UKRAS Technical Bulletin
No 3 March 1968.

An Experimental Automatic Electric Brake Scheme For 25 kV a.c. Locomotives

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It has been found that Rheostatic Braking, despite its proved effectiveness is often not used to advantage if it has to be independently applied. The experimental system described in this article causes the rheostatic brake to be applied automatically under the control of the normal proportional brake valve. Brake block wear has been substantially reduced on the locomotive fitted with this system and tests have confirmed that the automatic rheostatic brake is never inferior to the standard proportional brake.

One of the advantages of electric transmission in locomotives is that electric braking can be incorporated in the design. The saving in brake shoe wear thus achieved reduces the maintenance costs and increases availability by increasing the intervals between brake block replacement. A further advantage is that while electric braking is in progress the locomotive and train brake blocks are kept cool in readiness for an emergency application.

Sometimes where routes contain long, steep gradients, regenerative braking can be profitable, as current is then fed back into the overhead line. The power thus saved can be used by trains on other parts of the system or returned to the grid supply. The latter is not always easy to arrange and it is sometimes necessary to switch in sub-station resistors by high speed contactors to absorb the regenerated energy when the line is not receptive. Routes suitable for regenerative braking are comparatively rare in Great Britain, however, and the principle has only been applied so far to one electrified line, namely the route between Manchester, Sheffield and Wath. The power equipments for these locomotives, which also provide for rheostatic braking at the lower speeds, were supplied by AEI.

Where routes do not justify regenerative braking schemes, rheostatic braking can be used to advantage on both electric and diesel-electric locomotives. In these cases resistors are connected across the traction motor armatures, and the heat generated in them dissipated by means of cooling fans.

Control of the rheostatic braking effort has been effected in a number of ways. On some d.c. locomotives the circuits are arranged so that, while braking, the traction motors are self excited and feed into the normal starting resistors on the locomotive, the value of which can be varied by the power handle.

It is common practice on diesel-electric and d.c. locomotives to excite the traction motor fields separately and to control the excitation by means of a rheostat in series with the field of the exciter. On d.c. locomotives the exciter is a separate motor-generator set, but on diesel-electric locomotives the main generator may be used.

In all these systems the rheostatic brake and air brake are operated from separate controllers. Although rapid transit cars have been equipped with a common control and trolley buses are normally arranged so that electric and air brakes are operated from the same foot pedal, up to 1963 no British main line locomotive had been fitted with automatic electric brakes operated solely by the driver's brake valve.

At the request of the British Railways Board, AEI Traction Division, in conjunction with the Westinghouse Brake and Signal Company carried out an interesting modification to one of the British Railways/AEI 25 kV a.c. locomotives. The locomotive concerned was one of the forty of the AL5 Class, one of which is shown in Figure 1, and which were equipped with rheostatic braking in addition to the standard vacuum controlled proportional air brakes. The modification was designed to ensure that the rheostatic braking was used to best advantage.

The rheostatic brake on this type of locomotive was primarily intended as a speed checking or holding brake for hauling unfitted or partially fitted freight trains on graded routes where serious brake fading can result from overheated brake blocks. The rheostatic brake control on the unmodified locomotives is quite separate from the air and vacuum brakes. In practice the full potential of the existing rheostatic brake had not been realised for two reasons; firstly because opportunities for using it in the manner originally intended are, as yet, comparatively rare on lines so far electrified and, secondly, because in setting up the rheostatic brake circuits additional action is required from the driver, whose main preoccupation is to look out for and obey signals.

Experience had shown the rheostatic brake to be very effective not only for holding duties but also in providing a satisfactory stopping brake down to speeds of approximately 5 m.p.h. It was therefore, considered that the cost of a really effective rheostatic brake would only be justified if it were applied automatically without any action additional to that required for a normal vacuum brake application. Only in this way would its full potential be realised.

The system was designed so that the normal locomotive air brakes would be available immediately the driver applied the brakes and the rheostatic brake could take over automatically as soon as a comparable rheostatic braking effort was being exerted. Automatic reversion to air braking was provided when the speed reduction had caused the rheostatic brake to be less effective than the comparable air brake, and also in the event of rheostatic brake failure. The modified locomotive was used to test this system.

The Scheme

There are several ways in which rheostatic braking can be approximately proportioned to the vacuum brake and the one in use on the modified locomotive is probably the simplest. The traction motor fields are excited in series at low voltage from the main transformer, via a step down excitation transformer and main rectifier, as shown in Figure 2. The scheme is such that as the train pipe vacuum drops so the tapping on the main transformer winding is raised. Thus as the braking of the train itself is increased so the electric braking on the locomotive is also increased.

On a standard locomotive of this type, braking during a vacuum brake application is by means of compressed air under the control of a proportional valve in the vacuum train pipe. This is known as the proportional brake. An illustration of the driver's control desk showing the positions of the various controls is seen in Figure 3.

On the modified locomotive rheostatic braking starts to build up immediately the driver's brake valve is moved from the 'running' position and its effect is additional to the proportional brake. The transformer tap or the excitation notch selected is determined by the brake excitation controller. This is a device which causes the tap changer to notch up or down according to the pressure applied to the proportional brake.

As soon as the rheostatic braking current has reached a predetermined value, fixed at 400A, the air brakes on the locomotive are cut out. This is done by one of three voltage sensitive relays 'A', Figure 2 each connected across one of the braking resistors, which control an electro-pneumatic brake cut-out valve.

The brake cylinders are exhausted through a timing choke incorporated in the brake cut-out valve which ensures that the brake blocks are released gradually. In practice, the release time was set at 25 sec, the minimum time for the tap changer to notch up fully.

The total braking effort due to the air and rheostatic brakes is thus arranged not to exceed the adhesive limit. An independent air supply at 10 lb/in^2 (0·7 Kg/cm^2) is kept connected to the cylinders to keep the blocks in contact with the wheels. This ensures a smooth changeover to air braking when required. Vacuum braking continues to be applied to the train but only rheostatic braking is applied to the locomotive.

As the driver's brake valve is advanced, calling for more braking effort, the vacuum in the train pipe falls and the proportional air brake pressure rises, causing the brake excitation controller to notch up the tap changer further. If the braking current rises to the maximum permissible level, a second voltage-sensitive relay 'B' picks up. This prevents further notching up of the tap changer until the current has been reduced either by the falling speed of the locomotive or by the driver reducing the braking effort called for by the driver's brake valve, thereby signalling the brake excitation controller to notch the tap changer down. The tap changer will continue to notch up when the relay 'B' drops out and the sequence is repeated until the maximum number of notches called for by the brake excitation controller is reached. In practice the train will probably have come to rest before the top notch is reached on a full application.

When, due either to reducing speed or reducing excitation, the falling braking current allows one of the relays 'A' to drop out, the proportional air brake is automatically re-applied in the standard application time of the proportional brake. Relay A dropping out also runs the tapchanger down to notch 1. It will thus be appreciated that failure of one of the braking circuits with loss of braking current during an application will also reapply the proportional brake and run the tap-changer down. Power circuits are only restored when the driver's brake valve has been returned to the running position.

Originally the rheostatic brake was removed and the proportional brake re-applied when the vacuum brake valve was

moved to the 'emergency' position. Subsequent tests, however, proved the rheostatic brake to be superior to the proportional brake at all speeds, and to avoid the anomalous situation of an inferior emergency brake the circuits were adjusted to make the rheostatic brake available over the complete range of the vacuum brake valve.

In the event of the driver removing a brake application quickly, by returning the vacuum brake valve handle to the 'running' position, the rheostatic brake is run off rather than removed suddenly in order to avoid snatch at the locomotive coupling.

The circuits are arranged so that 'brake' takes preference over 'power' if both are called for simultaneously. However, the associated selection relays normally return to their power position to avoid a locomotive failure being caused by faulty relays. In that case further braking is automatically carried out using the proportional brake.

In common with the rest of the British Railways/AEI fleet with this feature, the rheostatic brake can only be selected if all motors are in use. This selection is automatic with operation of the motor cut out switch.

The independent straight air brake is retained to allow the locomotive to be manoeuvred locally in the normal manner and is in no way connected to the rheostatic brake. Provision is also made for isolating the equipment in the event of a fault; the locomotive can then be worked in the normal manner.

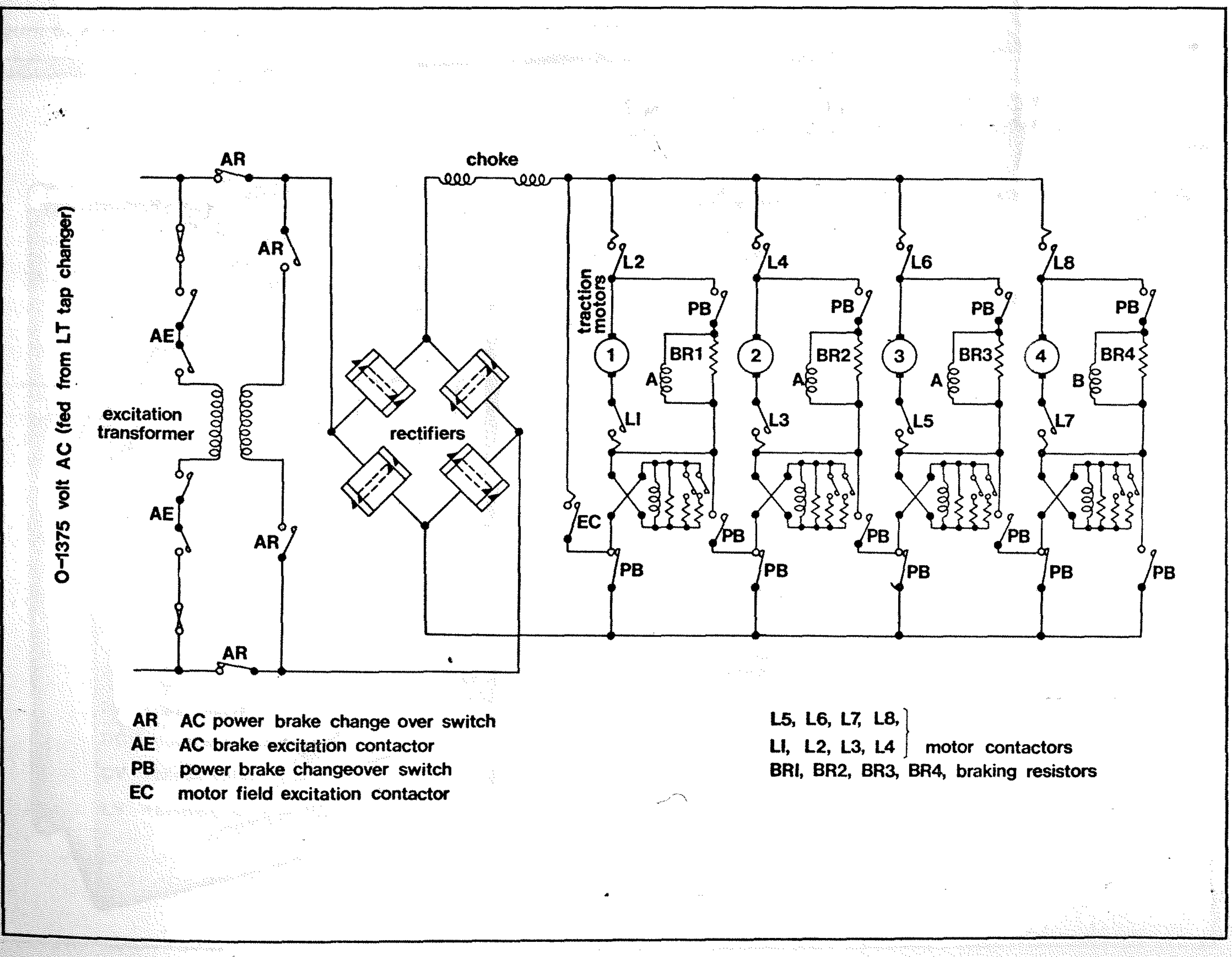
Electrical Modifications

Electrical modifications are confined to the control circuits and are concerned mainly with the automatic transfer of the control of the main transformer secondary tap changer, when braking, from the power handle to the drivers brake valve. This is achieved with a device known as the brake excitation controller. This controls the tap changer with respect to the locomotive proportional air brake pressure, which is in turn governed by the train pipe vacuum controlled from the drivers brake valve. A photograph of the brake excitation controller is given in Figure 4 and a diagram explaining its operation is given in Figure 5.

The brake excitation controller incorporates a compressed air actuator which extends in proportion to the air pressure supplied to it. The actuator drives, via a rack and pinion and differential gear, two brush arms in opposite directions around a commutating disc driven from the tap changer camshaft. The complete locomotive equipments supplied by

Figure 1. British Railways/AEI Class AL5 25kV a.c. locomotive fitted with rheostatic braking.

Figure 2. A schematic diagram of the electric braking circuit on the modified class AL5 locomotive.



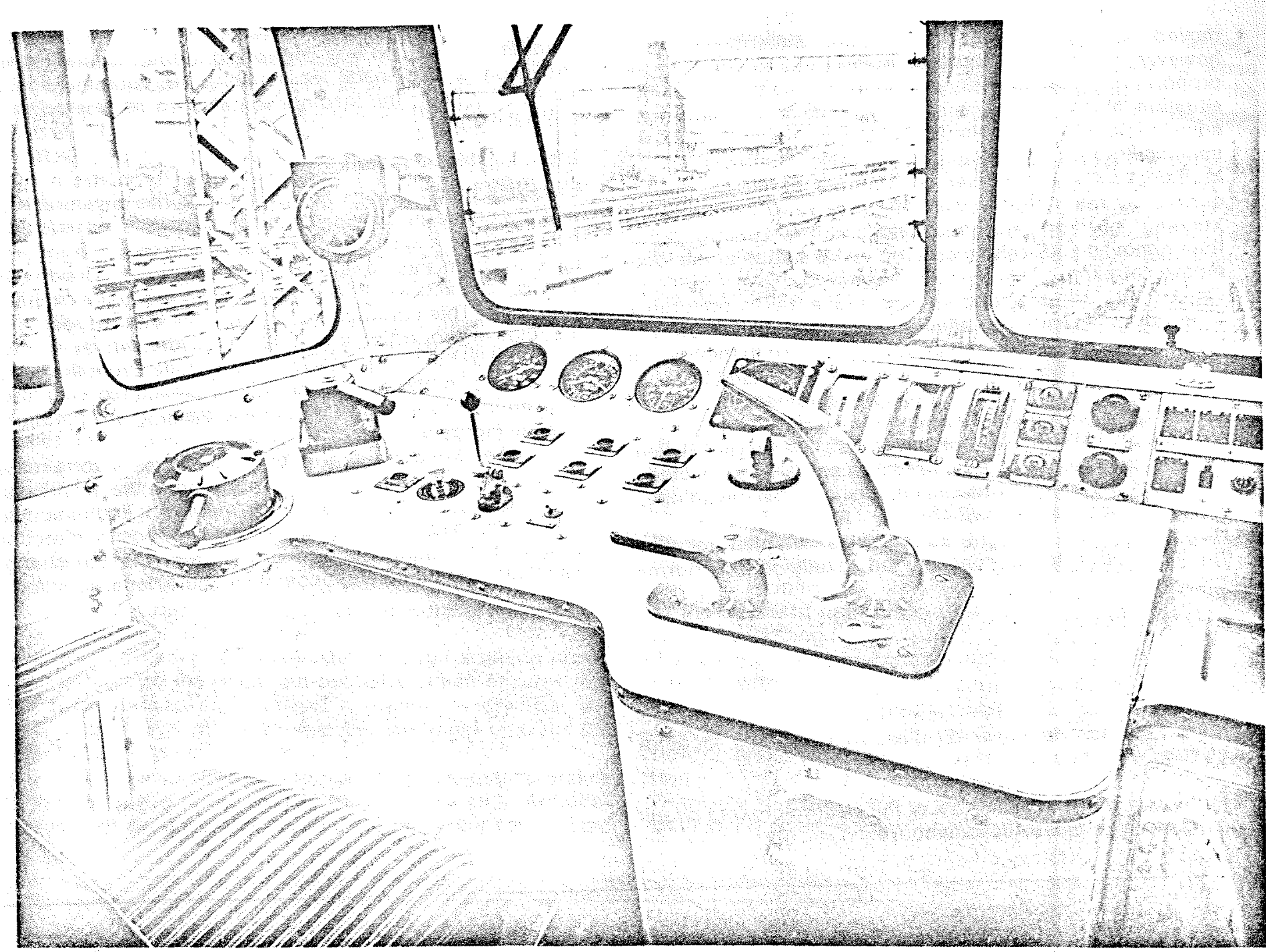
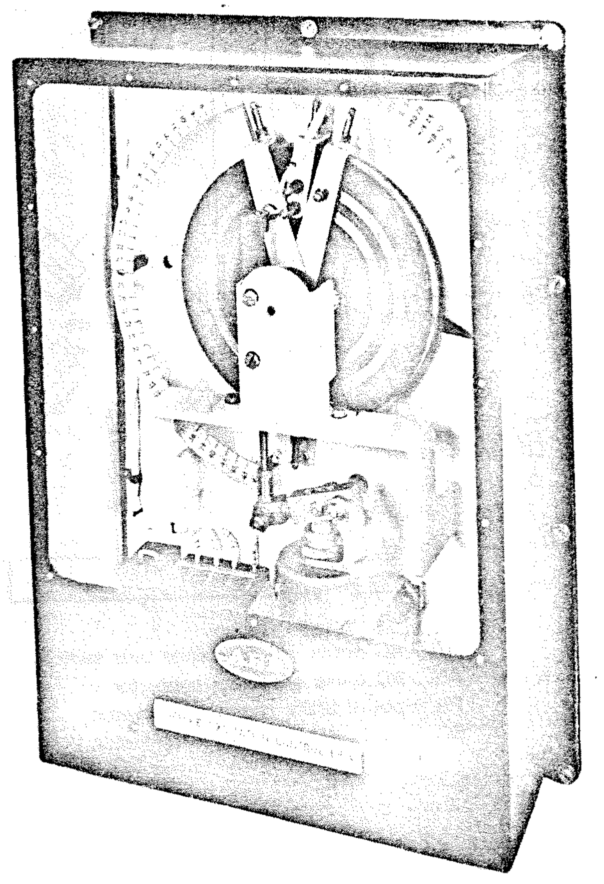


Figure 3. The drivers control desk showing the positions of the various controls on a standard (unmodified) class AL5 locomotive.

Figure 4. The brake excitation controller showing brush arms and disc.



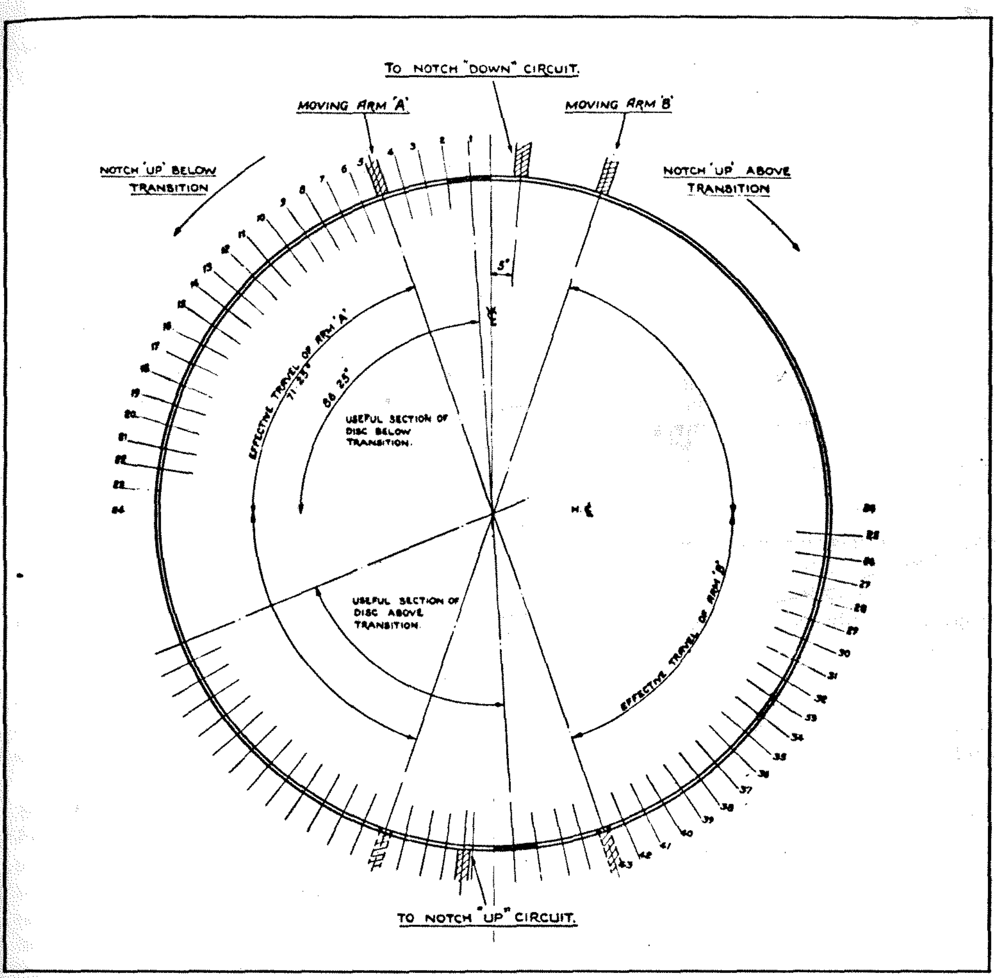
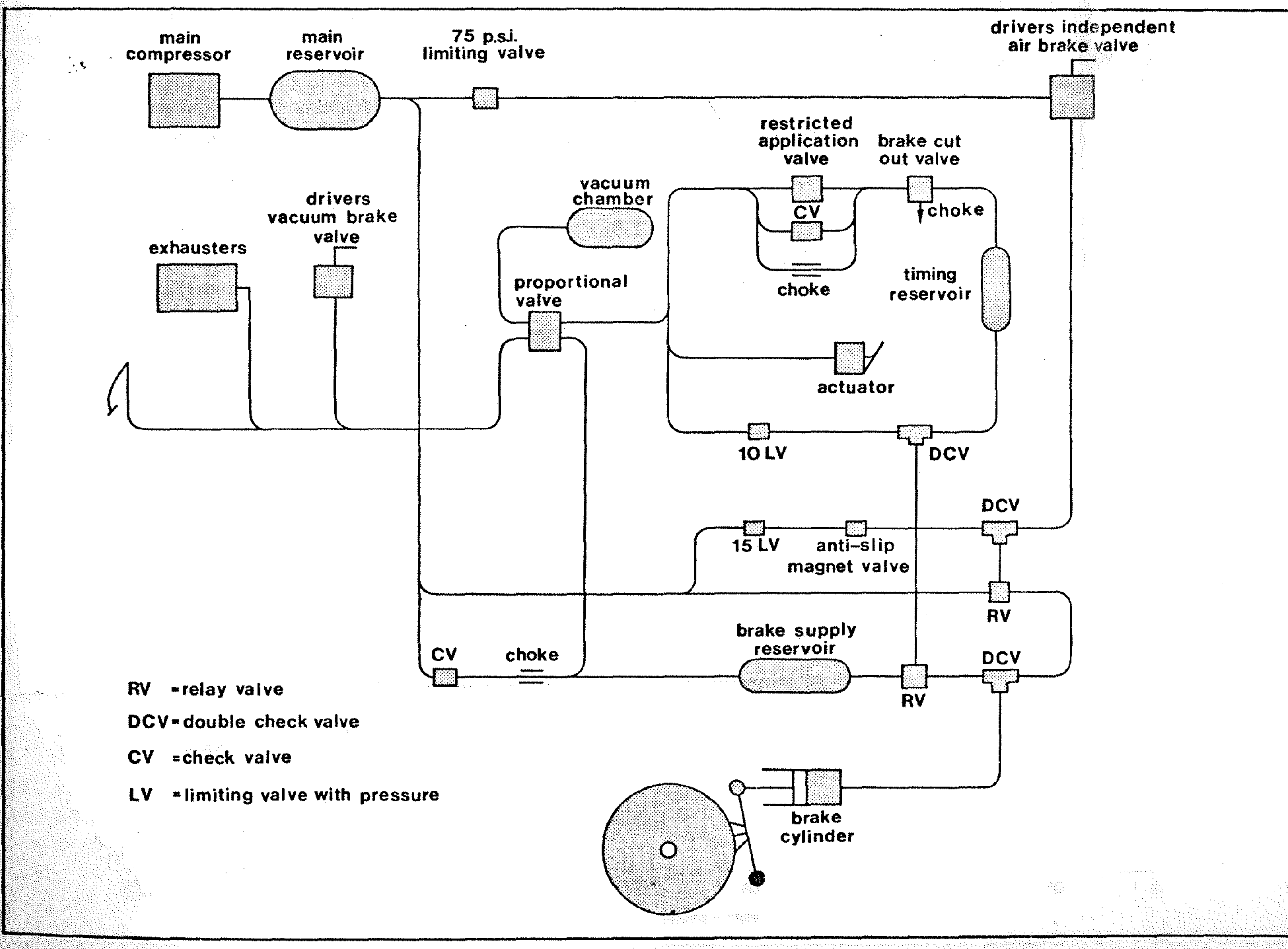
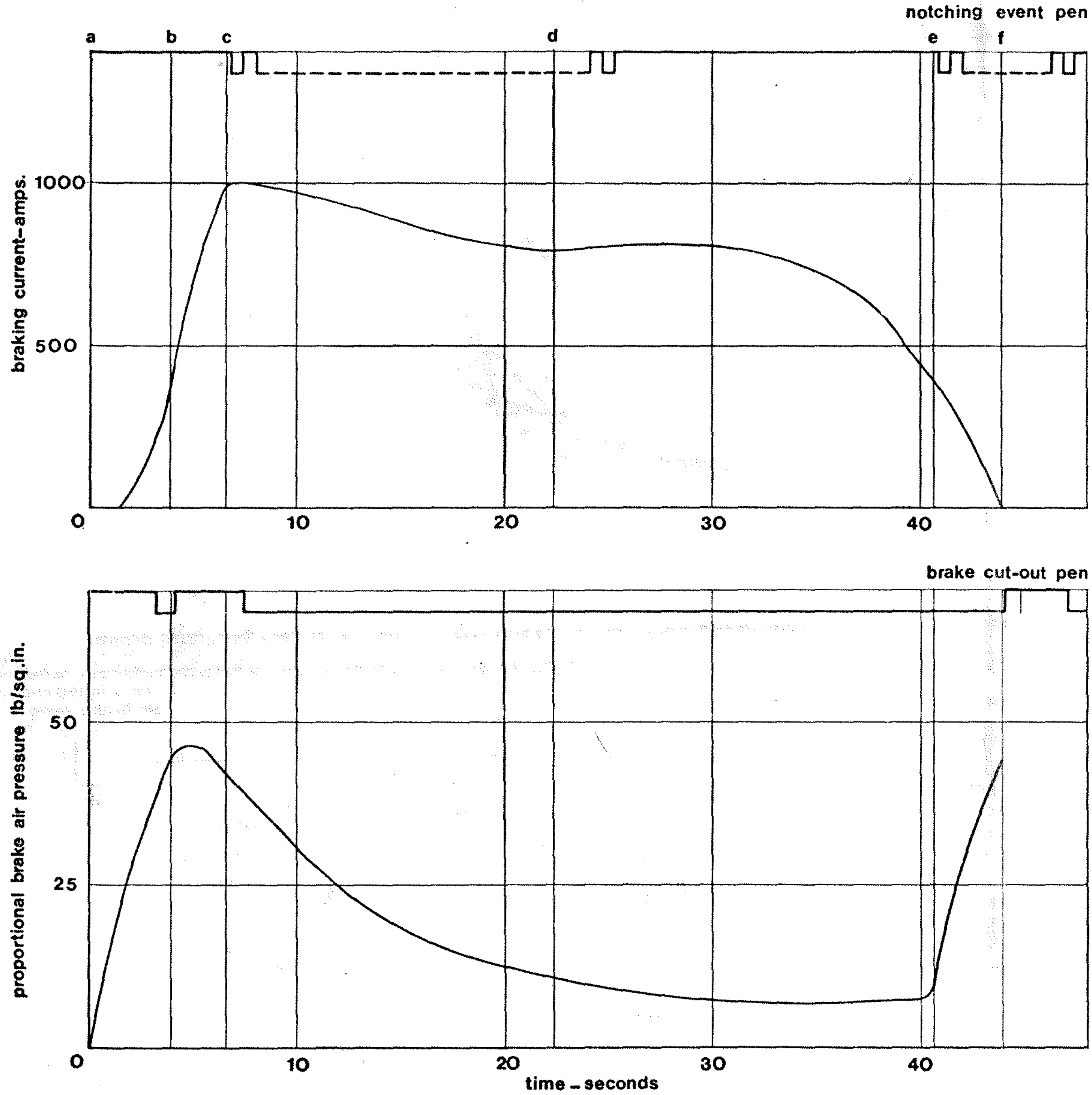


Figure 5. A diagram showing the operation of the brake excitation controller.

Figure 6. A simplified schematic diagram of the modified air system associated with the rheostatic brake.





a start of brake application
b proportional brake cut-out (relays a pick-up)
c notching stops relay b picks up
d notching recommenced
e proportional brake reapplied
f standstill

AEI incorporate transformers with a split secondary winding, one of which is tapped and reversed during the notch up sequence to buck or boost the other. The tap changer, therefore, reverses half way through the sequence and this reversal is known as 'transition'. One arm is used when the tap changer is below transition and the other when above.
The supply is transferred automatically by an existing relay which is energised above transition. The disc which is driven through a 4:1 reduction gear has on its periphery two conducting brush tracks of equal length, with insulated gaps between them. One track is connected to the 'notch up' circuit and the other to the 'notch down' circuit by fixed brushes. Depending on which track through which the effective moving arm is conducting, the camshaft notches up or down until the circuit is broken when a dead section coincides with the moving arm brush. Arcing between the brush and tracks has been completely eliminated by the use of small 'Metrosil' discs connected across them.
The original driver's power-brake switches are replaced by standard relays normally in the 'Power' position. The relays are energised by the closing of the circuit set-up switch, which is energised by the standard contacts in the drivers brake valve, made in the 'application' position in connection with the restricted application magnet valve. These relays isolate the vacuum control governor and the various tap-changer control circuits from the Power Handle, and also connect the brake excitation controller in circuit.

Air Brake System Modifications
An additional cut-out magnet valve is introduced between the proportional valve and the timing reservoir in the proportional brake supply to cut out the brake when the rheostatic brake reaches the setting of Relay 'A'. The exhaust from the brake cut-out valve is piped to a convenient point to allow adjustment of brake release time by choke changing during tests.
A by-pass feed to the brake cylinders from the proportional valve is piped through a 10lb/in^2 (0·7 kg/cm^2) limiting valve to retain the brake blocks against the wheels during rheostatic braking.
The actuator air supply is piped directly from the air outlet of the proportional valve.
A simplified air schematic showing the relevant pipework is given in Figure 6.

Tests
Observations were made, both on the locomotive and on the train of the effect of the changeover from air to rheostatic braking and back again during a full application, but no surging on the locomotive or train was apparent.
Comparison tests were carried out making timed and measured stops from various speeds with the automatic rheostatic brake and the standard proportional brake in turn. The comparison tests, which were made to prove that at no time was the automatic rheostatic brake inferior to the proportional air brake, were run over the same sections of track so that any effect of gradient or curvature would be the same in each case. The tests were made with the locomotive running light to obtain a clear comparison and eliminate the braking effect of a train. It was proved that at the higher speeds the minimum stopping distance was reduced in some cases by as much as 30% when using the automatic rheostatic brake. At speeds below 30 m.p.h. (48 km/h.) the improvement was marginal, as the initial air brake application slowed down the locomotive so quickly that the rheostatic braking had insufficient time to build up to a useful value. However, the automatic rheostatic brake will be extremely useful at this speed with unfitted or partially fitted trains when more time is available for its effect to build up.
Comparison tests were also carried out to simulate the driver applying the brake when the tapchanger was at the position where the longest delay is experienced before it has wound down and the rheostatic brake has been applied. The failure of a tapchanger motor supply fuse, when the rheostatic braking current was just sufficient to hold in the voltage sensitive relay 'A', was also simulated. In this case the proportional air brake could not be applied immediately (the independent straight air brake was, however, still available if necessary). In neither of these cases was the stopping distance inferior to that measured when using the proportional brake.
Exceptional conditions that were thought likely to produce the most severe shocks in the train, when braking at high speed, such as overhead line failure and running into a neutral section with consequent loss of traction motor excitation, were simulated, but little more than slight surges were experienced either in the cab or in the train. Certainly worse shocks are not uncommon in everyday service when travelling

≪Figure 7. Typical braking current and air pressure characteristics for trial locomotive running as light engine making a full application from 90 m.p.h. (145 km/h.).

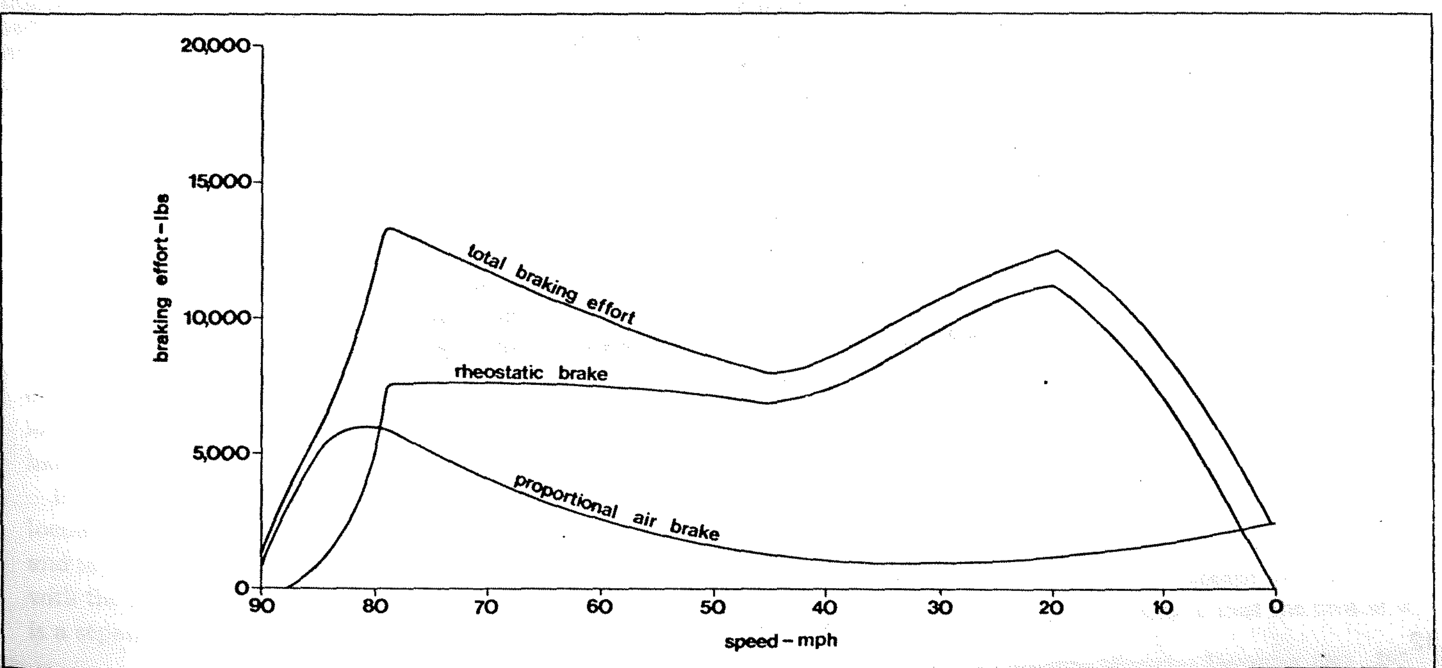


***Figure 8.** Approximate total and component braking efforts for a trial locomotive running as light engine making a full brake application from 90 m.p.h. (145 km/h.).*

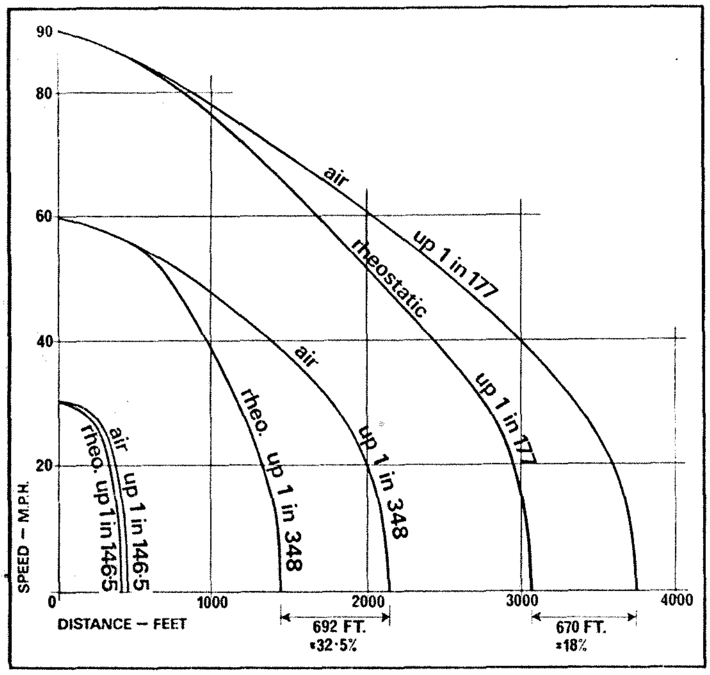


Figure 9. Comparative stopping distances recorded on the trial locomotive running as light engine with full brake applications from 90 m.p.h., 60 m.p.h. and 30 m.p.h. (145, 97 and 48 km/h.).

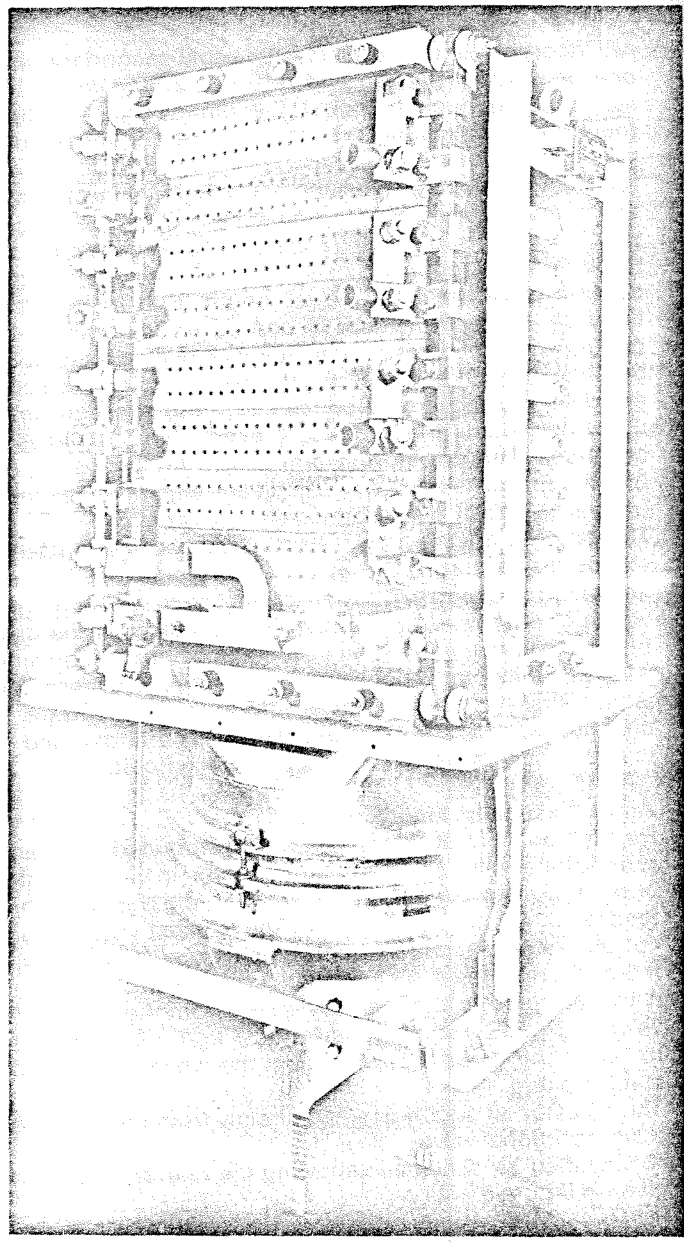


Figure 10. A.E.I. Rheostatic Brake resistor and fan assembly as fitted to an AL5 class locomotive.

in a mixed rake of vehicles where some are fitted with direct admission valves and some without.

The lack of severe shock is attributed to the 10 lb/in² (0·7 kg/cm²) pressure applied to the brake cylinders. This retains the brake blocks against the tyres and so eliminates the time that would otherwise be lost in moving the brake cylinder pistons when the air brake is re-applied on the locomotive following the loss of rheostatic braking.

Partially fitted as well as loose coupled unfitted freight trains were also attached and tested with much the same results. It was found that any slight surge which might occur could be eliminated by adopting the common practice of making a small 'independent' brake application while controlling the train on the vacuum brake valve.

A recording ammeter and a traingraph machine were operated during the stopping trials. A typical result is shown in Figure 7 for a stop from 90 m.p.h. (145 km/h.).

A calculated combined braking characteristic and its components are shown in Figure 8. The characteristic is necessarily approximate due to the uncertainty of the coefficient of friction incorporated in the air brake component, but it does show the trend. The air brake curve has been calculated on the basis of Galton's tests on the decline of the coefficient of friction due to heating.

Figure 9 shows three actual stops recorded from 30 m.p.h., (48 km/h.) 60 m.p.h., (97 km/h.) and 90 m.p.h. (145 km/h.) and demonstrates the reduction in stopping distance with the automatic rheostatic brake. This reduction can be partly controlled by adjustment of the brake excitation controller and current sensitive relay 'B'. These have been set to give the greatest reduction possible without overloading the traction motor armatures and braking resistors.

The prime object of the experiment, however, was to demonstrate the saving in brake block wear.

Results

Although the trial locomotive had only been in service some months, the indications of increased brake block life soon became apparent and were most encouraging. From measurements of block wear taken over a known mileage, the indications were that the mileage between block changes was likely to be increased from the normal 6,000 miles (9650 km) to approximately twice that distance.

So successful did the trial locomotive scheme prove the British Railways Board decided to incorporate an automatic rheostatic brake based on similar principles in the design of the one hundred type AL6 25 kV a.c. locomotives.

Since this experimental scheme was tested, experience with automatic rheostatic braking fitted to the class AL6 25 kV a.c. locomotives has led to further developments which it is hoped to describe in a future article.