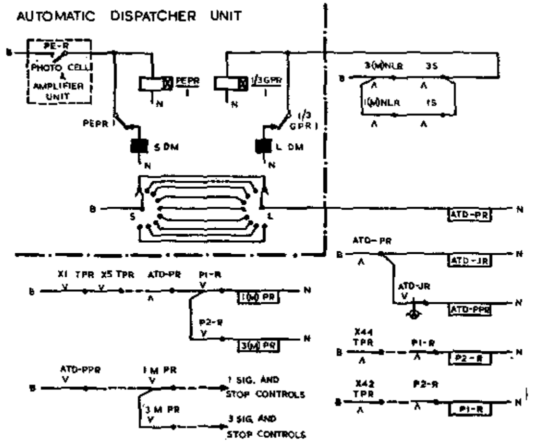


FIG. 25 CIRCUIT ELEMENTS OF AUTOMATIC DISPATCHER

Basic circuits of Automatic Dispatcher

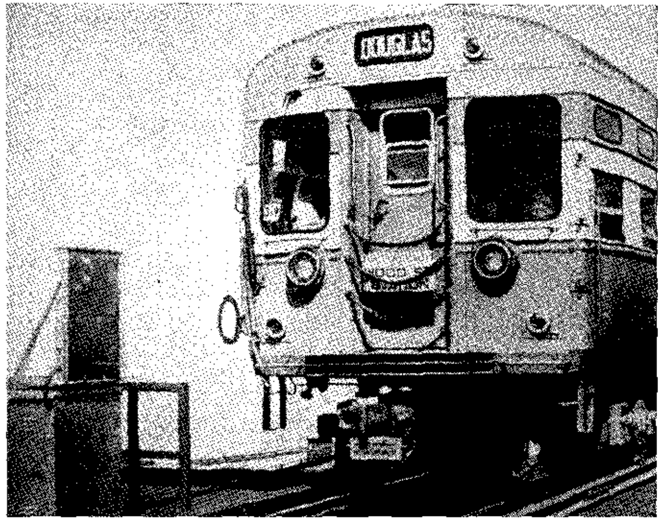


Fig. 26. Train with coil passing wayside coils. Chicago Transit Authority

Fig. 27.
Automatic train description
on the Flushing line.
New York City Board of
Transportation