RAILWAY ELECTRONICS

by B.K.COOPER

Railways were early users of electricity for telegraphy, and soon applied electric locking devices to signalling controls. Until the large scale development of electric traction, however, railways tended to remain outside the stream of general industrial development, being served by their own specialised suppliers. The advent of the 25 kilovolt 50c/s a.c. system of traction in the 1950's, calling for the rapid adaptation of new techniques to railway operation, brought electronics into the railwayfield.

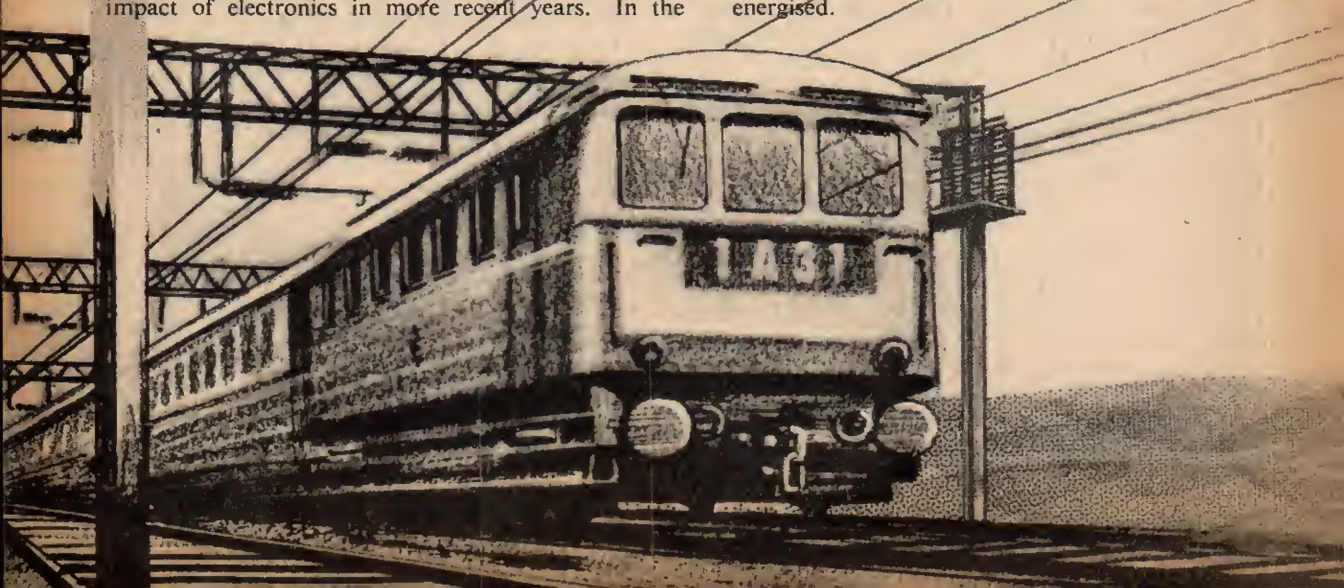
IT IS often forgotten that railways grew up side by side with electricity. Michael Faraday's discoveries in electromagnetic induction were published a year after the opening of the Liverpool and Manchester Railway, and in 1937, when Euston Station had just been opened, the electric telegraph was far enough advanced for it to be tried out between Euston and Camden in North London.

Communications were essential to train operation and safety from the earliest days, and various special forms of telegraph were soon developed which served both for exchanging messages between signalmen and for applying safeguards against incorrect signalling procedures. This situation, now infinitely more sophisticated, has lasted into the era of electronics. Signal engineers are only beginning to think seriously of doing away with the fixed lineside signal, which remains the basis of railway traffic control, although it may be supported by automatic systems to ensure that its message cannot be ignored.

Both signalling and electric traction have felt the impact of electronics in more recent years. In the 1930's the pumpless mercury-arc rectifier, in its glass bulb and steel tank forms, revolutionised traction supply practice by enabling sub-stations to be unattended and remotely controlled. It also made it possible to feed railway sub-stations from the 50c/s distribution systems.

Previously rotary converters had been used to provide direct current for the trains, but there had been some difficulty in designing them to operate satisfactorily on the standard frequency supply. Railways had therefore built their own power stations, which generated at a lower frequency such as 25c/s. Today the mercury-arc rectifier for railway service is giving place to arrays of silicon diodes just as is happening in industry.

Another feature of the 1930's was the development of "push-button" signalling, based on electromechanical relays which controlled signals and points. They also ensured by their contact arrangements that once a movement had been signalled, the circuits capable of signalling a conflicting movement could not be energised.



SIGNALLING CONTROL

Electric signalling greatly extended the area that could be controlled from a signal box compared with what was possible by manual methods. Electronics have enabled a most important further stride in this direction to be taken. A signal box with direct control of an electric signalling scheme of the type just described can also use an electronic link to control numerous similar satellite schemes spread over many route miles of line.

All railway signalling control systems must be "supervisory". That is to say, not only must they send operational commands to the remote equipment, but they must also carry return information which provides the signalman with a continuously updated picture of all signal aspects and the lie of points throughout his territory. Such a system can only be economic if all the equipment shares a common control and indication channel.

Electronic remote control of signalling began modestly on a branch line in the Isle of Sheppey in 1959. It has since been used in the most important power signalling installations on the recently electrified main London Midland Region line between Euston, Manchester and Liverpool. One of the systems on this route is the "Westronic" of the Westinghouse Brake and Signal Company. In principle this may be considered as providing a single circuit between the signal box and all the signalling equipment at the satellite location. Each control switch is connected to the circuit in turn for a fraction of a second in a continuously repeated cycle.

Simultaneously, the various items of remote equipment are connected to the other end of the circuit in a cycle synchronised with the first, so that each switch is interconnected momentarily with the item it controls (Fig. 1). During this interconnection an impulse corresponding to the position of the control switch is sent to the satellite, and an impulse is returned showing the state of the controlled equipment. Only two conditions have to be represented—a switch open or closed, or relay contacts "up" or "down"—and these requirements are met by four frequencies, two for controls and two for return indications.

The sequence of interconnections is controlled by a master pulse generator which drives a series of transistor "flip-flop" circuits at each end of the system Pulses are supplied to all stages in parallel, but clamping circuits ensure that only one can respond at a time. When the first circuit switches, it releases the second in readiness for the next pulse, and so on. In changing over, each stage sends a signal to its associated transistor oscillator, causing it to transmit a frequency corresponding to the state of the linked equipment.

"Westronic" is a time division multiplex (t.d.m.) system. Where less information has to be handled, groups of different frequencies are allotted and transmitted simultaneously by frequency division multiplex (f.d.m.) systems.

TRACK CIRCUITS

The various remote control systems for railway signalling are quite distinct from the safety circuits which prevent the signalling of conflicting train movements. If a signalman operates a control switch incorrectly, the "command" will travel out to the satellite, but the interlocking provided by the local relays will prevent the points and signals from responding unless it is safe for them to do so. Interlocking is a form of logic, and would seem an obvious area for electronics. In practice, railway signals engineers are proceeding cautiously in this direction.

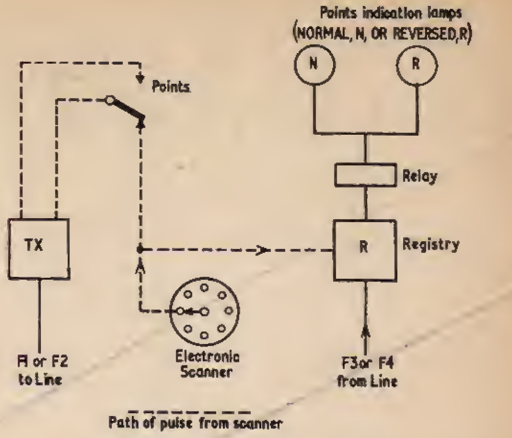


Fig. 1a. Control end equipment of a Westronic system

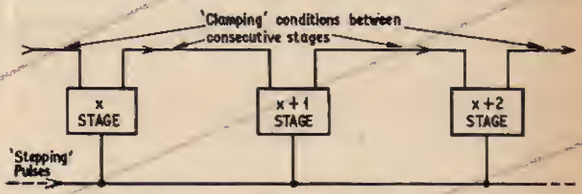


Fig. 1b. Operation of "Westronic" step-by-step scanner

An experimental static interlocking system using ferrite cores and transistors has been in service experimentally at Henley-on-Thames since late 1961, controlling access to three terminal platforms from a single running line. The equipment was developed for British Railways by Mullard Equipment Ltd. (now The M.E.L. Equipment Co. Ltd.). Ferrite elements are also used in a small interlocking installation on the London Midland Region electrified main line from Euston at Great Bridgeford, Staffs., by the Westinghouse Brake and Signal Company for controlling crossovers.

All signalling schemes depend on information on train movements derived from track circuits. In its simplest form a track circuit is a length of track insulated electrically from its neighbours, with a battery connected across the rails at one end, and a relay at the other. When no train is present, the battery current flows through the relay coil, using the rails as the circuit conductors. As soon as a train enters such a track circuit, its wheels and axles short-circuit the coil so that the relay is released (Fig. 2). The relay has multiple contacts, some open and some closed in the released condition, so that it performs a number of signalling functions.

Main-line electrification with 25kV, 50c/s a.c. gave an impetus to the use of electronic track circuits. It was essential to separate the frequencies of traction and signalling currents, and when d.c. could not be employed for track circuits it was necessary to resort to audio frequencies.

In the system of AEI-GRS Limited the feed to the track is taken from a vibrating reed device driven by a transistor oscillator at a frequency between 363 and 378c/s. Currents induced in the pick-up coils surrounding the reed are amplified and fed to the track.

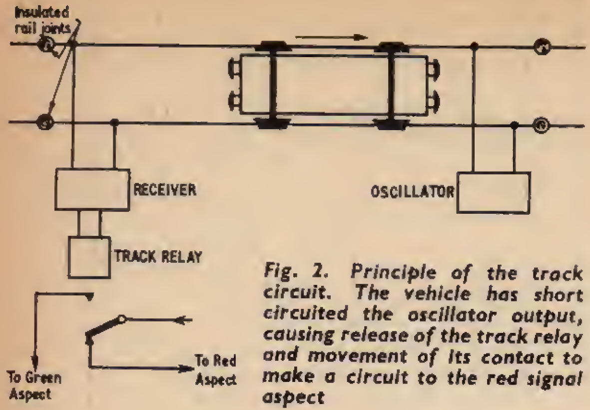


Fig. 2. Principle of the track circuit. The vehicle has short circuited the oscillator output, causing release of the track relay and movement of its contact to make a circuit to the red signal aspect

At the relay end of the track circuit they drive a reed receiver tuned to the same frequency. Currents induced in the receiver pick-up coils are amplified and rectified to operate a d.c. relay.

The essential feature of these devices is that each contains two reeds with the same natural frequency of vibration, mounted on a baseplate which provides mechanical coupling between them. When one is made to vibrate, the second reed follows suit due to the energy transmitted through the baseplate. Together they form a highly selective filter, permitting frequencies spaced by only 3c/s to be used without risk of a receiver responding to currents not intended for it.

CIRCUITING PROBLEM

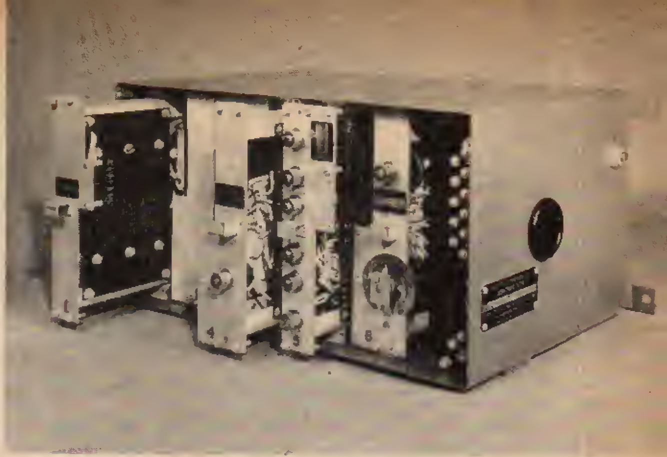
Tunnels present a track circuiting problem in that damp may provide sufficient leakage between the rails to shunt the relay when no train is present. This is a "fail safe" condition, but can cause serious operating delays. A solution used in the 1 mile 666 yard Kilsby tunnel near Rugby, on the main line from Euston, is to feed the rails with a very low a.f. voltage, which is transformed up at the relay end.

Feed frequencies of 125c/s or 175c/s are generated by transistor oscillators and coupled to the track through a step-down transformer. This low-level signal is raised in voltage by the relay end transformer, amplified and rectified for relay operation. The equipment was developed by the Compagnie de Signaux et d'Entreprises Électriques of Paris, and supplied to the London Midland Region by S.G.E. Railway Signals Limited.

At junctions where one line is relatively little used, a poorly conducting film on the rail head may make normal track circuiting unreliable. Raising the voltage is likely to cause leakage and waste of energy. An alternative is to apply a high voltage to the rails in the form of pulses. Equipment supplied by the Lucas organisation to meet these conditions employs a transistor relaxation oscillator to generate positive d.c. pulses with a peak amplitude of 20 or 40 volts from a 4 volt d.c. input. At the other end of the track circuit the pulses pass to a conventional half-wave rectifier with reservoir capacitor for energising a relay.

OVERHEATED AXLEBOXES

Remote control of signalling by electronic systems has greatly reduced the number of signal boxes needed on main lines. It follows, however, that trains are less often under observation than in the past and there may be delay in spotting faults. Serious attention



Control box of AEI speed indicating equipment for locomotives

is therefore being given to methods of detecting overheated axleboxes in freight or passenger rolling stock, and transmitting a warning so that the train can be stopped. A technique used at several places on the French National Railways uses infra-red detectors of indium antimonide mounted close to the rails.

In order to obtain high sensitivity, the indium antimonide is "polarised" by being situated in the field of a permanent magnet, which gives it photo-emissive properties and results in an output of about 1 microvolt in the presence of infra-red radiation from an axlebox at 50 degrees C. This minute signal is amplified and applied to a pulse transmitter connected by a telephone cable to a monitoring point where the pulses appear on a chart recorder.

Part of the control panel in Rugby signal box, from which remote interlockings are operated by an electronic supervisory system

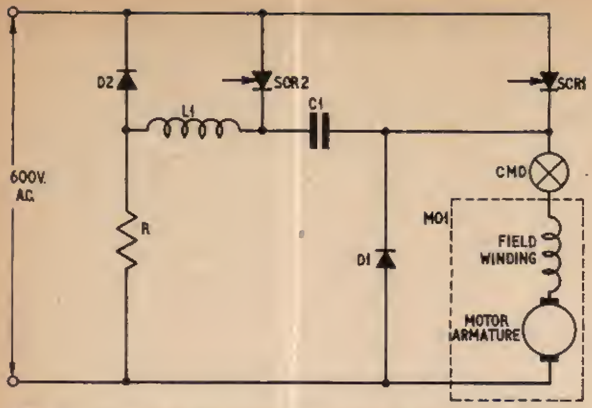


Fig. 3. Circuit for thyristor control of a traction motor

Semiconductor rectifiers, first of germanium and then of silicon, have been used in electric railway motive power since 1956. It is clear that the next step is to replace diodes with thyristors. At present traction motor voltage is controlled by resistances in d.c. traction, and by a tap-changer on the transformer in a.c. traction. Both forms of control operate in a number of steps, which is a compromise between the ideal of "stepless" voltage variation and the practicable cost and complexity of the equipment. Thyristors offer an alternative to each method.

STEPLESS CONTROL

Experiments have been conducted with a 600V d.c. motor coach in which stepless control was provided by thyristors, no resistors or contactors being used. The basic circuit is shown in Fig. 3. Control is effected by varying the length of the "on" and "off" periods of thyristor SCR1, this being done automatically through the current monitoring device CMD in the motor circuit. While SCR1 is "off", current continues flowing round the loop provided by diode D1 due to the armature inductance. A second thyristor, SCR2, is used to switch T1 off, acting in conjunction with the circuit components D2, L1, C1 and R.

In a.c. traction the thyristors would replace the normal rectifying diodes and would turn off automatically in the negative half-cycles of the supply.

The preferred method at present is to use thyristor control in two steps. At starting, the traction motors would be connected to a half-voltage tapping on the transformer, and the firing of the thyristors would be controlled so that the motor voltage was raised smoothly from zero to that value. At this point the motors would be reconnected across the whole of the secondary, and the thyristors would repeat their firing cycle to raise the motor volts from half to full. If it were decided to do away with tap-changing altogether, it is likely that a scheme which varied the length and repetition frequency of the pulses would be preferred to simple phase-angle control of firing.

Thyristor circuits can also be arranged to invert, so that current generated by the motors of a locomotive when coasting down a gradient can be returned to the overhead line as a.c., thus developing a braking effort. The mercury-arc equivalent of the thyristor is the grid-controlled rectifier, and 95 electric locomotives of the French National railways equipped with rectifiers of this type make use of their inverting property for braking.

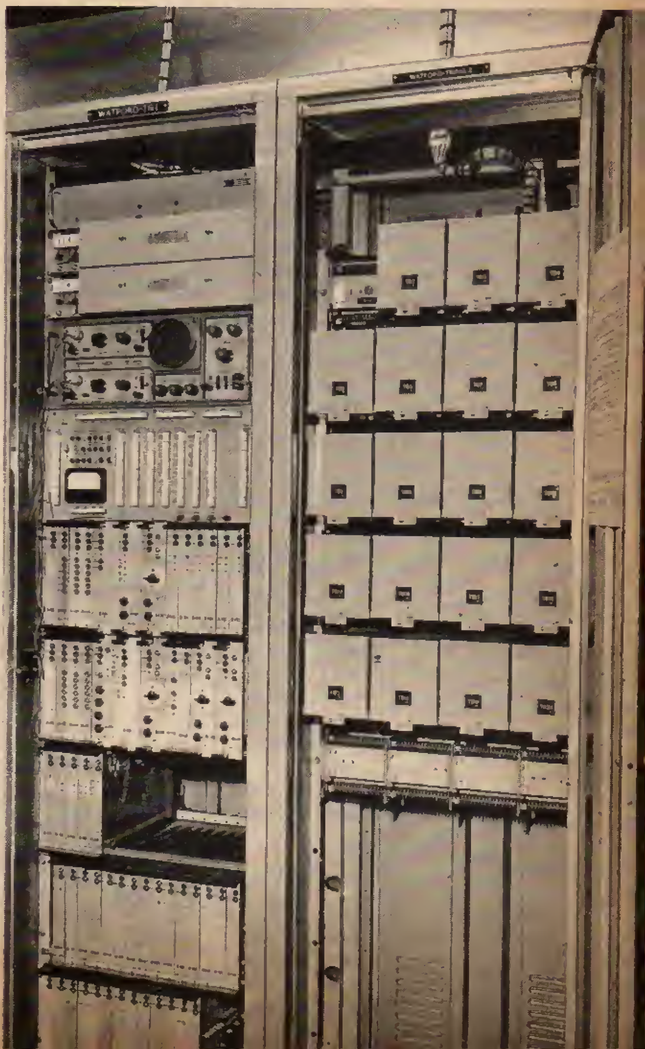
The efficacy of "regenerative braking", as this system is called, depends on other loads being available to absorb the regenerated power. Where there are long gradients, and the traffic pattern is such that descending trains are balanced by others travelling in the opposite direction, regeneration can at the same time save wear of the mechanical brake gear and economise in consumption of electric power.

An unusual application of static inverters is to be tested in some Russian 3,000V d.c. locomotives. In order to increase the power that can be transmitted from the sub-stations, it is proposed to connect two sub-stations in series and feed the overhead line at 6,000V. This supply will be changed into a.c. by inverters in the locomotives, transformed down to 3,000V and then rectified to feed the normal 3,000V d.c. power circuits.

THYRISTOR INVERTERS

Already traction engineers are looking beyond thyristor control of d.c. motors to the use of thyristor

Remote control cubicle installed in the relay room at Watford signal box



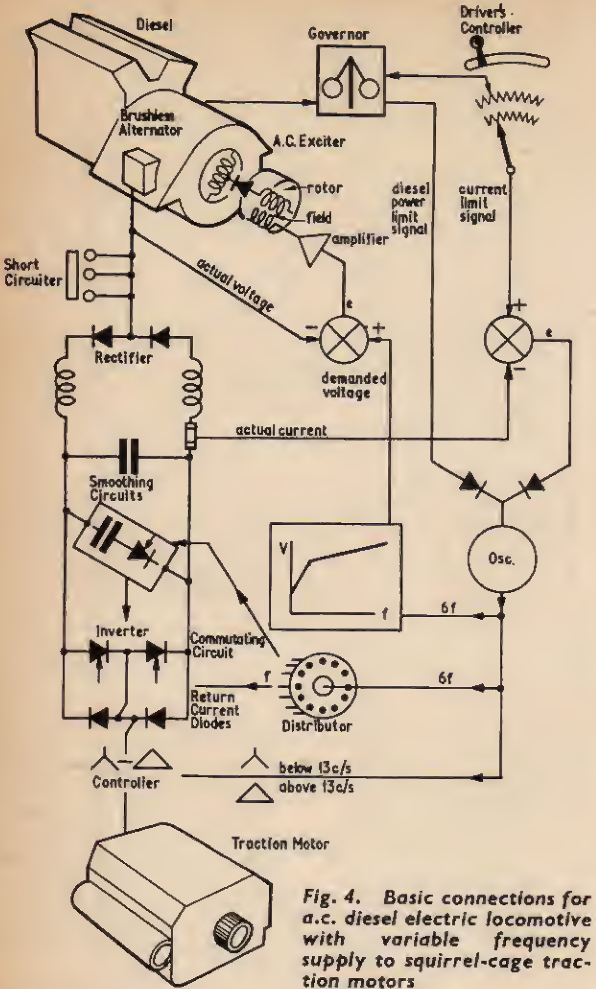


Fig. 4. Basic connections for a.c. diesel electric locomotive with variable frequency supply to squirrel-cage traction motors

inverters feeding a.c. at variable frequency to induction motors. A project of this kind is already in being, for the Brush Electrical Engineering Company has collaborated with British Railways in converting an existing diesel electric locomotive for this method of working.

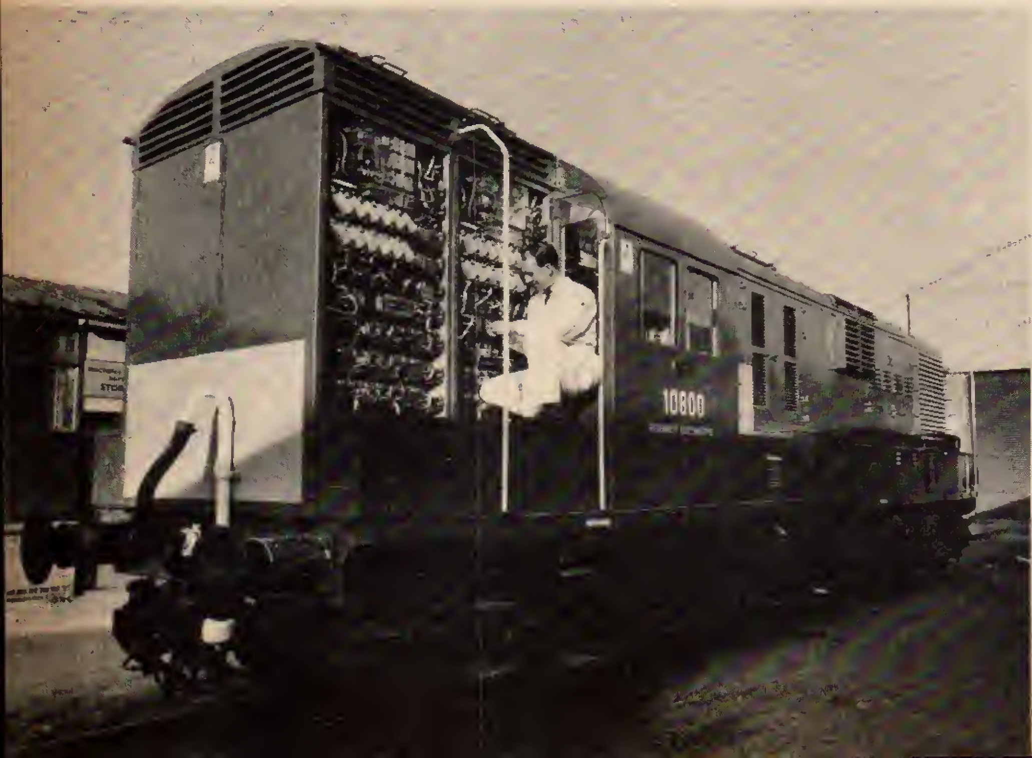
RESEARCH LOCOMOTIVE

The locomotive, known as the "Hawk", is powered by a 1,000 h.p. diesel engine driving a 1,000kW, 100c/s alternator. After rectification by silicon diodes, the alternator output passes to four thyristor inverters, each of which provides a variable frequency supply to a squirrel-cage traction motor (Fig. 4).

A similar scheme could be used in an a.c. electric locomotive, the difference being that a.c. power would be collected from the overhead line instead of being generated internally. Many years' experience has enabled d.c. traction motors to be built which achieve high reliability in the severe conditions of railway service, but few engineers would regret the passing of commutators and brushgear, and the inspection and maintenance they require.

The "Hawk" is a research project, and so far as locomotives in day-to-day service are concerned the main applications of electronics at present are to provide contactless switching in low-current control circuits rather than in power circuits. Some 750V d.c. locomotives on the Southern Region of British Railways use a Ward-Leonard control system instead of resistance control.

In one of these the usual generator field control contactors have been replaced by thyristors, giving stepless control of excitation, and hence of the traction motor voltage. However, a beginning has been made with the use of thyristors in the main power circuits, for a motor coach in the Eastern Region, which was fitted formerly as an experiment with control by a continuously variable transformer, has now been equipped with thyristor control.



Electronic apparatus compartment in the "Hawk" experimental diesel-electric locomotive with variable-frequency speed control

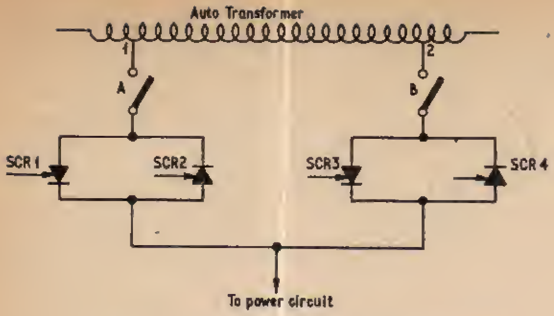


Fig. 5. Thyristor controlled tap-changing

THYRISTOR TAP CHANGE

On the Continent thyristors have been used in conjunction with an ordinary tap-changer in an a.c. locomotive to relieve the tap-changer contacts of the duty of breaking heavy currents. This is in the 8,000 h.p. "EO3" class of the German Federal Railway, which during the International Transport Exhibition in Munich in 1965 worked demonstration trains between Munich and Augsburg at speeds of up to 125 m.p.h. The basic circuit is shown in Fig. 5.

Before a tap-change from Tap 1, thyristors SCR1 and SCR2 are switched on and conduct on alternate half-cycles. When the tap-change is made, the gate current is cut off and, as soon as the motor current passes through its next zero, the thyristors switch automatically to the blocking condition. At this instant contact "A" opens off-load, contact "B" closes, and thyristors SCR3, SCR4 are switched on. This occurs so rapidly that there is no interruption in the flow of current to the traction motors.

In a conventional tap-changer, similar continuity of supply has to be achieved by allowing two tappings to be momentarily connected to the power circuit at the same instant, providing transition resistors which are cut in and out of circuit on each tap-change to prevent the flow of short-circuit current between the two tappings. In the German scheme the thyristors are only brought into circuit when a tap-change is about to take place. They are thus able to handle starting currents of some 700A, although the nominal rating of each parallel circuit is only 440A, and no provision for forced air cooling is necessary.

SOLID STATE SERVO

Solid-state devices are coming into use in British diesel-electric locomotives to replace hydraulic or electric servo systems previously used to control a variable resistance in the generator field circuit so that the electrical output matches the power input from the diesel engine.

In a system developed by the English Electric Company, which will be used in fifty 2,700 h.p. locomotives being built for British Railways, a transistor multivibrator is used to control two thyristors which apply a control voltage across the generator field. A potentiometer linked with the engine governor controls the duration of two square wave outputs from the multivibrator which trigger the "on" and "off" thyristors. The ratio of "on" to "off" periods determines the mean field current.

Among many ancillary electronic devices now coming into use in electric and diesel-electric traction, the various forms of electronic speedometer have some of the most important possibilities. In addition to the accurate presentation of speed to the driver, their output can be used for controlling speed at a selected level. Thus they could be essential elements in automatic train operation, either in accordance with instructions from the driver, or with command signals received through an inductive link with the track. ★

Siemens EO3 electric locomotive