Technichal Meeting of the Institution

held at

The Institution of Electrical Engineers

Thursday, 15th December, 1966

The President (Mr. R. DELL) in the chair.

The Minutes of the Technical Meeting held on 16th November, 1966, were read and approved.

The President introduced and welcomed to the meeting Mr. R. R. Maxwell (Student) who was present for the first time since his election to membership.

The President welcomed Herr G. Lentz of Siemens & Halske, Germany, and requested him to read his paper entitled " The Automatic Control System for High Speed Trains in use on the Deutsche Bundesbahn."

The Automatic Train Control System for High Speed Trains in use on the Deutsche Bundesbahn

*By GÜNTER LENTZ**

1. REVIEW OF SYSTEMS

Endeavours to communicate with or act on moving trains from lineside locations in Germany had already begun in the 1920's. From the very beginning it was evident that lineside-located devices, by means of which influence could be imposed continuously on moving trains, would quite naturally prove to be more perfect than systems where such action or influence would be communicated to the train at certain intermittent lineside locations, that is, short of signals.

A continuous automatic train control (CATC) makes a trackside power source compulsory, whereas such supply is unnecessary for the counterpart intermittent type ATC system. Therefore first trials in Germany with the CATC system were carried out on the network of the Berlin subway, which had available lineside power sources, equipped with automatic block systems.

Continuous automatic train control can be achieved by using running rails themselves as a conducting medium for the activation current, the electro-magnetic field of which serves to permeate one or several vehicle-mounted receiving coils, and induces corresponding voltages in these. This, however, requires that the running rails are isolated against one another. Formerly, a great part of the trunk network of the German Railways used steel sleepers and the costs for their insulation would have been prohibitive indeed. Systems which utilize a special line conductor (for instance, of a centre-of-track design) as feed conductor, and the running rails as a return, have the

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advantages that they can be used on steel-sleepered track sections. Nevertheless, the common return for all line sections has its obvious drawbacks, which must be compensated for by the provision of supplementary equipment. The ultimate, in respect to electric transmission, is doubtlessly the line conductor or cable loop where the well insulated wires run inside of the rails, whereas it must be pointed out that the system is unsuitable for steel-sleepered sections. Nevertheless, under present conditions the latter drawback is of only minor importance, inasmuch as steel sleepers themselves have further disadvantages, and their use and existence has consequently ceased almost entirely.

Indispensable for all line conductor systems is—as previously stated—a trackside power source. Resultant outlay for this has, however, a minor importance if one takes into consideration that such CATC system will initially be installed only on such lines having automatic block ; this in itself answering the question of the power source. Apart from this, local track-occupied or clear indication, by means of insulated track sections or axle counters, constitutes the underlying principle for the block, and safety reasons strongly advise reliance on it also in the case of the CATC system, that is, to make the issuing of information to trains dependent on and interlinked with the status of track clear or occupied. Besides this, the conventional track-clear or occupied indications will be necessary also in future for such vehicles having no CATC apparatus.

Despite the superiority of the line system over its intermittent counterpart, the former " Deutsche Reichsbahn " decided, at the end of the 1920's, on the introduction of the latter system ; the decisive factor was that for an overall introduction on all lines there could be used only such systems which operated without trackside power source. Lacking financial means prohibited the general adoption of the automatic line block, and its power supply, for all lines ; this even more so, as German trunk lines at that time—and even now—were equipped with a highly developed manual block. The 3-aspect or intermittent information system finally decided on, eventually reached an unexcelled degree of perfection. From the very beginning the system was laid out to cater for all speeds up to 250 km/hr., as one assumed that trains of the future would travel at that speed ; and actually in the 1930's the network of the German Railways saw train speeds of up to 100 m.p.h. On the other hand, it was essential to have reliable working at very low speeds, for which reason DC systems as introduced in Switzerland could not be used ; and it was eventually decided to introduce the AC resonance system, termed " Indusi " (inductive type automatic train control), which is currently installed on 12,500 km of the Deutsche Bundesbahn network, on which operate 5,000 train sets or motive units respectively. Every motive unit has 3 resonance circuits of 500, 1,000 and 2,000 c/s resonance frequency. The induction coils of these resonance circuits act on similar induction coils of the trackside units or magnets which, in conjunction with capacitors, also make up the resonance circuits. Circuited in the resonance circuit of the vehicle equipment is a relay the normal position of which is the energized one.

As soon as the induction coil of the motive unit passes over the track magnets induction coil, energy is diverted from the vehicle's resonance circuit, provided that both circuits are tuned to the same frequency. This leads to a decrease of current in the resonance circuit, the relay drops and triggers either an audible indication or a braking action. The 3 frequencies used on the system employed by the Deutsche Bundesbahn effect 3 different " points of influence or action " which are located between the distant and main signal, so that even if the driver should be totally incapacitated, the train will definitely come to a stop in the approach of the danger point with signal at stop. With cleared signal, contacts of this shunt resonance circuits of trackside device. Although reliability of the system is exceptionally high, periodic maintenance of the trackside magnets is a ' must,' as a permanent proving, by closed circuits, is impossible. Equipment of the motive units works on the closed circuit principle and effects a self-check ; drop-away features or characteristics of pulse relays are checked from time to time. The system underwent continuous improvements and was finally equipped with electronic generators—in lieu of the former converters—and improved to a degree which can be termed up-to-date, even under present day standards. The development of a 50 kc/s system on which all components had been miniaturized continued concurrently. On installing corresponding supplementary devices, intermittent systems can also communicate information from the train to the track, and if requirement for an activation at exceptionally low speeds is dispensed with, the direct current system can be used in lieu of its AC resonance counterpart. In this case two trackside magnets are required, one of which acts as a receiving medium for the energy emitted by the motive unit and imposes this—or retains it—to the second magnet, depending on the position of the lineside signal. The second magnet in turn acts on the vehicle magnet.

In the case of the CATC system, train-to-track communication is possible only if line conductor or conductors are used inasmuch as the high-damping characteristics of the running rails render them unsuitable to function as receiving aerials. Nevertheless, they are able to conduct high currents at low voltages, for which reason they are suited as transmitting aerials. Their drawback, however, apart from losses caused by shunt resistance, is the high self-inductance. Therefore only low-frequency currents (c. up to 1,000 c/s) can be transmitted over sufficiently long distances, whereas the high-grade insulated line conductor, with low inductance, is able to convey frequencies of up to 60 kc/s. In Germany there is used as line conductor, a 2 mm dia. solid wire, double-insulated of 12 mm overall diameter clamped to the rail foot. Its rugged design makes it comparatively immune against mechanical injuries.

Apart from the systems described, there can also be used combinations of the intermittent and continuous type, which prove advantageous in such cases where the scope of information transmitted over the continuous system is so small that the running rails can be utilized to convey the information, and where requirements are such that call for temporary transmission of brake control orders (for example in approach of permanent way construction sites etc.) without having to revert to an adaption or modification respectively of the signalling system. In such cases a trackside magnet can be installed (this can be done by unskilled staff). Permanent " slow speed " sections are best supervised by means of the continuous mode of control.

By no means can the system of the Augsburg-Munich line be termed a " combined " system in the sense of the word, even though the high-speed locomotives which run on it are not equipped solely with continuous control gear, but also have the inductive type Indusi, because locomotives commute also on other lines The Indusi remains switched on also when the locomotive operates on the high-speed line.

2. AUTOMATIC STARTING, SPEED CONTROL AND BRAKING

With the above systems, fully automatic running of trains on lines and through stations has become a reality. Nevertheless, all these efforts on the part of the Deutche Bundesbahn must be seen in the light of a much greater aim and constitute part of a modernization programme to be realized in the distant future. All efforts undertaken in this respect aim at the control of extensive areas by central control offices or cabins. Such control should by no means be confined to the task of the lining up of routes—as is the case with remote-controlled interlockings — but rather all train movements should be communicated and reported to such " district " interlocking, which would then, from the supplied information, deduce and utilize the optimum in traffic movements and convey, directly over the line-wire, corresponding movement orders to the various motive units. In this respect the Augsburg-Munich high-speed section may well be regarded as a forerunner of this trend of development. The keypoint of the problem is therefore by no means to prevent high-speed trains from overrunning danger signals ; this is realized by the function of the Indusi system which, over decades, has proved its reliability to such an extent that there exists in Germany no reason whatever to adopt the CATC system as used on foreign railways. However, exceptional

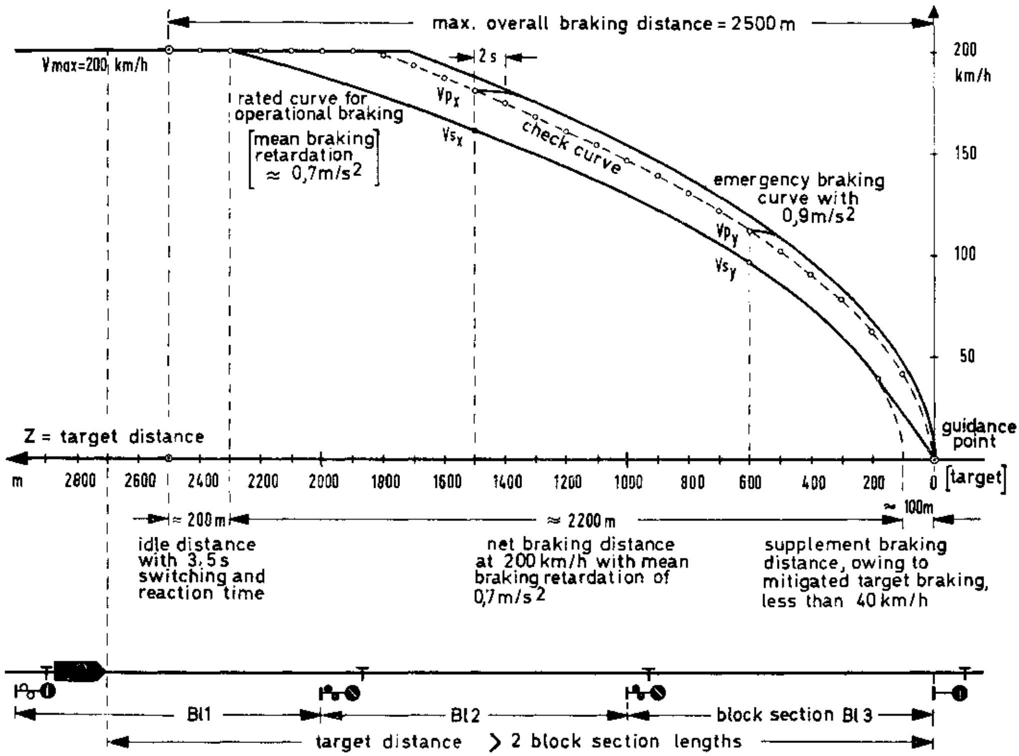

Fig. 1. Target distance—dependent brake curves.

measures and efforts as those experimented on the Augsburg-Munich line are necessary, if, in normal operation, fast trains are to be interspersed between slow ones.

To begin with, it will be necessary to to give the driver advance information of at least 3—5 km on the conditions of the line he is travelling on, thus enabling him to select the most suitable, and also most economical, train speed ; to observe the respective authorized maximum speed of the line, speed restricting signal aspects, slow-speed sections, open barriers ; and to supply him with figures as to the distance his train is from such points, as well as speeds which must be adhered to on reaching them. Acting on such information, the driver can then either decelerate or accelerate and if he should become incapacitated, braking will be effected by the automatic system whose accuracy is such that the train will come to a stop within yards of the predetermined point.

The line conductor is connected to a trackside transmitting device which in turn receives the necessary indications as to the position or status of signals, barriers and so on that concern the train itself, which communicates to the device continuous information as to its position, speed etc. It also receives information on permissible top speed of line, slow-speed sections and so on which are fed into the information transmitter as required. Range of the control transmitting unit and its associate indication receiver is approx. 12 km., and sections are interlocked amongst one another, thus ensuring an uninterrupted supply of information to the train when it passes from one area into the following one. The above described mode of operation, where all trains of an area are centrally controlled by one interlocking, is possible by combining a greater number of transmitters and receivers to one interlocking, controlling a district or area.

3. HIGH-SPEED SECTION AUGSBURG-MUNICH

Extensive preliminary tests carried out on the line Forchheim-Bamberg preceded the construction of the train control system installed on the Augsburg-Munich section. Measurements on the line conductor's useful and interference level over the line wire were carried out, as well as investigations on distance measurements and brake tests to determine target or destination braking function etc. Finally, extensive detailed research work had to be devoted to the electric locomotives in respect to high speeds at which these were to run.

The authorized maximum speed for normal trains on the Augsburg-Munich section is 140 km/hr., and an increase of this to 200 km/hr. spells a doubling of the train's kinetic energy. However, as braking forces decrease at high speeds, braking distance increases 2.5-fold if one takes into consideration an average braking force of only 0.7 m/s² instead of 0.8 to 0.9 m/s² (fig 1) and a reaction or responding time of the driver of 2 sec. and a brake reaction or lag time of 1.5 sec. At a distant signal-spacing or distance of 1,000m, aspect of this would have to be positively identifiable at 1,500 m distance which is not always possible, especially under conditions of poor visibility or possible line curvage ; generally speaking, the identification of fixed trackside signals becomes difficult at high speeds.

Track-circuit controlled automatic block signals on the section Augsburg-Munich are spaced at approx. 1,200 m, and generally the main signal also mounts the distant signal for the following main one, this indicating to the driver either the occupied or clear condition of the section ahead.

Had the Deutsche Bundesbahn decided on retaining the conventional signalling on this high-speed line, it would have been necessary to resignal this, and install numerous additional signals, reading solely for high-speed trains. It was eventually decided to retain the existing system unchanged as it was remarkably well suited for a dense traffic of trains operating at maximally 140 km/hr., and to superimpose or overlay a new system for high-speed trains operating with cab signals, on the existing one. A mixed traffic of fast and slower trains is possible and the

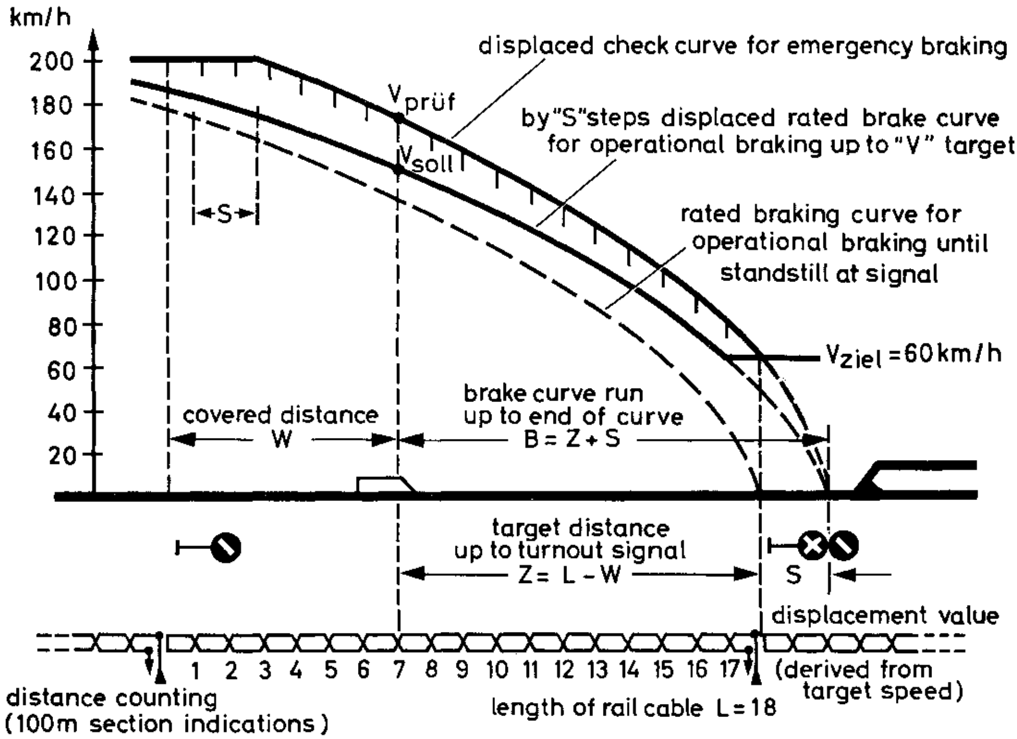

Fig. 2. Speed restriction at signal reading over turnout.

re-briefing of train staff operating slower trains became unnecessary.

It goes without saying that the highest degree of safety is provided for, and is of paramount importance for trains travelling at high speeds, and a misinterpretation of the aspect displayed by the signal last passed is ruled out entirely. Adequate advance information as to the occupied or clear condition respectively of the line ahead makes possible an economical running of trains and a permanent control effected on these prevents an overshooting of signals at danger. With unserviceable CATC system, a train can proceed at max. speed of 140 km/hr., the driver observing trackside signals.

With continuous control system in working order, the driver observes only speed-restricting signals (main signals at danger, signals in approach of points reading over the turnout, slow-speed disc signals etc.). To ensure that the train has correct target speed at such signals, deceleration must take place soon enough so that during the braking distance the driver still encounters cleared signals which he must, however, disregard, the governing factor for him being the cab identifications. The objective is to give the train an even braking curve. Distant signal indications are also of no significance to the driver inasmuch as their spacings to the main signal vary. (For all other trains there applies the rule that train speed at distant signal must not be in excess of 140 km/hr.).

An uninterrupted and economical running of trains requires that the following indications are displayed to the driver :

1. Target distance Z, that is, distance to such point at which train must have reduced its speed.
2. Target speed Vz = km/hr. in approach of " slow-speed " sections.
3. Commanded speed Vs as a directive value for correct deceleration.
4. Respective travelled actual speed Vj (tachometer).

The rated values were calculated from the brake curves and adjustments are made for gradients, rail slip and so on, so that corresponding flat topped curves were obtained. Save for the braking range, rated speeds tally with maximum permissible speeds of the respective section, or with those resulting from the train schedule. As will be described later on in this paper, one can lay down for any random lineside point, any desired speed up to the maximum authorized one, and enforce adherence to it. Values as to boundary speeds are communicated to

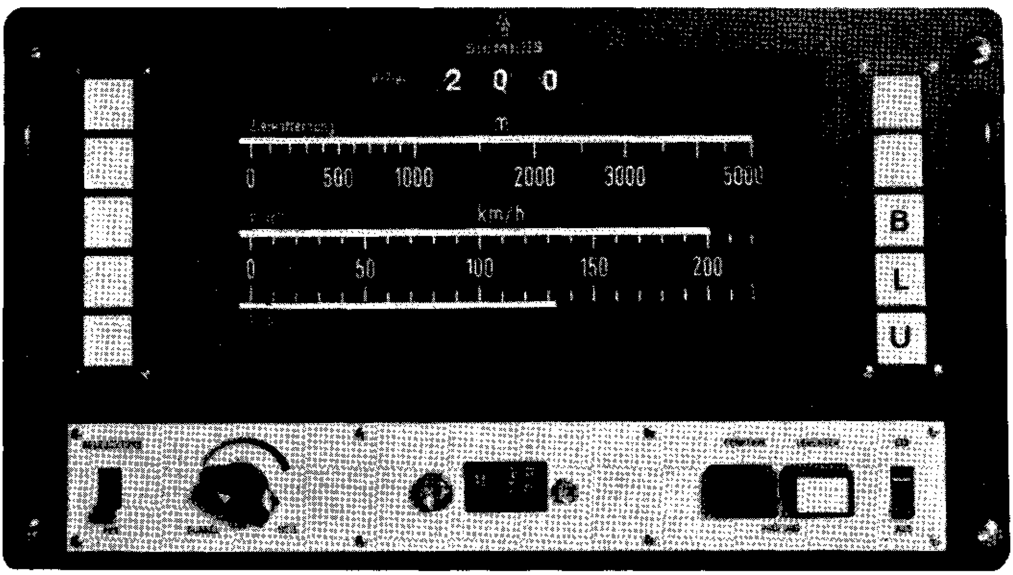

Fig. 3. Cab indicator on locomotive.

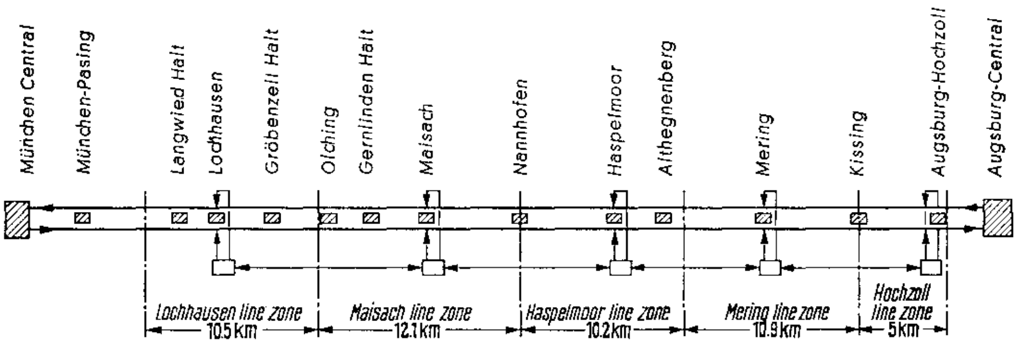

Fig. 4. Layout of Munich-Augsburg express route.

the train control gear, which calculates from them, and indicates on the cab console, such instantaneous values as are required in order to reach the target boundary speed. Fig. 2 shows a speed restriction at a signal indicating turnout. Target speed is 60 km/hr., that is, brake curve does not end at signal location proper but continues over the distance " S " behind this, and the rated curve begins later by the said shown figure " S " ; the figure resulting from the target speed Vz. The train can, as will be described later, plot its position between two signals and therefore "knows" the distance up to the next following one, adds to this the distance " S " and therefore the distance " B " up to the termination of the brake curve, the value " Vs " invariably associated with the latter. However, value " Vs " varies continuously during the run. Moreover there is assigned to the value " Vs " yet another test, value " Vp", which is in excess of the " Vs", on exceeding of which an emergency braking is initiated. To ensure that the train is definitely brought to a stop short of the danger point, even with inaccurate application of the brakes, braking retardation of an emergency braking action is somewhat more prolonged than that of an operational one.

Fig. 3 shows the cab indicator, the upper part of which shows the target speed, underneath the target distance, and furthermore the rated and actual speed. Luminous indications show whether an imposed speed restriction was initiated by a danger signal, " slow-speed " section, open barriers or so on.

4. TRANSMISSION SYSTEM

Only a CATC system which uses a line conductor is able to transmit the above described informations, and a time division multiplex system with a coding by alternating frequencies was chosen. Such line conductor section covers several block sections and is approx. 12 km long (fig. 4). Arrangement of the line wire in the track

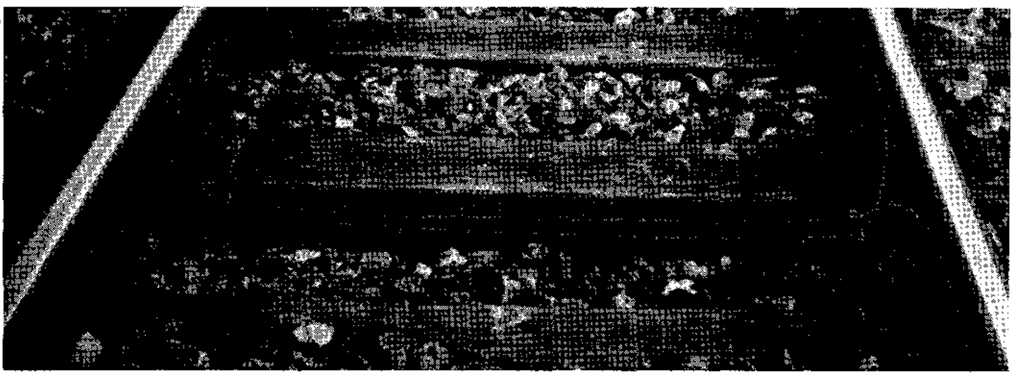

Fig. 5. Arrangement of the line wire in the track.

is shown in fig. 5. The transmission of a telegram requires about 50 ms (56 bits) and included in it are test or checking steps which ascertain that it is complete and not mutilated. Reversal of the frequency (frequency deviation) consists of the frequencies 29.4 and 30.6 kc/s for the transmission line-to-train and the frequencies 55.8 and 57 kc/s for train-to-line transmissions. Repetitive transmission of telegrams—until their evaluation—was dispensed with, inasmuch as provision of test or check steps ensures a greater degree of reliability (no two-cycle evaluation).

Line wire is not used only to transmit either controls or indications. It crosses over from one rail side to the other (zig-zags) every 100m, this being necessary to eliminate interference fields (fig. 5). At these conductor crossing points, the phase of reception voltage reverses when locomotive reception coil passes over it and this phase reversal is utilized for distance measurement (fig. 6) by operating a distance counter with it, and on the locomotive the phase reversal is counted from a defined output spot, for example, the beginning of a loop of a line conductor section. The conductor crosses over every 100m and is therefore a guiding factor as to the distance covered.

Initially, this position plotting is used as an identification for the train and this changes during the course of its run, characterized by the location it is in. The train, therefore, receives directives addressed to its location. Moreover, position plotting is necessary in order to calculate the distance the train is from its target (danger or caution signal etc.). Every counting step is therefore not only recorded by the locomotive equipment but also reported to the controlling function or office which is linked up with the line conductor. The controlling function or office is likewise equipped with a counter which is a mimic diagram of the line, with its 100m long sections, each of which represents an element that can either report an " occupied " or " clear " condition, and counting step—initiated by the train on passing over the crossing point of the conductor—is indicated " occupied" and with next following

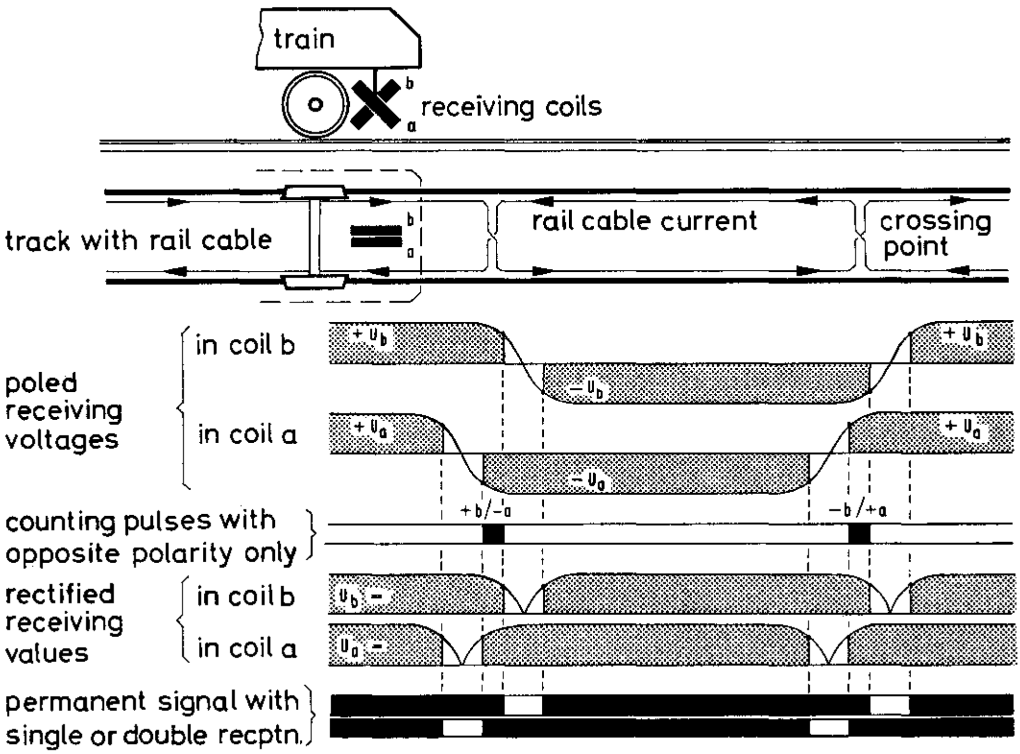

Fig. 6. Permanent reception of rail cable current with distance counting pulses.

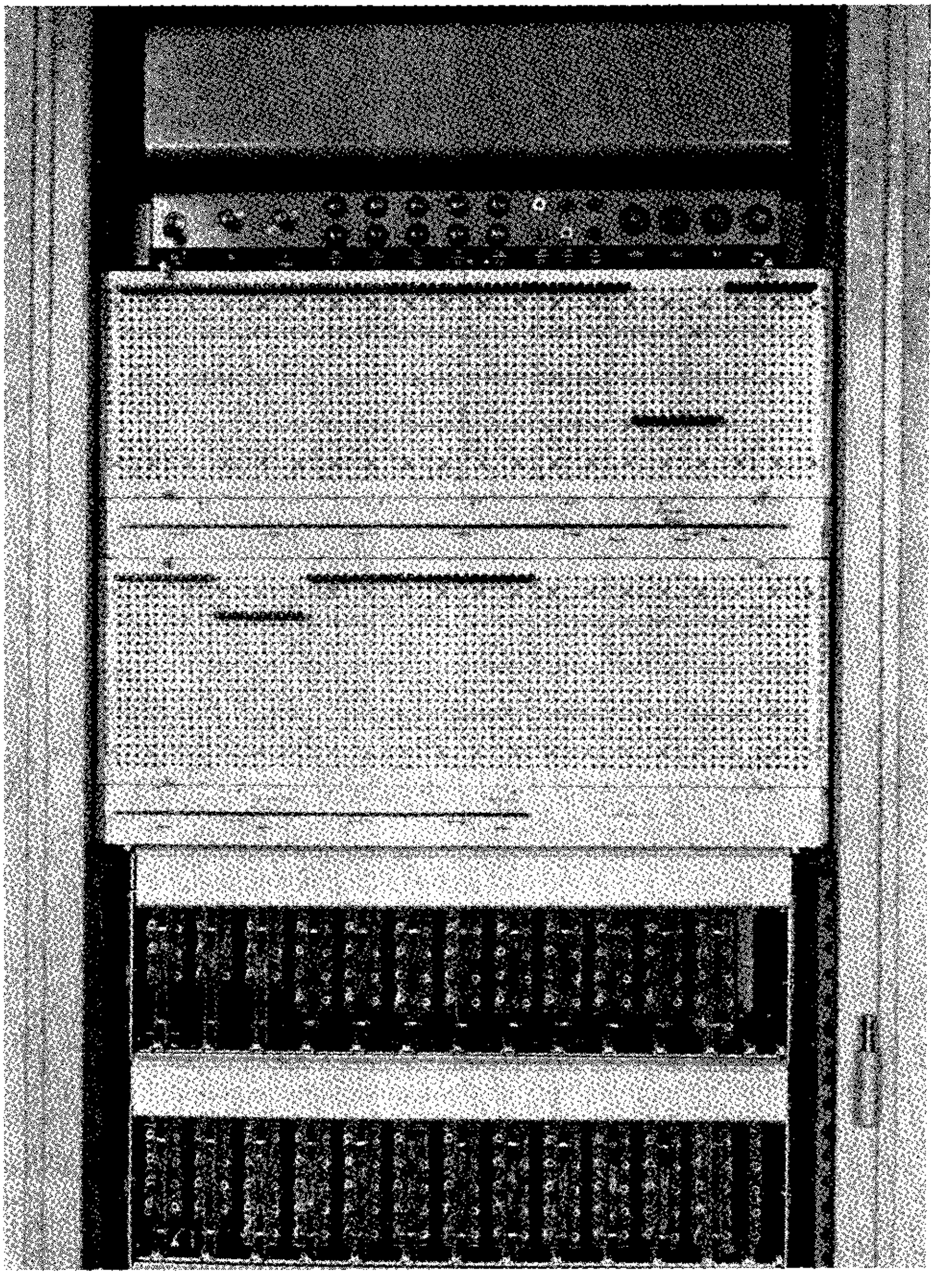

Fig. 7. Programming section.

counting step reported "clear." By no means can this "vacancy" or "occupancy" indication be compared with a section track relay release in conventional signalling, and the entire continuously automatic train control function has, as was previously mentioned, been made conditional on the function of the existing track relays. The longest loop on the Augsburg-Munich section has a length of 12.1 km, this making out 121 sections of 100m length each and therefore 121 train "call signs" or numbers. To ensure that counting begins anew at every loop, these have been marked (x, b, j and so on) and for this reason lineside control points are linked up to connecting lines.

Once the train was called or addressed with its loop identification or marking, there is transmitted to it further information, for example distance to a danger signal ahead. Such locations are termed "guidance points" as, with the aid of the information, the train is guided to them.

On the mimic diagram of the line, every "guidance point" P is represented by a special element which is able to assume a circuited condition in which it prevents a count-off of clear elements. At the beginning of "slow speed" sections, such elements retain their position permanently, whereas in the case of signals this depends on the respective position of the signal concerned. After the train has reported its position in a certain loop section, the lineside control function counts the number of clear elements up to next "guidance point" ahead and communicates obtained value to train as target value. With several "guidance points" located in the same control area, there is initially transmitted only such information as refers to the first guidance point and on the train reaching this, control functions communicate information concerning the following one. The scope of communicated distance figures amounts to 63, which is equivalent to an "optical range" of 6.2 km.

To provide an adequate braking distance for the train, on this entering into a new control section, first "guidance point" of a section is reported back to rearward control function and treated by this as if it were a "guidance point" proper.

The control function adds up its clear section distance, or reported target distance, thereby obtaining correct target distance. On entering into a new area, the train, as well as the control function, starts counting from the beginning.

The beginning of a "slow speed" section is also a new "guidance point." Nevertheless, the speed of train must not increase while passing through a "slow speed" section, for which reason the train is also provided with boundary speed figure. This, however, is not intercoupled with a distance figure as is the case with the target speed. By means of a programming section (fig. 7), boundary speed for every point along the line can be memorized. The advantage of a simultaneous transmission of boundary and target speed is that only such targets are communicated to the train as "guidance points" which lead to a speed reduction. With all signals in a section at "proceed" and with no "slow speed" areas in this, a maximum target distance of 6.2 km is transmitted.

Transmission of the boundary speed can, at a later stage, be issued by an area control cabin, which would then be able to control centrally train operations, make good delays, or detain certain trains if privileged handling of others should require this. Actual train speeds would then be calculated at the control functions, this involving less effort and outlay than is involved if doing it on every motive unit. Envisaged for the distant future is a centrally located computer which will calculate for every train a suitable running, depending on the situation prevailing in the entire area and a driver will be provided solely to override automatic operation in an emergency. However, the capability of the transmission system, as far as communication between line and train and indication of trackside and station signals, would be quite inadequate, and one would require for such operation a long range communication system interlinking all train control and despatcher stations, and a control or supervision office for the entire area or region.

5. EQUIPMENT DESIGN

Fig. 8 shows the build-up of the trackside gear. A memory unit for the reported signal aspects, "slow speed" orders and mimic line-diagram with memory elements (the latter for the continuous incoming train location plottings) receive from a pulse transformer continuous pulses which, with clear elements, are also considered and counted by the target distance measuring unit. Target and speed values of occupied elements are fed into the evaluating unit, into which is also given, via the transmitting memory, the data of the adjacent control function. In the

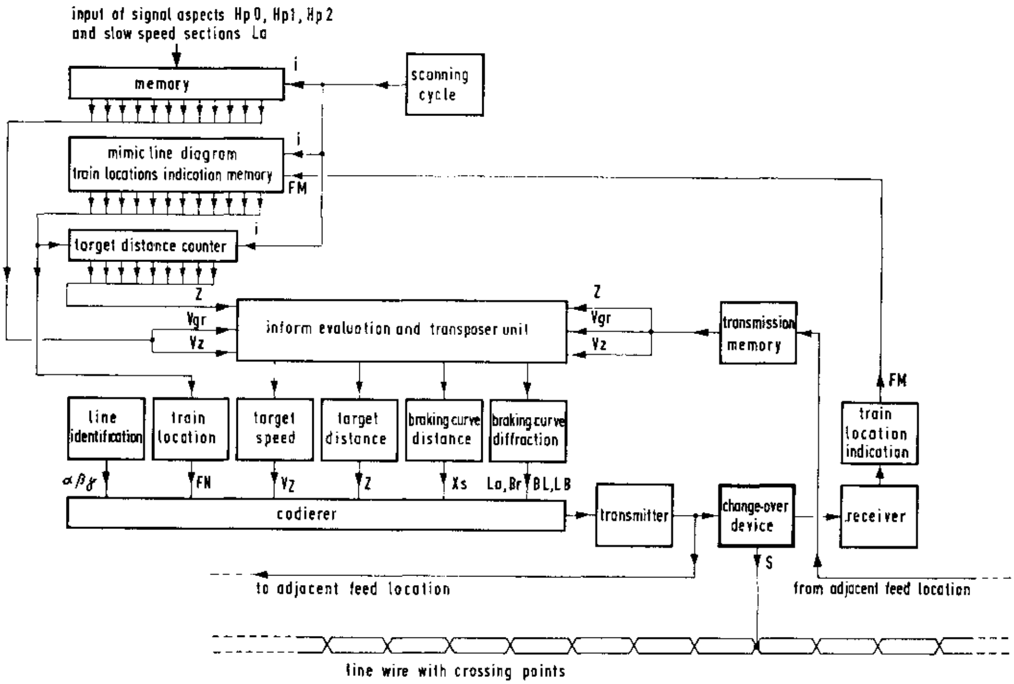

Fig. 8. Block diagram of trackside device.

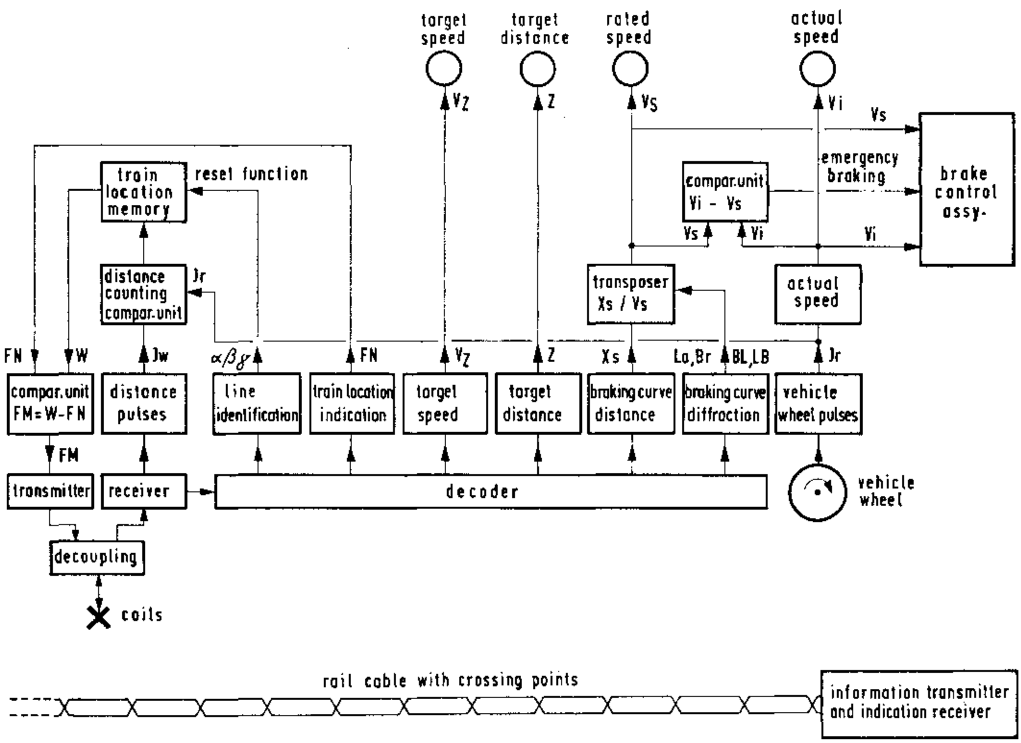

Fig. 9. Block diagram of vehicle device.

evaluation unit there is transposed information on target and brake curve data which is to be transmitted and is then, together with the line coding or identification and the respective position plotting number, fed into the coding unit which from this data makes up the text of the " telegram or order " and activates the transmitter. Via the change-over unit, transmitted pulses are run into the line conductor and picked up there by every train, evaluated however, only by that having the transmitted plotting or location number.

Back-indications transmitted by the train, on the other hand, are taken via a change-over unit to the receiver of the local function, which conveys them into the mimic line-diagram as the new position as soon as the train passes over a conductor crossing.

Fig. 9 illustrates diagramatically the evaluation by the train equipment. The received pulse diagram is decoded in the decoding unit, and sequentially received and time-staggered code pulses transposed in information units and issued in parallel.

Distance pulses, generated when the train rides over a wire cross-over location, correct a locomotive wheel - mounted mileage recorder and step the position memory unit, which communicates to the " location comparing device " FM the number of the respective location. Here, the distance is compared with the location number FN and on the two tallying, an " O " is communicated to the controlling location, and a " 1 " is transmitted if the train meanwhile passed over a further cable-crossing location.

Meanwhile, there was data communicated to the indicator, as to the target speed Vz and target distance Z. The actual speed Vi (given by the revolutions of the vehicle wheel) are also indicated and matched in the comparing unit Vs and an emergency braking triggered if actual value is appreciably exceeded. With the aid of a monitoring unit, into which is fed the same data, the tractive and decelerative actions are controlled. Precision of the target braking is conditional on the accuracy of the said monitoring unit.

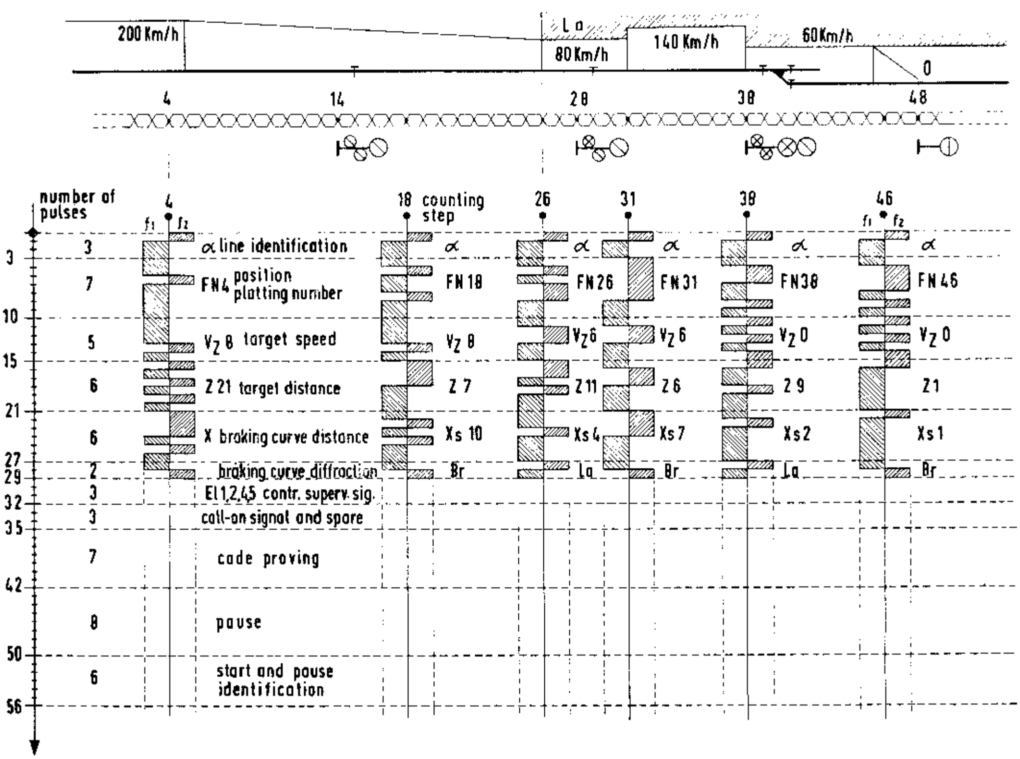

Fig. 10. Pulse telegram at various train locations.

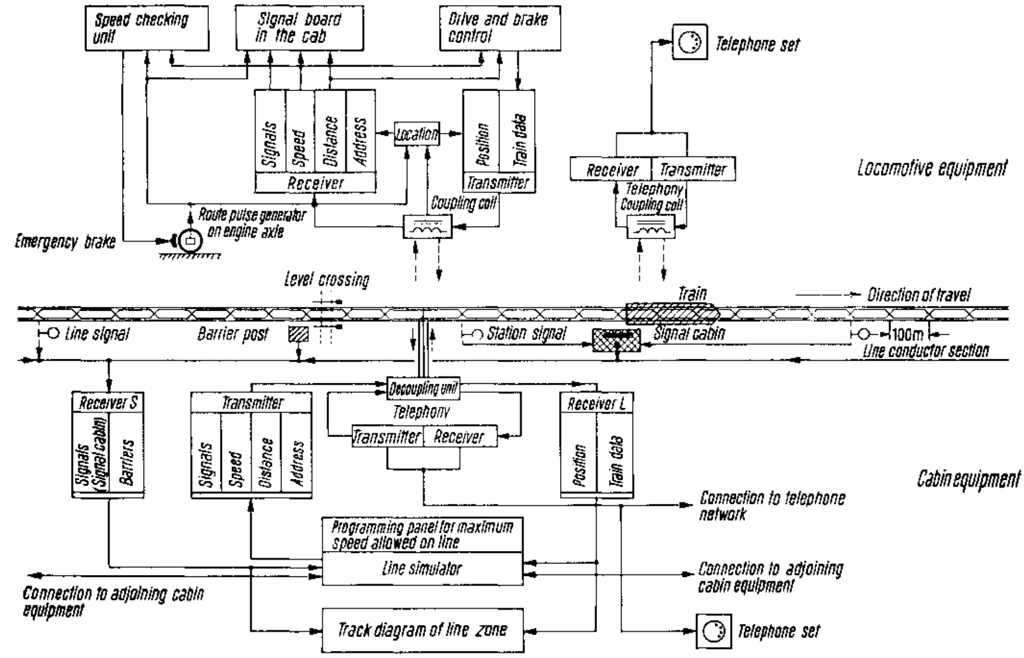

Fig. 11. Overall layout of transmission system between train and line.

Fig. 10 shows the pulse telegram or train, using as an example the braking function short of a " slow speed " section.

Fig. 11 demonstrates the entire build-up of the transmission system between train and line. In addition to the described means of communication, there is provided a telephone connection which, by means of special reception coils, is coupled with the rail wire and facilitates voice communication with moving trains.

DISCUSSION

Mr. B. Reynolds opening the discussion immediately suggested that congratulations were due to Herr Lentz on a very interesting paper, one which had summarised the development of the various systems introduced earlier and which in turn had led up to the present Augsburg-Munich installation. He also said that Herr Lentz earned sincere admiration for overcoming the personal difficulties inherent in presenting such a paper to an English audience. When it was considered, he went on, that a member of the Institution from overseas arrived here to present a paper in what was to him a foreign tongue, the extent of the difficulties could be realised. He also pointed out that Herr Lentz was concerned not only in the presentation of the paper, but in the spontaneous answering of questions also.

There were, he said, several questions he wished to put to the Author and the first of these would be to ask him if anything compelled the cutting-in of the train-driver's equipment for 200 kilometres per hour signalling prior to his accelerating for the high speed section. This, he stressed, was surely an essential since the paper had shown that the existing signalling of itself was inadequate for such speeds. The second question referred to a statement on Page 111 that the equipment described would, when in full operation, enable the optimum in traffic movements to be brought out. That, he suggested, would appear to open the way to both-way working on all tracks. Was such working contemplated ?

He then asked if the system would be suitable without modification for use on electrified lines.

The fourth question concerned the electronic generators referred to at the beginning of Page 3. British Railways had themselves turned over to electronic generators in connection with the equipment installed for suitable warning system purposes. They had, however, experienced many troubles, because the electronic generators were connected to the vehicle battery in common with a multiplicity of other equipment. The incidental operation of various items of that other equipment had resulted in surges on the battery, which had reacted as " spikes " in the feed to the electronic generators and had on several occasions caused severe damage to the transistors incorporated therein. Some idea of the magnitude of these spikes, he continued, could be gathered from the fact that on a nominal 70 volt battery feed spikes of the order of 700 volts had been recorded. He would be interested to hear if similar troubles had been encountered with the electronic generators mentioned as forming part of the installation described in the paper.

Finally he asked if there would be any difficulties in connection with mechanised permanent way maintenance due to the arrangement of the line wire in the track, shown in Figure 5. He referred specifically to tamping machines.

In conclusion Mr. Reynolds offered his congratulations to Herr Lentz and his colleague in overcoming the unseen frustrations that must have ensued in the pioneering and research work carried out over the years to enable him to lay such results before the Institution.

Mr. B. Grose said he thought it was common ground to all that some staggering economies had been made by the signal engineer with regard to the use of manpower, using relatively simple means, very well established. It was quite clear from what they had been told that they were standing on the brink of another big step forward. They were all aware that there were some very clever men working on these systems round the world ; but the point that interested him was that all clever things—no matter now clever—in this age of L.S.D., had to justify themselves, and he would be very interested to hear what the Deutsche Bundesbahn saw for them, in the use of this system, or any system developed from it.

On page 110 he noticed that the Deutsche Bundesbahn had now discarded steel sleepers. He understood they were very widely used on the German railways in the past, hence their great interest in axle counters. British Railways had some interest at the moment in steel sleepers, so he would be interested to know why the Deutsche Bundesbahn was discarding them. On that same subject he noticed the conductor was laid actually on the rail, and held there with clips. Was there any objection to the steel sleeper from that point of view ; that one cannot tolerate a steel sleeper between the rails because it interfered with the impedence of the loops ?

On page 111 Herr Lentz had mentioned a system which had communication between the train, the ground and back to the train again ; what advantage did that have over the Indusi system, which he understood was simply ground to train ?

On page 117 it was stated that the track circuit was still relied upon for safety in present installations but that in a complete system there would be no conventional signalling system. He would like to ask how safety was assured against a breakdown of the communicating system, so that the information from track circuits ahead of the train could be used to communicate to a train which had lost its system of communication.

Mr. D. S. Jewell said he would like to express a few thoughts aloud, as covering his opinions on this subject, not necessarily to ask questions. They had seen that evening one particular method of laying the cable against the inside of the rail, where it was well protected. That he thought provided an open loop, and those who had some occasion to deal with the subject were concerned about the interference level. As it was a wide loop there must be considerable coupling between adjacent tracks. He knew that it was partly safeguarded by the fact that each message was addressed to a particular train. But he thought that if there were a number of tracks on a long section one was going to run out of addresses. Hence they must come back to fundamental safety, that what was in one track loop must not be picked up by the loop in another line.

There was also, of course, the question of attenuation ; but Herr Lentz had said that a loop 12 km in length could be used.

Interference from traction : that was also perhaps associated with the width of the loop. It would also, he thought, be associated with the duration of each signal composing the telegram. That was something which had not been discussed to any great extent.

He had thus expressed his thoughts on the layout of the cable. It was a difficult question, and in addition the cable had to work not only when it was dry but also when it was covered with, should he say, 12 cm of snow.

It would appear that one cannot have steel sleepers, because they would give a short-circuited loop, and that removed most of the energy. Therefore, the particular system seemed rather vulnerable under permissive working, with trains very close together. He thought it had been shown theoretically, that with one train between two others, that was to say the locomotive pick-ups were very close to the short-circuiting axles of the train in front, the attenuation could be prohibitive.

The other point he would like to express a few thoughts on was centralisation. Centralisation as they had seen it that evening—was it right ? He would hope that a sophisticated system would be capable of being arranged just like automatic signalling ; like a roll of carpet, which could be paid out for mile after mile. If they were always going to have to repeat every track circuit and every signal into the central point, there would be miles of cable, and he would suggest that they were lessening the factor of safety by having such long repeating lines.

One last question which he thought was of interest in this country. One of the indications on the locomotive referred to was ' level crossing.' He took it, that applied to automatic level crossing equipment, so that, if it were not operating, the driver got an indication and treated it as a danger signal. His question was, could they afford to wait for the barriers to come down while the train was still a braking distance away, because if they did the brisk operation of the level crossing would be lost, and that was most undesirable. On the other hand, perhaps, the indication merely showed that the automatic operation of the barriers had commenced.

Captain L. Hix, continuing the discussion, said it was necessary to count the cost. They had been looking at a system which was justified by the fact that it permitted the train to run at a speed of about 125 m.p.h. How would this situation be regarded on British Railways where we were, at the moment, confined to speeds up to 100 m.p.h.? Would it justify its cost ? They were looking at systems of that kind. They were being considered from many points of view, but they had to be justified in terms of their pay-off, as compared with present day signalling practice. The nearest thing comparable with the type of system which Herr Lentz had described was perhaps A.W.S., but in a far more sophisticated form than they had on British Railways today. In thinking of a far more sophisticated system they also had to think of a much more expensive system which gave greater safety. It gave continuous speed supervision, so that the driver was continuously under some form of control. This was an admirable objective, but at several times the cost of A.W.S.

Taking things a little further, Captain Hix continued, in this country, and also Europe, as Dr. Waltersdorf would know railways were discussing this matter. They wanted to look further, because the system that Herr Lentz had described could provide a great deal more than just a speed supervision system, because it provided a continuous means of communication between the track and the train. Now what could be done with a railway system in which, instead of colour lights or semaphore arms as the means of communication with the train, there is substituted something which was at least the equivalent of, shall we say, a telephone ? That was beyond anything that could be done today, except with the aid of such systems as had been described by Herr Lentz.

Within European railways they were now talking of a subject called ' cybernetic control.' He would not attempt to explain what was meant by cybernetics—but at least it could be associated with the handling of information, computers and the like. Herr Lentz had included in his paper some reference to the fact that they could use that system in a more sophisticated way. He welcomed his reference to it. He had perhaps understated the situation, because one could visualise a much more sophisticated form of control which would permit a railway system to be run with a degree of automation which was far beyond what now applied. It was necessary to think therefore in terms of cybernetic control opening up a means whereby the operators could know precisely what was happening to their trains, could instruct their drivers, could get a feed back so that they would know what their trains had actually achieved, and could apply corrections. It might, of course, be commented in more conventional railway terms, on regulation and control; but he thought perhaps one needed to think even more broadly than that. " Let us think " Capt. Hix added, " of communicating right back to a control centre."

So he would ask two specific questions of the Author? First he would appreciate some indication of the cost per single track km, plus the cost per locomotive, of the system as he had described it; secondly could he enlarge on the remarks he had made in his paper regarding extending the control. Would there be a much bigger pay-off in adopting a system of that kind, whether or not they were aiming at raising speeds to 125 m.p.h. or more?

Mr. H. H. Ogilvy said that on page 110 the author had suggested by implication that, steel sleepers excepted, the favoured position for the track conductors lay along the rail foot. Apart from excessive attenuation there were circumstances which brought special problems. For example, calculations showed that on the approach to impedance bonds, or Aster track circuit terminations, the received signal would fall to a minute level. This was due to the short circuit loop, which Mr. Jewell referred to, formed by the axle. There were also a number of similar disadvantages arising for the same reason. For instance the inability to receive the signal behind the first axle of a locomotive, and the mismatch produced by the short-circuiting loop causing standing wave phenomena. Would the Author please comment on this problem.

His second point was connected with reliability. The system described by Herr Lentz employed very obviously, large numbers of electronic components. Could he say what the calculated M.T.B.F. was for the locomotive and the track-side equipment. It was emphasised that only the calculated values and not the results of tests on the Munich/Augsburg installation are of interest. He thought the results of one or two tests, taken in isolation might not be a true representation of the expected M.T.B.F. (Note: M.T.B.F. = mean time between failures.)

Mr. P. J. Barker said he would like to ask one or two questions on the details of the transmission of the telegrams to the trains.

Firstly, were these telegrams, with speed and braking instructions, addressed only to the 100 metre sections of line in which the central equipment expect a train to be?

Secondly, if this was so, was there not a possibility that a miscount at the central office could cause a train to be ' lost ' as far as the central office was concerned? He took it that in that event the train would fall back on its Indusi system with the 140 k.p.h. speed limit.

Finally, where more than one train was in a controlled loop—it was mentioned that one loop could be 12 k.m. long—would he confirm that each train would only report on receipt of its own addressed telegram, and that the central office would cyclicly and continuously address each train?

Mr. M. Birkin said he had three questions to ask. The first one; how accurate were the emergency braking curves used, compared to the actual emergency braking distances that the train would take. On British trains the variation in the emergency stopping distance could be as great as plus or minus 50 per cent; depending on the condition of the brakes and the length and weight of the train.

His second question; how were the braking curves generated? Were they of an analogue, or a digital form? That is, were they generated from a series of ramps or a staircase ?

His final question ; what form of encoding of the binary signal was used to that the telegram could be checked for validity ? Was it a Hamming code, a cyclic code or was it one of the more exotic ones employed. According to Hamming's original paper there was some difficulty in generating Hamming codes with a distance greater than 4. Were these codes generated initially by trial and error, when the code book was written out, or did they have a mathematical programme.

The President, Mr. R. Dell, in concluding the meeting said it was his pleasant duty to propose a vote of thanks to Herr Lentz.

He had come over specially from Germany to read his paper and he was sure they were all very grateful. The paper had created very intense interest, as had been shown by the number of speakers, and the various questions which they had asked.

Mr. Reynolds had already mentioned admiration of Herr Lentz, and the assistance he had from Dr. Waldersdorf in dealing with their language. One could fully appreciate that when questions were asked such as they had been this evening, how difficult it was to understand in another language, and to give answers quickly. He thought they were filled with admiration of the way in which this had been tackled.

Mr. Dell then proposed a hearty vote of thanks to Herr Lentz, which was carried with acclamation.

The following written reply to the discussion was subsequently received from Herr Lentz.

1. The existing automatic provision against exceeding the normal maximum speed (e.g. 140, 160 K.p.h.) is suspended on entering a section equipped with the continuous train control system by receipt of a special control. The receipt of this control requires the device on the locomotive to be switched in.

2. The system will provide for two-day working and for central control in order to optimise traffic movements.

3. The system is set out for application to electrified lines, and indeed for A.C. as well as D.C. electrified lines. The section Munich-Augsburg is electrified.

4. The generators for the Indusi, mentioned in a question, are not connected directly to the vehicle batteries or to the power network, but to a voltage stabiliser with a supervisory unit. The peak interference voltages do not react on the generators, but are smoothed by the stabiliser. During development of this stabiliser similar difficulties were experienced initially, as were mentioned in the question.

5. The track maintenance machines work in the track bed approximately 40 cm., to the right and left of the rails. If this area is avoided for the laying of track conductors, then no difficulties will arise in practice. Where there are points and crossings this cannot always be achieved. In these cases the track machines must be used with care, or supplemented by work carried out by hand.

6a. The German Railways have included the use of the system in their future planning.

6b. No authoritative reply can be given on the reasons put forward by the German Railways for not continuing the use of steel sleepers. It is known that the number of sections of line equipped with steel sleepers is small, and that timber sleepers are used on electrified lines. The present position concerning the use of steel sleepers has not arisen from the introduction of CACT.* The considerable importance attached to axle counters is not confined to the applications involving sections equipped with steel sleepers, in view of the fact that their introduction is thought to be economically more advantageous than conventional track circuits. On sections equipped with steel sleepers, the track conductor of the CACT system will be laid as a loop in the centre of the track with a spacing of 50 cm., owing to the attenuation when laid along the foot of the rail. Another method is to lay one conductor in the centre of the track and the other along the foot of one rail.

7. For the sake of completeness, reference was made to the D.C. system in the mention made in the lecture of point

*The initials representing the system of train control described in the paper.

train control systems. With regard to Mr. Grose's question on the advantages of this system, the author of this paper is of the opinion that, in view of the operating principles and experience obtained, Indusi is superior to the D.C. system, as regards safety and possibility of application.

8. Interruption of the transmission releases emergency braking via the vehicle equipment. In the case of Munich-Augsburg, the braking is removed when the speed is less than 140 K.p.h., providing that braking to a stop has not been previously ordered by the continuous control system. The train then continues its journey in accordance with the safety facilities given by the existing fixed signals. If there are no other safety devices apart from the continuous control system, e.g. track circuits or axle counters, then all trains affected by the braking transmission must, after coming to a stand, continue at such a speed as to stop on sight.

9. The question as to whether a barrier within the braking distance ahead of a train has already closed, or as to whether the closure must be activated, is independent of the type of train control, and is a question which must be answered by each user. In the case of Munich-Augsburg, the German Railways decided that the barriers must be closed and locked before the 200 K.p.h. train. The indicator in the cab informs drivers of the reason for a stop at an unexpected point.

10. The levels of costs per km for the CACT system as derived from the apparatus for the fixed stations and for the locomotive equipment, are of the same order as the costs for a modern automatic block system. The CACT system offers advantages in both safety and traffic working. The exploitation of these advantages and their evaluation in any economic appraisal are clearly matters for consideration by all large railway administrations. The extent of the applications for CACT as described will to a very large degree be determined by the structure of the railway of the future.

11. According to the degree of coupling between track conductors and rails, cross connections between the rails (e.g. impedance bonds or bonds for Aster track circuits), attenuate reception in track conductor loops laid along the rails.

The same observation is valid for reception between the axles of a vehicle. The effect of cross connections can be met in two ways. The resistance of the cross connections can be increased by tuning to the frequency of transmission, or by reducing the coupling between track conductor and rail. The coupling is reduced when one or both conductors are moved away from the rails, or when the track conductors are crossed over several times in the vicinity of a cross connection. Standing waves, to which Mr. Ogilvy made reference, have not produced any interference in the operation of the line Munich-Augsburg, nor in other tests.

12. The basis for the MTBF is the failure rate for individual components.

These presuppose given limiting values which must be maintained by the components until the specified time has expired. In our circuits the limiting values are very often not used to the full extent, that is the circuits still operate in a trouble free manner when the components do not conform to the various limiting values. The transistors used in the circuits may be mentioned as an example. The current amplification factor plays a significant part in determining the failure rate of transistors. As however in this case the transistors are only used as switching components, the data concerning the failure rate for transistors cannot be applied for the purpose of determining the MTBF of the installation. The MTBF to be calculated must therefore be determined by the failure rates which apply to the critical data for the particular application considered. Such values in respect of failure rates are not generally available.

13. The " Centrals " only send telegrams to the sections which are known to be occupied. The first section of the track conductor loop is an exception to this rule. This section is continually called irrespective of occupation, and so any further trains which arrive are detected.

14. The " Central " is not what is generally understood as a computer. Errors at the Central always have reactions which are on the side of safety.

The loss of a train in the Central is counteracted in various ways. If, due to continuing faults, the transfer of a train from one section to the next remains in the central store, this can be repeated in one of the following sections by means of the reports which subsequently arrive, and this process can be continued until there is agreement as to location between the Central and the train. Should the fault extend over a lengthy period, so that correction does not take place, then the train will no longer receive its call and therefore lack authority to proceed. After a predetermined waiting time the brakes are applied. Further running is possible at less than 140 k.p.h. under protection afforded by the Indusi system.

15. For emergency braking a braking curve with a braking delay is used. This curve contains a measure of reserve in relation to the effective braking delay which can be obtained, with the result that in practice braking distances are no greater than those derived from predetermined braking curves. This procedure requires the availability of several braking curves, which must be matched to various train categories in relation to braking distance.

16. Braking curves are in digital form and have a sufficient degree of precision in grading to meet the practical requirements of automatic braking.

17. The transmission system for the continuous train control system is protected by a cyclic code process. The Hamming distance and therefore the difference between two code words is 4. The cyclic process was selected, primarily because it achieves the prescribed Hamming distance with the smallest redundancy.