GEC TRACTION

Inertia simulation on traction combined test

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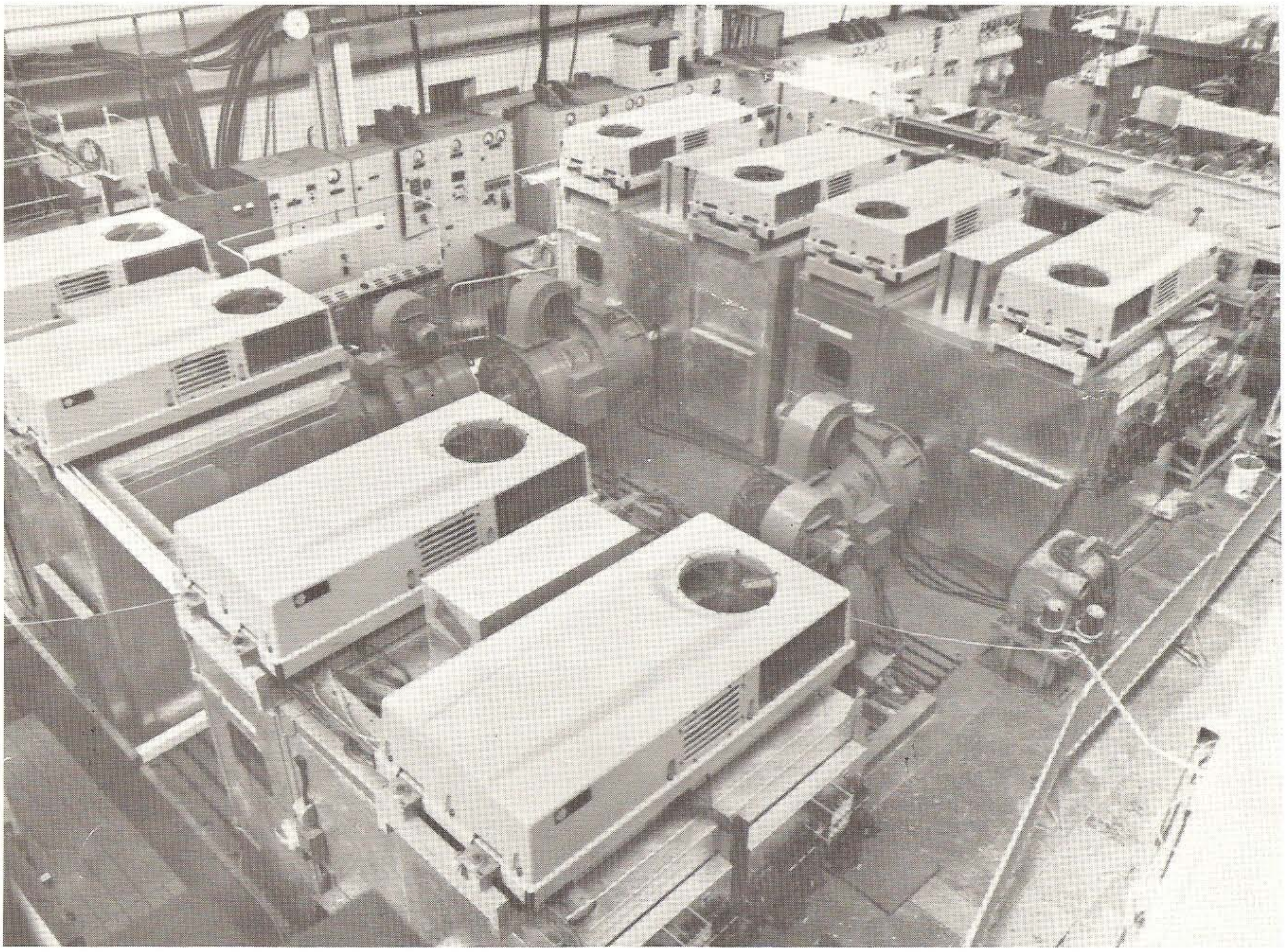

1. INTRODUCTION

GEC Traction Limited has extended its combined test facilities at Preston with the installation of inertia simulation loading equipment. This test bed is used for testing, *as a complete system,* the traction motors and control equipment for a railway vehicle. The traction motors are coupled to a loading system which should, ideally, have the same characteristics as the load the motor will have in service conditions if all tests are to be valid.

Previous arrangements used a combination of electrical and mechanical loading by coupling the traction motors to flywheels and dc machines operating in a manually controlled Ward-Leonard connection. Although this load enables full torque and power tests to be made, the inertia was both low and fixed, thereby restricting dynamic testing.

The requirements of today's railway systems often demand traction control equipment containing many control loops and sequences which cannot be fully tested without realistic dynamic loading of the traction motors. The inertia simulation equipment, described in this article, not only presents an inertial load to the traction motors, but it can also vary the load according to the gradient profile of the route the vehicle will use in service. Route data including gradients, coasting points, speed limits, and station stops is available via a data link from the Company's computer at Trafford Park. An operating mode is incorporated which allows the equipment to be *driven* automatically over the route.

Other features include the loading effect due to air brakes and an adhesion simulation which allows both wheelslip and wheelslide protection equipment to be tested.

2. LOADING SYSTEM

Two possible traction motor loading arrangements to simulate train inertia are:—

(i) Mechanical — using flywheels.
(ii) Electrical — using machines controlled to simulate inertia.

Although an arrangement using flywheels is the more simple, it does not allow easy changes of inertia, and the effects of gradient and train resistance are not readily incorporated. Furthermore, the simulation of a heavy freight train requires large flywheels which, even if practical, are not desirable.

The use of electrical machines for loading requires conversion equipment to both absorb and supply energy, but the inertia and loading effects are incorporated in the machine control system. A computer allows simulation of the dynamic equations and changes are made easily via a keyboard. Previous test rigs used manually controlled dc loading machines coupled to flywheels which provided some inertia. The loading machines were connected together via speed synchronising shafts which restricted the mechanical layout.

The new arrangement uses four dc machines (boosters) arranged electrically in two identical groups. The two armatures are connected in series and are supplied from another dc machine coupled to an induction machine (supply set). All three dc machines have separately excited fields supplied independently from dc thyristor drives. This Ward-Leonard arrangement allows power flow in both directions thus enabling both motoring and braking duties to be simulated. No synchronising shafts are required between boosters as the speeds are equalised by field control.

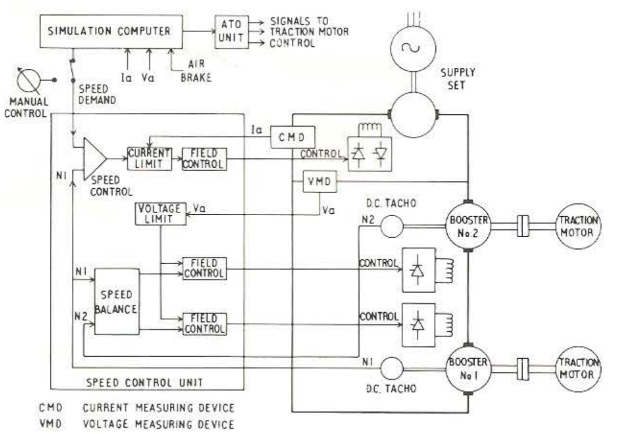

Fig. 1 Simplified block diagram of the inertia simulation system.

The booster machines are English Electric type EE836/1B with the following characteristics:—

Maximum Torque	10,000Nm
Maximum Speed	2000rev/min
Continuous Power	950kW
Inertia (including flywheel)	107Nm.s^2

The torque rating is sufficient to load a large locomotive traction motor of typically 10,000Nm via a direct coupling. Rapid-transit stock traction motors will usually have a higher top speed than the booster but a torque of typically only 3400Nm. Two such motors can be coupled to each booster via gearboxes with right-angle shafts.

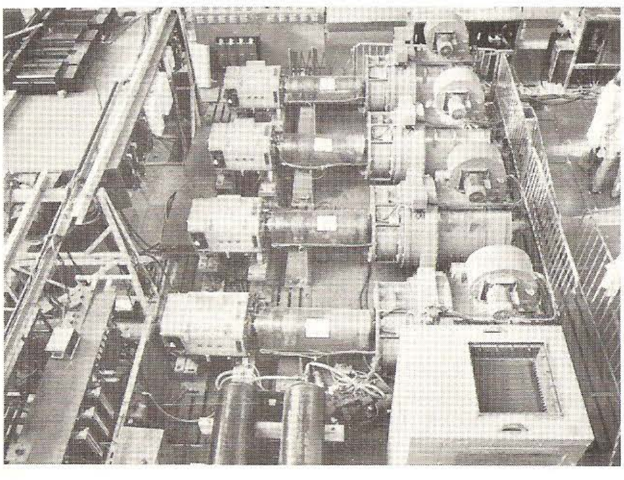

Fig. 2 A view of the test bed as seen from the control cabin. The main boosters are on the right, the four traction motors are centre-left and the control equipment cases are far left.

An alternative scheme would have been to replace the supply set with a thyristor converter which has a faster time response compared with the field control system. However, the supply sets were already installed and the flywheels incorporated within the boosters provide sufficient energy storage to make the field control time response satisfactory.

3. SPEED CONTROL

Booster speed is controlled by a master-slave system in which the speed of one booster (the master) is made equal to the *speed demand* by control of the supply set field, and the speed of the other booster (the slave) is made equal to the master by control of the booster fields. Booster speed is measured by a dc tacho-generator belt driven from the booster shaft.

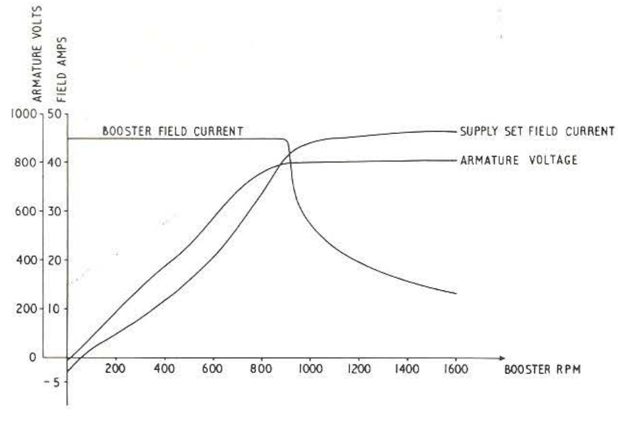

Fig. 3 Booster control characteristics.

At very low speeds, with the traction motors motoring, both booster fields are set to full excitation (although one field may be weakened to equalise speeds), and the supply-set field current will be reversed to cause sufficient armature current to circulate to generate an opposing torque. As the speed rises, the supply set reverse field current is reduced to zero and is then increased in the forward direction. When the armature voltage reaches the limit for the supply set, the booster fields are weakened to maintain that voltage as the speed rises further. At all times, however, the speed control system for the master booster acts on the supply set field.

When the circulating armature current is small, the booster torque is also small and it may not be possible to produce sufficient torque difference by field control to synchronise speeds. Instead, electro-pneumatic friction brakes are applied to the faster booster to equalise the speeds.

3.1 Current limit

Armature current is limited to a maximum of ±2200 amps at low speeds and can be further limited at higher speeds to restrict the maximum power. Current and power limits are usually determined by the particular supply set in use and so all levels which may vary between supply sets are located on one plug-in electronic module. A range of preset modules are marked with the supply set number to facilitate change of supply set.

Under normal operating conditions the armature current limit is not reached, as the limit circuit overrides the speed control and the inertia simulation would be incorrect.

3.2 Manual operation

When the equipment is operating in the inertia simulation mode, the 'speed demand' signal will be derived from the simulation computer. However, as it is easier to perform some tests at constant speed a manual operating mode is available in which the 'speed demand' signal is derived from a potentiometer. Speed is automatically held at the set level for all loads which do not exceed the current and power limits described above.

4. INERTIA SIMULATION

The equations for inertia simulation and loading are programmed on a microcomputer (MINC). The main program calculates train speed and outputs this to the speed controller as the 'speed demand'. In addition there are options available which include adhesion simulation and a route profile.

Associated with the simulation programs is a range of options which are concerned with data entry and correction, and the transfer of route profile information from the VAX computer at Trafford Park.

All the programs are linked together by a selection procedure which presents the operator with the options available at each stage.

4.1 Train speed

The fundamental equation for the simulation calculates train speed by integrating nett tractive effort divided by train mass.

ie $$\text{Speed } V = \int \frac{T}{M}\, dt \qquad (1)$$

where T is the nett tractive effort on the train of mass M.

The nett tractive effort T is given by:—

$$T = TE - T_g - T_r - T_b \qquad (2)$$

where TE is the traction motor tractive effort.
T_g is the resistance due to gradient.
T_r is the train resistance (due to friction and air resistance).
T_b is the brake effort from the friction brakes.

Linear units are used in these equations to conform with traction practice. However, as the test bed is a rotational system only, conversions are made on the signals between the test bed and the MINC.

Train speed is updated every 0.3 or 0.4 second depending on the options chosen.

4.2 Tractive effort

The motor tractive effort (TE) is measured 'live' off the test bed for each update of the train speed. In this way the simulation program is 'driven' by the traction motors and, at all times, the performance of the equipment can be compared with that predicted.

TE is calculated from booster torque which itself is calculated from armature current and voltage. At low speeds, when the booster fields are at constant excitation, torque is calculated from armature current. Once the armature voltage is reached the booster fields are weakened and, because of the non-linear field system, torque is then calculated from power divided by speed. Since the boosters are a fixed part of the installation, the torque measurement is independent of the type or number of traction motors used.

4.3 Gradient

Track gradient is set either manually, or automatically if the track profile is used. The effect of track curvature is also taken into account by this term (T_g).

4.4 Train resistance

This is given by the equation:—

$$T_r = A + BV + CV^2$$

where A, B, C are constants for a given train formation and depend on whether the train is outside or inside a tunnel. Five sets of constants, each associated with a train mass, can be stored in the MINC and any one can be selected from a switch.

4.5 Air brakes

The effect of air-operated friction brakes is simulated by an equivalent electrical loading by the boosters. The value of T_b in equation (2) is obtained via a pressure transducer sensing the air pressure which would have been applied to the brake blocks. If the air brake equipment itself is not available on the test bed an equivalent signal representing brake pressure is generated and used instead.

4.6 Calibration

Since the boosters, traction motors and gearboxes have both inertia and losses, the calculation of torque and tractive effort from booster voltage and current does not represent the true traction motor output. A calibration program is incorporated which runs the boosters at a steady speed to measure losses, and then at a constant deceleration to measure inertia. These constants are then used by the simulation program to correct the torque calculation. The calibration program is normally run once at the start of a combined test.

5. ADHESION

Wheel to rail adhesion is simulated to allow wheelslip and wheelslide correction equipment to be tested. The adhesion level A is the percentage of the weight on an axle which can be transmitted as tractive effort:

$$A = \frac{TE_{max} \times 100\%}{M_a \times g}$$

where TE_{max} is maximum tractive effort transmitted by the axle.
M_a is the mass on the axle.
g is the acceleration due to gravity.

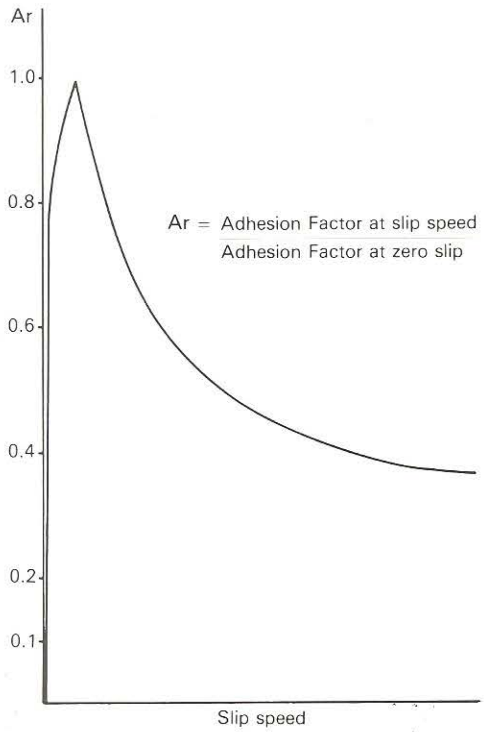

Fig. 4 Maximum adhesion (ie maximum transmittable tractive effort) occurs with a very small slip speed (micro-slip). As the slip speed increases the adhesion factor falls significantly.

The simulation program calculates the maximum transmittable tractive effort for adhesion level selected and the train speed. This is compared with the tractive effort the traction motors are producing and if the maximum level is exceeded the difference causes a nett torque to be applied to the wheel and axle system. Once this condition exists the wheel speed is calculated separately from the train speed. If the motors are accelerating the train, and the maximum tractive effort is exceeded, the wheels will begin to accelerate at a higher rate than the train and the speed difference (slip speed) will increase. As the slip speed increases, the adhesion level reduces dramatically thereby reducing the transmitted tractive effort and increasing the nett torque applied to the wheel. This is an unstable system and the motor torque must be reduced to prevent overspeed, although the simulation program will limit the booster speed should the wheelslip correction equipment fail to operate.

If the motors are braking the train, and the maximum braking effort is exceeded, a similar sequence is followed except that the wheel speed is reduced below the train speed and the wheel can eventually lock if braking effort is not reduced.

When the maximum tractive effort is exceeded, the 'speed demand' signal to the booster speed control unit is no longer the train speed but the wheel speed V_W, which is calculated as follows:—

$$V_W = \frac{1}{M_W}\int (TE - TE_{max})\ d_t + V_O$$

where M_W is the effective mass of the wheel and axle system referred to the rail.

V_O is the train speed prior to the wheelslip.

Train speed continues to be calculated by equation (1) but the tractive effort is T_{max} and not the motor tractive effort TE.

6. ROUTE PROFILE

A route profile option allows simulation of the duty the train will experience in service. The profile contains gradients, coasting points, speed limits and station stops, arranged in order of distance from some datum. The information, which is used initially for the design of the vehicle, is stored in a VAX-11/780 computer at Trafford Park. When the profile data is required on test bed, a data transfer option is selected and the MINC will then make the transfer via a data link over a GPO line.

In the typical route profile option shown, train speed, calculated by the inertia simulation program, is integrated to give distance travelled. When the train reaches a point specified on the profile the data is read and the appropriate action taken. Gradients are used for inertia simulation calculations, but the other information is sent out from the MINC to an Automatic Train Operation (ATO) unit.

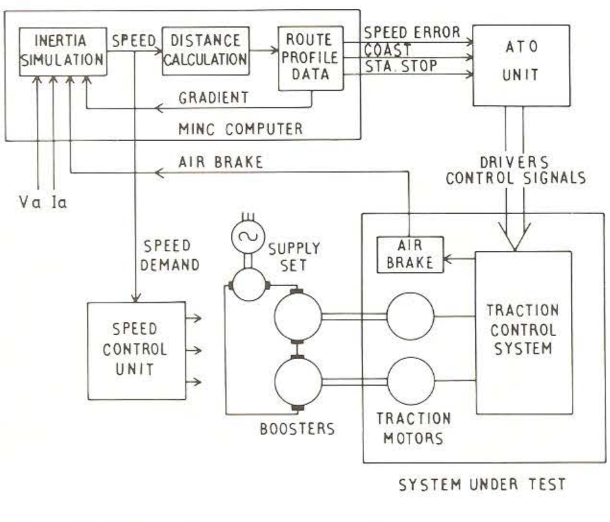

Fig. 5 Block diagram of the route profile option.

The ATO unit effectively takes the place of the driver and controls the equipment under test according to the signals from the MINC. Its main function is to maintain the train speed at the speed limit defined by the profile. However, it will also respond to coast signals which require all motoring power to be switched off, and station stop signals which require the brakes to be applied to standstill.

A typical section of a route profile test is shown in Fig. 6, the equipment being tested being a 1500V dc chopper supplying four traction motors. The driver's master controller has four motoring notches and seven steps of braking using a combination of dynamic on the motor car and air on the trailers.

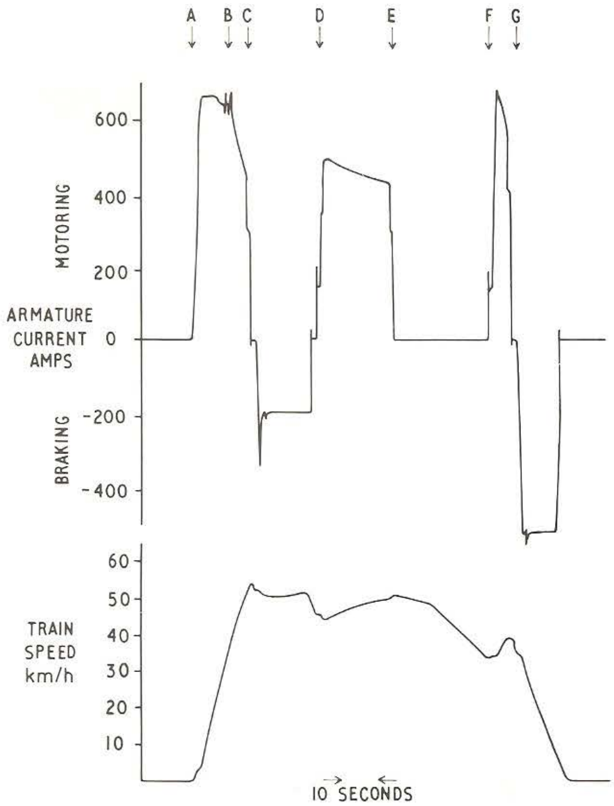

Fig. 6 The results from a very small part of a typical route are shown in this diagram. At point A power is switched on and the train accelerates down a 3.1% grade with a line speed limit of 50km/h. Weak field contactors are closed in two stages at B. Train speed exceeds the speed limit and at C brake is applied to hold at 50km/h. However, the gradient changes to 3.5% uphill and at D motoring has been selected to maintain speed. At E coasting has been demanded and the gradient reduces to 0.5% up followed by a 2.4% up causing a sharp deceleration. Coasting is cancelled at F and motoring reapplied until station stop is requested and at G the brakes are applied to standstill on a downhill gradient of 3.3%.

Although only the main gradients have been identified in this illustration, the actual profile used on the test bed contained 13 gradient changes over this section and a total of 59 different sections for the complete profile. Time from end to end is 2 hours 10 minutes including 20 seconds stop at each station.

7. COMPUTER PROGRAMS

The programs are written in BASIC on a DEC MINC microcomputer. A 'menu' format leads the operator through the various options which are split between DATA and SIMULATION. **Data** is concerned with both the constants for the equipment on test (eg mass, gear ratio, train resistance) and also the route profile information and its transfer from the VAX computer. **Simulation** contains the options for inertia simulation using the constants and profile information from **data.**

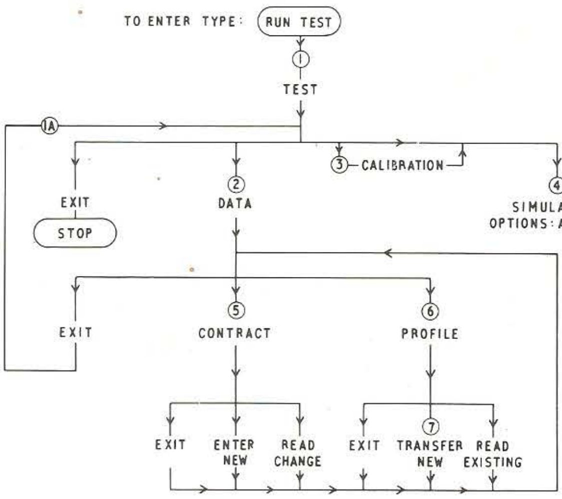

Fig. 7 Inertia simulation system 'map'.

The options of **simulation** are contained in sub programs which are merged with the main program using the 'overlay' technique.

When the simulation is running, information displayed on the vdu is updated each cycle of the program.

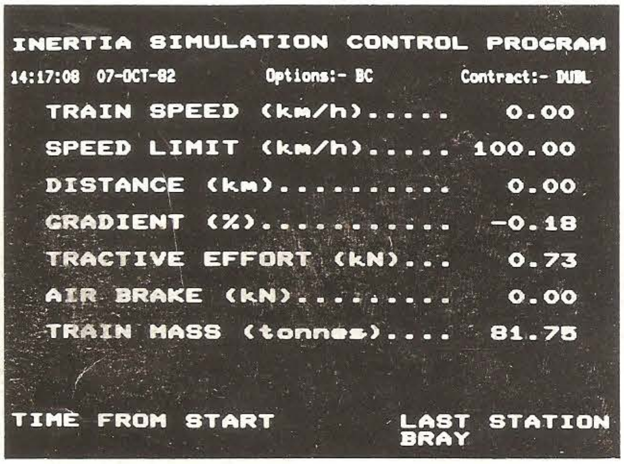

Fig. 8 Typical information displayed on a vdu in the control room.

8. PROTECTION

The boosters are protected from **overspeed** by mechanically operated switches and also by a detection system sensing the tachogenerator output.

Since the loading system is used for testing equipment, there is a chance of excessive torque being generated by the traction motor due to a control fault. In order to protect the machines and gearboxes **torque limiting couplings** are installed which disengage if the torque exceeds the limit.

Although the armature and field currents are controlled by closed loop systems, separate **overloads** are incorporated to trip the armature and field contactors in the event of a control failure.

Emergency shut-down buttons are located at strategic positions to cut off all power and apply the booster friction brakes.

9. TEST PROCEDURE

Although each equipment will require special tests, the test programme normally includes the following stages.

Firstly, the control sequences are checked with the power circuits isolated.

Power tests follow, often beginning with a resistive load in place of the traction motors.

Fig. 9 The control room which overlooks the test bed.

Once traction motors are connected the control sequences are checked and the stability of each control loop examined. Initially, tests are made with constant speed loading.

Finally, the equipment is tested with inertia simulation over the route profile(s) to check for correct operation, maximum equipment temperatures, and energy consumption.

The ATO unit allows prolonged testing over the route profile and 18-hour tests have been performed on several equipments.

10. CONCLUSIONS

As control systems become more complex, it is even more important to ensure that a new equipment is thoroughly tested before production commences so that problems on site are minimised. The inertia simulation equipment has improved test bed facilities by bringing the railway track one step nearer to the test bed and allows a wide range of operating situations to be simulated. The ATO unit has been particularly useful for prolonged tests over route profiles which require up to 18 hours continuous running.

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