BARCELONA

LENINGRAD

MOSCOW

NAGOYA

NEW YORK

PARIS

STOCKHOLM

TOKYO

Eight cities test automatic train operation

Brief descripions of these ATO tests and related problems are reported by B. Hillbom, chief planning engineer, and L. Almquist, research engineer, A. B. Stockholms, Sparvagar, to the International Union of Public Transport. An abstract of the report follows:

When drawing up the questionnaire, the following basic principles were indicated for the realization of an automatic train operation.

(1) The whole equipment is mounted on board the train. Practically no impulses are transmitted from track to train (transmitted signal information is left out).

This basic principle mainly refers to the method where the train is equipped with a computer unit. A great number of data on track, profile, curves, station distances is programmed and stored in a memory unit. After more or less complicated calculations, directions for running of the train are given to the train equipment from the computer. The calculations depend on a number of variables such as deviations from the timetable, duration of stops at stations, and length of distance covered.

(2) Besides the car equipment, some kinds of apparatus are placed along the track, more or less regularly, in order to give impulses to the train.

This basic principle is based on certain equipment on the train, acting together with one or more impulse-giving devices along the line, between each station. From these devices, various information can be transmitted to the train. The car equipment, not being fed with any track information, is mainly based on an accurate information of the braking performance.

(3) As a further development of system (2), information can be transmitted to all trains from one or a few stationary equipments via radio.

If we regard the impulse-feeding in (2) as decentralized, we could regard the impulse-giving in system (3) as centralized. This system includes one or a few stationary equipments, which transmit directions to the trains via a radio system and possibly also receive information from the trains.

The system intended for lines with rubber wheel operation in Paris is based on continuous information (speed) and one could say that this system fits somewhere between system (2) and (3). Barcelona has stated that they consider that their system falls within neither of the groups. Some of the conditions according to system group (2) are, however, fulfilled by this undertaking, viz., impulse-devices in the track, and certain equipment on board the train. On the other hand, there is no programmed deceleration curve against which to check the speed.

The question if the equipment should be fixed, installed on the train, or to some extent made portable, is also of primary importance. It seems as if this question has been raised too early, as only a few answers were received. Stockholm has stated that part of the equipment must be permanently installed, the more expensive equipment, however, with logical circuits will be made portable. The reasons are in the first place that the total number of equipments could be kept down thus admitting a limitation of the costs for an automatic train system.

BARCELONA

Tests have been running since 1960 on the Valapiscina-Sagrera line and the Barcelona engineers are very satisfied with the results.

Along the line, between the rails, small shields of iron plate are located. Below the front-end of the car, mounted in the framework of the truck, two photocells are installed in special housings. On the center line of the car a two-lens-lamp is placed and directed against the two photocells. When the train passes the shields in the track, the rays of lights between the lamp lenses and the photocells are interrupted on either the left or the right side, or on both sides of the lamp. On these three elements of information the automatic operation is based. In the earlier tests, sliding mechanical contacts were used instead of the above-mentioned electronic devices. The reason for the change was that the contacts were liable to break. When the train passes over a shield to the right (a in Figure 1) in the train direction, the ray of light between the right lamp and photocell is interrupted. Some relays are energized disrupting the current supply and thereby bringing the train to coasting.

If necessary, the train speed along the line can be reduced. When the left ray of light is interrupted by means of the shield marked (b), the relays establishing the brake circuit are activated and operate the controller. The cutting out of resistors is later interrupted by a new shield (c), operating the right photocell. The brake circuits are still closed and the controller stops in its new position.

To start the braking when approaching a station, the left ray of light is interrupted by the shield marked (d), and the brake resistance is automatically cut out successively by a current relay operating a servo motor.

At a proper distance from a stop signal, two shields are mounted in the track along with two lamps for the illumination of the shields. When the wayside signal is red, the two rays are interrupted at the same time, the traction current is cut off and the brakes are applied. When the signal is green, the wayside lamps are lighted and the reflection from the shields is enough to keep the photocells activated, though the ordinary rays of lights are interrupted. It is thus possible for the train to proceed on green in spite of the shields. If the signal is red, however, the shields in the track are not illuminated by the lamps and the train is stopped. After such a stop, the motorman has to take over the driving by hand, as a fuse is blown out. The stopping points at the stations vary between 16.4 ft and 19.7 ft depending on whether the train is empty or loaded.

The basic assumption for the Barcelona system is that the trains always are running the same way between the stations. Acceleration, deceleration, top speeds and so on, are the same.

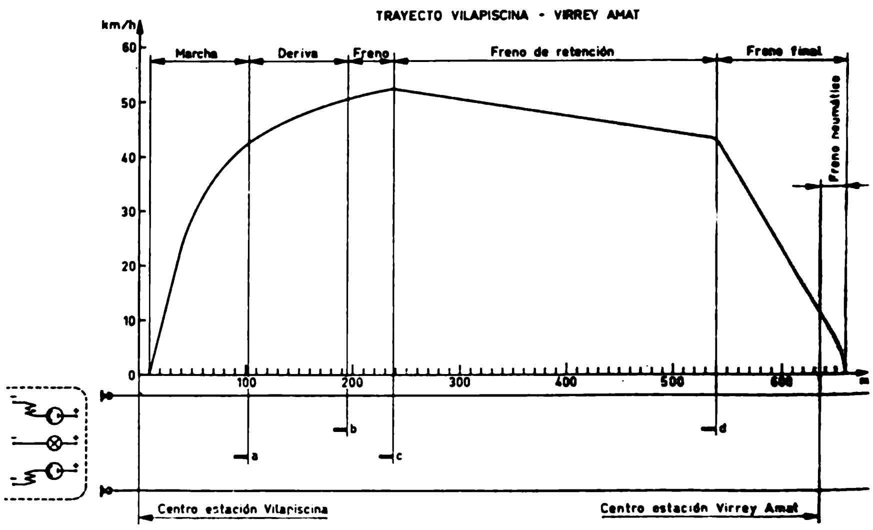

Figure 1: Running curve—centro estacion: station center; marcha: running, current applied; deriva: coasting; freno: braking; freno de retencion: braking with constant resistance; freno final: final braking; freno neumatico: air braking.

LENINGRAD

On the Leningrad Metro, trials are made with ATO and also with equipment for an automatic reversing of trains at terminals.

The automatic operation comprises automatic acceleration, running between the stations and automatic deceleration. Furthermore, braking in steep inclines by speed control is included.

The equipment for the automatic operation is located in the leading cars of the train, possibly brought together in one car. Besides the car equipment, there are devices placed along the track. The transmission between the track equipment and the car equipment is made by induction.

The tests carried out have given a variation of the stopping point of ±3 ft for ordinary stations. At new stations, where the platforms are provided with walls and doors along the whole platform side, the stopping point has varied with only ±6". The doors in the platform walls are operated at the same time as the sliding doors of the trains. As the platform doors are but slightly wider than the train doors, this high accuracy is required for the stopping of the train.

This device is to cut down the costs for station constructions and to prevent passengers from falling on the track.

MOSCOW

In 1962, two trains for automatic operation were put into regular passenger service on the Moscow Metro Circle line. At the end of one year, these trains had transported 4 million passengers and run 50,000 miles. During 1963, 15 trains were equipped for automatic operation on the same line.

The equipment for automatic operation consists of a computer unit on each train. A programming device or memory is provided for storage of certain code information regarding the track profile, times, train routing, stations, speed limitations and other quantities, such as weight of the train and braking distances needed for the regular driving of a train according to the timetable. By means of this information, the computer solves a series of differential equations, after which it makes an optimal calculation of the traffic conditions and decides the speeds as well as the braking and stopping moments.

The automation equipment runs the train with greater accuracy than a human driver is capable of doing. On the basis of earlier test runs it is stated that deviations on the 12.5 mile line have been less than 5 sec.

When all the trains are equipped for automatic train operation, a considerable increase of the line capacity is expected. According to newspaper statements, the headways of the line would be decreased from the present 110 sec to 70 sec.

It is interesting to note that the Moscow Metro intends to change from a signal system with wayside signals to a system with cab signals. The number of signal aspects is not known to the authors.

NAGOYA

The first tests with ATO started in October 1960 and since that time there have been four test periods of different lengths. The tests were very successful and the undertaking is now waiting for final permission to start operation with a train in regular passenger service. The underground network today is not so extensive (about 7.5 miles), but in some years the metropolitan railway system will have a length of about 93 miles of single track.

Their signal system includes five wayside signal aspects: red, 0 mph; yellow-yellow, 15 mph; yellow, 25 mph; yellow-green, 35 mph; and green, 40 mph. These are maximum speeds. The signal system also includes automatic train stops of the electromagnetic type.

Along the line, between the stations, train running is checked at several points. At such points a number of resonant components are placed on the track. Two of them form closed circuits, the rest are open. The combination of active, resonant components is determined by the wayside signals. The train measures the distance between two resonant circuits as well as the time for passing them. By means of this information the train speed is checked. Approaching a station, the train picks up, from three or four of the resonant circuits, an impulse for brake application. The braking performance is directed and checked from a programmed standard braking curve. The braking effort is controlled by a comparison between the train speed and the programmed speed curve.

If the doors are closed, the motorman has only to operate a pushbutton to start the train (the train cannot start if the doors are open). The opening and closing of the doors is manual and not automated. Therefore, it is not combined with the automatic operation of the train.

The speed checking being very important, two speed-generators have been installed on the train. A device always compares the output of the two generators. When divergencies occur, the train is automatically braked.

Judging from the experience of test runs, the variations of stopping points at stations are approximately 20". As the automatic train operating equipment is subordinated to the signal system, any fault occuring in the automatic system normally calls for the most restrictive signal. Faults occuring on the train result in the immediate application of the brakes.

Whether the connections between the track components and the wayside signal system, and between the components themselves are in all respects reliable is not clear from the answer.

NEW YORK

New York City Transit Authority's automatic train operation has had more than 4,000 successful test runs. In January 1962, the automatic train was put into experimental passenger service. The train operates on the shuttle line between Grand Central Terminal and Times Square, about 2,600 ft (Figure 2). The train makes on an average 3 round trips an hour. There is only one train going with this automatic equipment back and forth on the same track. The two end-cars in the 3-car-train are equipped with necessary devices supplied by two different signal companies. The equipment is designed to be completely compatible.

Control of the train is accomplished by feeding 100 cps AC to the rails. The AC is interrupted 0, 75, 180 or 270 times per minute. Absence of code or zero code also causes activation of controls. The car receivers pick up the coded current, which is decoded, amplified, rectified, filtered and finally fed to the proper relays in the car.

At 270 code, the current releases the brakes, applies power to the train and gives an acceleration of 3.6 ft per sec per sec. The maximum speed is 30 mph.

At 180 code, approach code, the motive power is removed and the full service brake is applied. The brakes are released at a speed of about 16 mph. The train speed will decrease and the real and constant speed of the train will be about 5 mph.

Zero code or lack of code or AC current means a full service brake application and brings the train to a final stop.

A 75 code opens the doors, establishes the direction of traffic, changes the destination signs on the train and also the lights in the car ends.

The regulation of speed is dependent on the different codes fed to the rails. As a matter of fact, there are only two speed limits excluding stop. The speed (at 270 code) is restricted between 29 mph and 31 mph. There is an automatic speed checking device on the train.

The 75 code (for the door-opening, etc.) is fed into a special loop, about 8 ft long, and placed between rails at the stations. So called trackside proximity detectors check that the train is at the right stopping point, before the 75 code is applied. The limit for stopping is ±20″. The 75 code opens the doors, etc., and makes the train ready for the trip back.

Along the track, other proximity detectors are located at various points. A detector is normally in balance, but when a train (steel body car) passes, the magnetic flux is changed, and the signal can be used for time-comparison with a detector passed earlier. If the time is too short, a trip arm strikes an emergency trip cock on the train, and the train is brought to a standstill.

Every time the train starts a new trip, the automatic devices are checked, including the battery voltage and air pressure.

The train stays at the terminals during a predetermined time, after which it is dispatched by means of an automatic dispatching unit incorporating a synchronized time clock and a continuous loop of punched film, programmed for a 24-hr period.

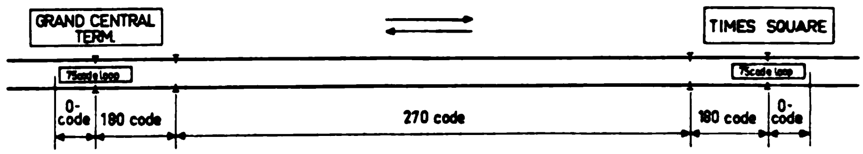

Figure 2: Shuttle line in New York which carries ATO subway test train.

PARIS

In Paris tests are going on with automatic train operation. Preliminary tests have been carried out on a 2,300-ft test section. As the tests have been favorable, they will be extended to Chatelet-Mairie des Lilas, the line on which rubber wheeled cars are operated. Primarily three track sections and a few trains will be equipped for automatic operation.

A continuous inductor wire is installed along the track, between the rails, in a zigzag figuration for a "grecque" or meander pattern. The wire is symmetric to the track axis, with an amplitude of about 7″ and is fed with an AC of 150 cps. On the leading car, two receiving coils are mounted at about 7″ on either side of the axis (see Figure 3). The duration of the current induced, when the receiving coils pass the grecque is inverted to the train speed. The induced current is transmitted to an operating equipment, a so-called autopilot. The task of this autopilot is to regulate the train speed according to the relation between the duration of the excitations picked up alternately by the two receiving coils on one side, and a fixed basic time on the other side.

The steps of the grecque formation can be varied in such a way as to regulate the speed at different points along the line.

Depending on the relation between the duration of the induced current and the fixed time, the train equipment calls for progression, when the train speed is lower than permitted. On the contrary, if the train exceeds the speed permitted, the autopilot calls for more or less braking.

The system also includes a maximum speed limit which cannot be exceeded under any conditions.

At stations, the steps of the grecque formation are continuously decreasing and form a retardation loop which reduces the train speed until just beneath 3.1 mph. Then the grecque formation ceases and is replaced by a U-shaped cable loop, a stopping loop, over which the train stops. The loop can be fed or not fed depending on the aspects of the departure signal.

If the departure signal is on stop, the stopping loop is not fed with AC, and the two receivers are disengaged at the same time, and the train is stopped. This braking is not possible to cancel in the automatic control position. If the departure signal changes to green, the loop is fed and the receivers are engaged. Even in this situation, the train is brought to a stop.

When the AC is fed to the stopping loop, the motorman can, by means of a pushbutton, close the doors and activate the autopilot. With the departure signal at red, no current passes the loop and the above-mentioned operations cannot be performed.

In front of a wayside signal, there is also, besides the ordinary grecque figuration, a special retardation loop, as at the stations. With the signal at red, the current in the ordinary wire disappears and the special loop is fed. The train decelerates down to 3 mph and at that speed the special loop is interrupted and the current in the receiving coils disappears. The train stops, and this operation is impossible to cancel in the automatic control position.

A rupture of the wire or interruption of the current in the ordinary loop on the line will cause a brake application, which is not possible to cancel in the automatic operation position.

The feeding of AC to the retardation loop at signals, as well as the disrupting of the current in the ordinary grecque figuration is an extremely important function. The requirements on the time constant device against which the speed is compared must likewise be very high from the safety point of view. Any faults incurred must always give the most restrictive order.

The train speed is decided by the time constant for which the autopilot is set. If this time constant is made adjustable, a possibility is open to regulate the travel times for different trains involved in any kind of disturbances.

At disturbances it is always possible to change over from automatic to manual operation. A change in the opposite direction can only be made at a station.

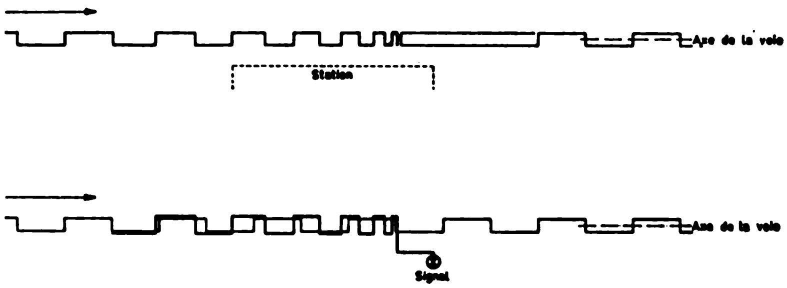

Figure 3: Inductor wire in grecque figuration on Paris subway.

STOCKHOLM

A primary condition for the Stockholm method of automatic operation was that the autopilot should be subordinated to the signal system.

A continuous cab signal and train control system is used. On a car in front of the wheels, there are two receiver coils. The coils in the leading car of a train pick up the signal current in the rails by induction. The cab signal is placed in front of, and to the left of the motorman, and gives three aspects: H (high speed, approximately 44 mph); M (medium speed, a maximum of 31 mph); and L (low speed, a maximum of 9.5 mph). The H-aspect means that the train can be run at the maximum speed allowed, and this depends on the construction of the train and the track at that particular point. There is no top speed limitation in the signal system at this aspect.

The track circuits carry either constant or coded AC (75 cps). The cab signal normally shows H, and by this aspect the track circuit occupied by the train is fed with 180 code.

When the distance between two trains decreases, the train behind gets the restricted M signal, corresponding to the 75 code. When the distance has become still shorter, the second train obtains the L signal corresponding to constant AC (non-coded). The minimum speed aspect is also applied if the AC should disappear.

It must be mentioned that driving at L signal does not occur in normal operation except on stub tracks. Should a motorman not obey the speed restrictions indicated, the emergency brake will be automatically applied within 1 to 1.5 sec; a so-called automatic train control.

Normally wayside signals are not used, except before switches or groups of switches, where it is not sufficient to reduce the speed of a train to 9.5 mph, since the train must be prevented

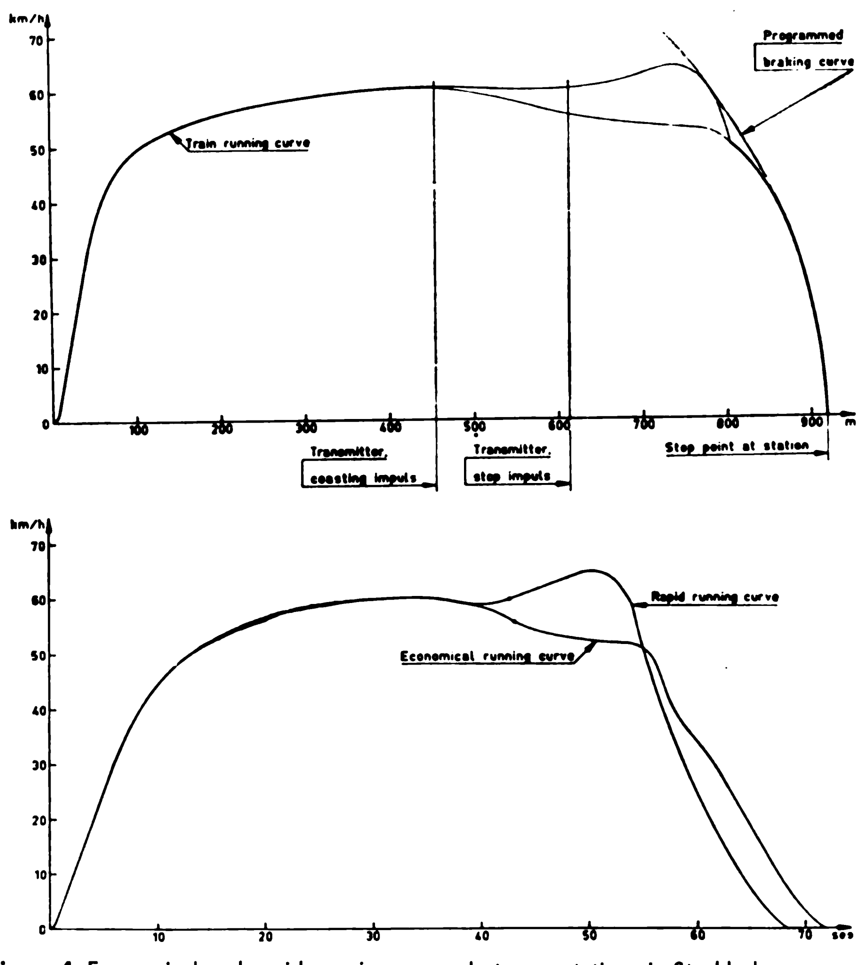

Figure 4: Economical and rapid running curves between stations in Stockholm.

from running into switchpoints which are being changed.

The system for ATO is constructed in the following way:

The car equipment is made up of one fixed installed and one portable unit, of which the latter contains, amongst other things, logical circuits. Stockholm has chosen to make part of the equipment portable, mainly because they want to keep down the costs of the automatic operation. The automation of the starting progress of the train has not caused any difficulties, the controller having but three driving positions. The difficulties do not appear until the train is to be braked at a station. The basic principle is that the train shall be braked according to a preprogrammed braking curve, corresponding to a retardation of about 3 ft per sec on level track.

When the motorman has closed the doors and given the departure signal, the autopilot starts the train automatically. The train runs toward the next station, taking into consideration the signal aspects transmitted from the rails to the cab signal equipment on the train. When approaching the next station, the autopilot receives a signal from an impulse transmitter, located in the track some 328 ft before the stopping point of the train. This impulse transmitter emits an audio frequency signal (±5 kc) to a receiver on board the train via an antenna in the underframe. As a result, a circuit is energized, and this integrates pulses from the tachometer generator. Via a non-linear circuit, this provides the reference value of the speed as a function of the travel for constant retardation, and selects the correct stopping point on the platform. The running of the train is not influenced by the circuits until the actual speed exceeds the reference speed for the first time. Compare with Figure 4. Braking is then initiated and the train is brought to a halt at the correct place by regulation between two braking forces. In tests performed, the stopping points have varied between ±3 ft. The results are based on tests made from 19-44 mph.

The autopilot now on test is provided with two different programs, one intended to be used during rush hours when running the trains in the shortest possible time. If no restricted signals occur, the train is accelerated to top speed and decelerated down to stop practically without coasting. The other program lets the train coast, making use of the track gradients to save power. It is intended to be used during off-peak hours.

In the latter case, the autopilot receives an impulse on a second frequency from a transmitter between the rails. The place of this impulse transmitter is calculated by a computer for each station distance. During the day, the train is made up with a varying number of cars. It is desired that trains should stop with the middle car at the middle of the platform, and for that reason, the autopilot is equipped with a switch marked for different numbers of cars. The reference curve is displaced in parallel so that the stopping point is moved backwards in proportion to the number of cars in the train.

In the following situations, the motorman has to take over the operations: (1) When the trains get the L signal (9.5 mph); (2) coupling of trains and (3) during occasional speed limitations, workers on the line, etc.

It will be easy to change from automatic to manual operation and back again by means of a switch in the motorman's cab.

TOKYO

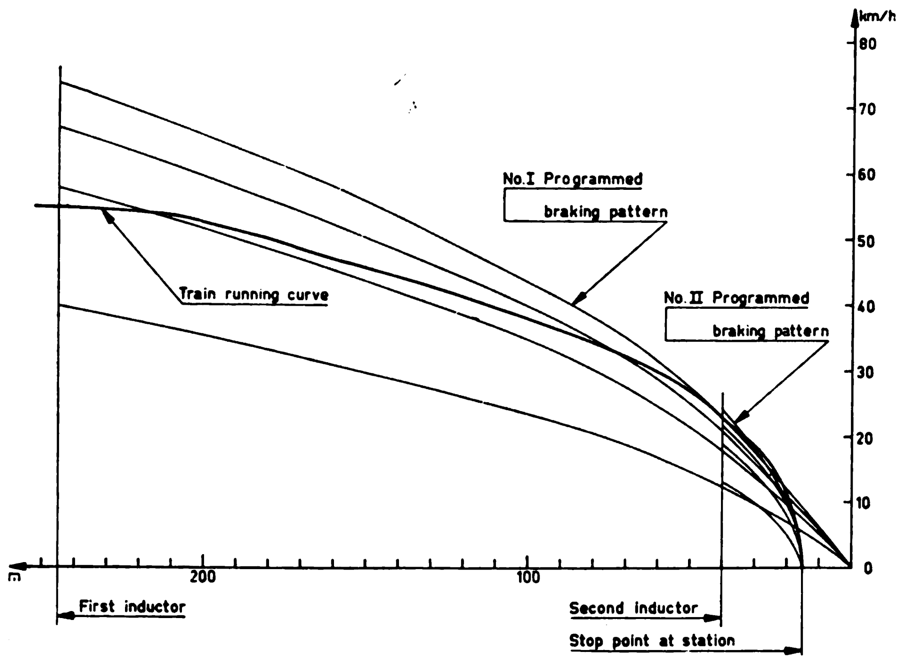

Figure 5: Braking and train running curves for Tokyo. Accuracy in stopping at a predetermined point is within ±4 inches. In one test, fault was +1.8 inches.

The first tests with automatic train control were started in 1959. Two years later, a system for automatic train control was installed on the Hibiya line, where it still is working with good results.

During 1962, an equipment for automatic train operation was developed giving remarkably good results. A train was equipped for tests at long sight and the tests are still under progress.

In this connection, Tokyo has considered the possibilities of replacing the present overlapped block signal system by the ATO system.

The automatic train control system applied on the Hibiya line means, amongst other things, that the trains receive their signal aspects inductively by means of track circuit currents fed with the carrier frequencies 2.7 kc and 3.1 kc. One frequency is probably used for each direction. The track circuit current is coded, with regard to the desired signal indications, with the signal frequencies 10, 15, 25 and 35 cps.

These predetermined signal aspects control the speed of the train. They are compared with the results of the speed control carried out by a speed checking device equipped on the train. In accordance with the results, logical relay circuits give commands to the main controller and the brake equipment.

The system which has later been developed for automatic train operation functions in the following way: By pushing a starting button, the train is started. Its speed is then subordinated to the automatic train control.

When the train reaches a point at a given distance from the next station (see Figure 5), its electronic equipment receives an impulse from a wayside inductor, to start a distance integration in relation to the stopping point. A braking program is then prepared taking into consideration the actual as well as the desired speed. In this connection, it may be mentioned that the train speed is measured by means of the frequency of a tachometer generator of inductive type set face to face with the cog of the gear wheel.

From Tokyo's opinion, the variation of adhesion, characteristics due to wheel slips or the like, does not harm the speed measurement on underground railways with a maximum speed around 44 mph. At a short distance from the stopping point, the train receives a final command from a second wayside inductor to change the braking program. As will be seen from Figure 5, the reference curves make a jump at the second reference point. In this way, it is made possible for the braking curves always to equal the actual speed of the train. The reference curves are obtained, as far as can be seen, via a so-called functional generator giving a voltage output which corresponds to the speed according to the reference curves. This voltage is compared with the real speed from the tachometer generator in order to correct the integrated distance errors and to stop the train at the predetermined stopping point with an accuracy of ±4". At the test run illustrated on Figure 5, the fault measured is +1.8 inches.

In case of faults on the ATO equipment, the train is automatically braked. The train equipment can be cut off and the motorman operates the train manually, obeying the wayside signal aspects.

ATO must be coordinated with the signal system

It is interesting to note that all the respondents to the questionnaire are of the definite opinion that at least one man should be on the train. Reasons mentioned are:

- Trains may stop on the line and in tunnel sections because of emergency or electrical or mechanical failures.
- Obstacles and hindrance of various kind, human and otherwise, may occur on the line. This is impossible to include in any signal system.
- Psychological reasons such as how passengers would react, if they had to travel by unmanned train.
- A rather complicated equipment would be necessary at stations to check that the trains really stopped at the correct stopping point at the platforms.

The next question is, where to place this one man in the train? Only a few respondents expressed any points of view on this question. But those who have answered are of the opinion that the motorman (or what this person is to be called) ought to be located in the motorman's cab, primarily for visual observation along the track. If something abnormal should happen, he will be ready for action. In this connection, the reader's attention must be drawn to the following problem. If the motorman has very little to do while on route and only has to sit or stand in his cab, he may become inattentive and not observe an obstacle or a person on the line. We, therefore, think it necessary to introduce some kind of observation control, such as an acknowledger pushbutton, or the like.

A problem connected with the automatic operation is how to keep up the driving skill of the staff. The man on the train is supposed to take over driving in critical situations, but under normal conditions, he will have few opportunities to practice manual driving. It seems, therefore, necessary to arrange regular training of the motormen (in normal operation) to keep up their manual driving skill.

A very important question related to the automatic train operation refers to the combination, signal system and ATO. The signal system is based on the fail-safe principle, that is, the signal installation shall, for the majority of occurring faults, give the most restrictive signal aspect. Great efforts have furthermore been made to render the signal system as reliable as possible by choosing well tried and high-quality components. It has thus been possible to keep traffic accidents caused by failures on the signal system at a very low level. This is evidently a safe foundation on which to base the automatic operation.

All metropolitan railways answering the questionnaire have installed a block signal system with track circuits. All the 19 metropolitan railway systems in operation use wayside signals except Stockholm, which has a cab signal system where the signal aspects are inductively transmitted from the rails to a signal in the motorman's compartment.

The metropolitan railway system being built in Oslo, Norway, will be equipped with a cab signal system for four signal indications. In Milan, Italy, it has been discussed to provide the metropolitan railway with wayside as well as cab signals. Milan explains that they want the two systems because they will have long suburban lines with high speed traffic, so that the motorman, before he enters a block section, shall be informed about the signal aspects. The signal indications transmitted to the cars are principally used for control of the train speed.

Two cities with regular or experimental service with ATO have stated that they are considering introducing a cab signal system, viz., Moscow and Tokyo. London have contemplated making some changes in their signal system, and eventually introducing a cab signal system on the Victoria line, while they have also been discussing plans for ATO on this new line.

In cities more or less engaged in ATO where wayside signals are used, the number of signal indications varies between three (stop, caution, proceed) and five. Three indications are most usually applied as for instance in Barcelona, Chicago, Glasgow, Leningrad, New York, Paris and Toronto, while Tokyo and Nagoya use five aspects.

One question referred to opinions on the possibility of coordinating existing signal systems with the automatic train operation. All metropolitan railways applying ATO have stated that a coordination is feasible. Nagoya asserts that it is a very central question, and that the wayside signal system always has preference to the driving. The same opinion is expressed by Stockholm, where the automatic operation is subordinated to the cab signal system. Also, Tokyo points out that ATO is subordinated to the signal system and is based on the automatic train control system which is made up to control the train speed in accordance with the wayside signal conditions.

It seems that the following demands should be put for the control of running the trains:

- Automatic transmission of signal indications to the train for automatic control of the traction equipment. The indications can be transmitted continuously, as with the cab signal systems, or at certain points, by building out the wayside signal system.
- Automatic speed control implying control of the motorman or autopilot so that the train does not run faster than the actual signal indication permits.

The speed control can be performed either at certain points, for instance by means of train-stops, or continuously by transmitting the signal indications to the train. This latter method must be regarded as more suitable than the system with train-stops. Signal systems comprising only stop and clear indications (possibly also caution) do not as a rule require speed control. From a signal safety point of view, the braking distances can be calculated according to the actual speeds. For signal systems comprising different signal aspects for different speeds, it must be checked that the signal indications given are followed. It seems necessary, in connection with ATO and a signal system with signal aspects for different speed limits to have also an automatic speed control.

The speed control can also brake the train automatically should a signal be missing or faulty. The automatic train operation ought to be subordinated to this control function.

Another problem is how the speed restrictions, for instance at sharp curves or inclines, would be obeyed where ATO is applied but not automatic speed control is exercised. Presently, several transit railways have erected speed indicator signs along the tracks showing the maximum permissible speed. It may be questioned how these speed restrictions are obeyed today where no automatic speed control is included in the signal system. With ATO, the human speed control may be considered excluded. The accidents which might occur, if sections with speed restrictions are passed with too high a speed, can be quite serious. Either such sections should be eliminated by realignment of the line, or a speed control sufficiently safe from a signal point of view, should be introduced.

On certain sections, for instance at station approaches and on inclines, London has introduced speed control in order to allow closer headways. Here, a number of coils are located in the current rail and when the current collectors of the cars pass over them, the frequency induced in the coils is measured. Thus the train speed is measured on a very short section (about 6 ft) contrary to the method employed by other equipment which take the average speeds on longer sections by time measurements.

On some systems it is implied that all trains shall stop at all stations. Calculating of track circuits and dimensioning of braking distances are based on these assumptions. In a system with ATO, it seems imperative to base the calculations on the highest speed the train can reach, if this stipulation should not be respected, and the train should pass a station without stopping.

PROBLEMS OF ATO

A vital question within ATO is speed measurement and what may be even more important is the integration of speed values which sometimes are applied for the measurement of distance. Skidding, or more seriously, locking of the wheels at braking, can distort the values of the measurements with the result that the train stops outside the platform.

As a rule, a high braking accuracy is demanded as the difference in length between trains and platforms is usually only a few feet. By letting the trains run on a shorter or longer section within the station area with a constant and low speed, 3-9 mph, it is possible to stop with great accuracy. On the other hand, such a system lengthens the time for trains to enter a station. This may have serious effects on the capacity of the line. The increase in traffic density which ATO could bring about, may thus be changed into a decrease.

Of all the systems discussed, with ATO, Barcelona is the only one not using any kind of speed measurement, nor do they measure the distance covered. In Barcelona, the current is cut off and the brake applied at predetermined points along the track. The braking performance is neither controlled nor compared with any reference curve. If, for some reason, a train should pass a current-cutting or brake-applying point at a speed differing from the intended values, the train will stop at a point which roughly speaking depends on the square value of the quotient between actual and intended speeds. As no comparison is made between the actual braking performance and a predetermined braking curve, the braking is constant. Fault on one or some cars leads to a changed stopping point. In Barcelona the train sets have a length of about 115 ft and the platforms are 295 ft long, so for this city the variations are less important. During the tests, the variations have not exceeded 16.4-19.7 ft in total.

The main part of the other cities running regular or experimental operation with ATO use the measured speed values in one way or another. The braking performance itself is based on a comparison between a programmed reference curve and the actual speed values. The reference curve also needs information on the distance traveled in comparison to a fixed point in the track. As far as the authors have understood, the distance measurement must be done by integration of the speed measurement values or by counting the number of revolutions made by the wheel, for example, impulse measurement. If the wheels used for speed measurement should skid the distance measurement would consequently be faulty and the stopping point dislocated. A vital question is then how great is the risk for the skidding of the wheels? Braking is usually performed by electro-dynamic means, possibly supplemented by compressed air brakes, with retardation values of about 3.3-4.9 ft/sec sec, which roughly corresponds to a friction coefficient between wheel and rail of about 0.1 to 0.15, a relatively reasonable value for the coefficient of friction. In spite of this, skidding does occur depending on the braking system, brake blocks, time for brake application, variation of the friction coefficient with the speed, etc.

If the whole network runs in tunnels and not in the open on the outer sections, the risk for skidding is considerably less. Winter conditions, and still more, fogs, and the fall of leaves bring with them a certain risk for wheel-slips for lines which also run in the open.

The system applied in Paris is completely independent of skidding or locked wheels, but as earlier stated, it requires a wire mounted all the way along the track. For conventional lines with crossties and macadam ballast such a system causes certain drawbacks with regard to maintenance work. There is also a risk for mechanical damage to the wire.

(Please turn to page 30

ATO TESTS IN 8 CITIES

(Continued from page 20)

The importance of a correct speed control is emphasized by the fact that Nagoya uses two tachometer generators, checking each other, and at deviations commanding braking of the train.

Related to braking is the question of whether the brake should be load-dependent or not. The solution depends on the relation between loaded and empty car, and also on how the braking process is regulated. Stockholm intends to introduce a load-dependent brake, the relation between fully loaded and empty cars being about 1.5. The load dependence ought to be considered in a discussion about ATO.

The major part of the automatic systems is based on the principle that the application of the brakes and the cutting off of the traction current to the motors is made by means of transmission of some kind of impulses from the track to the train. In Nagoya, Stockholm and Tokyo, for instance, an active impulse is transmitted for the initiating of certain processes on board the train. Should the stopping impulse fail, however, the train can pass the next station without stopping.

ATO in service on the London Transport

Four 4-car trains are now operating over a 4-mile section of the London subway, serving 5 stations. The one-man crew operates the doors and starts the train, otherwise the trains run automatically. The equipment comprises two systems: speed control and safety signaling. Both depend upon coded track circuits, and picked up by induction coils mounted at the front of the train. The safety signaling uses 420 code for full speed running, 180 code for speeds up to 25 mph, and no code for stop.

Speed control is obtained by feeding audio-frequency current into a "spot" on one rail. The frequency is proportional to speed (100 cps represents 1 mph). When the train reaches the spot, an electronic counter compares actual speed with that required, and applies the brakes if necessary. A 15 kc signal applied to the spot, switches off the traction motors causing the train to coast. At 20 kc, the spot acts as a distant signal, and light braking is applied.

Traffic safety must not be risked if a train should happen to pass a station. When calculating braking distance and track circuit dimensions, such occurrences must be taken into consideration. If a train should pass a station without stopping, it may cause the passengers inconvenience. The condition that the motorman takes over the driving is no guarantee for the train being stopped in time.

The Barcelona system with its ray of light between lamp and photocell, the ray being broken when a shield is passed, may be regarded as based on the closed circuit current principle. As the impulse device in the track is wholly passive, the risk seems to be non-existing that an impulse fails to appear.

Some of the railways have stated that the cost of an automatic system is too high. On the other side, all those who have carried out tests with ATO have stated that it to some extent is possible to reduce the operating expenses by means of this system. The most important advantages of ATO are:

- As a consequence of easier driving, the system may allow one-man operated trains where today are two-man operations. Against this, it could be said that the motorman's duty on the train probably will be severe. At the same time as he supervises the running of the train, he shall operate the doors, and at least at some stations supervise the boarding and alighting of passengers.

- A uniform running of trains which keeps the variations in travel times between stations for different trains down to a minimum. Thus, the uniform running ought to open up possibilities to increase the traffic density and, therefore, the capacity of the line. The uniform running can further be expected to result in:
- Savings in power consumption by the elimination of unnecessary switching on and off of current. It will also be possible to economize with regard to energy consumption, for example, by letting the trains run with the traction current cut off on a predetermined section.

PLATFORM ATTENDANTS

Within a great number of railways, the train guard operates the doors and supervises the boarding and alighting of passengers. At certain stations and perhaps only at certain hours, platform guards may help them with this supervision. A further variant is one motorman and no train guard on board the train, but a platform guard at every station. By the introduction of ATO, the authors think it possible to have only one man on the train (in the leading end). In principle, no platform guards would be needed. Some stations with high passenger frequency and perhaps with bad visibility (curves) could need to be manned by a platform guard. Many stations will probably need a closed-circuit television with a receiver set installed at the platform end.

In some connections serious opposition against ATO has been heard from the labor unions. Against this background and also with regard to the care for the passengers on the part of different authorities, it was asked if there were any direct obstacles preventing the introduction of the ATO. No special points of view were expressed in this connection.

As a special question in the principle reasoning about ATO, information on payability, supplemented by costs and savings was asked for. The answers to this question were very few. Possibly the question was raised too early. Barcelona is the only undertaking which has given a concrete reply. They say that the simplicity of their system allows it to be amortized within one year, only by means of labor savings by introducing one-man instead of two-men operation. RS&C