Technical Meeting of the Institution

held at

The Institution of Electrical Engineers

Thursday, October 23rd, 1958

The President (Mr. J. F. H. TYLER) in the chair

The minutes of the Technical Meeting held at the Lighting Service Bureau, Savoy Hill, London, W.C.2, on Wednesday, March 12th, 1958, were read and approved.

The **President** then invited Mr. R. Dell (Member) to read his paper entitled " Automatic Junction Working and Route Setting by Programme."

Automatic Junction Working and Route Setting by Programme

By R. DELL (Member)

The automatic operation of points is not new and the automatic operation of a crossover or crossovers at a terminus has been in use for many years, but for completeness, simple sequential operation is included in this paper.

Three types of automatic setting of points and clearing of signals will be described:

(1) Sequential operation, where a set sequence of operations is always followed;

(2) Train describer operation of facing junctions—" First come, first served " operation of trailing junctions;

(3) Programme operation of junctions.

Interlocking Machine Working

On London Transport, all automatic junction working is done through an interlocking machine which carries all the safeguards for the signalling proper.*

The principle of the system is the provision of contact shafts in the machine, one used for each signal or pair of points. Mechanical locking is provided between the shafts, exactly as in the earlier power frames. An electric lock on each shaft is controlled by the track circuits and provides backlocking on signal shafts and track-locking on point shafts.

The signal and point circuits start from the contacts on the shaft and are then taken through contacts on track relays, point detection relays, etc., in accordance with normal signalling practice. The shafts are rotated through 60° to operate the contacts by two compressed air cylinders. The electro-pneumatic valves for these cylinders are controlled from the operating circuits, which determine the routes to be set up.

These circuits can be of a non-safety type and employ plug-in relays of the Post Office telephone relay 3000 type, and com-

*Dell, R.: " Power Worked Lever Remote Control Signalling System " I.R.S.E. Proceedings, 1942 paratively small wire for connections, with thin insulation.

The interlocking machine thus provides a physical separation between the non-safety circuits and the safety ones. Further, the safety signal circuits are kept very simple.

It is appreciated, of course, that similar results can be arranged with circuit interlocking, but the author is of the opinion that there is a grave risk of inadvertently mixing safety and non-safety circuits in this case, which, if done, could have very serious results.

Route Releasing by Rail Circuits

A particular safety feature which has been incorporated in all automatic junction working is that no route is released until not only are all the track circuits clear, but also the train is proved to be at the end of the route, by a special rail circuit. The

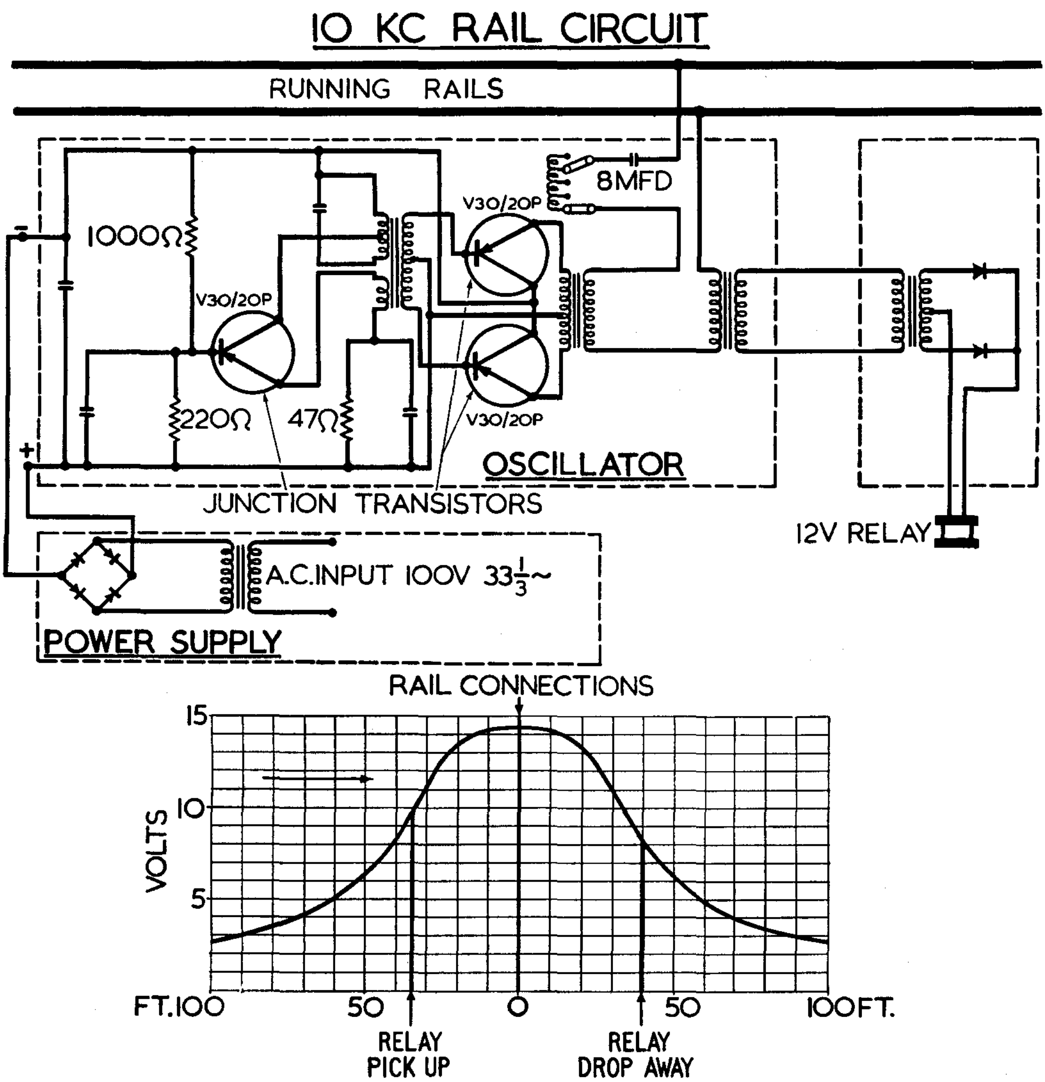

Fig. 1 Circuit for 10 kc. rail circuit with operating curve for one pair of wheels passing the point of connection

position of the rail circuit is arranged so that it cannot be operated by the longest train, until the rear of that train is clear of the last facing points on the route.

In earlier installations, these rail circuits were connected to a short length of rail, 11-ft. 6-in. long, insulated by block-joints from the rest of the track circuit; and with this arrangement, an ordinary a.c. track relay was employed on the rail circuit. More recently, rail circuits, using a transistor oscillator and operating at 10,000 cycles per second, have been employed. With this arrangement, no blockjoints are needed and the normal track circuit is not broken.

10 k.c. Rail Circuit

The 10 k.c. rail circuit, the connections for which are shown in fig. 1, comprises a transistor oscillator supplied with 12 v. d.c. by means of a transformer and rectifier from the signal supply. The output of the oscillator is stepped down to 0·7 v. at the output transformer. A step-up transformer is used to feed the line. The secondary of the output transformer and the primary of the line transformer are connected together and to a point on each running rail opposite to each other. A condenser connected in series with this circuit prevents any appreciable effect upon the normal track circuit of this additional connection to the rails. The wheels of the train complete the circuit to energise the relay. An additional transformer is used at the relay end of the line to prevent stray d.c. getting to the relay. The 10 k.c. current is rectified and operates a d.c. neutral relay of the usual type.

The operation of this unit has been found to give very satisfactory results, and it is found that the relay can be mounted up to 2,000 ft. from the oscillator unit, using ordinary lead-covered, 2-core cable, without any serious loss in the line.

At 10 k.c. the impedance of the steel rails is so high that the relay is only operated when the wheels are quite close to the point of connection to the rail. The effect is further accentuated by connecting a choke in series with the connection to the rails, and this choke tunes the circuit to resonance when the wheels are actually standing at the point of connection to the rails.

The voltage curve at the bottom of fig. 1 shows the operation of the rail circuit, with a pair of wheels approaching the point of rail connection. The voltage is measured in d.c. at the terminals of the relay, and it will be noted that the wheels must be approximately 35-ft. from the point of connection before the relay is energised. Similarly, the relay is released when the wheel is just under 40-ft. from the point of connection.

The rail circuits are distinguished from the ordinary track circuits by using the Greek letter delta, together with the letter of the track circuit on which the particular rail circuit is located. On plans, the symbol ⊥ is used to mark the position of the rail circuit.

Sequential Point Operation

The simplest form of automatic point operation is a single crossover at the terminus of a line. Fig. 2 shows such a layout. In this arrangement, with all the track circuits clear, points No. 3 would be normal and signal No. 1 clear. Approach clearing of signal No. 1 can be provided by track circuit A occupied, if desired. When the train has run in and occupied D track, No. 3 points reverse and No. 2 signal clears. Such a simple installation would not justify an interlocking machine or the use of non-safety circuits. The diagram, fig. 3, shows the circuit employed, which would be of the safety type throughout, and a special 2-position relay, gravity biased in each direction, is used to hold the points in each position.

It is thought that it is sufficient description of this circuit, if the circuit for setting No. 3 points reverse and controlling No. 2

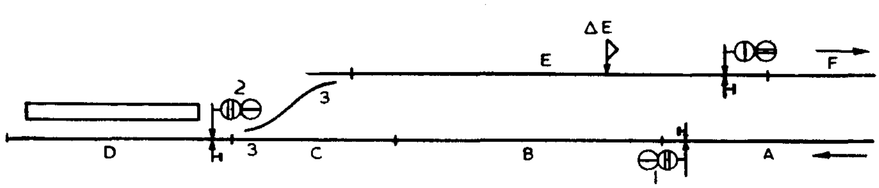

Fig. 2 Plan of terminus with automatic operation

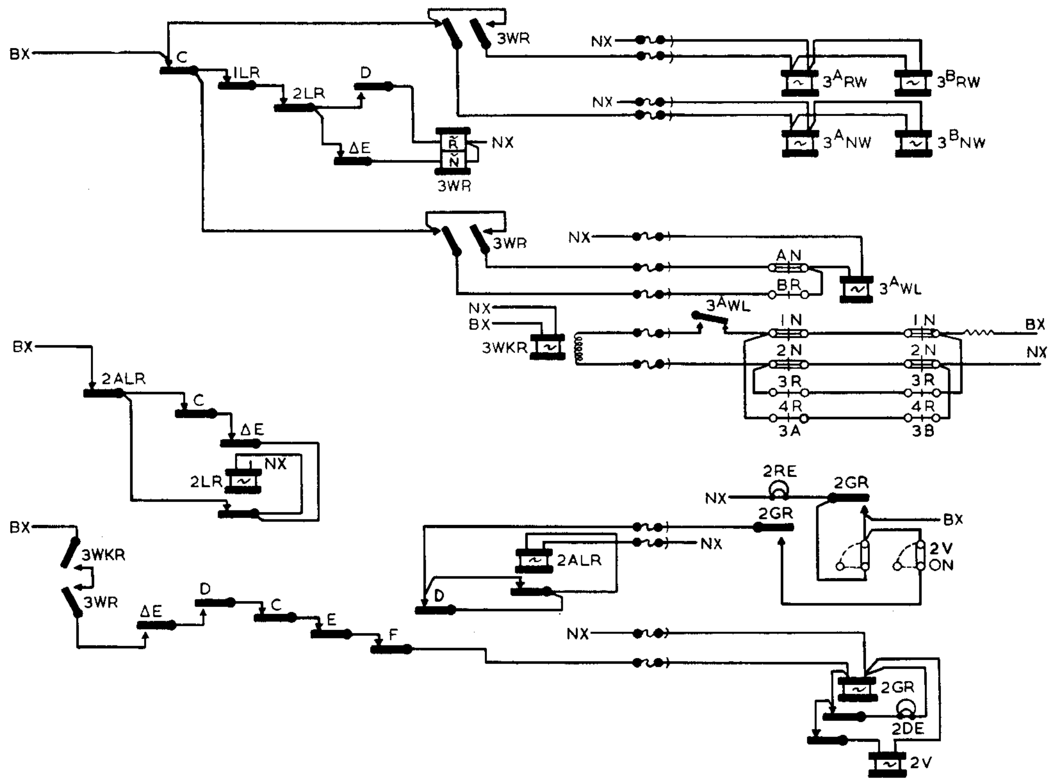

Fig. 3 Circuits for terminus with simple sequential operation

signal is described, as this particularly illustrates the use of the rail circuit for giving the final release of the backlock.

The point control relay 3 WR is the special gravity biased relay. This is a vane type a.c. relay in which the vane holds the contacts closed by gravity, in either the normal or the reverse position, and requires the application of current to move the relay in either direction.

The circuit to operate 3 WR from normal to reverse is C track clear, 1 lock relay energised, 2 lock relay energised, and D track occupied. The contacts of 3 WR then complete the circuit to the points 3 RW. The ground tracklock 3 WL is energised only when track C is clear and 3 WR is in a position to be out of agreement with the position of the points, as completed by the point detector. As soon as the points have thrown reverse, signal No. 2 is cleared through the circuit 3 WKR, 3 WR, delta E de-energised, D occupied, C clear, E clear and F clear. The back contact on delta E is included in this circuit to prove that this relay has correctly returned to the de-energised position. The clearing of the signal releases lock relay 2 LR and this prevents any further movement of the points until 2 LR is again energised. 2 Lock relay 2 LR requires the approach relay 2 ALR energised, which essentially proves that the signal is at danger and that the approach track circuit is clear, C track clear and delta E energised to pick up 2 LR. The position of delta E is 480-ft. from the facing points No. 3, so that when delta E is energised by the leading wheels of a train, the last car of the train will be past the facing points.

Another arrangement of sequential operation of points provides for the automatic signalling of the shunting movements of a locomotive.

Fig. 4 shows part of the track layout on which this arrangement is employed. The signalling generally of this layout is push button operated by remote control from

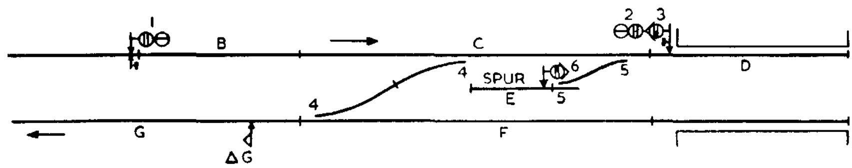

Fig. 4 Signalling layout for automatic shunting of locomotive

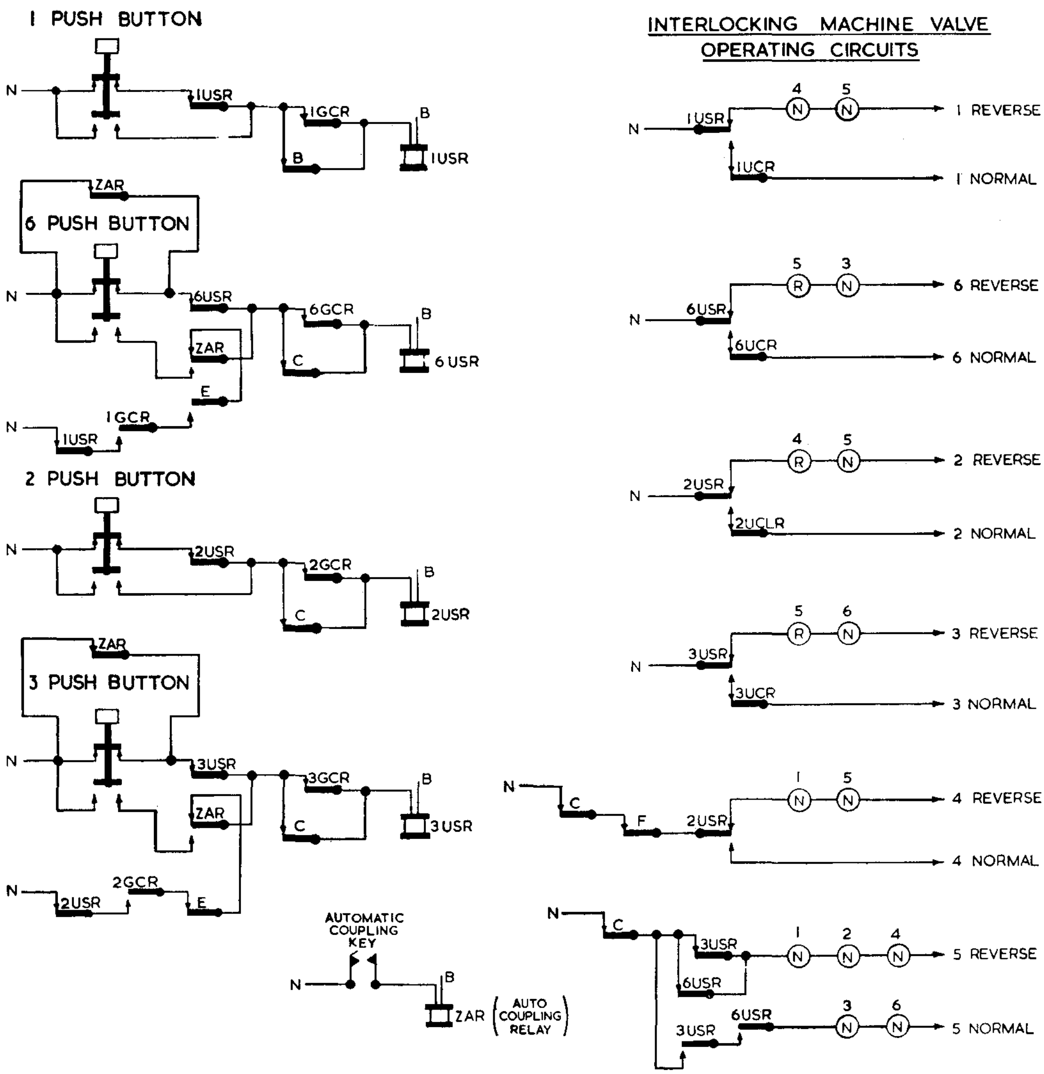

Fig. 5 Circuits for automatic shunting of locomotive—sequential operation

a signal cabin several stations away. The automatic shunting has been provided to reduce the work required of the signalman.

At this situation, locomotives are in use on the trains, and at the terminus, these locomotives have to be changed and shunted for each train that is reversed. The arrangement provided requires the signalman to signal the train into the terminus by operating one push button. When the train has arrived in the platform, the route for the spare locomotive to be shunted on to the end of the train is automatically set and the shunt signal cleared. When the locomotive has been coupled and the train is due to depart, the signalman signals it away by pressing one button. After the departure of the train, the locomotive left behind is automatically signalled into the spur road ready for the next operation.

Referring to the plan on fig. 4, the movement initiated by the signalman pressing his button clears signal No. 1 and the train runs into the platform road—track circuit D. A spare engine is standing on the engine spur, and immediately track circuit C is cleared, the locking for the incoming route is released and points No. 5 automatically reverse. Signal No. 6 then automatically clears and the engine is shunted from the spur on to the end of the train in the platform. When the locomotive has cleared C track, the locking on the route is released and 5 points return to normal. The train is now ready to proceed, and the signalman, by pressing one of his push buttons, clears the starting signal No. 2, and this signals the train away. When the tail of the outgoing train has cleared track circuit F and has operated delta G, the backlocking on the starting signal will be released. No. 5 points then automatically reverse and shunt signal No. 3 is cleared. The locomotive left behind in the platform can then proceed through 5 points reverse into the spur road. As soon as the locomotive is clear of track circuit C, 5 points are returned to normal.

Fig. 5 shows the operating circuits which terminate at the valves for rotating the shafts in the interlocking machine. The circuit for operation of signal No. 1 starts at the top of the diagram and is straightforward. The clearing of the backlock for signal No. 1 is—with the clearing of C track, the shaft is restored to normal by the circuit 1 USR down and 1 UCR up, energising No. 1 normal. This frees the circuit for the operation of No. 6 route, with No. 5 crossover reversed. The movement is initiated by the energisation of 6 USR, the circuit seen on the left of the diagram. This, in turn, operates No. 5 points through the circuit, C track energised, 6 USR, 1 normal, 2 normal, and 4 normal. These latter contacts are only inserted to prevent the shaft cylinder straining against the locking.

No. 6 signal is cleared by the circuit 6 USR, 5 reverse, 3 normal, and the shaft operating valve 6 reverse, and the locomotive from spur E is signalled on to the end of the train.

The movement for the train to depart is started by the signalman pressing button 2 which clears the starting signal. When the train is gone, the route automatically sets for the locomotive to proceed into the spur.

Train Describer Operation of Facing Junction

Where a train describer exists as part of the signalling installation, it is convenient to use the information of the destination of the train, given by the train describer, to set the route over facing points at a junction.

Fig. 6 shows a simple facing junction, and it should be appreciated that this, in fact, might be part of a more complicated layout. It should be borne in mind, and is helpful in considering some of the later descriptions in the paper, that any track layout, however complicated, really comprises a number of facing junctions and a number of converging iunctions. It greatly

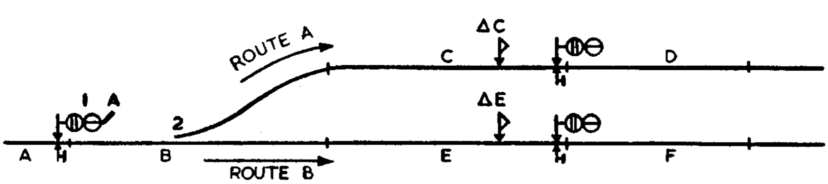

Fig. 6 Plan of simple facing junction

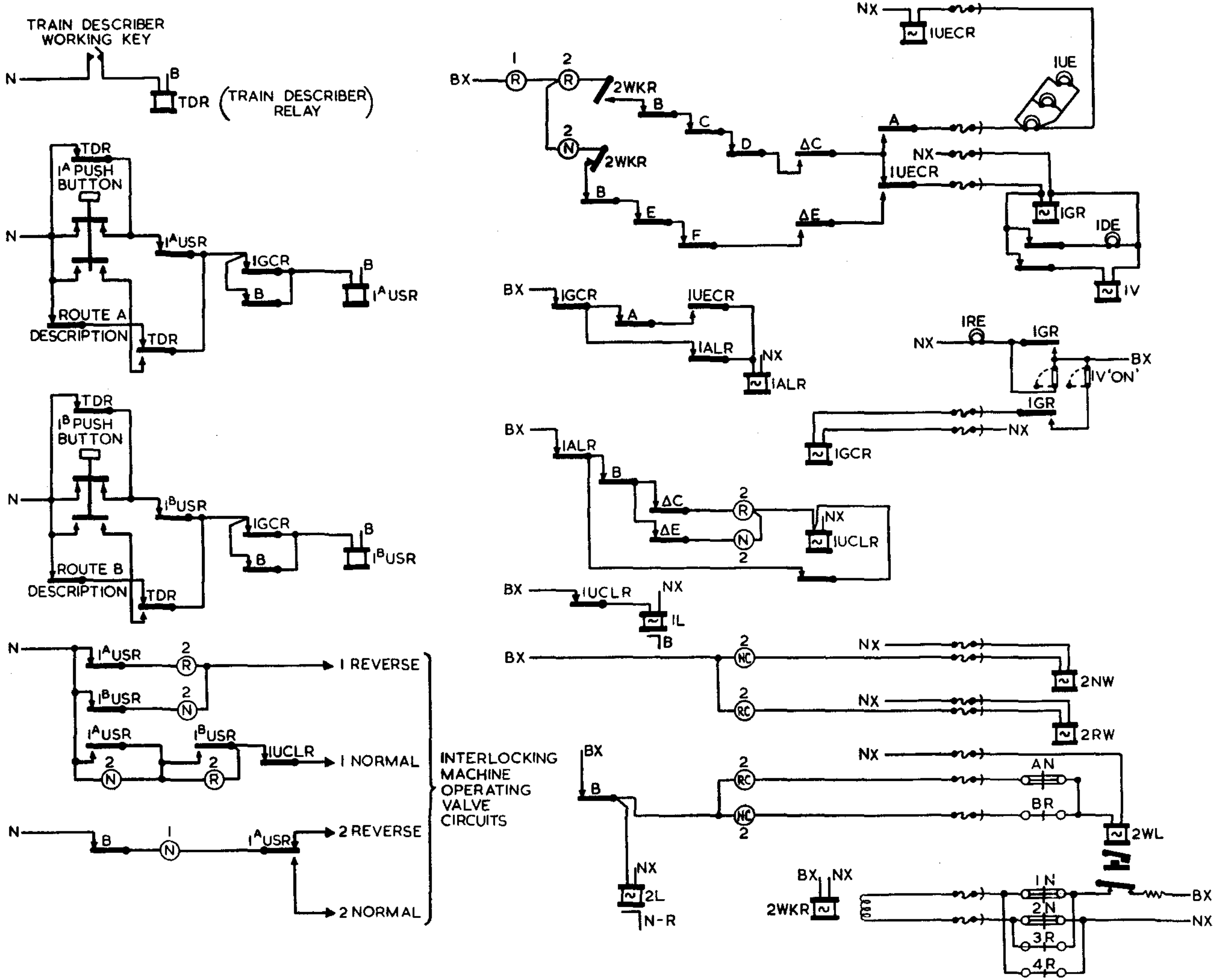

Fig. 7 Circuits for operation of facing junction by train describer

simplifies the consideration of the layout as a whole, if it is separated into these individual components.

In order to operate the route over this facing junction, it is only necessary to arrange the circuit so that the information from the train describer is sorted out into those trains with destinations requiring them to be routed to the left, and those trains whose destinations require them to be routed to the right. By suitable connections, the points are set to the appropriate route and the train signalled.

Fig. 7 shows details of the circuit.

This circuit is basically the push button circuit, which is widely employed on London Transport, and which is retained for the route setting under manual conditions. To provide for train describer operation, it is only necessary to bridge the push contact of the push button by a suitable contact operated by the train describer. For convenience, this is usually a contact on a relay, the relay itself being operated from the train describer descriptions. In order to provide that either train describer or push button working can be used, the additional contacts TDR are provided, which are actually contacts on a relay operated by a switch. When the relay is operated, the train describer control is effective and the push inoperative, and when the TDR relay is de-energised, push button working is restored.

Below the circuit for the two push buttons which operate, respectively, 1 A and 1 B USR, are circuits from these relays to the shaft operating valves in the interlocking machine. The circuits to the right of the diagram are the signal safety circuits, which are individual to the points and signals.

" First Come, First Served" Automatic Trailing Junction

This arrangement is very simple. The route is set by the operation of approach track circuits on the two converging lines. These track circuits are arranged to set the route and clear the signal before it is seen by the driver, so that no speed check is imposed. Which approach track circuit is occupied first decides the precedence of the trains. In the event of two trains arriving on the approach track circuit at the same split second, the relative speed of the relays will decide which route is set.

Fig. 8 shows a plan of a simple converging junction.

Fig. 9 shows the circuits for operating this junction automatically on a " first come, first served " basis.

Programme Machine Control of Junctions

It will have been noted that train description and " first come, first served " working will provide complete operation of a junction, but it has a number of disadvantages:

(1) The service is not necessarily kept in time table order and a very slight lateness or earliness at a converging junction results in trains being run out of order.

(2) The method cannot originate the running of a train, that is to say, it cannot provide for the starting up of a train from a siding or from a terminus.

(3) No time control of train movement is provided.

It is to cover these items that the programme machine has been introduced. It

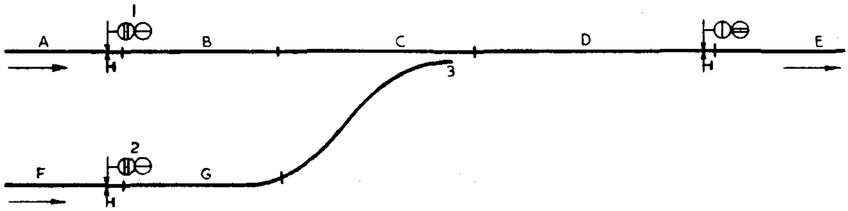

Fig. 8 Plan of simple trailing junction

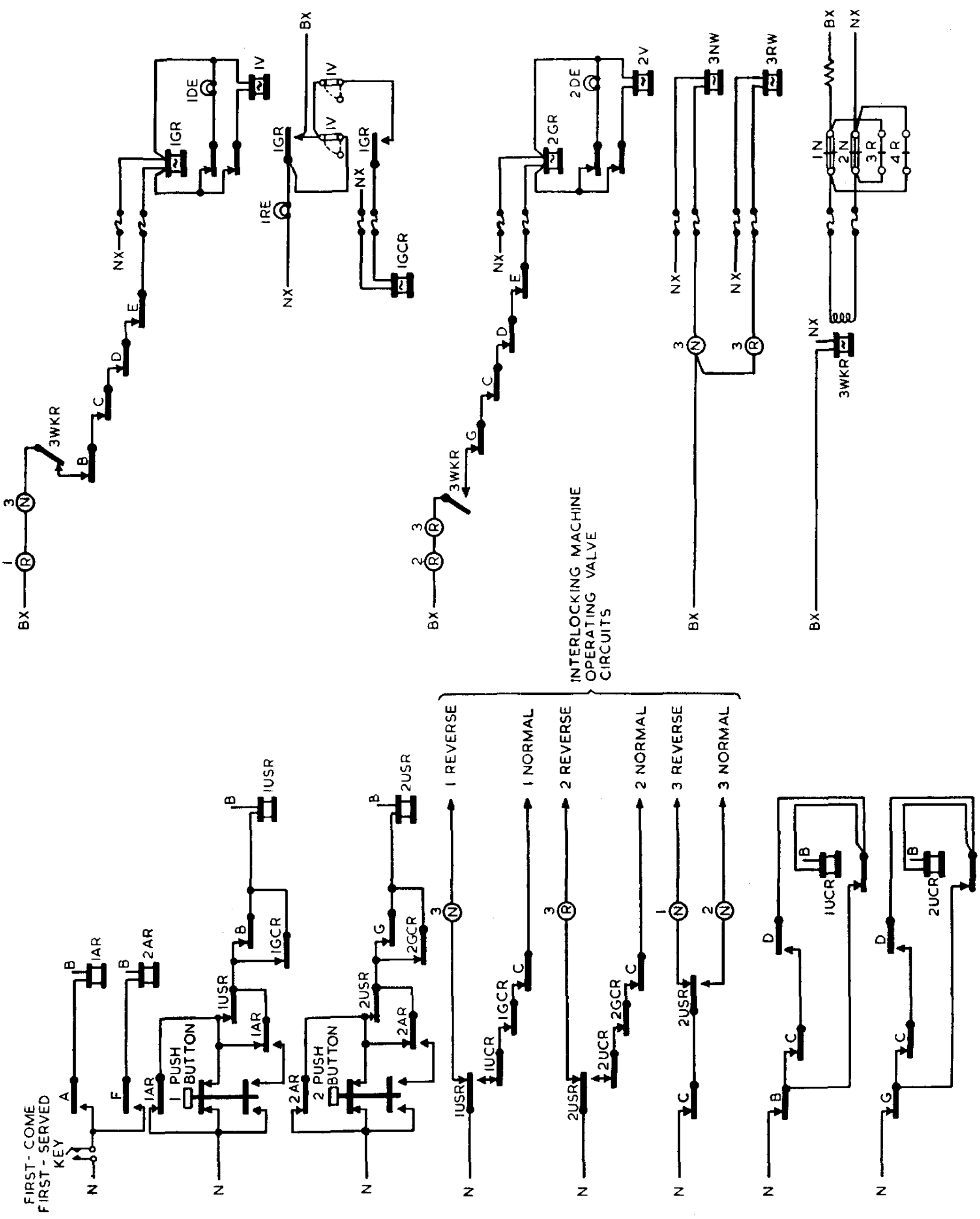

Fig. 9 " First come, first served " control of trailing junction has been designed to provide the following features:

(1) It carries the full details of the train service for a day and can set the routes over a junction from this information, in time table order.

(2) In conjunction with a second machine, it can check the time of each train, and as a result:

   (*a*) Sound an alarm if a train is late by more than a predetermined time.

   (*b*) Delay the clearing of a signal until it is time for the train to depart.

(3) Check the correct operation of the train describer.

(4) When a train is originated by the machine, such as starting it out of a siding, to transmit the destination on the train describer.

(5) In conjunction with the electrical circuits, to signal a waiting train out of turn, if the train scheduled to run before it is late by more than a predetermined amount, and to store the information that this has been done, routeing the late train as soon as it arrives.

The design of the programme machine has been arranged so that the machine carries the programme on two rollers. The programme itself is in the form of a roll of plastic film, 8-in. wide, and of a sufficient length to accommodate the programme for a complete day. Holes are punched in the roll to provide the information for each train, in one line across the roll. The spacing of adjacent lines of holes is $\frac{3}{8}$-in. and the length of the roll is determined by the number of trains. The maximum length that could possibly be accommodated on a machine would be of the order of 40-ft., which would accommodate 1,200 trains. In some instances, where two machines must co-operate to route trains over a common track, both services must appear on both rolls, and this is the reason for the machine being designed with such a large capacity of trains. Provision is made for a total of 32 holes to be punched on each line, so that a very large amount of information can be provided, and this enables the simplest possible circuits to be used for at least the most important part of the working. A separate hole is provided for each route setting required.

Fig. 10 shows a typical programme roll.

The rollers on which the programme is wound are mounted in a detachable carrier,

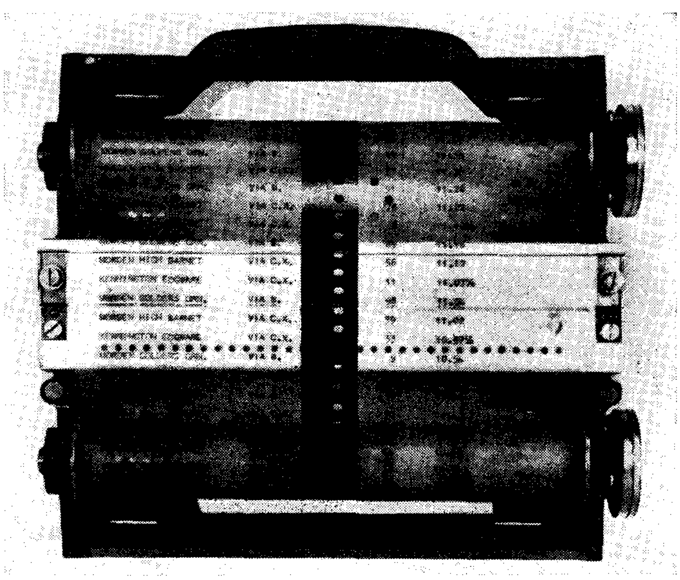

Fig. 10 Detachable carrier with programme roll in position

so that different programmes can be inserted for weekdays or Sundays.

The drive to the rollers to wind the roll forwards or backwards is by means of magnetic clutches from a small induction motor. Photo-cells, in conjunction with extra holes control the movement of the roll from one line of holes to another and control the rewinding of the roll at the end of the day's service.

The reading of the holes punched on the programme roll is by means of 30 feelers. Each feeler carries twin silver contacts, which are closed when the feeler enters a hole in the roll. All the feeler springs are mounted on a tilting carrier and are held away from the roll by a spring, so that the roll is free to move. When the roll has been positioned by the photo-cell, the feelers are pressed on to the roll by means of a small compressed air cylinder. Those feelers which enter a hole close their contacts, whilst those feelers which touch the surface of the roll have their contacts held open. The contact pressure on the twin contacts is 60 grammes and the contacts are designed to give a slight rub.

All programme machines are identical in design, but when used on an installation they are connected to operate in two ways:

(1) *Sequence Machine*
In this arrangement, the machine steps once for the passage of each train.

(2) *Time Controlled Machine*
With this arrangement, the machine is controlled by time in the form of half-minute impulses obtained from an electric clock. The machine is arranged to step after the lapse of the time between each two trains, in accordance with the time table. One time controlled machine can be arranged to operate with several sequence machines up to the capacity of the programme roll.

Fig. 11 shows a photograph of a programme machine.

Fig. 12 shows a diagram of the stepping circuit.

The basic principle of the stepping circuit is that, at the operation of a track circuit or some other suitable control, the motor is started and the forward clutch energised. The motor drives the roll forward and the light which was energising the forward photo-cell is cut off by the hole in the roll moving. The motor continues to drive the roll until another hole comes

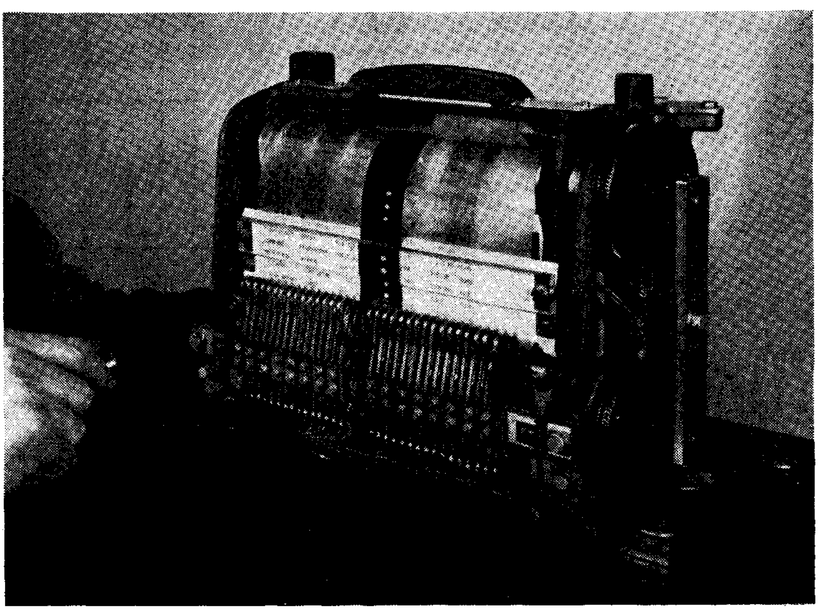

Fig. 11 Programme machine complete

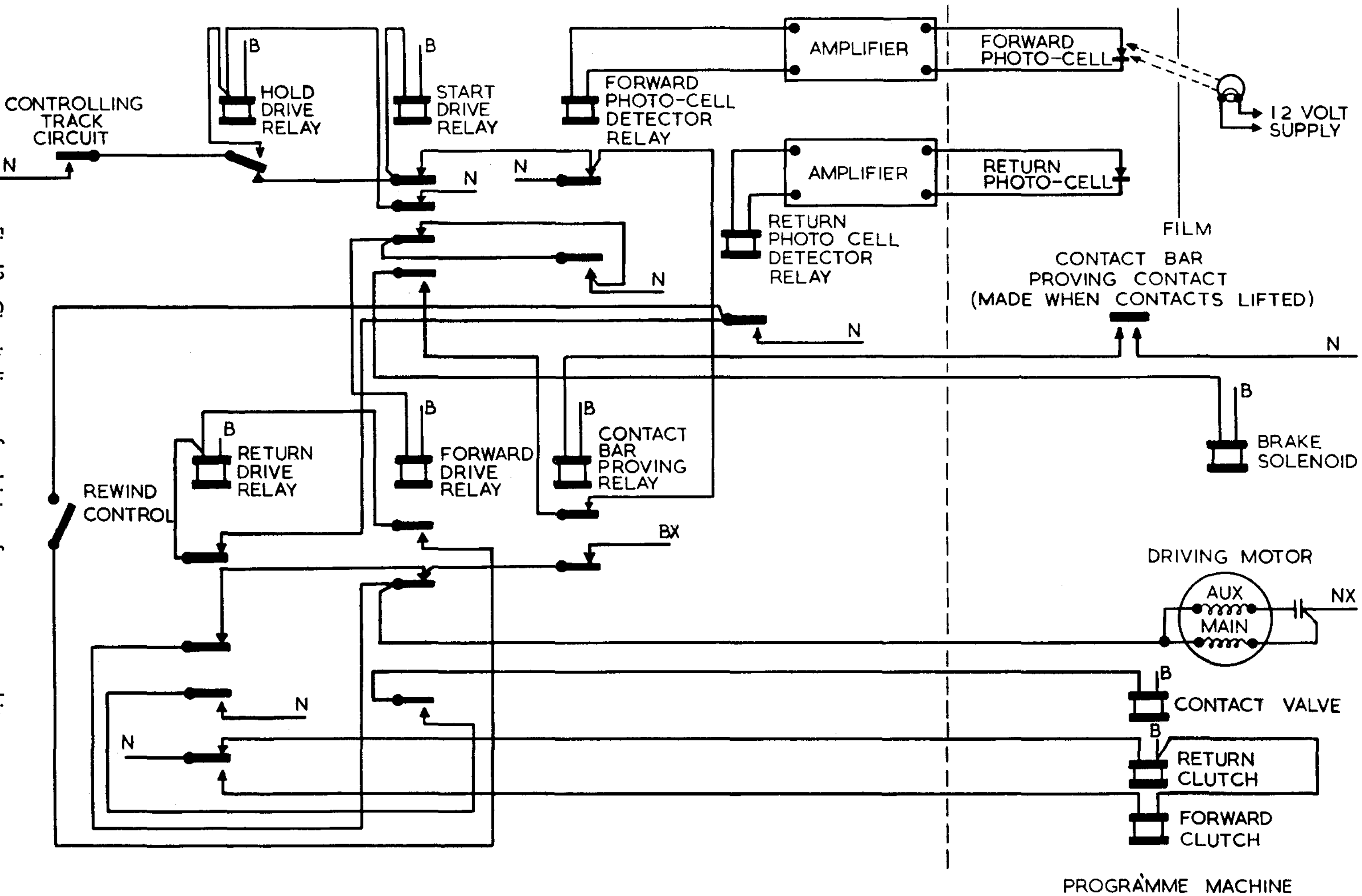

Fig. 12 Circuit diagram for driving of programme machine

in front of the forward photo-cell, permitting it to be illuminated, and this cuts off the drive to the motor and applies the brake.

The photo-cell amplifier is a transistor amplifier containing one transistor. The two photo-cells operate from the same lamp. The forward photo-cell controls the stepping forward of the roll one line of holes at a time. When the roll reaches the end of the day's programme, by means of the rewinding control contact shown on the left-hand, which is actuated from an extra hole on the roll, the return clutch is energised and the roll runs the whole way back until the return photo-cell receives light from a special hole at the beginning of the programme.

Operation of Programme Machine by Time Control

The same circuit is used for the actual stepping of the machine, as described above for the sequence operation. The difference in method is that, for the time control, the machine carries a special set of holes which are punched to coincide with the time between each two trains, and thus the machine reads off from the roll in half-minutes the time between trains and is arranged to step when this time has elapsed. Five holes are allocated on the roll for counting these half-minutes. These holes follow the binary system of counting, and the five holes permit counting up to 31 half-minutes or $15\frac{1}{2}$ minutes. This time is sufficient for the normal interval between trains on London Transport, but if a greater interval is occasionally required, this is simply obtained by punching a second row of holes for the same train and thus doubling the possible time interval.

Fig. 13 shows the binary system allotted to the five holes for counting the time interval.

The timing holes are read by the feelers on the programme machine in the usual way and transferred to a relay binary counter. This counter counts the number of half-minute pulses from the clock to make up the number represented by the punched holes, and when that number of half-minutes has been received, completes the circuit to step the roll to the next line of holes.

Fig. 14 shows the circuit diagram for the relay binary counter used.

This counter works on the principle that it is set up to the required number from the programme roll and then counts down to zero before completing the circuit for the machine to step. The programme machine contacts are shown on the left-hand side of the diagram and they are connected to the relays momentarily, after the programme roll has stepped and when the feelers first enter the holes. After a suitable time, arranged by the slow release feature of the cut-off relay, the feeler contacts are disconnected from the relays, those relays which have been energised remaining up and forming the number that has to be counted off.

The principle of the operation of the binary counter is that each relay is arranged to move from its existing position to the opposite position on receiving an impulse, and to stay in that position until it receives another impulse, when it reverts to its opposite position.

In this circuit, telephone-type relays are employed, each relay having two windings, and one of these is used for the stick circuit. The other winding is used for picking up the relay or releasing it, according to the polarity of the current passed through the winding. The current to energise or de-energise the counting relays is obtained from a charged capacitor, and the polarity of the charge in this capacitor is changed

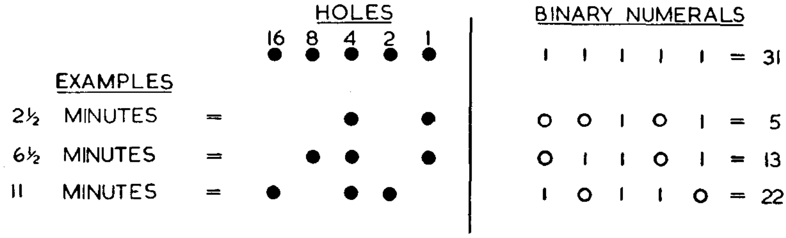

Fig. 13 Use of binary numeral system for counting time interval

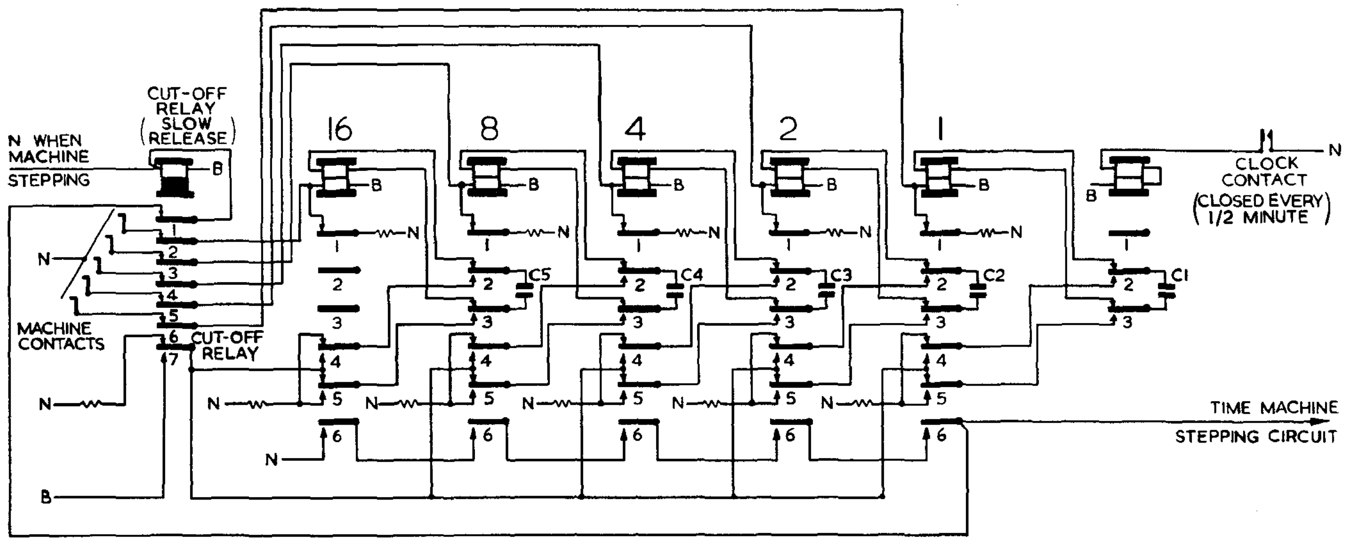

Fig. 14 Circuit of binary counter for time interval counting

according to whether it is desired to energise the relay or to de-energise it.

Looking at the right-hand side of the diagram, the contact operated by the master clock is shown, and this actuates a relay in the counter repeating the master clock impulses. Connected to a pair of contacts on this relay is the capacitor C1. This capacitor is charged through the down contacts and the polarity of the charge is reversed, according to the position of relay 1. When relay 1 is in the de-energised position, the charge on capacitor C1 is of the polarity necessary to energise relay 1, and when the master clock closes its contacts, the charged capacitor is connected across the windings of relay 1, which immediately picks up, and the stick circuit is closed, which holds it up. The master clock contact then opens and the impulsing relay de-energises. The capacitor C1 is now charged to the opposite polarity, and at the next impulse of the master clock, will send current through the winding of relay 1 in the opposite direction to the current in the holding circuit on its other winding. The two magnetic fields, being in opposition, neutralise one another and the relay releases.

Exactly similar circuits are used for operating relays 2, 4, 8 and 16, capacitor C2 operating relay 2, capacitor C3 operating relay 4, and so on.

The operation of the counting circuit is probably best understood from a table of the count, and this is shown in fig. 15. The relays represent binary " 1 " when in the energised position, and binary " 0 " when in the de-energised position. This table is shown for the full count of 31 and starts with the binary numeral " 11111." Each relay representing a binary numeral, which is standing at " 0 " on receiving an impulse changes to " 1 " and, at the same time, passes an impulse to the next relay. This causes the next relay to change its state.

It will be noted that the numbers are arranged in the table so that the unit counts down. The impulses are shown on this table by the arrows. The complete line of arrows on the right-hand side represents the pulses passed each half-minute by the master clock, and the remaining

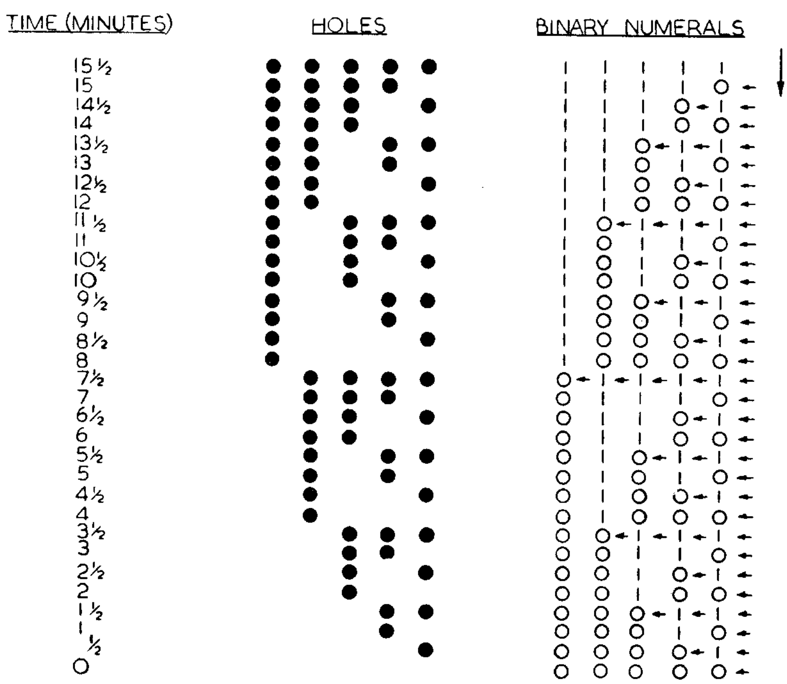

Fig. 15 Complete time count to 31, using binary system

arrow-heads indicate the pulses passed on by the relays of the counter.

Coincidence Working of Sequence and Time Machines

The working between the sequence machines and the time machine is arranged by a coincidence circuit actuated by a code of four holes provided in each of the programme rolls. When the code is the same on both the sequence machine and the time machine, this is the indication that it is time for a particular train. During most of the day, the time machine is one step behind the sequence machine, and it is only at the actual time that the train is due that the time machine catches up. It is then that the coincidence circuits complete any necessary working circuit dependent on the time of day.

When the train passes, the sequence machine steps forward one step ahead of the time machine, and the process is repeated for the next train.

The time machine is also, where necessary, used to set a route direct from its programme, for example, when a train is originated from a terminus or a siding.

Supervision of Operation

The machines and circuits are designed to deal with the whole of the normal traffic working, but provision is made for the supervision of the working from a central supervision room or from some other convenient point. The man in charge here can deal with any special circumstances that arise, such as the need to make a drastic change in the service, as the result of a breakdown.

The room is provided with the following equipment:

(1) A complete illuminated diagram.

(2) Repeaters of all the sequence programme machines.

(3) Push buttons which enable the routes to be set by hand, if necessary.

(4) A switch for each programme machine enabling the signalling to be set to operate:

  (*a*) Programme machine working.

  (*b*) "First come, first served" working.

  (*c*) Push button working.

(5) A train cancel push enabling a train to be cancelled on the programme.

(6) A set of alarms worked from the programme machines, which draw attention to any discrepancy in the service, such as a train late or a train the description for which does not agree with the programme.

The train cancelling arrangement comprises four pushes, each with a visual lamp. The pushes are connected to a relay counting chain set to count 1 to 4 and arranged to count the trains as they pass.

To use the cancel facility, the operator, on receiving advice by telephone that a particular train is cancelled, looks at the repeater programme machine and notes that the cancelled train is, say, the third train to come on the programme. He presses cancel button 3, the relays then count the trains and, after two trains have passed, cause the programme machine to step twice, thus eliminating the cancelled train from that day's working.

The required information for operating the illuminated diagram at the central supervision room and all the other facilities is carried by means of a multi-core cable, with one wire allotted to each function required and using a common return. A special cable is used for this purpose, employing a very thin conductor for the cores, the copper conductor being 0·01-in. diameter. This results in a cable of overall small dimensions and reasonable cost. It is felt that the use of a multi-core cable makes for simpler working than the use of a pulsed system over a single wire, and by the use of the very small conductors the cost of the multi-core cable can compare with alternative systems for moderate distances, say, up to 10 miles, and by using a d.c. circuit, the resistance of the conductor presents no serious difficulty. The cable is manufactured in layers of single conductors, with a screen on the outside formed of copper tape. This metal screen is insulated by an outer layer of P.V.C. The screen is used as a common return for all the circuits. If rectified a.c. is used to provide the d.c. for the circuits, smoothing of the output is advisable, as otherwise, the ripple can cause voltages to appear on circuits which should be de-energised, although by using d.c. relays, this ripple does not cause any difficulty in operation, but is deceptive when carrying out tests.

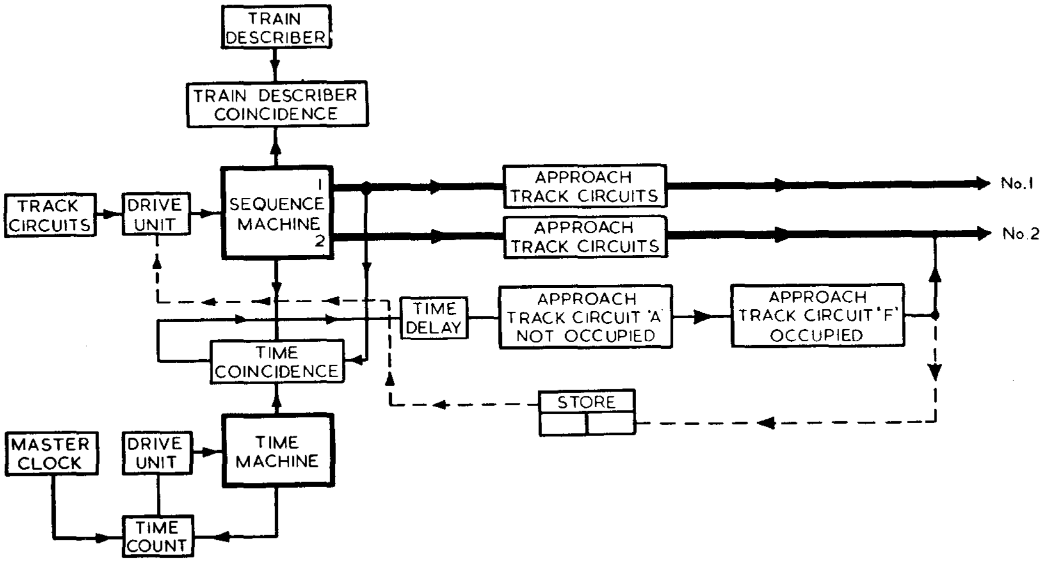

Fig. 16 Functional diagram for programme machine working a converging junction

Simple Conditions for Programme Machine Control

Before describing the application of programme machine working to complete layouts, two simple conditions are illustrated:

Programme Machine Control of a Converging Junction

(For illustration, refer to fig. 8, which is now to be shown programme machine controlled).

Fig. 16 is a functional diagram illustrating the control paths initiated by the programme machine for the control of the signalling of this converging layout, and several similar diagrams will be used for the more complicated arrangements later in the paper. They are not drawn as circuit diagrams, but are intended to show the requirements provided by the circuits. A convention is followed for the programme machine rectangle. The lines entering on the left indicate paths which will cause the programme to step. Lines leaving the rectangle at top and bottom are the train describer check and time coincidence check. The lines leaving the rectangle on the right indicate information originating from the programme roll.

The diagram is drawn with heavy lines to indicate the path of the main route control, with light lines to indicate alternative paths, and with dotted lines to indicate feed back into the store for control of machine stepping.

The control starts from the sequence machine for route No. 1 and, with the occupation of the approach track circuit, No. 1 route is set. No. 2 route is exactly similar. In this case, neither train describer check nor time coincidence check is required, and this represents the normal working for a service running to schedule. As each train passes over the fouling track circuit C, the programme machine is stepped one step forward.

Provision must be made for out of turn working in the event of either of the programmed trains not arriving. As an example—the programme machine is showing the next train to be from signal No. 1, but no train has arrived. On the other hand, the following train, which would pass signal No. 2, has arrived and is waiting on approach track F. Provision must be made for this train to be signalled after waiting for the set time interval after the train itself is due. This is shown by the thin solid line from route No. 1 on the sequence machine checking time coincidence to ensure that, in fact, the train from route No. 1 is late; and after waiting the time delay and with approach track A not occupied, this completes the route for signal 2, The operation of this route puts into store the information that an out of turn train has been permitted to pass on route 2. This information carried in the store stops the sequence machine from stepping, and it is not until the train on route No. 1 eventually arrives, that the machine is permitted to step.

It may be that, due to a hold-up on the one branch, in fact, several trains will have arrived on the other branch, No. 2, and will have been signalled out of turn by the circuit provided. Each one passing will step up the store, one by one, so that the information carried by the store is, in fact, the particulars of the number of trains which have proceeded out of turn. Meanwhile, the programme machine is still waiting for the train which has not arrived. When this train does arrive, the programme machine is stepped forward first by the actuation of track circuit C, but after this one operation, it is further stepped by the store for the number of steps corresponding with the number of trains which have passed and which have actuated the store. The machine will then have returned into step with the service.

The store, which is in the form of a chain of relays, is made to hold five storages which, so far, has been found adequate for service conditions. The same relay store serves the two branches of a converging route, and it is determined whether it is storing for route 1 or route 2 by a controlling relay at the input and output of the store.

Programme Machine Control of a Facing Junction

Considering fig. 6 as a layout suitable for a facing junction to be controlled by a programme machine, fig. 17 shows the functional diagram of controls.

The control starts from the programme machine and passes through the train describer coincidence circuit to ensure that the train describer is in agreement with the programme, and sets the points and signals for route A. For route B, exactly similar conditions apply.

These controls form the normal controls with the trains arriving in accordance with the programme and with their description as shown on the train describer in agreement with the programme.

Should there be disagreement with the train describer, an automatic alarm is given at the central supervision room and a time delay set in motion. After the lapse of a

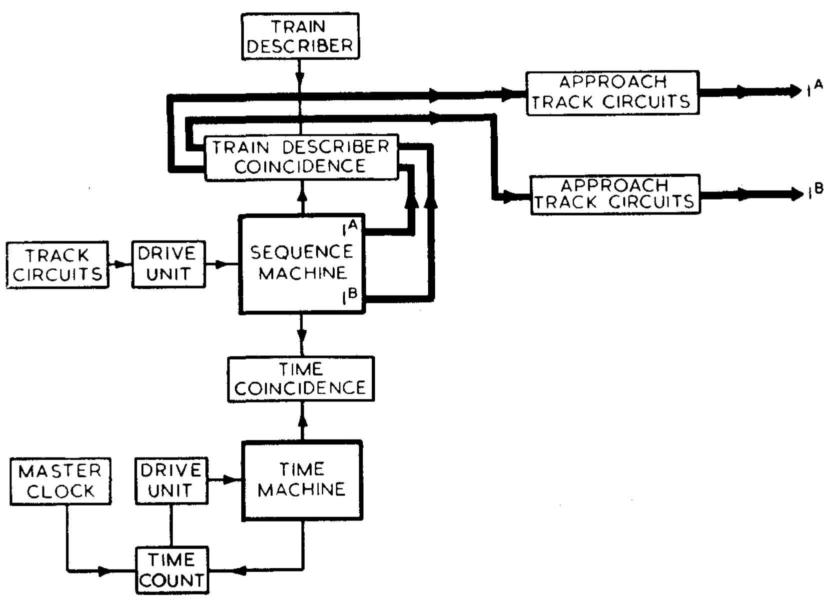

Fig. 17 Functional diagram for programme machine working a facing junction

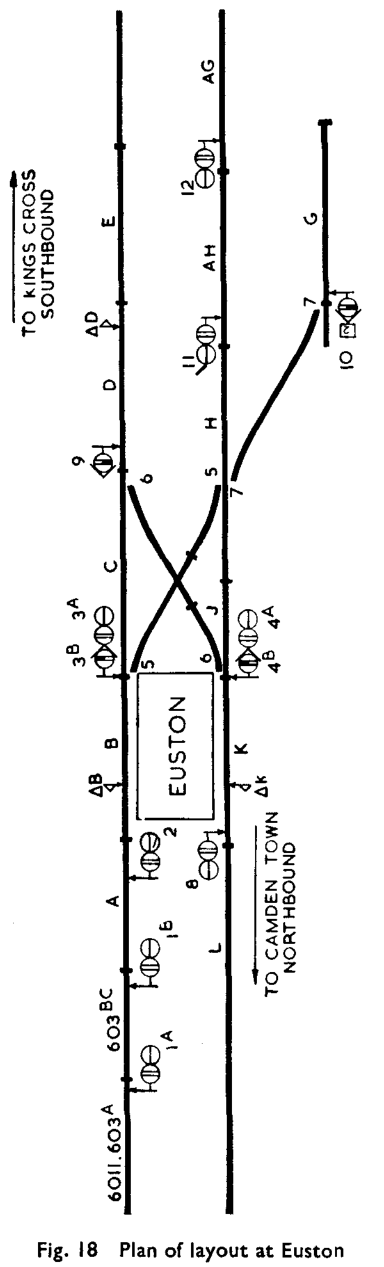

Fig. 18 Plan of layout at Euston

minute, if no action has been taken by the operator in the supervision room, the route is automatically set in accordance with the train describer indication. If, however, the operator in the supervision room is aware that there is an error in the describer, by pressing an acknowledging button before the minute elapses, he can arrange that the machine sets the route in accordance with the programme machine indication.

Application of Programme Machine Working to Track Layout

Fig. 18 shows the layout at Euston and provides two through lines, with a scissors crossover for reversing part of the service and a siding into which trains can be signalled, as required.

To operate this layout, two sequence programme machines are allocated as follows:

No. 1 Machine—Southbound Road.
Basically this deals with the converging junction at No. 6 points and also deals with the facing junction at No. 6 points on the northbound road.

No. 2 Machine—Northbound Road.
Basically controls the facing junction at No. 5 points, also deals with the converging junction at No. 7 points.

One time-controlled machine serves both the sequence machines.

The circuits are arranged so that both sequence machines co-operate to set routes that involve both roads.

No. 1 sequence machine steps, when a train occupies track circuit C.

No. 2 sequence machine steps once, when a train occupies track circuit H, and again, when the train has run into the northbound platform and is standing on K track.

This double stepping of No. 2 sequence machine enables the reading off of information concerning the consecutive movements of a train to be carried out. A northbound train, for example, may reverse in the northbound platform, or it may go forward northbound.

The table in fig. 19 shows the controls for the respective routes.

The interworking between the machines will be noted. For example, route 3B is originated by No. 1 sequence machine, but receives permission from No. 2 sequence machine before the route is set.

The above arrangements deal with all the trains, provided that they arrive in order and in accordance with the time table, but provision must be made to keep the trains running, even if they should be

ROUTE	ROUTE	SET UP BY	TIMED	TRAIN DESCRIBER CHECK	PERMISSION
1	CAMDEN TOWN TO SIGNAL No. 2	No.1 SEQUENCE MACHINE	NO	NO	NONE
2	SIGNAL No.2 TO SOUTHBOUND PLATFORM	No.1 SEQUENCE MACHINE	NO	NO	NONE
3 (A)	SOUTHBOUND PLATFORM TO KINGS CROSS	No.1 SEQUENCE MACHINE	YES	YES	NONE
3 (B)	SOUTHBOUND PLATFORM TO SIDING	No.1 SEQUENCE MACHINE	NO	YES	No.2 SEQUENCE MACHINE
4 (A)	NORTHBOUND PLATFORM TO KINGS CROSS	No.1 SEQUENCE MACHINE	YES	NO	No.2 SEQUENCE MACHINE
4 (B)	NORTHBOUND PLATFORM TO SIDING	No.2 SEQUENCE MACHINE	NO	NO	NONE
8	NORTHBOUND PLATFORM TO CAMDEN TOWN	No.2 SEQUENCE MACHINE	YES	NO	NONE
10 (A)	SIDING TO NORTHBOUND PLATFORM	No.2 SEQUENCE MACHINE	YES	NO	NONE
10 (B)	SIDING TO SOUTHBOUND PLATFORM	No.2 SEQUENCE MACHINE	YES	NO	NONE
11 (A)	SIGNAL No.12 TO NORTHBOUND PLATFORM	No.2 SEQUENCE MACHINE	NO	YES	NONE
11 (B)	SIGNAL No.12 TO SOUTHBOUND PLATFORM	No.2 SEQUENCE MACHINE	NO	YES	No.1 SEQUENCE MACHINE
12	KINGS CROSS TO No.11 SIGNAL	No.2 SEQUENCE MACHINE	NO	NO	NONE

Fig. 19

Table of normal programme machine controls—Euston

too late to take their allotted place or they arrive out of order.

The table, fig. 20, shows the conditions allowed for and the action provided.

The allotment of the holes in the programme roll is simply arranged. The provision of thirty possible hole positions allows the allotment of an individual hole for each signalling operation. Coding is used in a code of four for the train description and also for the coincidence check with the time machine. The code of four gives fifteen different combinations, and the coincidence code will therefore repeat after fifteen trains.

The programme roll allotment for the northbound sequence machine is shown on fig. 21.

The first four holes are always used for the train describer check. Holes 27 to 30 are reserved for the time coincidence. Holes 17 and 18 are used to operate the repeater machine at the central supervision office. In this case, it is required to originate and transmit a train description for trains reversing or starting from the siding, and holes 13 to 16 form the code for this purpose.

Holes 5 to 12 are used for setting the routes.

Fig. 22 shows the functional working for the equipment to operate the layout shown in fig. 18.

Taking a series of trains carrying out different movements, all the movements can be followed on the heavy lines on the diagram:

(1) *A Northbound Train to Run Straight Through*

The route for this train is set by No. 2 sequence machine, which clears 12 and 11 signals, and the route is cleared as soon as the approach track circuit is occupied. The train runs into the northbound platform. No. 2 sequence machine will have stepped when the train passed over H track, and will then read that the train is required to proceed northwards past No. 8 signal. This information is transferred to a relay store, which causes No. 8 signal to clear, when the time is due for the train to depart, as confirmed by coincidence with the time machine. The relay store takes the form of four relays, storing the time coin-

ROUTE	CONDITION FOR OUT OF TURN	TIME INITIATED BY	ALTERNATIVE ACTION	STORAGE
No.1 & No.2 CAMDEN TOWN TO SOUTHBOUND PLATFORM	SOUTHBOUND TRAIN APPROACHING FROM CAMDEN TOWN. No.1 MACHINE SET FOR REVERSING TRAIN WHICH HAS NOT ARRIVED. NORTHBOUND TRACKS FROM KINGS CROSS NOT OCCUPIED.	NO TIME DELAY.	CLEAR ROUTES 1 & 2 TO SOUTHBOUND PLATFORM. PREPARE FOR 11(B) TO CLEAR IF TRAIN ARRIVES DURING TIME SOUTHBOUND THROUGH TRAIN RUNNING	NIL
No.3(A) SOUTHBOUND PLATFORM TO SOUTHBOUND LINE	SOUTHBOUND THROUGH TRAIN IN PLATFORM No.1 MACHINE SET FOR REVERSING TRAIN WHICH HAS NOT ARRIVED OR A REVERSING TRAIN IN NORTHBOUND PLATFORM NOT READY TO DEPART	TIME MACHINE AND DELAY CIRCUIT	CLEAR 3(A) FOR THROUGH TRAIN.	No.1 MACHINE STEP
No.3(B) SOUTHBOUND PLATFORM TO SIDING.	TRAIN IN PLATFORM FOR SIDING. No.2 MACHINE SET FOR NORTHBOUND TRAIN. NORTHBOUND TRACKS FROM KINGS CROSS NOT OCCUPIED.	NO TIME DELAY	CLEAR 3(B) TO SEND TRAIN TO SIDING	No.2 MACHINE STEP
No 4(A) NORTHBOUND PLATFORM TO SOUTHBOUND LINE.	TRAIN IN NORTHBOUND PLATFORM READY TO DEPART. No.2 MACHINE SET TO DESPATCH TRAIN No.1 MACHINE NOT SET FOR THIS TRAIN	TIME MACHINE AND DELAY CIRCUIT.	CLEAR 4(A) TO SEND TRAIN TO SOUTHBOUND ROAD	No.1 MACHINE STEP
No.4(B) NORTHBOUND PLATFORM TO SIDING.	NONE		SPECIAL WORKING BY PUSH BUTTON	
No.8 NORTHBOUND STARTING	NONE			
No.10(A) SIDING TO NORTHBOUND PLATFORM	NONE		SPECIAL WORKING BY PUSH BUTTON	
No.10(B) SIDING TO SOUTHBOUND PLATFORM	TRAIN IN SIDING READY TO DEPART No.1 MACHINE NOT SET FOR THIS TRAIN. SOUTHBOUND TRACKS FROM CAMDEN OCCUPIED	TIME MACHINE AND DELAY CIRCUIT	CLEAR 10(A) TO SEND TRAIN TO NORTHBOUND PLATFORM.	No.1 MACHINE STEP.
No.11(A) NORTHBOUND TO NORTHBOUND PLATFORM.	NONE			
No.11(B) NORTHBOUND TO SOUTHBOUND PLATFORM	REVERSING TRAIN APPROACHING No.1 MACHINE NOT SET FOR THIS TRAIN SOUTHBOUND TRACKS FROM CAMDEN OCCUPIED.	TIME MACHINE AND DELAY CIRCUIT.	CLEAR 11(A)	No.1 MACHINE STEP
No.12 NORTHBOUND TO No.11	NONE		ROUTE ALWAYS SET TO 11 EXCEPT WHEN No.1 OR No.2 MACHINE SENDING TRAIN TO SIDING. PUSH BUTTON ONLY TO OVER-RIDE THIS	

Fig. 20 Table of out of turn conditions provided by programme machine circuits—Euston

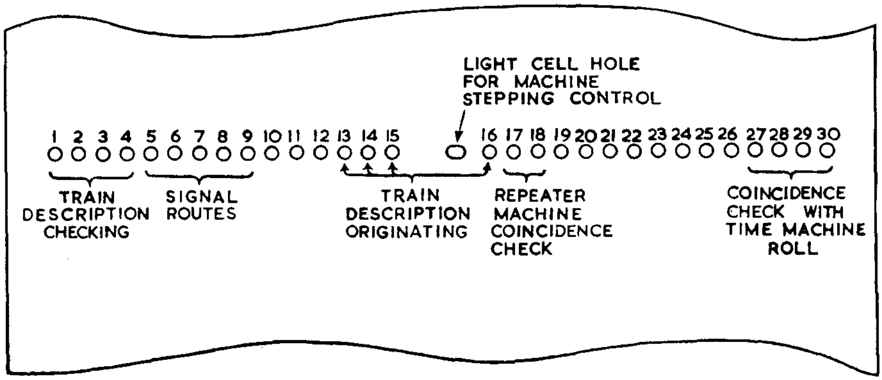

Fig. 21 Allocation of holes in programme machine roll—Euston

cidence. Only one stage of storage is necessary for this move. When the train has completely entered the platform and is occupying K track, and J track is clear, the machine steps again, so as to read the information for the following train, which could well be a train to reverse in the southbound platform.

(2) *A Northbound Train to Reverse in the Southbound Platform*

The primary information for this train movement comes from sequence machine No. 2, but permission is also required from sequence machine No. 1, as the train has to run through No. 5 crossover to the southbound road. With these two machines in agreement, number 5 points are reversed and No. 11 signal cleared for the movement into the southbound platform. No. 2 sequence machine will step as the train passes over track circuit H and No. 1 sequence machine, which was standing to read the permission for this train, will step as the train passes over track circuit C.

(3) *A Southbound Train Proceeding Right Through*

No. 1 sequence machine provides the information for signalling this train, and on the approach of the train, will clear signals 1, 2 and 3A. Signals 1 and 2 are cleared immediately the train approaches, without reference to time, but the clearing of signal 3A is delayed until the time is due and this is checked by coincidence with the time machine.

(4) *A Southbound Train to be Routed into the Siding (G track)*

The primary setting up of this route originates from sequence machine No. 1, and this signals the train into the platform by signals 1 and 2. Permission for the movement from the platform into the siding is required from sequence machine No. 2, and on this being provided, the route is set by sequence machine No. 1 for 5 points reversed and 7 points reversed, and shunt signal 3B is cleared. Sequence machine No. 1 steps, as the train passes over C track and sequence machine No. 2 steps, as the train passes over H track.

These typical train movements show the normal operation, with the service running in accordance with the programme. As already mentioned, provision is made for dealing with trains which are not quite in accordance with the programme.

The arrangement of out of turn working will be described by following the reversing of northbound trains to southbound.

Assuming the condition that the programme machine shows a northbound train reversing in the northbound platform and this train, due to some delay, has failed to arrive, No. 1 sequence machine will be showing the path for this train, but because the train is not available, it cannot be signalled. In the meantime, a through train appears on the approach track southbound. This condition is shown by the thin lines on

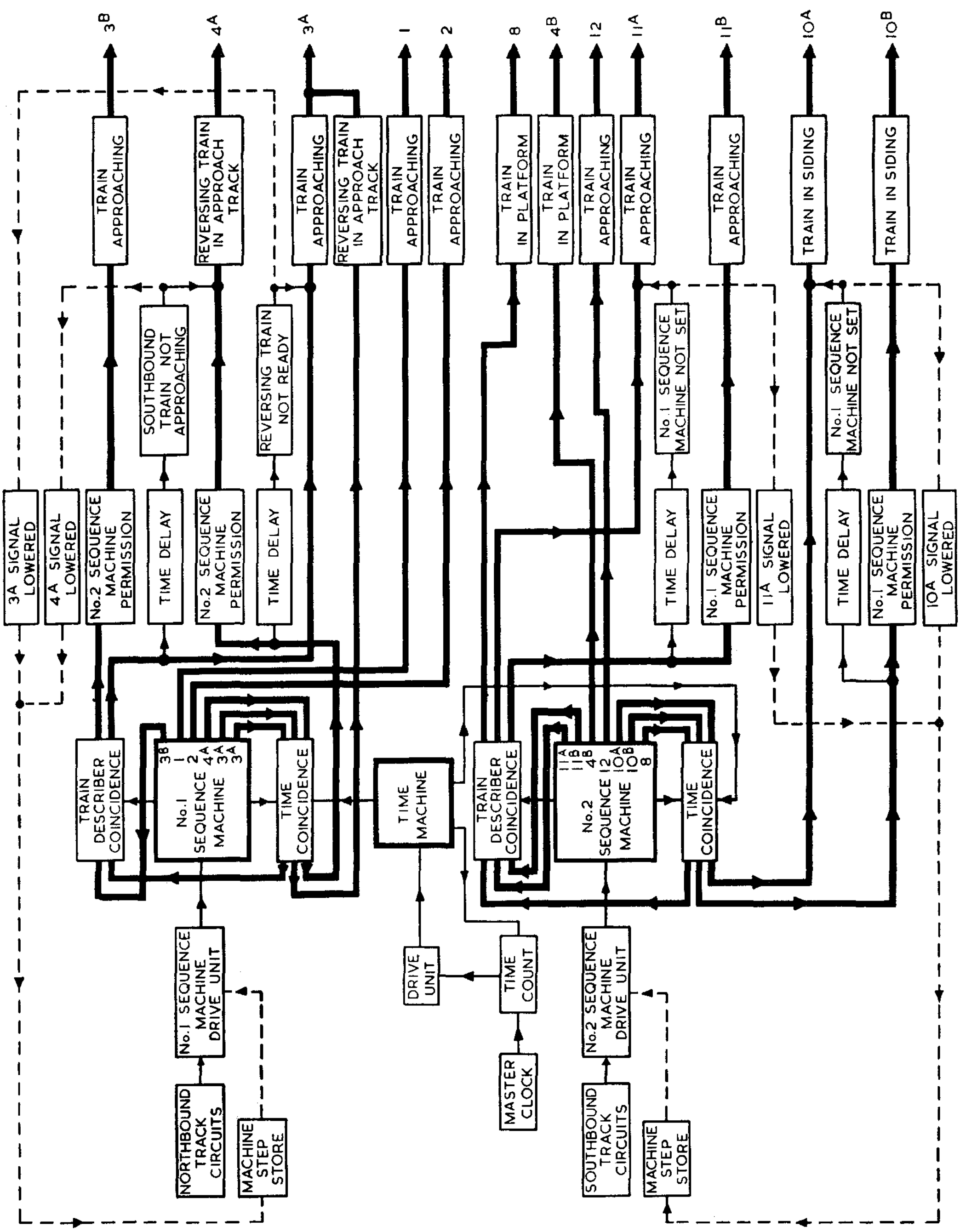

Fig. 22 Functional diagram for complete programme machine operation—Euston

the diagram, tapping off the path from the time coincidence before requiring permission from No. 2 sequence machine. After the set time delay has expired and further checking that the reversing train on the northbound road is not ready, a path is set to clear 3A signal for the through train.

Having achieved this out of turn working, the stepping of the programme machine must be modified, and the dotted line shows a feed back path to the machine step store. This store takes the form of a chain of relays and performs two functions—it stops the No. 1 sequence machine stepping for the passage of the through train and it counts the through train. It is possible, in the event of a serious hold-up on the northbound road that this movement of out of turn working of through trains will be repeated two or three times, and each one, as the route is set, performs another storage in the machine step store.

When the northbound reversing train has eventually arrived at the northbound platform, it is signalled through No. 6 crossover by the information originating from No. 1 sequence machine, which machine, due to the suppression of the stepping, is still reading this information, and with the permission of No. 2 sequence machine, the reversing train is immediately signalled away. As the train passes over C track, the stepping circuit of No. 1 sequence machine is actuated and the machine steps once for that train. The machine stepping store then comes into operation and proceeds to step the machine, the additional steps representing the through trains that have been put into store, and this brings the machine back into step with the service.

This out of turn working is typical of the arrangements provided in this layout, and as shown in the table, fig. 20, the remaining out of turn conditions can be followed in the thin lines on the functional diagram.

Another train movement that requires some special arrangements is the signalling of a train out of the siding into the southbound platform road and then away on the southbound main line. The routeing of this train starts from sequence machine No. 2 and requires permission from sequence machine No. 1, but not occurring until the time is due by a check of coincidence with the time machine. These conditions permit the setting of No. 7 and No. 5 crossovers, and No. 10 signal to be cleared.

The train runs into the southbound platform and there the driver must change ends, so that time allowance is provided for. Both sequence machines will have stepped by the train passing over the appropriate track circuits, and the control of the train starting away southbound then becomes solely from sequence machine No. 1, waiting for the time to operate the starting signal No. 3A.

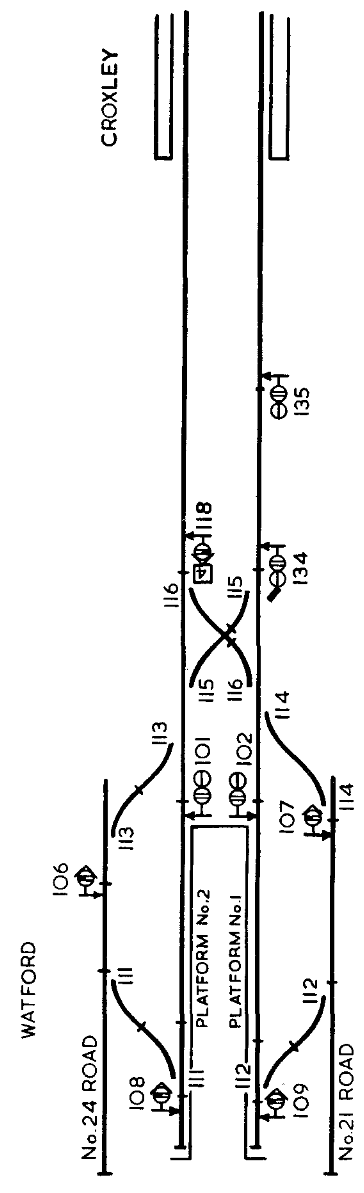

Fig. 23 Plan of terminus layout—Watford

This movement is different from the others so far considered, as the train did not bring its description with it and the train describer transmitter must, therefore, be operated from the programme roll. This is provided for by the special set of holes carrying the train description code that has already been referred to. In this case, it will be on No. 2 machine and will be transferred to the southbound train describer as the train leaves the siding. The destination of the train will then be displayed on the illuminated describer on the southbound platform and this description retransmitted on the train describer southwards, as the train leaves the station.

Programme Machine Working of a Terminal with Siding Facilities

Fig. 23 shows the layout at Watford (Metropolitan Line) arranged for programme machine working. In this case, the working of the programme machine is arranged to be supervised by the signalman at an existing signal box at Rickmansworth.

The programme machine is arranged to control the following train movements:

(1) Reverse multiple-unit trains in either of two platforms, starting them away at the correct time.

ROUTE	ROUTE	SET UP BY	STORAGE	TIMED	TRAIN DESCRIBER CHECK	PERMISSION
135/134 (A).	CROXLEY TO PLATFORM No. 1	SEQUENCE MACHINE	NO	NO	NIL	NIL
135/134 (B).	CROXLEY TO PLATFORM No.2	SEQUENCE MACHINE	NO	NO	NIL	NIL
102.	PLATFORM No.1 TO CROXLEY	TIME MACHINE	YES	YES	NIL	NIL
101.	PLATFORM No.2 TO CROXLEY	TIME MACHINE	YES	YES	NIL	NIL
109.107.118 (B).	PLATFORM No.1 RUN ROUND	SEQUENCE MACHINE	NO	NO	NIL	DELAYED INSTRUCTIONS
108. 106.118 (C).	PLATFORM No.2 RUN ROUND	SEQUENCE MACHINE	NO	NO	NIL	DELAYED INSTRUCTIONS
102.118(D).	PLATFORM No.1 TO No.24 RD.	SEQUENCE MACHINE	NO	NO	NIL	DELAYED INSTRUCTIONS
101. 118(D).	PLATFORM No.2 TO No.24 RD.	SEQUENCE MACHINE	NO	NO	NIL	DELAYED INSTRUCTIONS
102. 118(A).	PLATFORM No.1 TO No.21 RD.	SEQUENCE MACHINE	NO	NO	NIL	DELAYED INSTRUCTIONS
101. 118(A).	PLATFORM No.2 TO No.21 RD.	SEQUENCE MACHINE	NO	NO	NIL	DELAYED INSTRUCTIONS
107. 118(B).	RD. No.21 TO PLATFORM No.1	TIME MACHINE	NO	YES	NIL	NIL
107. 118(C).	RD. No.21 TO PLATFORM No.2	TIME MACHINE	NO	YES	NIL	NIL
106. 118(B).	RD. No.24 TO PLATFORM No.1	TIME MACHINE	NO	YES	NIL	NIL
106. 118(C).	RD. No.24 TO PLATFORM No.2	TIME MACHINE	NO	YES	NIL	NIL

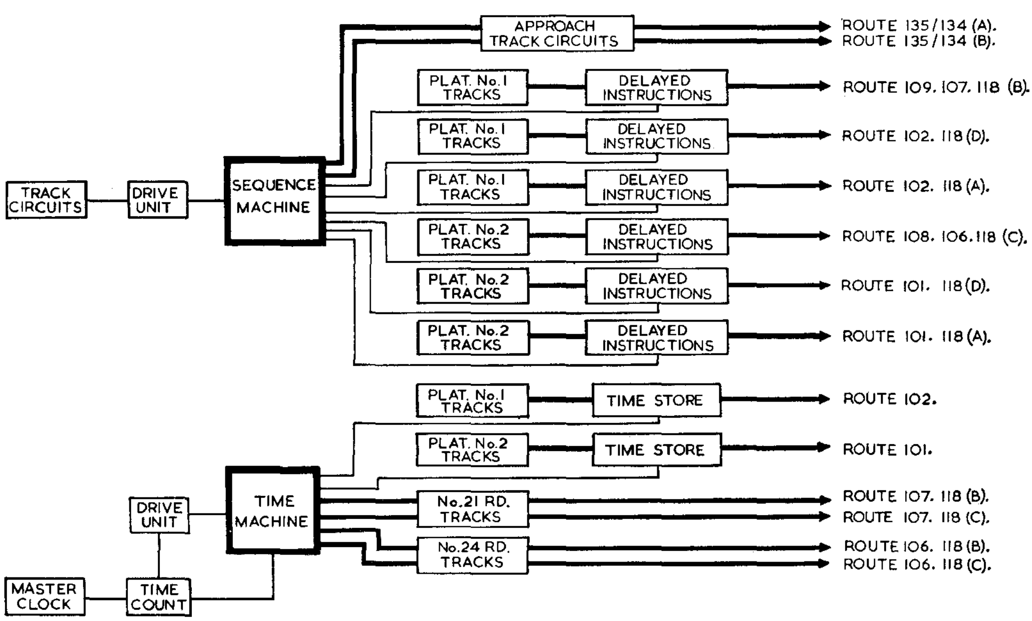

Fig. 24 Table of programme machine controls and functional diagram—Watford

(2) Reverse a locomotive-hauled train and change the locomotive from end to end by a run-round.

(3) Route a train into either of two sidings from either platform.

(4) Signal a train from either of the sidings to either platform, and signal it away on the main line at the correct time.

At this place, there are no train describers in use at present, but if required, the programme machine could be arranged to transmit the train description as each train leaves.

For this installation, one sequence programme machine and one time controlled machine are used.

Fig. 24 shows a table of conditions allowed for on the routes and also a functional diagram.

Because only one sequence machine is used, some items of information are taken from the roll and stored on relays, to allow the machine to step to the next train without waiting for the whole of a movement to be completed. For example, when a locomotive-hauled train has been signalled into platform 2, the information that a run-round must be routed is transferred to a relay store, thus freeing the programme machine to route the following train from Croxley into platform 1. These instances are shown as delayed instructions in the table and in the diagram.

The routeing of trains starting from Watford is carried out from the time machine direct and this is another case where storage on relays is provided. Unlike the sequence machine, the time machine does not wait for the trains and so trains signalled solely from the time machine would be lost, if they should be late, without the information stored separately.

This use of the time machine to set routes can sometimes be made, as in the instance at Watford, as an economy, reducing the number of sequence machines required. But it can only be adopted after very careful study, as it may introduce difficulties outweighing the saving in sequence machines.

It will be seen from the table that the sequence machine controls all routes for trains from Croxley to Watford and any immediately subsequent movements. The sequence machine is arranged to step as the

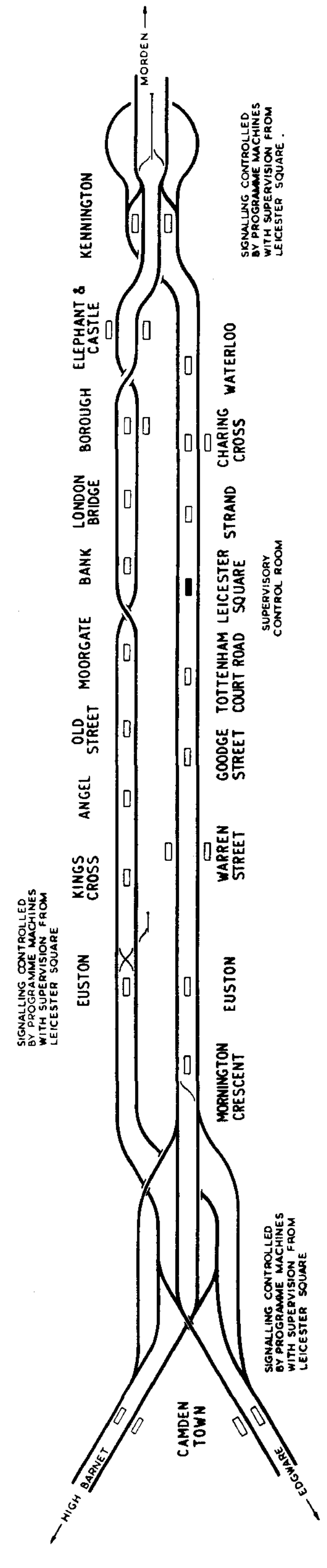

Fig. 25 Plan of the Northern Line, showing the area equipped with programme machine working

train passes No. 134 signal. The time machine controls movements out of the sidings and starts the trains away from the platform roads.

The operation of the equipment can be appreciated by following some typical train movements:

1—*A multiple-unit train from Croxley to reverse in No. 1 platform*

The sequence programme machine, by a hole in the roll, clears signals 134 and 135 and the train runs into the station. After the crew have changed ends and when the time is due for the train to depart, the time machine will cause 116 points to reverse and 102 signal to clear. Should the train have been late to arrive, the time machine will have stored the information to clear 102 signal on a relay, and 102 signal will clear as soon as the train has arrived in the platform, so that the train can depart when the crew are ready.

2—*A locomotive-hauled train from Croxley to reverse in No.1 platform*

The sequence machine clears the route for signals 134 and 135 as before, but an extra hole is punched in the programme roll for this train and this energises the delayed instructions relay. When the train has arrived in the platform, the delayed instructions relay starts a sequential route setting which signals the locomotive off the train to run-round via points 112, 114 and 116 to 118 signal. No. 118 signal then clears to permit the locomotive to run into platform 1 on to the front of the train. On completion of the run-round move, and when the time for the departure of the train arrives, the time machine will clear the starting signal in a similar manner to that described above.

3—*A train which has been stabled in No. 21 road to be brought into platform 2 and, after picking up passengers, to be started away to Croxley*

The time machine reverses points 114 and 116, clears signal 107 and also energises a sequential relay for the movement back into the platform. When the train has moved out on to the main line and is standing at 118 signal, No. 116 points are

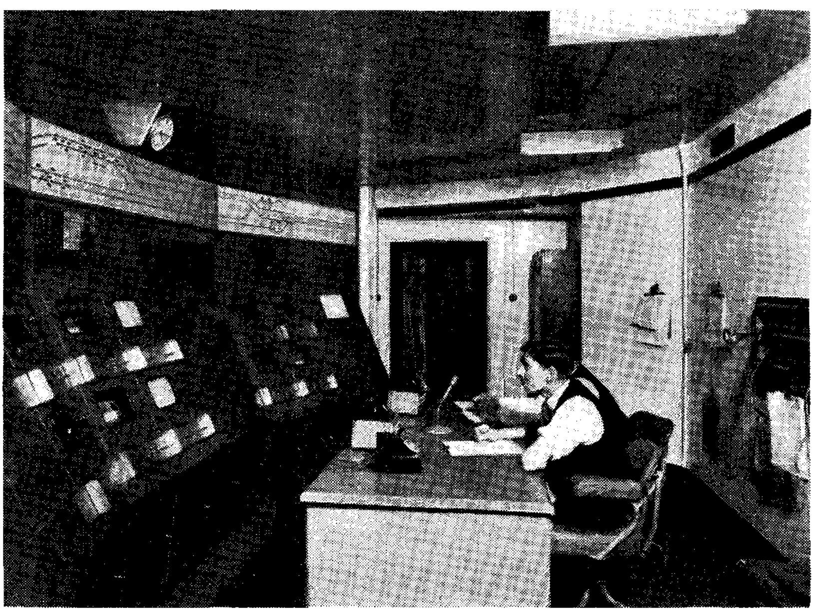

Fig. 26 Central supervision room—Leicester Square

returned to normal and 118 signal clears to signal the train into platform 2. When it is time for the train to depart, the time machine steps to a fresh line of holes, which causes 101 signal to clear.

Complete Programme Machine Working of the Central Section of the Northern Line—London Transport

Fig. 25 shows the layout of the central section of the Northern Line of London Transport, which has been equipped with complete programme machine working for the junctions at Camden Town, Kennington and Euston.

Supervision of the working of this area is carried out from a central supervision office at Leicester Square, fig. 26. The control panel has the illuminated diagram at the top. Below each section of the diagram are arranged the push buttons for manual control of the routes. Below these are the repeater programme machines. Only the sequence machines are provided with repeaters at the central office.

Each repeater programme machine has a panel of controls for its programme machine and associated circuits.

The staff normally sit at the table in the centre of the room and only need to approach the panel when some change in the working is necessary.

Conclusion

The foregoing gives details of some arrangements of programme machine working for the signalling of particular sets of train movements, which have already been carried out. The programme machine itself has been designed so that it can be adapted to meet a wide variety of conditions and there is therefore no reason why, by arranging the associated circuits suitably, it should not be able to carry out the signalling of a line under almost any conditions where a fixed programme of trains is to be followed.

DISCUSSION

Mr. J. C. Kubale, in opening the discussion, said that the subject was a most interesting one, because it was the application of so-called automation to the operation of traffic movements. He was sure that those who had thought about this subject had considered many alternative ways of doing what Mr. Dell had done, and he would like to ask whether, in considering the development of this automatic operation, Mr. Dell thought it preferable to do it by a set programme on a punched tape, as he had done, rather than by other means used on some railways today. This consisted of the train being identified by some apparatus carried on it, that identification setting the route for the points it was approaching. Mr. Kubale was sure that route setting could be devel-loped on those lines. It would be interesting to know what Mr. Dell's thoughts were regarding such a system on the London Underground. The London Underground system was relatively simple in comparison with the main lines, with their very much more complicated junction working.

In his early deliberations, did Mr. Dell consider controlling the few junctions that there were, on the section shown in the paper, from a centralised point? There was an elaborate control room set up in the section, and Mr. Kubale thought that perhaps all the automatic working and routeing could have been originated from that place.

Mr. W. Owen said that, some two years ago, when the idea was first mooted, there was a tendency among some of the staff in the London Transport signal engineer's drawing office to throw up their hands in horror and to say: "This is the end; it will never work." But Mr. Dell, with his persuasive powers, got them working on it, and the first attempt was at Kennington where, almost to the last day before the opening, some still said: "It will never work." But it did.

Mr. Owen felt that one thing which people failed to appreciate was the amount of work that human beings do, until they come to do it by some other method. One never dreamt of the amount of mental effort on the part of a signalman in working a train through a junction such as Kennington or Camden Town. Mr. Owen, for one, did now appreciate it, now that the programme machine was being made to do all the thinking instead of the signalman.

In his view, the system was proving very versatile. If the diagrams in the paper were examined, it would be appreciated that each of the layouts were different in detail and new problems were being met every day. After reading the paper, one might ask: "Does the system ever fail?" He would not be so bold as to say that it never failed, but the number of failures that have occurred have been so few, compared with the number of trains the system has handled, that they were almost negligible.

One thing not mentioned by Mr. Dell was that if the thin wire cable between Leicester Square and any of the outlying locations should fail, through fire, a careless workman, or any reason at all, the immediate layout would work itself — the programme machine would take complete control and work the service through. If the train service got out of order with the programme machine, the train describer would take charge; if that failed, the service would work on the "first come, first served" principle. From that it was obvious that the train service would be kept running by at least one of the methods mentioned, even when the location was completely isolated from any human control.

Mr. D. G. Shipp, in referring to the overlay rail circuit, said that when he was associated with its development in the early days, Mr. Dell produced a specification for its performance, and Mr. Shipp was struck at that time by one clause in particular. This clause stated that the train shunt sensitivity should be low and not greater than ½ ohm. That seemed strange because one was so used to thinking in terms of ordinary track circuits for which the requirement was that the train shunt should be as high as possible and, as far as L.T.E. practice was concerned, not less than 1 ohm.

The reason for this difference was interesting. By arranging for the rail circuits to have low shunting sensitivity in relation to that of the track circuits on which they are overlaid, they can be made to perform a second function; not only will they release routes as described in the paper, but also detect a faulty train which had developed for some reason a high resistance shunt between its wheels. For example, immediately the shunt of the defective train rose above ½ ohm, the rail circuit would be the first to fail, which would be a right-side failure, and and the faulty train could be located and removed from service before it deteriorated further and failed on the wrong-side to shunt the conventional track circuits.

Mr. Shipp went on to say that he was a little puzzled how it was possible for a single time machine to monitor two sequence machines. His understanding was that the time machine marked time, and counted in half-minute steps, the time internals between consecutive trains on the sequence machine. Now, in monitoring two sequence machines it seemed that the one time machine may be required, say, to mark time four minutes for the next train on one sequence machine, and a minute and a half for the next train on the other machine, and he wondered how a single time machine looked after these two conflicting requirements.

Mr. M. E. Leach, referring to fig. 3, noticed that the track relays were shown normally operated, which presumably was not quite correct, because they would be normally down, unless the delta track was actually occupied.

He would like some indication as to the function of the lock relay 2LR and the approach lock relay 2ALR.

Taking the "First come, first served" circuit shown in fig. 9, Mr. Leach proposed that they should go through the section of a train appearing on "A" track circuit. That would pick up 1AR which, in turn, picked up 1USR and set the route that cleared No. 1 signal. As soon as the train, which was on A track, passed the signal and occupied B track, it would replace the signal to danger, at the same time dropping away 1USR, because 1GCR at the time was down. But immediately afterwards 1GCR would drop away, and the train, stop going "on," would pick up the GCR again, providing an alternative path was available, because obviously A track would not have cleared by that time. 1USR would then remain up. Subsequently, B track would clear and provide an alternative path to hold up 1USR.

Had Mr. Dell experienced any difficulty with the plastic strip, used on the programme machine, becoming torn or scratched?

Mr. R. J. Post said that it had been explained in the paper that, in the event of the non-arrival of a train from route 1, another train on route 2 would be allowed through, and the fact that that had happened would be counted in a store. If several other trains arrived, they would continue to be counted, and when the missing train finally appeared, the programme machine would let it through. The machine would be stepped up by the occupation of C track (fig. 8) and would then step to correspond with the number of trains in store.

Mr. Post did not see why that brought the machine back into the right place in the service, because probably the trains had come from alternative routes and the machine had been stepped on by a train from route No. 2. What about the trains coming from route No. 1 ?

At Euston, if a train on the northbound track was due to reverse in the northbound platform and was late, in the event of a signalman being in control instead of a programme machine, would he not consider it better to allow the reversing to take place in the southbound platform, rather than to hold up the rest of a bunch of trains whilst the reversing was carried out in the northbound platform ?

Mr. F. G. Hathaway said that, from the description in the paper of the programme machine, there was a set of alarms to draw attention to any discrepancy in the service, such as a train being late, and so on, but nothing was mentioned with regard to alarms in the event of a failure occurring. What alarms were there ? And what procedure was followed to say if it was necessary to change over to local working at a junction ?

Mr. F. L. Holt enquired whether, if a train was coming into Euston from Camden Town, and coming in the wrong order, the programme machine set up the route or the train describer ?

Referring to permission between two sequence machines, **Mr. J. Waller** enquired whether permission for a move to take place on the second machine was actually recorded on No. 1 machine ? Or whether the absence of any conflicting information on No. 1 allowed the move to be made on the second machine ?

If No. 1 set the route, when No. 2 gave permission for it, and due to delay the train on No. 1 did not arrive, No. 2 machine might have to move on, because of alternative routes coming through that machine, and when the time came for No. 1 machine to set its route, how was permission still available ?

Mr. H. J. Riddle wondered how many attempts had to be made before the scheme was got on to the right lines.

Regarding the method of counting, he wished to know what finally decided Mr. Dell to choose the relay chain method of counting. There were well-tried designs of step by step switches which could have been used for the purpose, or going to the modern technique, there were spacing devices, which did the same thing, but rather quicker.

Mr. A. W. Damon said that he would have thought first in terms of quite a small terminal station for a scheme of this kind.

He would like to place on record the thrill that he received some time ago, when he saw that this installation had got a headline in a publication on the other side of the Atlantic. To read of something completely new, which was news on that side of the Atlantic was a very gratifying experience.

In connection with any automatic signalling installation, the thought ran through his mind that somebody had to take control, if it went wrong. He was not clear, in this case, how the Leicester Square controllers did take control. Did they make a practice of doing so, to keep their hand in ? It always seemed to him that, with a completely automatic installation, something could and would go wrong eventually. Then someone on site had to take over emergency control, and it seemed rather important that there should be someone there capable of doing it reasonably well.

The **Author** in reply to Mr. Kubale, said that he had read of the American inductive system and had seen it in use on the Stockholm Railways; but in fact, it only did what the train describers do on the London Transport system — provide information as to where the train was going. Therefore, there was nothing to gain by adding the inductive system. The use of an inductive train identification system did nothing to get over the difficulty of signalling trains in their correct order at a converging junction, and that was the primary reason for the use of the programme machine.

With regard to whether control from a central point without programme machine working was considered for the Northern Line, several examples of remote control at other places in London Transport lines such as Farringdon, had already been installed, but centralised control for the Northern Line without programme machine working had not been considered, as they went straight to the programme machine itself.

In replying to Mr. Owen, the **Author** felt sure that Mr. Owen spoke for many more of the Author's staff. He spoke feelingly of two years ago, when getting instructions to prepare circuits for this equipment, and that gave the Author an opportunity to pay a tribute to the very great help that he had had from all his staff in getting the equipment working. Mr. Owen probably understated the dismay that they must all have felt, when presented with the task. The Author wished to pay tribute not only to Mr. Owen, but to all the staff who worked with him, both inside the drawing office and outside, to whose efforts the success of the equipment was due.

In reply to Mr. Shipp, regarding the specification that the train shunt of the rail circuit should be low, although actually no benefit had been derived on this particular installation, on some previous installations with low shunt rail circuits, they were of value, when there was contact trouble with the wheels. There was, a few years ago, trouble with ferrodo brake dust, making the wheel shunt poor; the first indication was, they failed to operate the rail circuits.

One time machine could be made to operate with two sequence machines by just punching both sets of trains on the time machine, side by side; so one got two services, which might be on different roads, punched on the time machine, and the time machine stepped for whichever train was coming next. The coincidence code was not changed for the train not concerned in that step, but the train which was concerned had its coincidence changed. Then, when the time machine worked the next step, the first one's code changed, but the second one did not change. Provided there was enough holes on the roll, there was no limit to what could be done. In fact, it was the length of the roll and the number of holes that was the limitation.

Mr. Shipp asked whether there would be a duplicate set of binary counting relays.

The **Author** replied no; the time would be halved. With the next train on one road due in four minutes, and the next train on the other road due in a minute and a half the roll was punched one and a half and two and a half to make up four minutes.

In reply to Mr. Leach, the **Author** said that Mr. Leach was quite right; the contact should be shown open. It was the practice in his office, however, to show all contacts in the closed position.

The function of the relays 2LR and 2ALR was equivalent to the well-known approach lock and back lock circuits.

With regard to the circuit for 1USR repeating itself, he confessed he did not quite follow all the details made by Mr. Leach. That particular circuit was what they called a standard one, and he could state that it did operate as intended.

They had had very little trouble with the plastic roll on the programme machine. The original roll was made of "Melinex" which was transparent, and the only trouble experienced with that was, to get the photo-cell working, a black strip had to be painted on the roll, and some difficulty with the paint flaking had occurred. Afterwards, rolls were obtained which were naturally black. Apart from that, there had been no trouble with the programme rolls at all. In fact, the programme machines had been extraordinary in giving no trouble since they had been in service, there had not even been a faulty contact.

Replying to Mr. Post, the **Author** said that, with regard to out of turn working, an important point had been raised, and he could only apologise for over-simplification in the paper. In fact, the store did not count straight out, as he had said; it counted out until it came to a train on the other road, then waited for that train and then counted itself out.

Referring to Euston, again Mr. Post had put his finger on another simplification In fact, the time-table put quite a large proportion of the trains into the southbound road for reversing, in order to leave the northbound road clear; but if a train was programmed into the southbound road, and for some reason or other that road was not available, then out of turn working would put the train into the northbound road.

In reply to Mr. Hathaway, the **Author** said that they had never thought of providing alarms for failure of the equipment The alarms—there was quite a number of them—all provided information of traffic differences, trains being late, train describer disagreement with programme, and out of turn working procedure.

In his question, did Mr. Hathaway really mean local working at the site? If he did, there was not any provision for local working. One of the tasks which they set themselves was that the machine would go on working locally, if everything else failed. If there was a signal failure, it was dealt with by the platform staff as a signal failure and there was no provision for any emergency working other than from Leicester Square.

Replying to Mr. Holt, trains arriving out of turn did present some difficulty with the equipment. Actually, Euston southbound was not a difficult place; except where one of the trains was scheduled to go into the siding, they all went through, whether going to Kennington or Morden in the end. If one of them were to go into the siding, and the train which should come behind it came in first, the train describer would send it the way it should go. Basically, it was desirable if the platform signs announced that a train was going to a specific destination, it should go there. That was what the machine did.

In reply to Mr. Waller regarding permission given for a movement originated from one roll, from another machine, it was a positive permission provided by a separate hole punched on the roll. They did not like to be indecisive and say that the train could go, if there was nothing against it, so permission was actually put as a hole on the opposite roll, and the programme machine would wait for the train to arrive.

Replying to Mr. Riddle, the **Author** was glad that he did not count the number of wrong starts made. Actually, one or two schemes for particular items had been dropped, as better ones were found.

When considering the counting of the half minutes, they did start with a step switch; in fact, there was one working at Kennington to that day. The Author had an inherent dislike of step switches, so even before Kennington was installed, he was experimenting with neon tube counters. If he had had another year to experiment with them, he might have decided on neon tubes. As it was, he did know that relays would be reliable and adopting that method shortened the experimental time.

In reply to Mr. Damon on starting on a busy section of the line, the **Author** said that if he had commenced in an outlying place first, he would still have been experimenting and would not have got very far. He had felt, from the first, that to achieve success with this scheme, it was necessary to go in for it in a fairly big way. The real secret was the interlocking machine. Because interlocking machines controlled the signalling, one did not have to worry in adding all the other circuits—the signalling would be as safe as it ever was. So they could go go on making what looked like rash experiments, but in fact, they were not.

The **Author** could not quote the actual number of times the men at Leicester Square did, in fact, take control and operate a train. They did it probably once or twice a day. They did not take control of the equipment and proceed to work it for long periods to keep their hand in.

The **Author** then demonstrated a programme machine working a converging junction. There were also on view examples of some of the packaged circuits and thin wire cable used in the installations.

The **President** moved a very cordial vote of thanks to Mr. Dell for his excellent paper, and this was carried with acclamation.