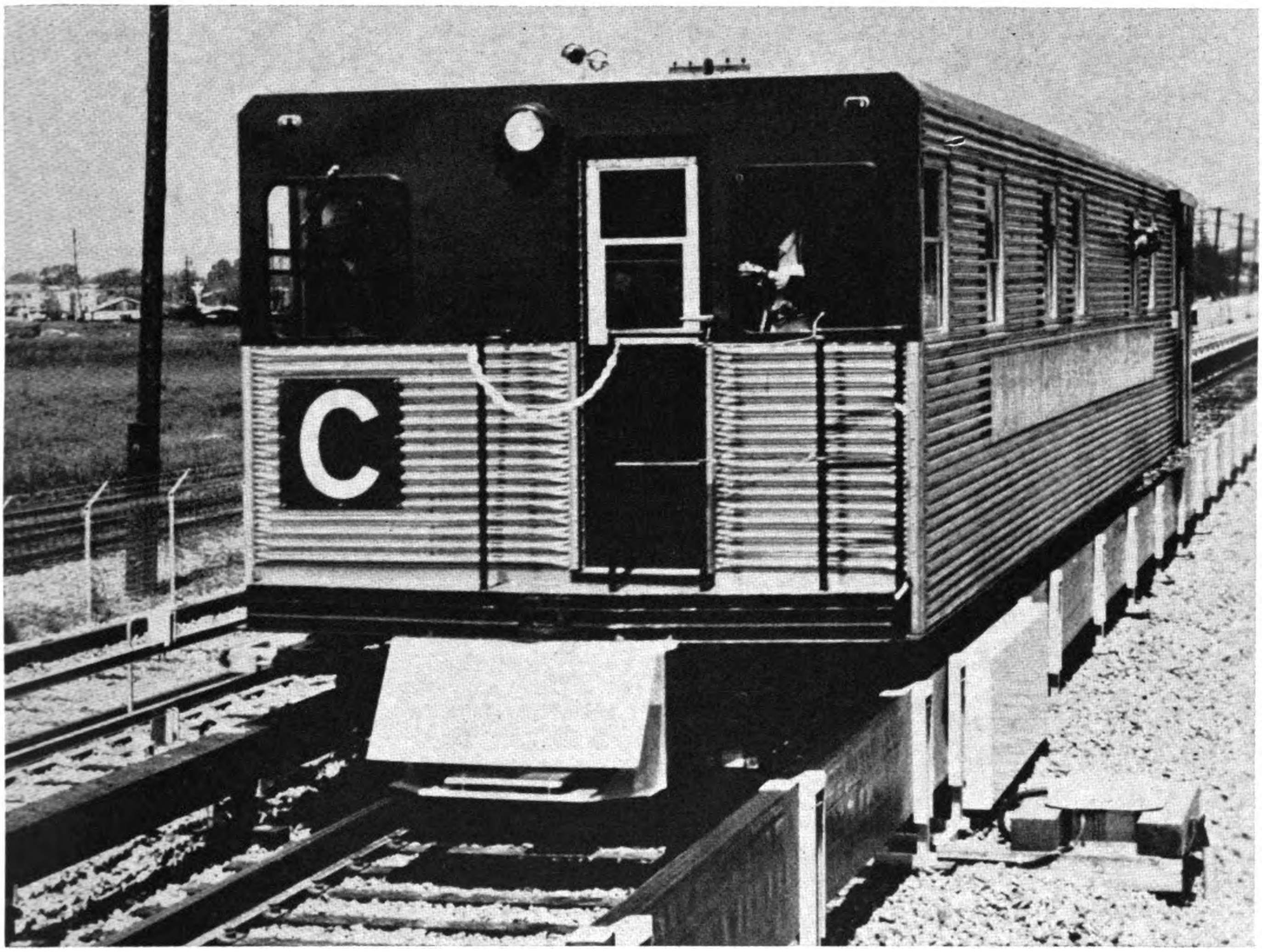
Railway
Signaling &
Communications



Laboratory car "C" of the San Francisco BARTD is now running on a test track near Concord, Calif.

Japan Sweden England test ATO

Automatic train operation is in the forefront of signal news. Of interest is the test track program of the San Francisco Bay Area Rapid Transit District. On May 12, laboratory car "C" (above) made a run under complete automatic operation on the test track near Concord, Calif. This brief test of ATO was made using equipment of General Railway Signal Co. Further tests will be conducted with two other test cars and with equipment of General Electric, Westinghouse Air Brake and Westinghouse Electric. On the following pages of this issue are three articles dealing with ATO installations in Japan, Sweden and England.

AUTOMATIC TRAIN OPERATION-I

ATO developed for Tokaido Line

Automatic railways was the subject of a convention held in London, England last fall. Sponsored by the Institution of Mechanical Engineers, the conference dealt with automatic train operation and related topics. Through the kind permission of the IME, we abstract herewith three paers from the conference. The first paper deals with automatic train operation by program control. Its authors are T. Ito and H. Ebihara of the Japanese National Railways. A second paper by O. Kekonius and N. O. Kallberg of the Stockholm Sparvagar deals with an automatic pilot for subway trains in Stockholm, Sweden. R. Dell, chief signal engineer and A. W. Manser, chief mechanical engineer, London Transport Executive, describe the automatic operation of trains on that facility.

Following is the paper on ATO on the Japanese National Railways (other abstracts begin on pages 18 and 24 of this issue):

The aim of notch programming is to have a train run automatically in conformity with the given train diagram. According to the distance and location of each operating section, the time, the speed and the notch position of the train are memorized in the equipment as a program. The train is made to follow this program mechanically.

The feature of this system is that the notch position N_p for each distance and location is memorized. By specifying a notch position, the turning effort of the traction motor is defined and the train runs at a speed adjusted to the running resistance. This means that, if conditions are the same, the speed remains constant. In this system though the notch position is unaltered, operating conditions change with the trolley voltage, the load of the train and running resistance, and the adjustment necessary will be made, as explained later, after being detected by the time delay in the operation of the train. However, the equipment will be kept simple because all direct instructions affect only the notch positions.

After the determination of a standard program, the problem of how to adjust the time lag detected in actual operation in order to secure on-time operation will arise. Simply speaking, the procedure is to modify the notch position by the amount proportional to the time lag Δt between the programmed time t_p and the actual time. t. That is,

$$\Delta N = K_1.\Delta t \quad . . . . (1)$$

The operating notch N is instructed with $N = N_p + \Delta N$. However, it is better to regard this ΔN as a function of the speed difference Δv between the programmed standard speed v_p and the actual speed v as well as of Δt mentioned above. This is because, when a train is delayed, it is operated by raising the notch in order to recover the delay. Suppose the train has recovered its delay at a certain point, the train speed will remain higher than the programmed speed because of its recovery operation with the notch raised. The train will keep running at a higher speed than the programmed one for a time though the notch is returned to the programmed position, resulting in the shortening of running time below the programmed one. Hence, speed difference Δv will mean a recovery capability and equation (1) can be modified as follows:

$$\Delta N = K_1.\Delta t - K_2.\Delta v \quad . . . (2)$$

where the coefficients K_1 and K_2 were determined by electric computer from the results of simulation of the characteristics of electric railcars for the New Tokaido Line.

In Fig. 1 is shown the block diagram of the notch program system. Different kinds of program are as follows:

(1) v_m Maximum restrictive speed.

(2) v_p Standard running speed.

(3) N_p Standard notch position for operation.
(4) N_m Maximum notch position for operation.
(5) t_p Standard running time.
(6) S_p Distance and location where instructions should be executed.

These programs are punched on the tape, read by the tape reader and stored in the device. When the train reaches a given point S_p, the difference Δt between the programmed time and the actual time, and the difference Δv between the programmed speed and the actual speed are calculated, thereby yielding the amount of notch change according to equation (2). This amount is added to the standard notch position and the instruction on the notch to be applied is delivered within the limit of the maximum notch position possible at that point. If the speed exceeds the maximum restrictive speed v_m at any point, a braking instruction is delivered.

The running distance is measured by means of the rotation of the axle. But this will not indicate the accurate distance. Therefore, wayside facilities are installed at regular intervals and the value obtained from axle rotation is adjusted when the train passes these points.

In the speed programming system, no programming is made on the basis of the notch position, but distance S_p, speed v_0 and time t_p are programmed and they are compared with the actual distance S, speed v and time t. The train is automatically controlled so as to keep these programmed and actual values the same as that mentioned in the previous section and its block diagram is shown in Fig. 2.

The required speed for a given running distance can be calculated beforehand according to the conditions of the track and the train diagram, and is stored in the tape in the form of an S and v program. This tape is moved at every unit distance the train has run, and the standard speed v_o for the distance S is obtained. In sections where the speed is restricted by track conditions, the maximum speed v_m for the distance S is programmed so as to restrict the instruction speed.

On the other hand, the required time t_r for the distance S is determined by the train diagram and is stored in the tape in the form of S and t. This is compared with the actual time t_r and the difference Δt is detected, so that the instruction speed signal Δv may be delivered accordingly. When the train is delayed it is for increased speed, and when going too fast for retarding. Eventually instruction speed v_r is given as $v_0 \pm \Delta v$ so as not to exceed the restrictive speed v_m. By so doing, punctual operation is made possible with automatic adjustment for such outside disturbances as change of running resistance and line voltage.

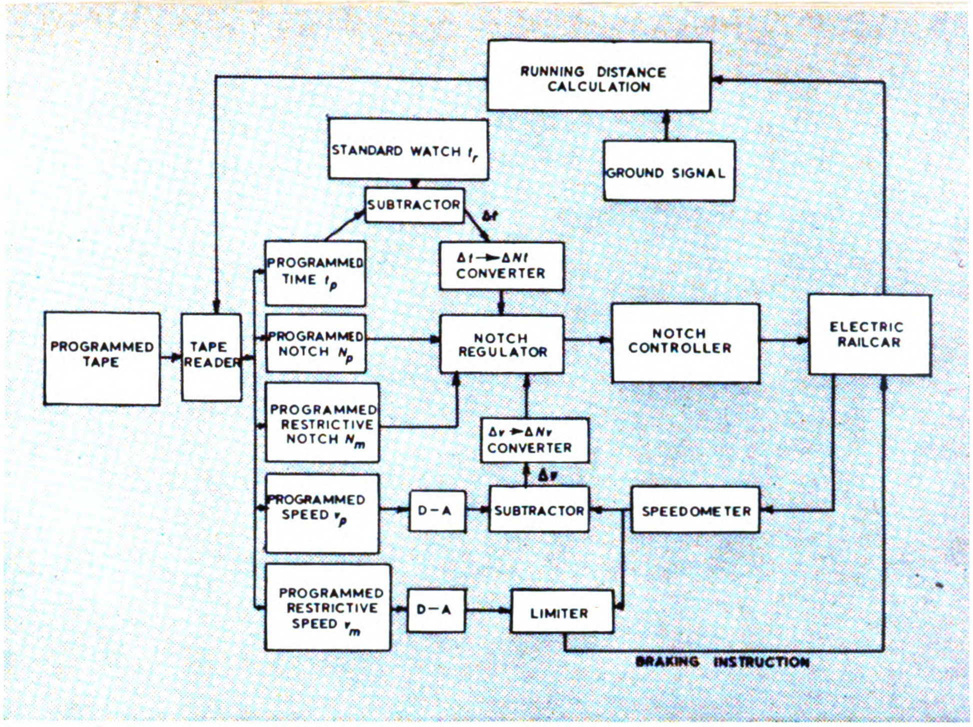


Fig. 1—Block diagram of notch programming.

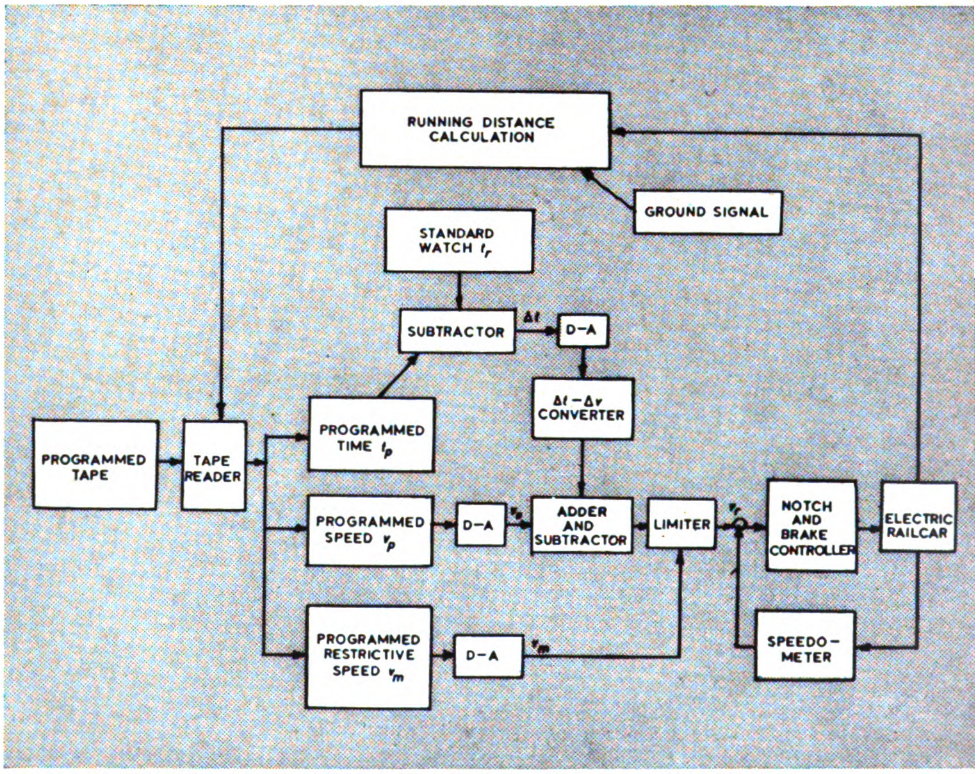


Fig. 2—Block diagram of speed programming.

When the required speed v_r is dispatched to the train, it is compared with the actual running speed v, and must be controlled to correspond with v_r. For this, many speed control systems are possible. The simplest is to have v_r and v in terms of voltage for the following arrangement: $v_r > v$ for power running: $v_r =$

v for coasting, and $v_r < v$ for braking. However, in the case of an AC electric railcar train, with many powering notches for various speeds and capable of selecting any one of the notches, it is possible to adopt the ordinary speed control system, under which the voltage for $v_r - v$ is amplified to select the right notch, and to have v conform with v_r to an appreciable accuracy.

What is shown in the speed controlling parts given on the right-hand lower side in the block diagram of Fig. 2 represents the improvement made to reduce the off-set. It is also possible to use the PID controller for speed control, and we have made experiments with this also.

Though it is possible to operate a train automatically as described, one of the most difficult aspects is to stop a train accurately, without impairing the riding comfort, at the prescribed point along the platform. It was to attain this objective that the following device was evolved. The principles of the device are as follows.

A signal is received from the ground installation at a certain distance away from the prescribed spot so as to create in the cab equipment a standard brake curve showing the relationship between speed and distance, as shown in Fig. 3. The end point of the curve indicates the desired halting point. The train then stops accurately at the prescribed spot by controlling the braking according to the curve so made up. There are many ways of making up the curve and controlling the braking, but we have a simple and accurate device completed for use.

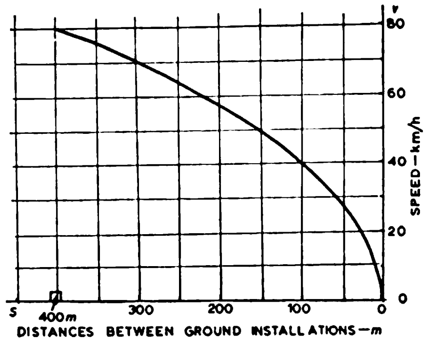


Fig. 3—Standard retardation curve.

In 1962 prototype control equipment for two different kinds of program control and automatic train halting apparatus as mentioned above were manufactured, and actual tests were carried out on the test run section in March and August 1963 on the new Tokaido Line. Examples of running curve showing the test results are given in Figs 4-6. Figs 4 and 5 indicate the distance-speed curve in test runs. The gradients in the section and the aggregate distance from Tokyo are also shown. Shown on the lower part is the difference between the programmed time and the actual opening time during the test. Fig 6 indicates the operating curve when the PID controller is used in speed control alone. Through these tests it was proved that automatic operation would attain good performance as expected. The automatic stopping device works well, the error being less than ±30 cm from the prescribed spot, and the train stopping without giving any discomfort to the passengers aboard. In the future the equipment will be further improved, primarily in the speed programming system, and the automatic braking apparatus refined to implement the automatic operation perfectly. **RS&C**

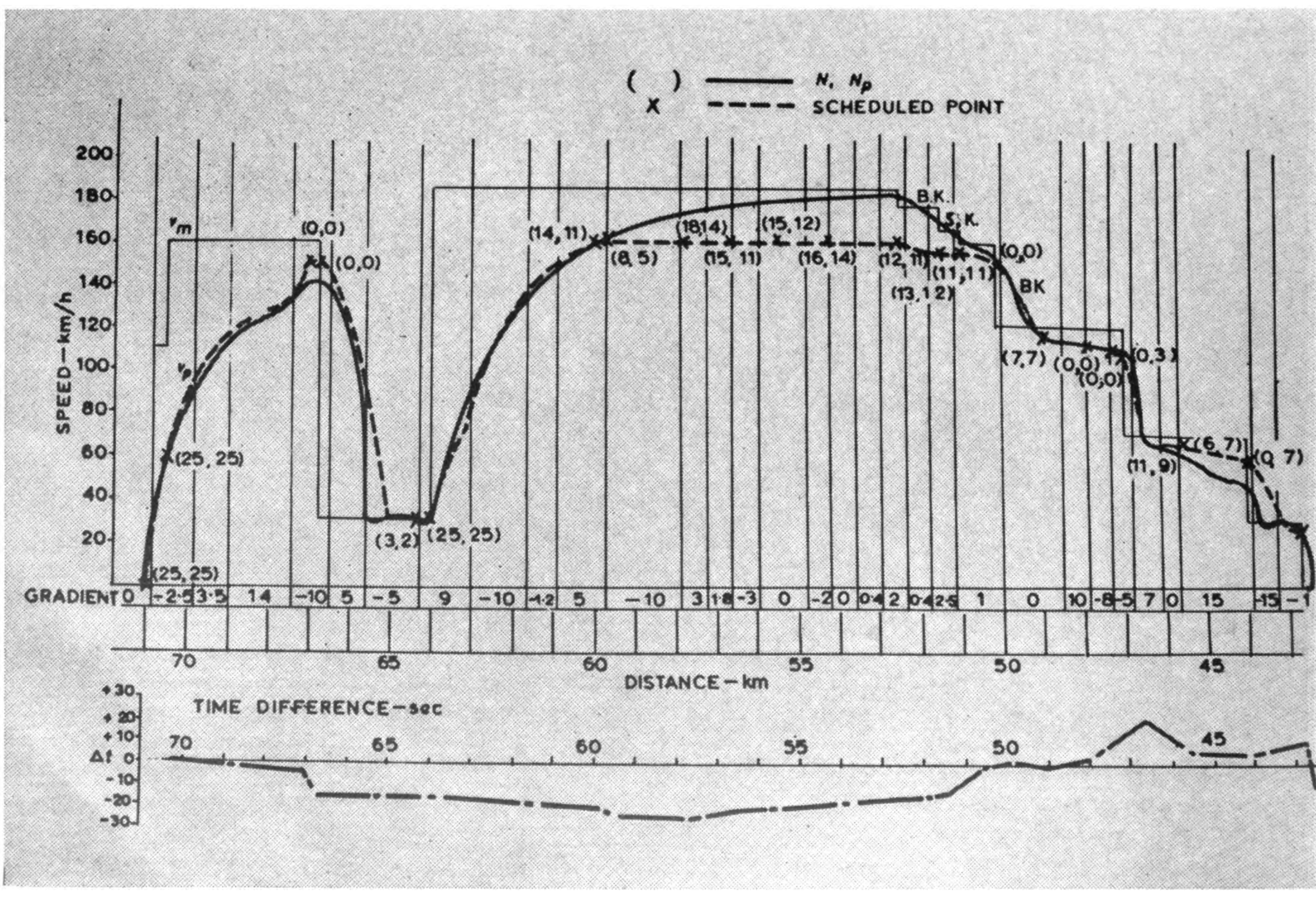


Fig. 4—Result of an actual test in notch programming.

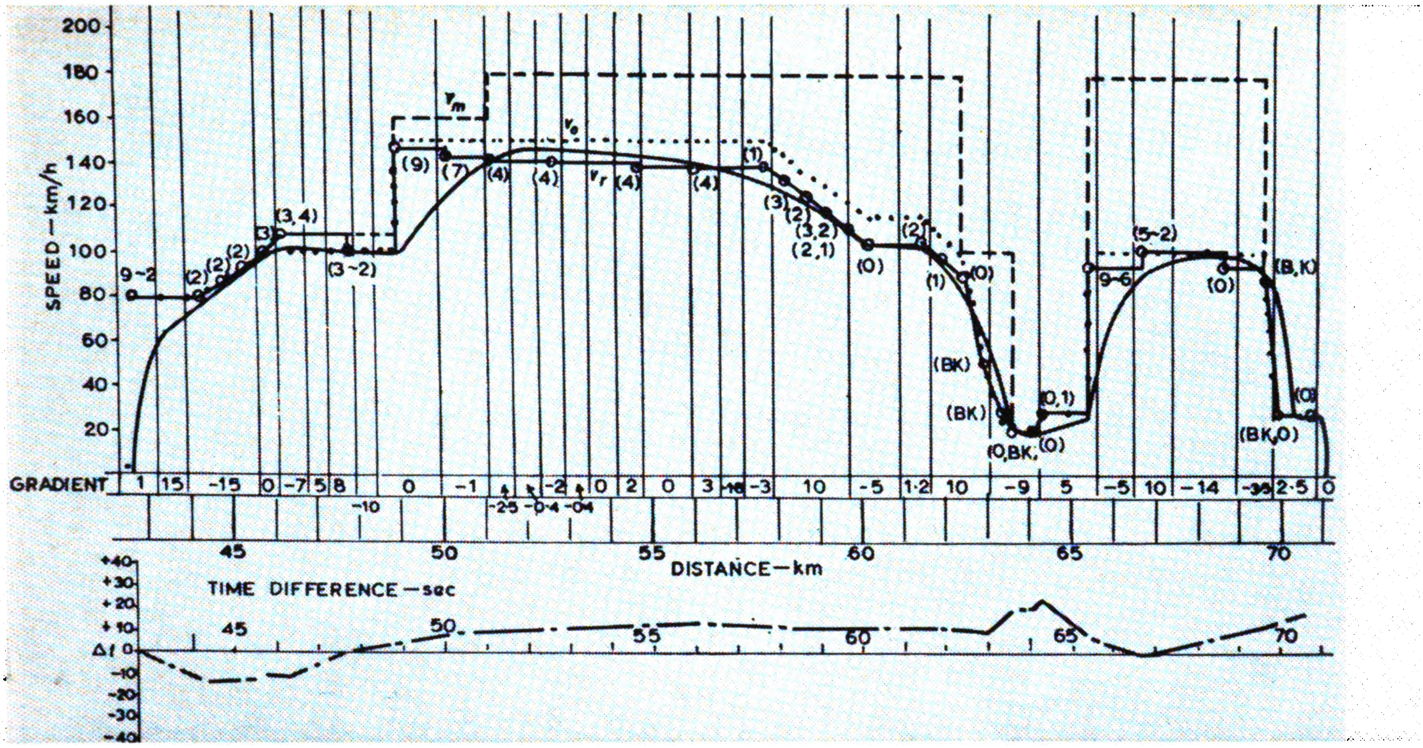


Fig. 5—Result of an actual test in speed programming.

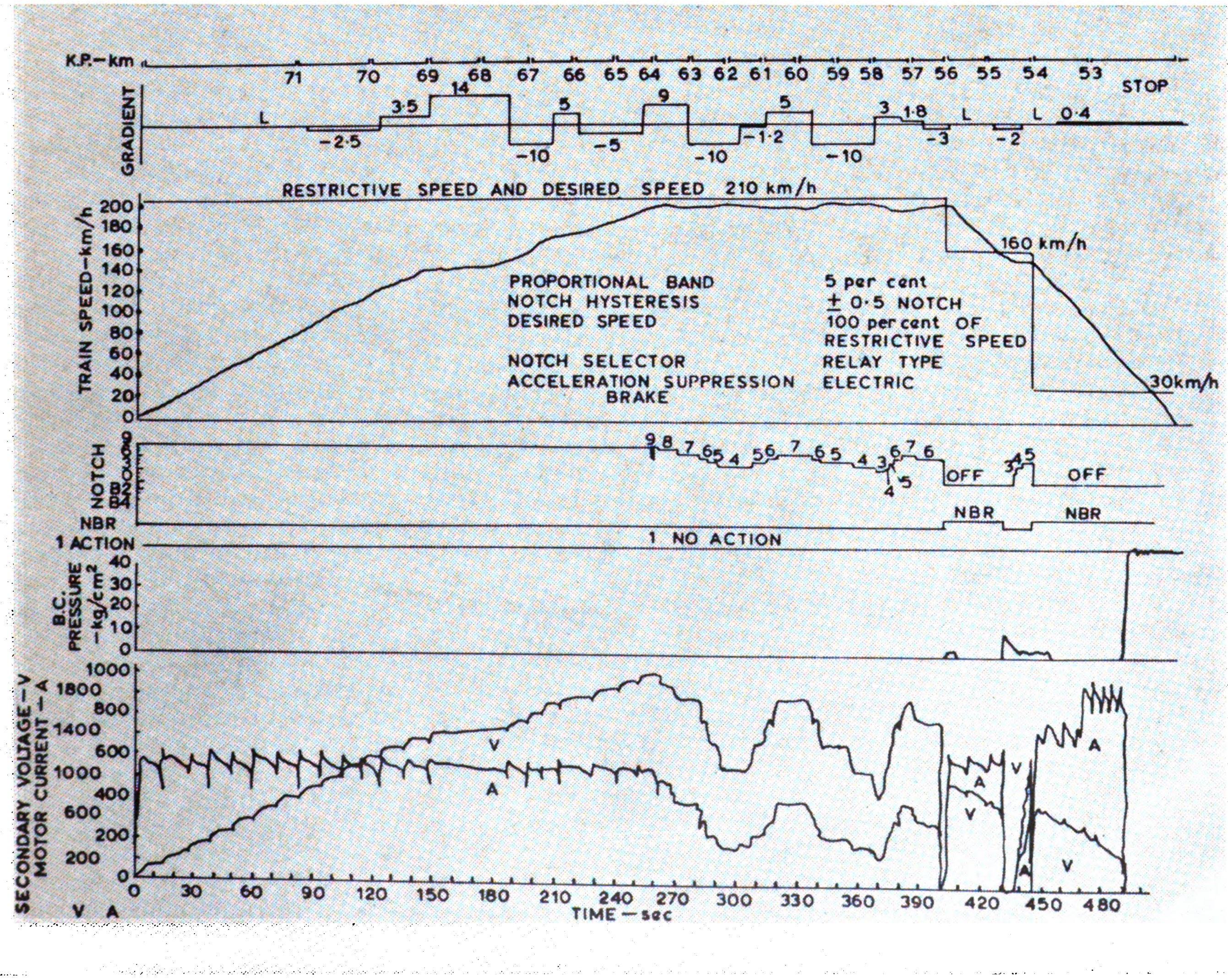


Fig. 6—An example of a running test of the automatic train speed control device.

Automatic pilot developed to run subway trains in Stockholm

The automatic pilot is capable of normal driving on an ordinary track in such a way that it starts the train as soon as the guard has closed the doors and given the departure signal. Before reaching the next station the automatic pilot cuts off the power, applies the train brakes and brings the train to a halt at the desired stopping point. Between the stations the automatic pilot in conjunction with a human pilot takes into consideration the different aspects which the ordinary cab signal equipment of the underground system may show and adapts the speed of the train to the signals.

The automatic pilot is provided with two different programs, a rapid run intended to be used in rush-hours, and an economic run intended to be used during off-peak hours when a somewhat longer but power-saving running time between the stations will be compensated by shorter stops.

The automatic pilot, however, is *not* able to perform any form of shunting or to drive when the most restrictive cab signal aspect L, i.e. a maximum speed of 9 mph, is given. In such cases the driver has to take over by turning a special switch from the 'automatic' to the 'manual' position.

A characteristic feature of the automatic pilot is its simplicity and the fact that it can be installed without too heavy a cost. That in turn is dependent on the design of the cars and of the whole underground system. For that reason it seems to be necessary to call attention to some features of this subject.

Editor's Note: This article is an abstract of a paper presented at the Automatic Railways conference in London, England, sponsored by the Institution of Mechanical Engineers. It is abstracted herewith through the kind permission of the IME. The authors are O. Kekonius and N. D. Kallberg, of the Stockholm Sparvagar, Stockholm, Sweden.

The underground system includes 6 lines with a combined length of about 35 miles and an average station interval of about 3000 ft. More than half of it is within tunnels. The lines have the following technical characteristics.

Maximum speed	75 km/h, 46 mph
Minimum train headway in absence of restrictive signal aspect	120 sec
Maximum gradient	1:25
with two exceptions, namely	1.24
and	1:20.8
Minimum curve radius	650 ft
Minimum curve radius at stations	1000 ft
Track gauge	4 ft 8½ in
Normal Voltage	650 volts
Maximum acceleration	2.24 mph/sec
Average deceleration	2.24 mph/sec

With the exception of some test cars the rolling stock consists of about 600 motor coaches with the same size and type of equipment for traction, brakes, door operation, etc. Each car has four traction motors for driving and for braking. The current is controlled by electro-pneumatic contactors. During driving and braking the contactors are governed by a current limit relay. The setting of this relay is influenced by the load in the car in such a way that the acceleration during the progression period is independent of the load. Similarly on about a fourth of the rolling stock the deceleration is practically fully independent of the load. The rest of the cars are to be changed so that all cars will in a year or two have load-sensitive brakes. The traction equipment is designed for multi-unit control of up to eight cars. The master controller has three driving positions of which only one is necessary for normal operation.

The cars are provided with the Westinghouse Air Brake SMEE brake equipment in which the dynamic and pneumatic braking are controlled by a single brake valve handle. There is also provision for handling a train only by pneumatic power in event of the dynamic and electropneumatic brakes not functioning. An emergency pneumatic brake is available at all times by means of the driver's brake valve, the driver's safety device, the passenger emergency brake handles, the timing valve in the cab signal system and so forth.

Fig. 1 shows a very simplified schematic diagram of the brake system. The brake valve handle on the driver's brake valve regulates the pressure in the straight air pipe running through the whole train. This is done by the self-lapping valve and the electric self-lapping unit, which through two multiple-wires, the 'Release' wire and the 'Application' wire, governs a pair of electro-pneumatic valves in each car of the train, one release valve and one application valve.

The pressure in the straight air pipe directly affects the dynamic brake actuator, and thereby the rheostatic control of the brake current. Simultaneously there is also some supplementary air pressure in the brake cylinders.

Tests have shown that the braking of a train will be satisfactorily graduated even though the pressure in the straight air pipe is regulated in two steps only.

The cars are equipped with cab signals and an automatic train control system, which will produce an emergency brake application if a driver—or an automatic pilot—neglects restrictive signals.

The cab signal system is of the continuous type, in which the signals are transmitted to the train by induction from signal currents in the rails. The system gives three aspects, H (free run), M (speed limit: 31 mph) and L (speed limit: 9 mph). Fig. 2 shows when the different aspects are given. This sys-

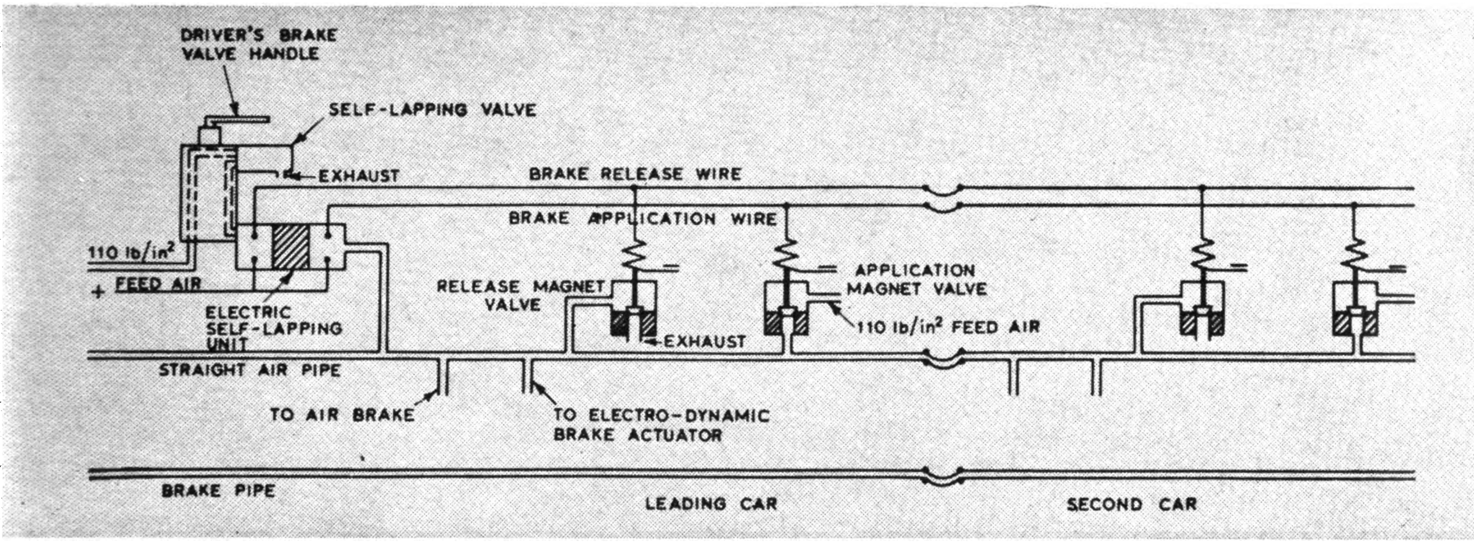


Fig. 1—Schematic diagram of brake system used on Stockholm subway trains having automatic pilot.

tem has been used for 14 years and has proved to be extremely reliable. It means that the safety of the underground system can be based entirely on the cab signal system.

These points can be summed up in this way. It is possible to operate a train simply by controlling some relays in the drivers cab: one for driving/coasting, one for full service braking, and one for half service braking. For special purposes it has been necessary to add another two braking relays, all of which are controlled by impulses from a door signal relay, the cab signal relays of the ordinary car equipment or from the electronic circuits of a computer.

Before the driver can give the train over to the autopilot he has to charge the air brake system as usual and put the handle in the running position. After that he turns a switch from Manual to Automatic and thereby energizes two magnetic valves. One of these cuts off the valve operated by the driver's safety device and the other cuts off the service brake part of the driver's brake valve, that is, the self-lapping valve. The emergency brake part, however, remains unaffected.

Besides these two valves the Automatic-Manual switch connects the Release wire and the Application wire with the brake relays via a brake pressure indicator, which is connected to the straight air pipe running through the whole train. This brake pressure indicator is fitted with a number of contacts, which have to energize and de-energize the Release wire and the Application wire when the desired braking relay controlled pressures

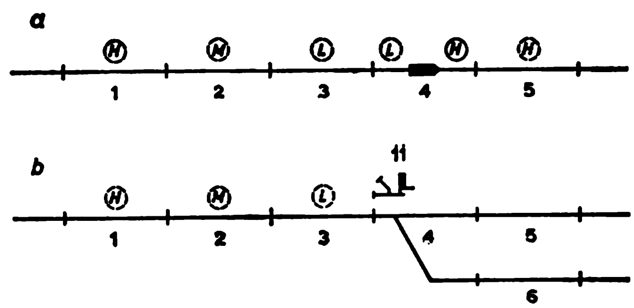


Fig. 2—Three aspects of cab signal equipment. If a train is on track circuit 4, and if signal 11 shows "stop", a following train will receive cab signal aspects H, M and L on track circuits 1, 2 and 3 respectively.

are reached in the straight air pipe. These three details, the two valves and the air brake indicator, are the only additions to the brake system of the cars.

Beside the Automatic-Manual switch and the necessary wiring to the electrical equipment of the cars the following have been added:

(1) A portable computer unit including a receiver for the wayside signals and an electronic computer.

The receivers and the computer are transistorized but the input circuits and the output circuits of the computer are controlled by or control micro relays. The latter simplify the circuits, and at the same time transients from the car equipment are prevented from intervening with the transistorized circuits of the computer. The computer is built up of logical circuit elements of the type now in common use. The elements are mounted on cards. The computer box has the dimensions 7″ x 8″ x 12″ and the weight is about 16 lb.

(2) A relay box with the power relay and the four braking relays mentioned above.

(3) A tachometer generator mounted on one end of a traction motor shaft and intended to give information of actual speed and distance travelled to the computer.

(4) An antenna for the wayside signals.

The wayside equipment consists of two impulse transmitters, each connected to a loop located between the rails and placed at the required distance from the stations. One indicates that the distance to the correct stopping point at the next station is 1070 ft. The other indicates a point where the motor current should be shut off in order to save power.

The transmitters are of a simple type. The power consumption is about 3 watts and the frequencies are about 4 kc and 6 kc, respectively.

Fig. 3 shows the schematic diagram of the automatic pilot. The computer receives information about:

(1) Permitted speed; from the cab signal equipment. The information is given as a voltage on one or two wires.

(2) Actual speed and distance

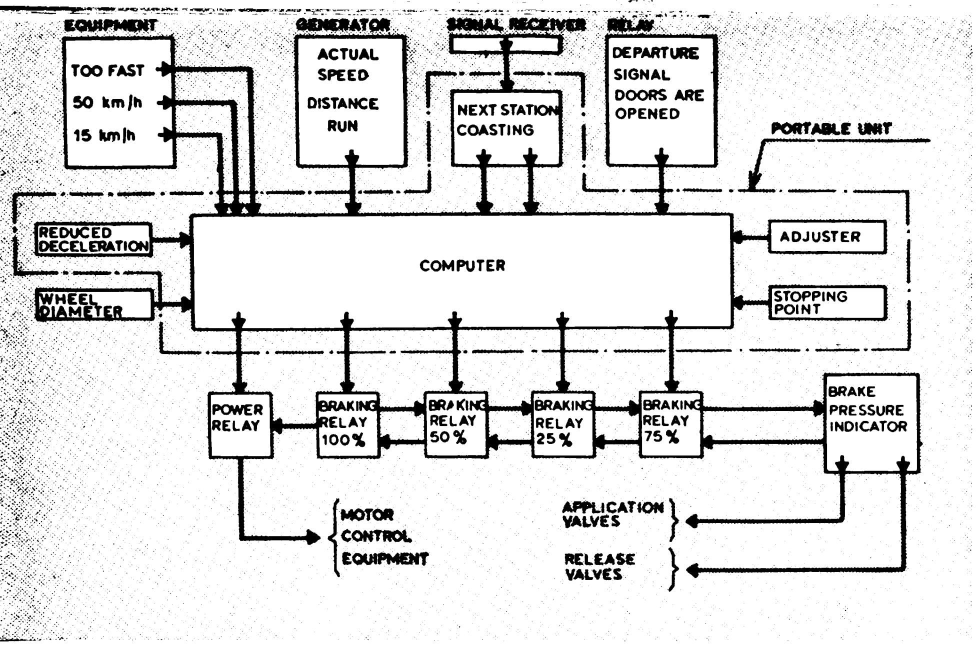


Fig. 3—Schematic diagram of the automatic pilot.

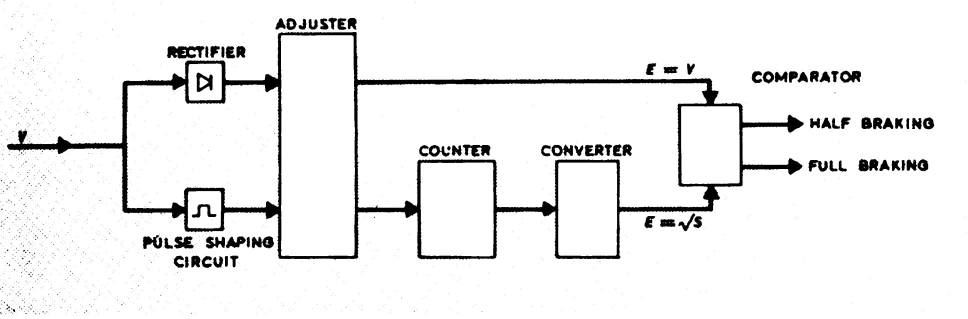


Fig. 4—Schematic diagram of the train halting device.

travelled; from a tachometer generator. The speed is given as a voltage proportional to the speed, and the distance travelled as a number of peaks on the alternating current from the tachometer generator.

(3) Distance to the next station and 'suitable point for coasting', from the wayside equipment. In both cases the information is given as an impulse from the signal receiver.

(4) Given departure signal and about opening of doors. In both cases the information is given as a voltage or as an interrupted voltage on a wire from the door signal system.

On the basis of this information the computer gives the order for power, full-braking and half-braking, and that is all that is necessary for ordinary running. The orders are given by energizing and de-energizing the power relay and the brake relays. Much of this ordering is carried out by simple logical relay circuits.

The method of operation is:

(1) When the guard has closed the doors and given the departure signal, the power relay and the brake relays are energized, which starts the train. Then the train will run until the automatic pilot is influenced by signals from the cab signal system or the wayside impulse transmitters. Apart from the notching time, the acceleration of the train during this period is entirely dependent on the tractive effort of the motors, the track profile and the load of the cars.

(2) If the train—when running faster than 31 mph—gets an M-signal (speed limit 31 mph), the power relay and the brake relays are de-energized, i.e. the train will be braked until the speed is below 31 mph.

(3) If the train for any reason gets the most restrictive signal L (speed limit 9 mph) the train will in the same manner be braked to a stop. Then the driver has to take command.

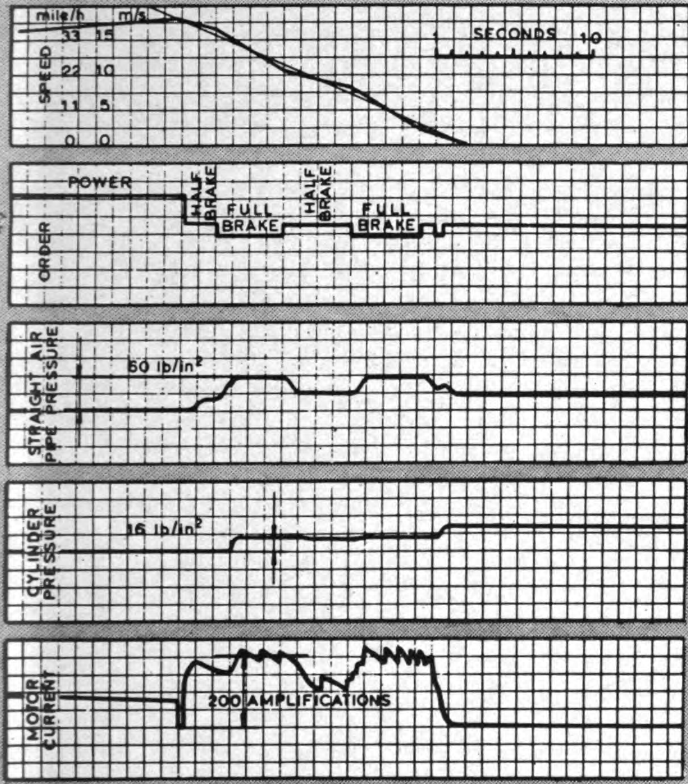
(4) If a door for any reason is opened during running, the power relay and the brake relays will be de-energized and the train braked to a stop.

Fig. 4 shows, however, how the somewhat more complicated stop at a predetermined point is arranged. When the train is running towards the next station the signal receiver picks up a signal from the wayside equipment 1070 ft before the stopping point. This signal starts the counter, which thereafter subtracts the number of pulses of the tachometer generator from a starting number representing the distance between the wayside transmitter and the desired stopping point. Besides this subtraction the counter divides the remainder in accordance with a pre-programmed pattern, which will provide an approximation of the square root of the remainder. Consequently the counter is at any moment able to generate an output that represents the square root of the distance to the desired stopping point. The counter is designed as a binary-digital device and the output is for that reason converted to a voltage, which represents the desired speed.

This desired speed, given as a voltage, is compared in a comparator with the actual speed given as the voltage of the tachometer generator. If the actual speed is higher than the desired, the comparator will order full service braking by de-energizing the full-braking relay and the half-braking relay. If on the other hand the actual speed is lower than the desired speed, half service braking will be ordered. In this way the computer is able to bring the train to a stop at the desired stopping point by interchanging the two braking forces. Ordinarily there are only a few alternations during braking from 40-45 mph to stop, but the accuracy is good enough for the purpose. The necessary adjustments will be treated later on.

Fig. 5 shows a typical braking performance record. As shown by the speed curve the train is not influenced until the actual speed approaches the desired speed for the first time.

If the cab signal equipment gives the aspect M (31 mph), the voltage of the tachometer generator is compared with a fixed voltage that represents the desired speed and in this case full braking, coasting or power will be ordered on the basis



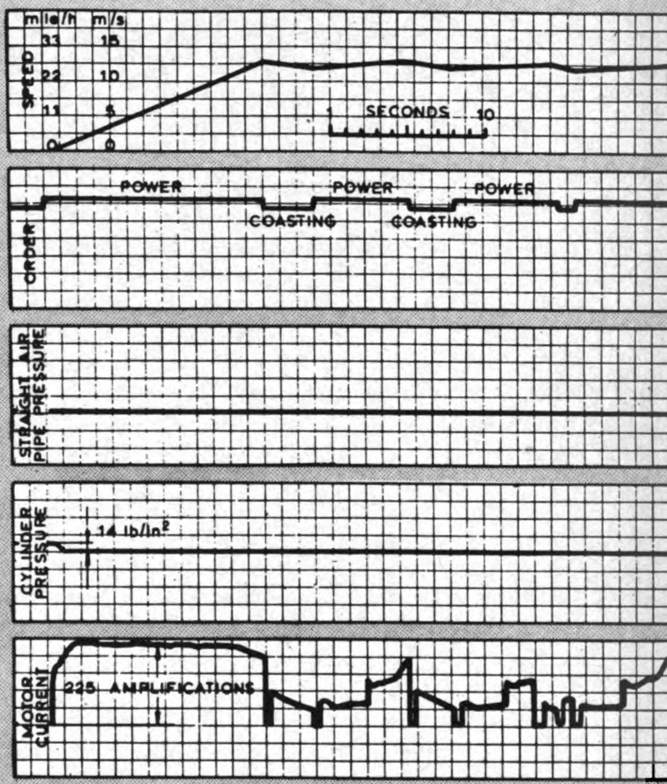


Fig. 5—(left) Braking performance ("order" line—computer to relays.) Fig. 6—Starting and running on basis of M aspect.

of the difference between the actual speed and the desired speed. Fig. 6 shows start and running, when the M-signal is given.

Fig. 7 represents some typical runs when the train is influenced by restrictive cab signals, the coasting signal, etc.

The safety of operation with this automatic train is based upon the cab signal equipment which has already proved to be reliable in the highest degree. For that reason no alterations have been made in the vital parts of the cab signal equipment. There are only connections to the signal lamp L and M and also to a buzzer, which normally indicates when the speed exceeds that permitted by the cab signal. It means that electrical or mechanical failures of the automatic pilot device have no influence whatsoever upon the cab signal equipment.

Concerning unexpected obstacles which may appear on the tracks, it is to be remembered that there is always an operator in the driver's cab who can supervise the track and be ready for action if necessary. He can take command at any moment by turning the Automatic-Manual switch, or by making an emergency brake application.

This, however, touches a problem that as yet has no final solution. As the operator normally is quite inactive during running between two stations, the question arises whether it will be necessary to fit a special device of some kind in order to keep him alert.

SERVICE BRAKING

In an ordinary train, as in the automatic train, the service brake is governed by the two train wires, the Application wire and the Release wire mentioned above. This means, for instance, that a failure in the car coupler may interfere with the braking force. For this reason there is a paragraph in the driver's instructions ordering him to apply the emergency brake, if he observes any weakness in the service braking force. To meet the requirements of this paragraph there is an alteration in the wiring of the automatic emergency brake application if the pressure in the straight air pipe for any reason is lower in the rear end than in the front end of the train. This means that the pressure in the straight air pipe is accepted as a criterion of the braking force, which seems to be justifiable in view of the proved reliability of the brake equipment.

It should be mentioned that the cab signal equipment will apply the emergency brake if the pressure in the straight air pipe in the front end is not increased rapidly enough when the aspect changes and the train is running faster than permitted by the cab signal.

In two-manned trains the guard is placed in the center of the train in order to facilitate his supervision of boarding and alighting passengers. In one-manned trains, however, the operator is to be located in the front cab and at some stations, particularly those with curved platforms and also where there are large

Special adjustments can be made to computer

numbers of passengers, his opportunity for supervision will be limited. This has necessitated the installation of industrial television at some platforms.

The ability of the operator to establish contact with the central control office, too, should be mentioned as a question of safety, and one which has increased the demand for radio communication. The technical difficulties with radio communications in tunnels are solved by installing a special feeder cable: a final decision on the radio installation is in sight. A portable train radio unit is contemplated and this has to be considered in relation to the portable computer box as the aim is to decrease the number and weight of the details which the operator has to carry with him to and from his trains.

The length of an 8-car train is 475 ft, the length of a platform is 495 ft. This means that the accuracy shall be within ±10 ft. These 10 ft represent less than one per cent of the braking distance and for this reason the method of distance measurement chosen has been judged to be very critical. The tests, however, have proved that the method will meet the demand in almost all weather conditions.

It is, however, known that on one or two days a year in Stockholm there might be weather with a special type of snow during which the human drivers have to drive with more than normal caution in order to be able to stop at the right point. Owing to this the computer box is fitted with a special switch by which the desired deceleration rate can be lowered from 2.24 to 1.67 mph/sec. This switch has to be used by the operator, if he observes any tendency to overrunning attributable to the weather conditions. As to the risk of skidding, i.e. that the value of the coefficient of adhesion may decrease from 0.15 to about 0.11, the test runs indicate that the lower value is the minimum to be expected.

REDUCE DECELERATION

This reduction of the desired deceleration is effected by a suitable decrease in the voltage from the tachometer generator, which thus gives fictive information of the actual speed to the comparator. Furthermore, the full-braking relay is replaced by one provided specially for the purpose termed the '75 per cent braking relay', which limits the maximum pressure in the straight air pipe and consequently the maximum brake cylinder pressure.

Another thing that is necessary to have in order to maintain accuracy is a compensator for variations in wheel diameter. This is a device which simultaneously makes a suitable reduction in the tachometer generator voltage and a corresponding reduction in the number of pulses from the tachometer generator fed to the counter. This reduction in the number of pulses is made by a special counter which, depending on the position of the adjuster knob, electrically suppresses every tenth or every ninth pulse, etc. Thus compensation is entirely numerical.

On the test equipment the knob is located on the computer box, but as this is to be portable and the wheel diameter compensation should be associated with each car, a part of the adjusting device is to be fitted on the cars themselves.

Besides the wheel diameter com-

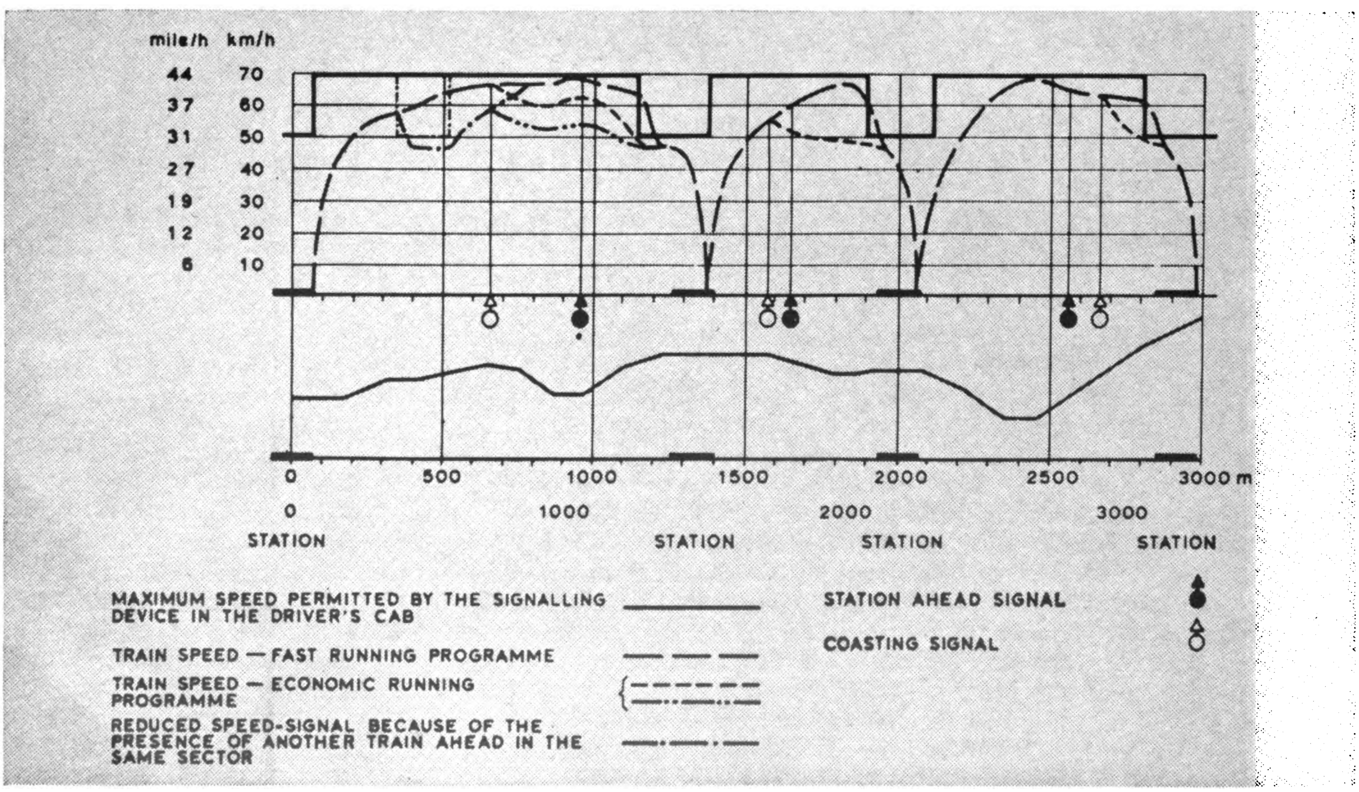


Fig. 7—Typical runs when train is influenced by restrictive cab signals, coasting signal, etc.

control on account of weather conditions.

pensator a 'normal' control, with a corresponding method of working has also been fitted. Its task is to enable the operator, if necessary, to select a better stopping point.

As the calculation of the desired speed in the computer, apart from the converter, is made numerically and the voltage of the tachometer generator is controlled by the wheel diameter compensator, it seems possible that this additional adjustment is superfluous, but it has been included for the sake of safety.

It should also be mentioned that the computer box is fitted with a special control by means of which the operator in the case of shorter trains can select a more suitable stopping point than that at the end of the platform. The method of changing the stopping point is to lower the initial figure at which the counter starts to calculate the desired speed, when the station ahead signal is received.

Passengers' comfort may be regarded as presenting two different problems. On one hand the method of driving with the train running at maximum speed may produce disagreeable accelerations for the passengers owing to curves or track irregularities; on the other the method of braking by interchanging half- and full-braking may be too rough.

As to the question of high speed it should be mentioned that the track system is built to permit this and that the cab signal equipment will always give restrictive signals where curves and gradients prohibit maximum speed.

It should be mentioned that if no restrictive signals occur the human drivers, too, at least during rush-hours, drive as fast as the tractive effort permits. Test runs on a great part of the lines have proved that there are scarcely any difficulties produced by the transverse accelerations of the cars. In spite of this fact a third signal receiver is fitted in the computer box as a reserve, should there be some points in the system where a speed reduction may be necessary. In that case the third receiver will pick up a signal from a special wayside transmitter suitably placed, which will order coasting and reduce speed.

As regards changes in deceleration during braking the fact is that the time constant of the brake system of the cars is so great that the brake application will always be comparatively smooth. Fig. 5 illustrates these points. As the normal brake application before a station—owing to the computer's method of working—always starts with half-braking, the time for changing from acceleration to full deceleration amounts to 3.5 sec. This produces a rate of change in acceleration of 1.3 mph/sec^2, which is tolerable. The changeover from full-braking to half-braking or the reverse gives about the same value.

If an unexpected restrictive signal occurs this may result in a change of acceleration of 2.2-1.5 mph/sec^2 independently of whether the train is driven by a human driver or not. Presumably the automatic pilot will brake somewhat more smoothly than the driver owing to the fact that the automatic pilot always does things in the proper sequence. In addition to this some small differences in the valve ports may promote smoother braking.

END OF BRAKING

The most critical point, however, is at the end of braking, when the brake current fades and the brake cylinder pressure increases. See Fig. 5.

In order to make a brake stop end smoothly the human drivers have to ease the brake pressure at the moment of stopping and similarly the logical circuits of the computer are so arranged that half-braking is always ordered when the speed of the train has been reduced to about 4 mph, i.e. when 1-2 sec of braking time still remains. This, however, may be a time too short to permit the desired release, which means a disagreeable jerk. For this reason several methods of softening this jerk have been discussed, but as every method involves a decrease in accuracy, they must be studied and thoroughly tested. Owing to this no decision on this question has yet been reached.

For the sake of completeness it should be mentioned that the brake pressure is released to about a quarter of its value at the moment when the train has stopped and the doors have been opened. This is effected by a special relay the '25% braking relay', which is energized when the doors are opened. The purpose of the arrangement is to get a brake force great enough to hold the train stationary, but rapidly releasable at the start.

Investigations proved that an appreciable saving in power consumption can be made by a slight increase in running time. A noteworthy example of this is the section between the Slussen and Gamla Stan stations, where an increase of running time from 50 to 58 sec reduces the power consumption by 40%.

As the capacity of the underground system must be utilized to the fullest extent in rush-hours, the necessity for two different programs is evident.

On the test equipment the choice of program is made by a switch on the computer box, but for the future there is the possibility of removing the choice from the operator to the central control office.

The correct location of the transmitter loop is of decisive importance in attaining the desired saving in power consumption. For this reason the location of the loops is to be calculated with the aid of computing machines.

The first prototype of the automatic pilot was demonstrated in September 1962 and regular test runs started in January 1963. The line prepared for automatic operation included seven stations and after a year about 10,000 test runs had been made. The test runs have been successful, but have, of course, led to some improvements in the equipment. Thus the '75% braking relay' and the '25% braking relay' have been fitted, some weak points in the car equipment have been discovered and removed, and so on.

The test train has been made up of varying numbers of different types of cars. Up to February 1964, however, only one car had been prepared as a leading car, but in March

(Please turn to page 42)

STOCKHOLM SUBWAY TESTS AUTOMATIC PILOT

(Continued from page 23)

1964 car number two was to be prepared and at the same time the test line for automatic operation was to be extended.

Almost all test runs have been recorded by instruments which record motor current, orders from the computer, etc. See Fig. 5. These records have been of great value for the investigation of observed irregularities. A large number of drivers have acted as operators. Most of them have been very interested and well disposed towards the equipment when they have overcome their initial scepticism. Their criticisms have mainly concerned the smoothness of operation.

At this stage of the development there are no tenders available and for this reason nothing but mere guesswork is possible.

The only comparison that is possible is to the installation of the cab signal system. There are, however, great differences owing to the following:

(1) The most expensive part of the automatic pilot, the computer, is intended to be portable, and only one or two are needed per train.

(2) The wayside equipment of the automatic pilot is very simple compared with track circuits and the relay rooms of the cab signal system.

The installation cost for the cab signal system including the car equipment is about 1.2 million Swedish crowns [about $240,000] per mile double track, and a bold guess would indicate that the cost of the automatic pilot will amount to 10 or 15 per cent of that of the cab signal system. That would amount to about 10 million Swedish crowns [about $2,000,000] for the existing network.

It is mentioned above that the line prepared for automatic operation was to be extended in March 1964. The next phase of the development probably is that the automatic train, still two-manned, should be put into regular operation, and if nothing unexpected occurred it would be possible to make a final decision concerning the automatic pilot in May or June 1964. About a year after that the first series-produced pieces of equipment may be put into service.

The pieces of equipment thus installed may be regarded as a relatively uncomplicated device, which may improve and facilitate the running and in that way make the changeover from two-manned to one-manned trains easy in the same way as power assisted steering once brought the one-manned buses within reach. Furthermore, this equipment will be regarded as an important step towards complete automation of the operation of underground trains.

As a result the Stockholms Spårvägar expects:

(1) reduced power cost,

(2) an increase of line capacity, from 30 to 35 trains an hour, and

(3) reduced operating cost owing to the introduction of one-manned trains. **RS&C**

PRODUCT NEWS

(Continued from page 41)

ST-2 can read print as small as pencil ledger entries and transmit a clean picture to a remote monitor as far as a mile away without additional amplification. It will operate in rugged environments—altitudes up to 14 miles, temperatures ranging from freezing to 158 deg F and humidity up to 95%.

ST-2's overall size is 6¼" diameter and 12⅝" length. Weight is 13 lb.

Because silicon solid-state electronics are used throughout except for the vidicon tube and the input stage, the camera affords high operating stability at high ambient temperatures. It is also unaffected by temperature and voltage changes which cause picture shrinkage, fading and blurring. Picture degradation will not exceed 5% in size, contrast or resolution with input power changes as much as 30 volts and temperature variations of 125 deg F.

The molecular circuitry allows incorporating of a binary counter type of sync generator within the ST-2. This binary counter requires no adjustment to obtain the proper count and is insensitive to frequency. The video amplifier bandwidth of 12 mc and a 70-gauss focus field provide the 800-line resolution.

The camera operates at 100 to 130 volts, 50 or 60 cycles. With slight modification, a direct current power source of 24-28 volts can be employed. *Diamond Electronics*

Train equipped for automatic operation is approaching a "co mmand spot" (wayside equipment at right) on a test run betwe

AUTOMATIC TRAIN OPERATION—III

London Transport has ATO i

THE ADVANTAGES to be achieved by automatic train operation may be summarized as follows:

(1) Regularity of service, deriving from uniformity of driving technique.

(2) Reduction in minimum headway achievable—and, therefore, an increase in the maximum line capacity.

(3) Maintenance of timetabled performance within minimum possible energy consumption.

(4) Enforced observance of speed restrictions.

(5) The ability to provide for automatic recovery from service delays.

(6) The possibility of reducing operating manpower.

It is true that in many respects the automatic control can do no better than a good human driver: indeed it is sometimes alleged that a good human driver can, in some respects at least, exceed the performance of the automatic controls. Experience shows, however, that on average the superlatively good human driver is likely to be followed by one of less than average ability and the net effect of the first man's superior driving is to widen the gap between the two trains to an extent which reacts to the increasing detriment of the following train. With automatic operation, not only is the running performance of the trains maintained to a consistent level, but, if due to abnormal influences a station stop is prolonged, means can automatically be invoked in an endeavour to recover the lost time and, what is perhaps even more important, on a system such as the London Underground, to regularize the service interval.

With any scheme of automatic train operation the question is bound to arise at an early stage in considerations—how are the instructions to be conveyed to the train? This problem resolves itself most usually by the recognition that a program has to be devised for the train operation, and that the alternatives available are:

(1) A program carried on the train, or

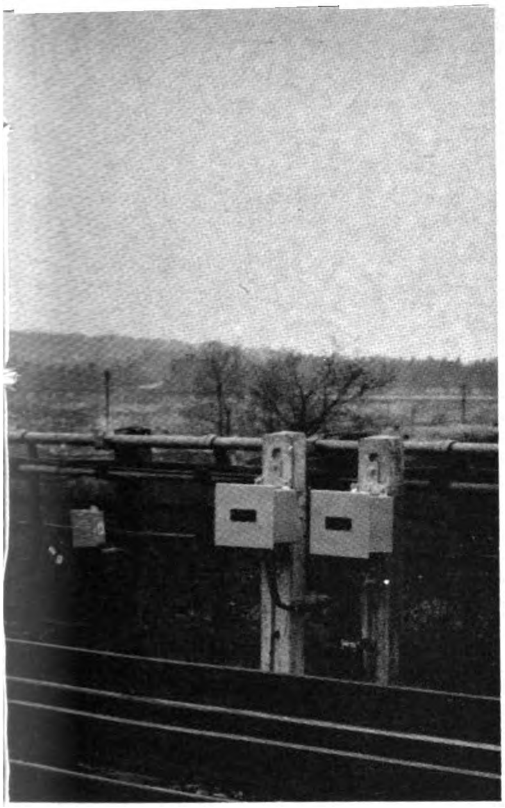
(2) A program indicated on the track.

Because of the fact that the London Transport services are, in the main, of an exactly repeating character it was thought originally that it would be most appropriate to put the program on the track and to equip the trains with apparatus which responded always in the same general way to the same indication transmitted from the track.

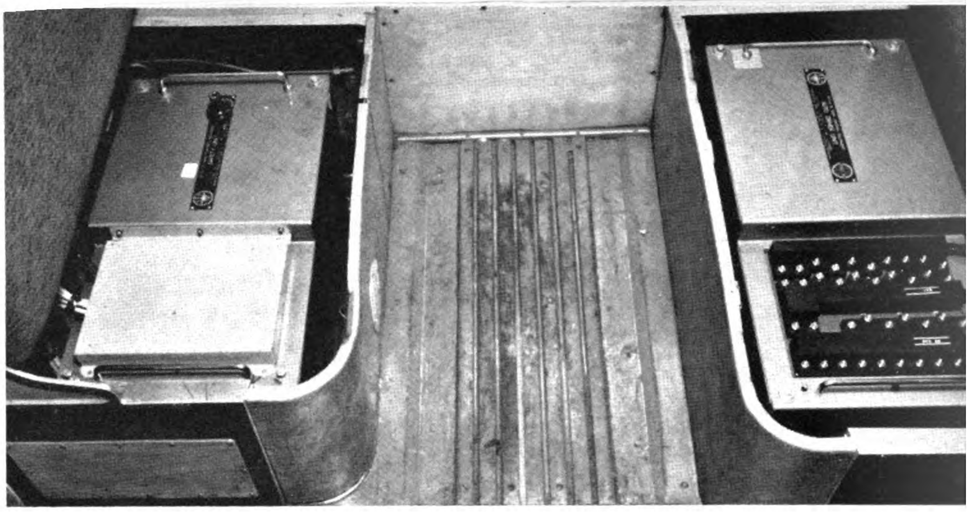
Although viewed originally as a scheme peculiarly suited to the London Transport requirements the experience in operation has shown the scheme to be flexible that its advantages for other types of service are considered to be manifest.

With the program on train concept there is always found the need to provide calibrating indications from the track, and there is ever

Editor's Note: This article is an abstract of a paper presented at the Automatic Railways conference in London, England, sponsored by the Institution of Mechanical Engineers. It is abstracted herewith through the kind permission of the IME. The authors are R. Dell, chief signal engineer, and A. W. Manser, chief mechanical engineer, London Transport Executive.



łainault and Woodford.



Safety signaling code equipment (left) and "automatic driver" on train.

service

present the problem that if the train is diverted from its timetabled route (or reversed in direction) someone must adjust the program device to take acount of what has happened. With the program on track, as described in what follows, no difficulty arises in the event of unscheduled working: the program is there ready for any train which comes along. Even with trains of varying performance all that is necessary is to provide separate indications to insure advance action in the case of stock which may be fitted with less than normally efficient braking.

Experiments and trials with automatic driving of electric trains have been in progress on London Transport since 1962. The work is now in its third stage, the first stage comprising laboratory tests of equipment and development of circuits, and then the production of one trial train which was run in passenger service for one year from April 1963 until April 1964. In April 1964 the present extended trials of automatic train working on the Hainault Loop were commenced. This installation comprises a section of double line having five stations and the service is entirely run by automatically driven trains in passenger operation. It is intended that there should be one attendant on the train and the design of the equipment has been arranged accordingly. The attendant opens and closes the passenger doors at stations and after closing the doors presses the starting buttons. Two buttons are provided to guard against inadvertent operation. After that the whole operation of the driving of the train is carried out automatically—the train starts from the station, stops if signals are at danger, restarts when signals clear and stops at the next station.

The automatic driving equipment is arranged to take advantage of the characteristics of the train, and no upper limit is imposed on the speed of the driving equipment. When the train is running under clear signals the speed is determined only by the natural characteristics of tractive effort and train resistance. The train is, however, provided with equipment enabling the speed to be controlled at 22 mph for use when trains are being brought close together with minimum headway and when a lower speed than the maximum is required on certain parts of the line by reason of track layout or condition. In addition to this, the automatic driving equipment provides a considerable measure of flexibility so that even lower speeds can be insured if required, for example, when passing through crossovers and junctions.

Subsequent to the one act by the train attendant (the pushing of the start buttons), the automatic driving is effected by signals conveyed from the track to the train by induction. The whole of these signals are conveyed through the running rails and picked up by coils mounted on the front of the train. A dual system is employed: the automatic driving commands, which are intermittent and are arranged to control all the normal driving conditions of the train, and in addition to this, a safety signalling system which is in the form of continuous coded signals which are also picked up from the running rails.

The automatic driving commands are in the form of signals in the range of audio frequency between 1 and 20 kc. Currents at these frequencies are passed through sections of running rail about 10 ft long, called spots, and these are positioned at points on the track where it is required to give a driving command. These commands are divided into two groups; one group is used for the application of the brakes for stopping at a station. One particular frequency, 15 kc, is used to cause the motors to switch off and another frequency, 20 kc, is used to apply the brakes when there is a signal at danger ahead. The audio frequencies employed for the stopping at stations are so arranged that 100 cycles represents 1 mph. In this way a command which can be interpreted as 30 mph is 3 kc and 20 mph is 2 kc. The audio frequencies for the braking command spots are applied in bursts of 127 cycles, followed by a pause of a similar duration and then a repeat burst of 127 cycles and so on. This is done for two reasons, (1) the use of 127 cycles allows a numerical form of comparator to be employed on the train and, therefore, achieves a very high degree of accuracy, and (2) it insures that the train recognizes only genuine signals which must comprise 127 cycles, no more and no less. The 15 kc coasting spot and the 20 kc signal stop spot are not gated in this fashion as the frequencies are above the range in which interference is ordinarily encountered and the accuracy of counting is not required; these signals are recognized by tuned circuits. Fig. 1 shows the arrangement of the electrical circuits for a command spot for station braking. The audio frequency is generated by a transistor oscillator which is adjusted to the frequency required to indicate the braking speed. The output from the oscillator is counted by a binary counter which operates a gate feeding the power amplifier. The binary counter with the gate open counts 127 cycles and then closes the gate for the next 127 cycles. The output from the power amplifier which produces a minimum of 5 va is then fed direct to the rail through a step-down transformer.

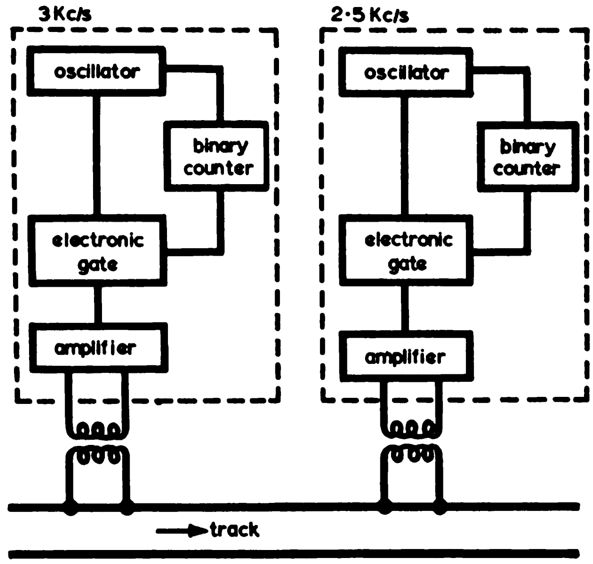


Fig. 1—Arrangement of electrical circuits for a command spot for station braking.

The train braking equipment is arranged, for automatic working, to give as required any one of three rates of retardation, maximum, normal and minimum. The speed at which the train can be expected to approach the station is calculated and the distance at which the brakes must be applied from the stopping point is also calculated for normal braking, and at this point a command spot is fitted on the track set for the calculated speed (on the basis already mentioned of 100 cycles being equal to 1 mph). The calculated speed-distance curve for the train from this point to the stopping point is plotted and the points at which successively lower speeds should be attained are ascertained from this calculation and successive command spots are fixed on the track, generally at speeds descending by 5 mph. The arrangement for this braking is shown in Fig. 2. As the train approaches the station it receives the first braking command and if the speed of the train is in accordance with the calculated value a normal brake application will be made. If the train at this point is running at a higher speed than the calculated value, then a maximum brake application will be made. Similarly, if the train is running at lower than the calculated speed a minimum brake application will be made. Provision is also made that if the speed of the train is more than 20% less than the command speed, a brake release is made if the brakes are on. The train having commenced to brake, soon reaches the next calculated spot where a fresh speed indication is given. A further check is made of the speed and if the speed is at the calculated value the brake application remains at normal. If, on the other hand, the train is going too fast the brake application is increased or decreased if it is going too slow. This process is repeated at each of the braking command spots until the train is brought to rest at the required position in the station. A circuit is incorporated in the train equipment which, when the speed has been reduced to 4 mph, causes the brakes to be partially released so that a gentle stop is made at the end of the braking run.

The command receiving equipment on the train is shown in the diagram Fig. 3. Signals from the rails are picked up by the coils on the front of the train and amplified by a transistor amplifier fed from the train battery. The train is equipped with a tachometer generator, the output frequency of which is on the basis of 100 cycles equals 1 mph; this frequency can, therefore, be compared directly with the command signals received from the track. The comparison of command speeds and actual speeds of the train is carried out digitally. After amplification the signal picked up by the train from the track is fed into one of two binary counters arranged to count 127 cycles. A second binary counter is switched in by the first signal received from the track, but is actually driven by the frequency from the tachometer generator and counts this frequency. The two counters, therefore, run at the same time, having started together; the track counter counts 127 and then causes both counters to stop. The number of cycles which have been counted by the tachometer generator counter then indicates whether the speed of the train is greater or less than the command which has been received, and a braking signal is given as an output from the point at which the train speed binary counter has stopped. If the command binary counter does not count exactly 127 then both counters are returned to zero and the signal disregarded as being a spurious one. It should be noted that this form of digital comparison gives a high degree of accuracy because even allowing for one cycle error in the pick-up of the tachometer signals this gives a maximum error of less than 1%. The output of the binary counters is arranged to actuate one of three relays and these in association with mercury tube retardation controllers insure that the required rate of braking is achieved and thereafter maintained by energizing or de-energizing as appropriate the various electro-pneumatic valves controlling the feed of air to the brake cylinders. The automatic driving command system, although arranged to operate with a high degree of reliability, because of its intermittent nature cannot be regarded as a fully fail safe system. Therefore, a second signalling system, providing the fail safe feature, is employed to insure the correct working of the train.

The safety signalling system is a continuous one based on coded track circuits. The coded track circuit current is fed through one rail of each track circuit, flows through the axles of the train and returns by the other rail of the track circuit. A coded signal must always be picked up by the second set of coils mounted on the front of the train to permit the train to proceed and should the coded signal not be received or be of a different value than that required by the train speed at the time, an emergency brake application is made and the train brought to rest. This emergency brake application stops the train and the circuit requires to be reset by special reset buttons by the train attendant before the train can restart.

The coded track circuits are operated at a special frequency of 125 cycles. This is a frequency which is different from any mains frequency or any harmonic of mains frequencies and, therefore, is likely to be free from any interference. The codes employed are given in the following table:

120 pulses/min for operation of fixed signalling equipment only.

180 pulses/min permits the train to run at a speed not exceeding 25 mph without application of motors.

270 pulses/min permits the train to operate at a speed not exceeding 25 mph and arranges for the motors to be switched on if they have been switched off previously by a coasting or braking command.

420 pulses/min permits unrestricted running within the capability of the traction equipment.

The 270 code brings into operation a control of the train equipment regulating the speed at a nominal 22 mph.

Fig. 4 shows diagrammatically the arrangement of a coded track circuit and also the pick-up coils of the safety signalling circuits on the train for making an emergency brake application. The 125 cps current from the mains supply is fed through a transformer to step it down to a suitable voltage for the transistor gate and then through a second transformer which steps it up to a sufficiently high voltage to feed the current through a series capacitor to the track rails. The current through the track circuit rails is arranged to be not less than 4 amp so as to give an adequate pick-up to the train. At the relay end of the track circuit is a track receiver for detecting that code is being superimposed on the track circuit current and the output from this track receiver operates a DC track relay. The train shunt value of this form of track circuit is not less than 1 ohm. The electronic gate used for superimposing the codes on the track circuit current comprises transistors bridged across a bridge rectifier, the rectifier enabling the transistors to operate on the DC side although effectively switching the AC. Pulses of DC are generated by code generators and these are switched on to the electronic gate by relays having their coils in circuits detecting the clearing of track circuits ahead so that the appropriate frequency of code is applied to the track circuit according to the state of the track ahead. When there is a train on the track immediately ahead of the track circuit under consideration, code at the rate of 120 codes per minute is applied to the track circuit. This code is not received by the train equipment at all, but is used only for actuating the track relay and hence for detecting the presence of a train on the track circuit. As the

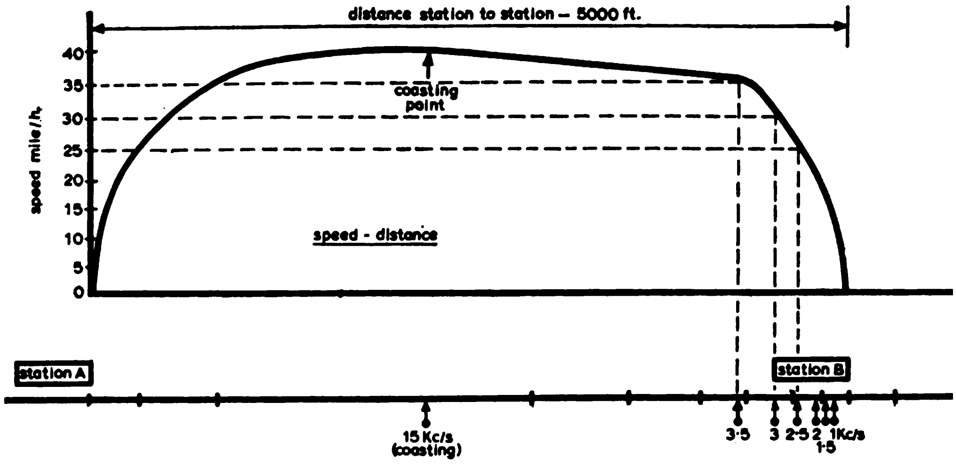


Fig. 2—Braking sequence as a train approaches a station.

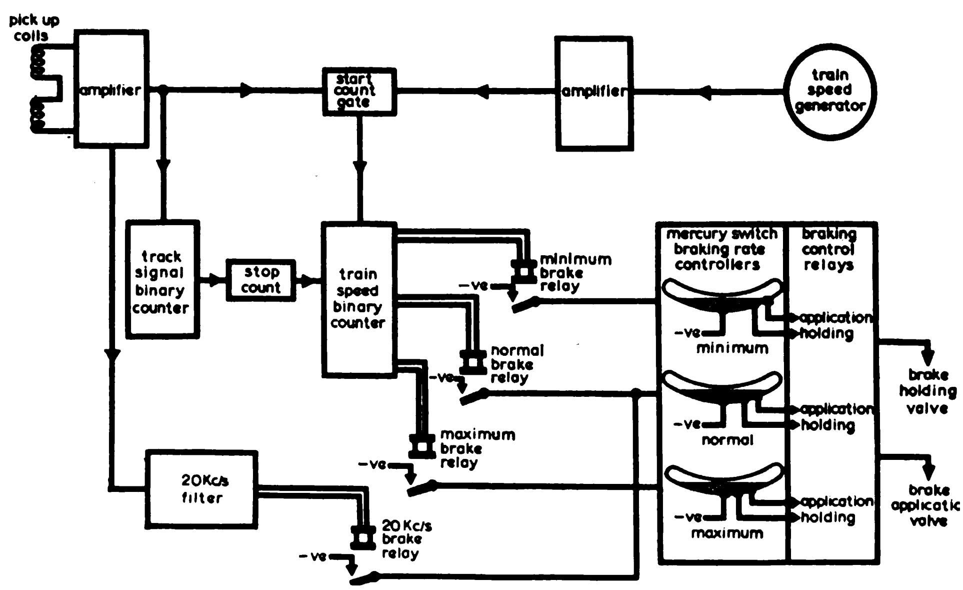


Fig. 3—Schematic diagram of command receiving equipment.

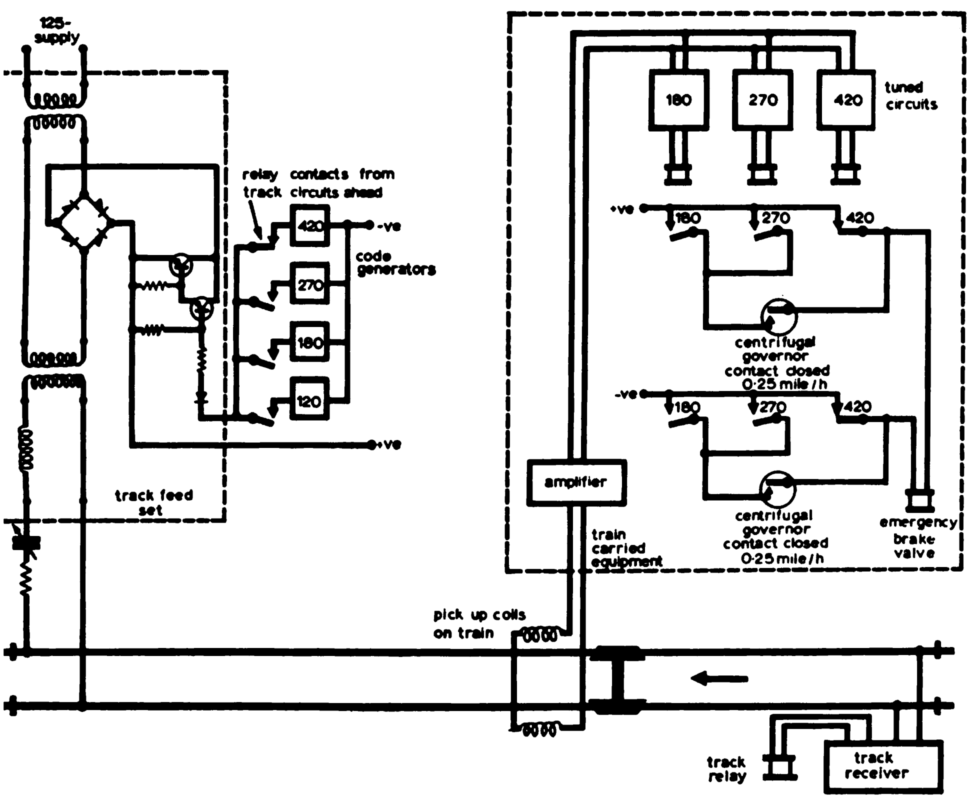


Fig. 4—Plan of coded track circuit and pick-up coils of safety signaling circuit.

track circuits applying to the track ahead become clear the codes are successively raised to 180 per minute, 270 per minute or 420 per minute, switched by the track relay contacts shown. The coded impulses are received by induction in the pick-up coils on the train and the 125 cycle basic frequency is recognized by a tuned circuit. The signals so received are amplified by a transistor amplifier, the output of this amplifier being fed into three tuned circuits each tuned to respond only to one of the code frequencies. The output of these tuned circuits is then used to actuate DC relays, the contacts of which maintain a continuous circuit to hold the emergency brake valve in the energized position. Failure of the supply of current from any of these code relay circuits to the emergency brake valve will result in this valve being released and a brake application made.

The code generators for producing the codes to be applied to the track circuits are arranged to have a high degree of accuracy and to be fail safe in the condition that no fault of the equipment shall cause it to give a higher frequency code than that for which it is designed. To insure that this condition is retained, the code generators for all the code frequencies, except 420 code, employ a tuned pendulum to generate the code frequency. The balance weight on the pendulum is formed of permanent magnets which react with two fixed coils; one coil is used to maintain the oscillation of the pendulum and the second coil to actuate the output circuits. The whole of the circuitry for maintaining the oscillation of the pendulum and for producing the output code is electronic, employing transistors, and no physical contacts are provided with the pendulum which swings entirely freely. This form of construction of the code generator is a complete assurance against the generator accidentally giving a higher code than that for which it is designed. For example, if the spring supporting the pendulum became cracked or weakened this would have the effect of slowing down the pendulum and giving a slower code. Also, because the weight is in the form of the permanent magnets which cause the pendulum to operate, if the weight were to become detached, the operation would then stop. Where track circuits are spread out individually along the line, separate code generators are provided for operating each track circuit, but where a number of track circuits are grouped together, especially in interlocking areas, then a signal code generator for each frequency is arranged to supply a power amplifier which in turn feeds code bus bars which are used to provide code for a number of track circuits. This is an advantage especially in interlocking areas as all track circuits then operate in synchronism and tests at insulated joints are made more easy and there is less disturbance of the received signal on the train when passing over the insulated joints. Special care has to be taken at insulated joints to maintain a continuous signal right up to the joint for the train receiver. It is the normal practice to connect cables a few feet back from the end of the rail and to maintain the continuous induction these cables are laid close to the rail parallel with it to the actual point of the insulation so that there is no break in the magnetic field at this point.

The automatic control of motoring presented no great problem. All modern London Transport stock has automatic acceleration control, the dropping out of a current relay permitting successive notching round of a pneumatically operated camshaft which cuts out the motor series starting resistances. Transition from series to parallel connection of the motors and a first stage of field weakening are controlled by the same relay, and a second stage of field weakening by another relay with a lower current setting. Two settings of the accelerating or notching relay can be selected and thus two rates of acceleration can be obtained.

TUBE STOCK TRAINS

The 1960 tube stock trains which are being used in the automatic train operation trials have 4 motors per motor car, the two in each truck being permanently connected in series. With this arrangement it has been thought desirable to limit the acceleration to a value corresponding to 15% adhesion (with 600 volt motors 20% is the nominal figure) which gives a rate of roughly 1.5 mph/sec. Wheelspin relays are provided which open the main line-breakers and thus return the camshaft to the starting position if a differential between the back e.m.f.'s of two series motors is detected. These two features have assisted the application of automatic train operation to this particular stock in that it has been possible to use the higher acceleration rate of the notching relay without causing any appreciable wheelspin trouble in wet weather.

For safety twin pushbuttons are used to start the trains from a station, energizing independent circuits which feed the two train wires needed to initiate motoring. Two other wires selecting parallel connection of motors and weak field are also energized under 420 code conditions. At a signal stop only one of the holding circuits is cancelled so that the application of 270 code can restart the train without action by the train operator, see Fig. 5.

The starting buttons circuits are arranged so that the train can only be started from a station when 420 code is being received, the train is stationary and the passenger doors and cab sidelights are closed.

NORMAL SERVICE BRAKE

The normal service brake on London Transport stock is electro-pneumatic, controlled by application and holding valves on each car. Blowdown valves are also provided which release air if the maximum rate of braking permitted by adhesion is reached. This rate is detected by a mercury switch, and it was a simple matter to provide further mercury switches to control the three rates of braking selected by the binary counters. Each rate is obtained by cutting off the feed to the application train wire at a retardation slightly below the nominal value, and cutting off the feed to the holding train wire if some rate slightly above the nominal value is reached. The three rates as applied to the Hainault-Woodford trains are approximately 1.5, 2.1 and 2.6 mph/sec.

When the speed falls to 4 mph control of brake cylinder pressure is transferred from the mercury switches to pressure switches, partially easing the brake to avoid a jerk on stopping, and providing sufficient pressure to hold the train against any gradient which may exist.

The tachometer generator used to provide the frequency which is compared with the braking command spot frequencies is mounted on the end of a traction motor. It employs two toothed wheels, one having 144 and the other 150 teeth each with a pick-up head, either of which can be selected to permit some degree of compensation for wheel wear.

This generator is also used to feed an electronic governor which controls the train speed at 22 mph on 270 code by motoring below this value and applying the electro-pneumatic brake if a higher speed is reached on downhill sections.

The EP [electro-pneumatic] brake is not arranged to be fail safe and the various safety devices on the train (e.g. Deadman's handle, passenger emergency valves, etc.) operate on a proprietary pneumatic brake. The automatic train operation safety system, therefore, uses the pneumatic brake and applies the emergency brake when required by releasing air from the brake pipe, which is continuous down the train. This causes triple valves on each car to operate, admitting air from auxiliary reservoirs to the brake cylinders.

A trip valve provides the link between the automatic train operation safety circuits and the pneumatic brake, and is held closed by feeds from the code relays. It has four somewhat conflicting design requirements:

With no supply to the coil, and over the normal range of brake pipe pressures, the force tending to open the valve must be great enough to eliminate any possibility of the valve 'sticking-in'.

The 'way through' the valve should be equivalent to a 1" diameter pipe.

The valve current should be such as can be handled by safety relay and mechanical governor contacts.

A delay in the drop-out of the valve of the order of 1 sec after opening of the relay or governor contacts should be achievable. This is to cover the delay which occurs during the change from one code to another.

The valve, which has been specially produced, is a slightly enlarged version of a current design of EP brake magnet valve. Brake pipe air is connected to the central chamber in the valve body and is

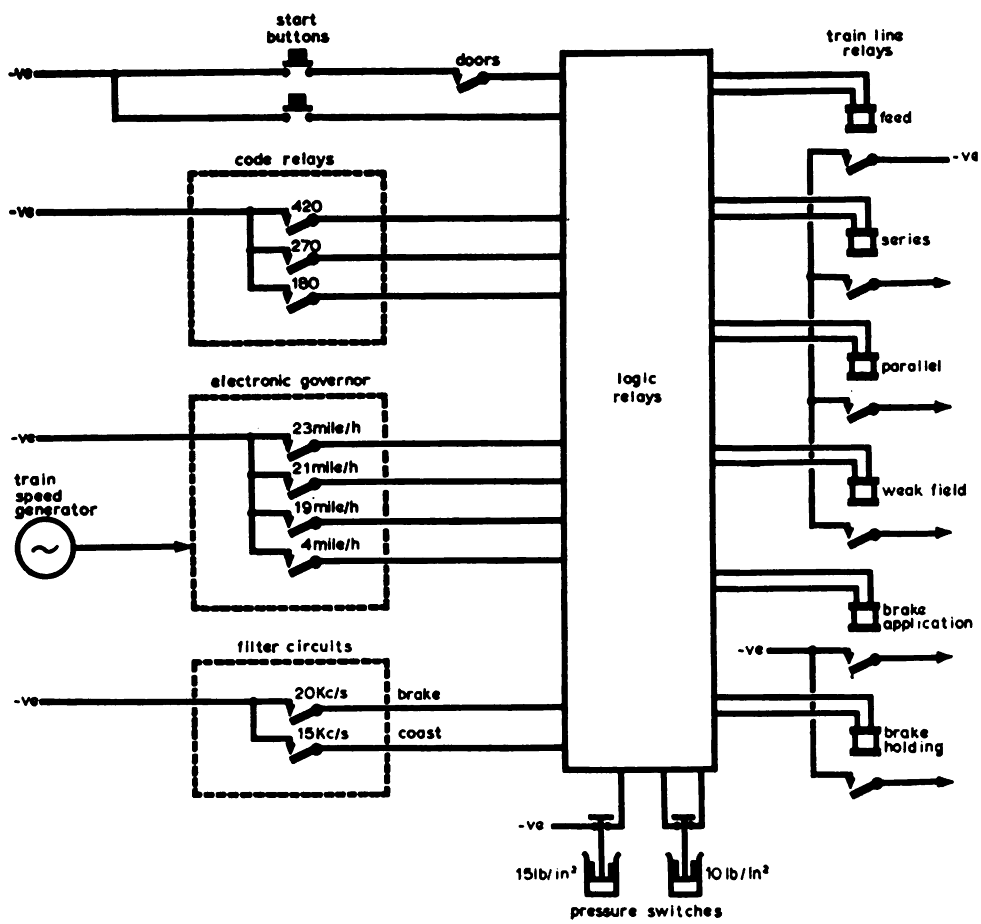


Fig. 5—Diagram to show how train is started and its speed controlled.

retained as long as the lower valve is lifted against its seat. When de-energized the valve drops and air escapes to atmosphere via the chamber between the lower valve and diaphragm. The upper valve merely acts as a stop in this version. Both valves are of synthetic rubber.

The valve stem assembly is held central by guides which can deflect to permit the vertical movement. Adjacent to these are the diaphragms which partially balance the valve. The degree of balance varies depending on the position of the stem assembly. In the 'closed' position, with 65 lb/in^2 pressure in the brake pipe the unbalanced force would be 250 lb but the net force allowing for the diaphragm effect is 25 lb in the energized position and 5 lb in the de-energized position.

The encapsulated coil is mounted above the valve body, the moving core being integral with the valve stem. This latter is located by the flexible guides but a PTFE ring is let into the base of the coil to prevent any possibility of the core rubbing at this point.

Below the valves is an arm which operates the micro switches which are used for interlock contacts.

When running at the controlled speed on 270 code the electronic governor holds the train speed within ±2 mph of the average of 22 mph, but neither the governor nor the EP brake which it controls are fail safe. A mechanical governor of proved reliability is, therefore, brought into action on 270 and 180 code to open circuits to the trip valve if a speed of 25 mph is exceeded. This is a version of a governor which has been used with cab signalling installations on a number of railway systems for many years, but whereas it is normally axlebox mounted, clearances on London Transport tube stock preclude this arrangement. It has, therefore, been adapted for gear drive from the center portion of an axle, using a mounting similar in principle to that used for traction motors. All four axles on each motor car already carry traction motors and it has, therefore, been necessary to mount the governor on the adjacent trailer car. The governor is provided with easily set adjustment to allow for wheel wear and to retain the calibration within ±2%.

Fig. 6 shows a speed-distance diagram for a train running between two stations, the second train following closely behind the train in front, and at the bottom of the diagram are shown the safety codes applied to the track circuits under the various conditions of positions of the two trains. Train No. 2 on the diagram, having been started from station 'A' by the train attendant pressing the starting buttons, accelerates to full speed and continues to motor until it reaches the coasting point at which the motors are switched off. It then coasts until, by reason of track occupation ahead (train No. 1), it reaches a 20 kc command spot; this causes a normal brake application. The speed of train No. 2 is then reduced by the brake application and if train No. 1 does not move out of the station train No. 2 would be brought to a complete stop to wait for the track to clear. It can be assumed, however, that the train ahead is already moving out of the station and the first track circuit clears, putting 270 code on to the track for the second train. This occurs just after the speed of train No. 2 has fallen below 22 mph and the brakes are released and the train then proceeds to follow into the station at the governed speed of 22 mph, the safety signalling maintaining a braking overlap of sufficient distance to bring the train to rest from a speed of 25 mph. Train No. 2 running into the station at its governed speed of 22 mph passes over the first braking command spot, but as the speed is so much lower than the command speed no response is called for and the train equipment ignores this command spot. Similarly, for the successive command spots until the train reaches the command spot at 2.5 kc or 25 mph. This spot initiates a normal brake application and the train then commences its braking to stop in the station, the speed is checked at successive braking command spots and, the brakes being adjusted according to the comparison of the train speed and the command spots, the train is brought to rest at the same point as it would have done had it come in at the full speed run.

It is virtually impossible to provide code on depot tracks, and arrangements had also to be made to permit clearance of a train following failure of track or train equipment. A further set of mechanical governor contacts have, therefore,

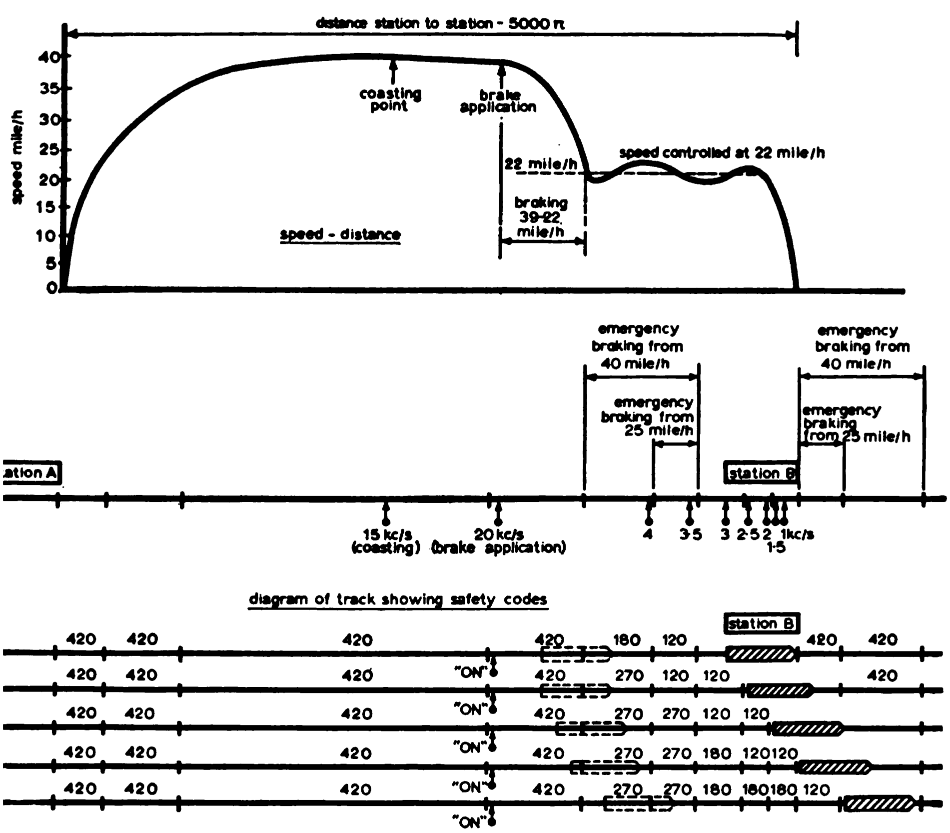


Fig. 6—Speed-distance plan of two trains with safety codes applied to track circuits.

been provided which open at about 10 mph. When working into depot or past a signal at danger the train operator must lift a 'flag' switch (termed the 'slow manual switch') which is visible at the front of the train. This, in manual driving only, provides an alternative feed to the trip valve through the 10 mph governor contacts. A warning is provided to the train operator about 1.5 mph below the tripping speed to assist him in observing the restriction.

The northern section of the Hainault Loop between Hainault and Woodford has been operated as a separate self-contained 'shuttle' service ever since the line was elecrified in 1949.

Prior to the introduction of automatic working the service on this line was operated by 4 trains during the peak and 2 trains during the off-peak periods.

TRAINS HAD 4 CARS

The trains were composed of 4 cars. The line provides examples of most features commonly to be found in a railway layout and was thought, therefore, to be particularly well suited for the trial of the third stage of London Transport's automatic train operation developments.

Fig. 7 shows a plan of the line which comprises double track branching off from the main line just north of Woodford station. At Woodford station trains are reversed by proceeding to a siding and returning to the opposite platform. At Hainault trains reverse in the single platform. There are three intermediate stations. The service on the line is provided by four automatic trains of tube stock type. Before being converted for the operation of automatic trains the line was signalled with London Transport's standard signalling of 2-aspect color light signals, track circuits and power operated switches. This wayside signalling has been retained as the line is also used for the passage of a number of manually driven trains which require to proceed to and from the car depot at Hainault. The arrangement of the automatic train working has been provided to conform to the fixed signals. The section of line has been provided with coded track circuits throughout and with the necessary command spots

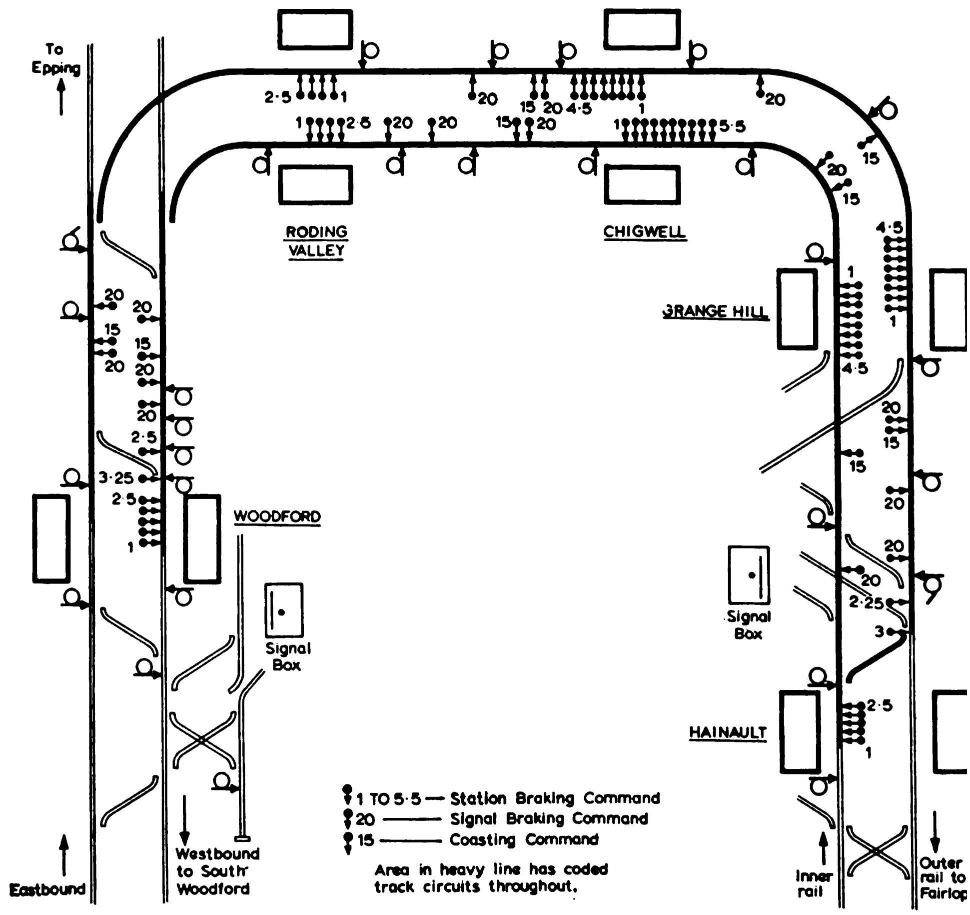


Fig. 7—Plan of Woodford-Hainault line on which experiments were conducted.

to govern the automatic working of the trains. There were existing signal towers at Woodford and Hainault and alterations have been made to the circuits of the signalling at these towers to provide for the application of codes to the track circuits through the interlocking areas. The speed of the train passing over the junction just north of Woodford is required to be regulated to 22 mph and the speed through the crossover approaching Hainault station is regulated to the value of 15 mph. In addition to these permanent speed restrictions there are two temporary speed restrictions on the line on account of work in progress on the banks. These restrictions require the speed of 22 mph to be employed, and the arrangements of the automatic command equipment have been made to provide for the train speed to be regulated to comply with these speed restrictions.

At the Hainault end of the section the train automatically runs through the crossover into the platform and stops automatically. The train operator then reverses the train equipment for the train to proceed in the opposite direction and when the starting signal clears he operates the starting buttons and the train commences the return run.

At the Woodford end of the line when the train has automatically stopped in the station the operator then changes over from automatic driving to manual driving of the train and drives it into the siding; this is at the governed speed below 25 mph, 180 code being received. In the siding the operator reverses the train equipment and when the outgoing signal is cleared he manually drives the train through the crossovers into the platform and at this point changes over again to automatic working. The automatic running of the train is then resumed for the passage through the line back to Hainault.

In the event of a speed being required of a different value from that provided by the governed 22 mph speed, for example for a speed restriction over a shortsection of line, it is possible by suitably positioning command spots to achieve practically any speed desired. For example, the crossover approaching

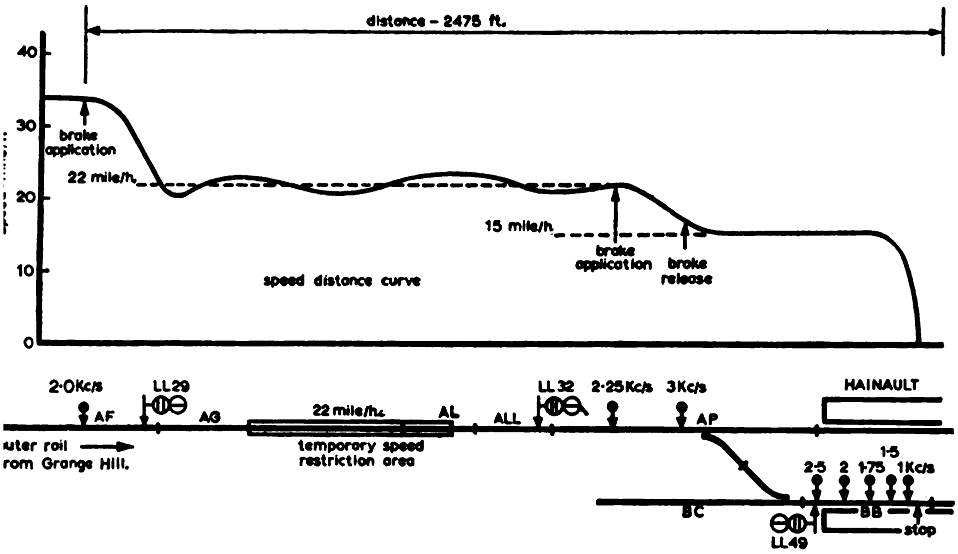


Fig. 8—Track approaching Hainault with speed restricted area and command spots.

Hainault station is constructed for a calculated speed of 15 mph, and running at an average of this speed is achieved by means of two command spots. The arrangement is shown in Fig. 8. It so happens that before reaching the crossover in question there is a length of track over which a temporary speed restriction of not more than 25 mph occurs and the speed of the train over this section is regulated by means of the automatic speed control on the train to 22 mph. Then when the train approaches the crossover a command spot of a frequency of 2.25 kc is provided as the speed of the train approximates to this speed. This will cause a normal brake application and the switching off of the motors if they were on at the time. Calculations have shown the distance that the train takes to reduce to between 16 and 17 mph and at this point another braking command spot of a frequency of 3 kc is fixed. The application of the brakes will have reduced the speed of the train at this point and so when reading the 3 kc command the comparator on the train will determine that a brake release is required and the brakes will be released. This enables the train to continue coasting at approximately 15 mph through the crossover and into the station where it is stopped by the station command spots in the usual manner. Because of the low approach speed an intermediate value of station command spot 1.75 kc has been provided to insure suitable application of brakes.

From the opening of the service of automatic trains on the Hainault Loop advantage has been taken to continue tests with the working of the trains. One test taken demonstrates the working of the automatic train under various conditions of speed. The section between Grange Hill and Chigwell is 0.835 mile and is on a slightly down gradient, therefore providing a suitable section for demonstrating any different speeds of approach to Chigwell station. Tests have been carried out with the train accelerating the whole distance until the first braking at Chigwell has been applied, and also under the normal conditions with the motors cut off at the coasting point and, therefore, a reduced speed of approach, and finally with a slow speed approach resulting from the train having been checked at the signal approaching Chigwell station. The results in the form of the speed-distance curves are shown in the diagram Fig. 9. It will be noted that the stopping distances from the calculated zero are 1 ft, 8 ft and 8 ft.

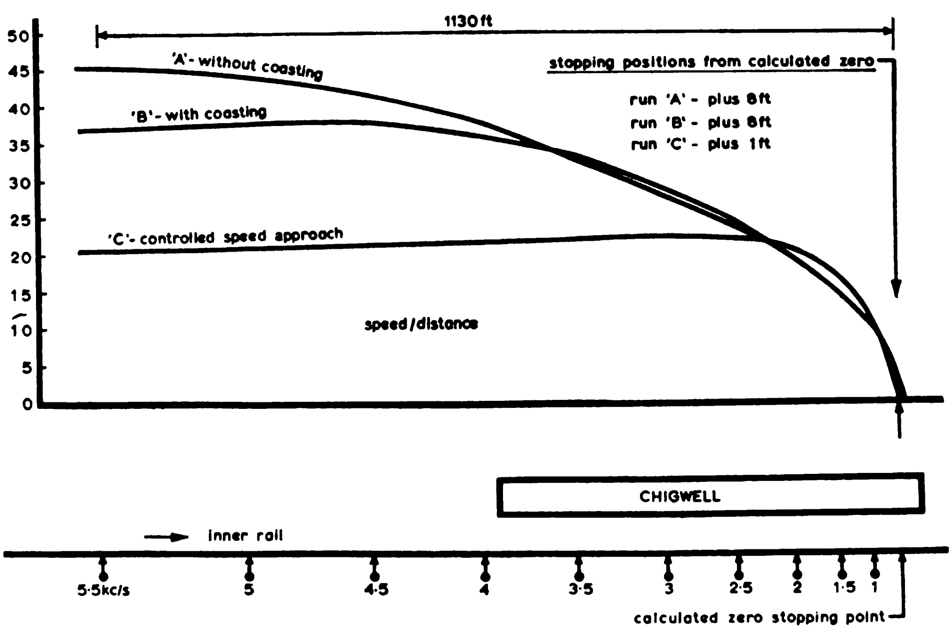


Fig. 9—Speed-distance curves resulting from experiments with braking.

It should be particularly noted that in designing the automatic train equipment for London Transport much more emphasis has been placed on utilizing a high average rate of braking from the commencement of braking right up to the stopping point than emphasizing a very high degree of accuracy in the actual stopping, as it is felt that this high accuracy could only be achieved by reducing the speed of a train sooner than is otherwise required, thus enabling an accurate calculation for the final braking to be made at the expense of the average speed of the run into the station. This could have an adverse effect on the service on a close headway line.

Introduced into passenger working on 5th April 1964, the automatic trains have, up to 13th June, covered some 94,052 car-miles in service and the results achieved give prospect of it being possible to achieve a good standard of reliability with such equipment in passenger train service. **RS&C**