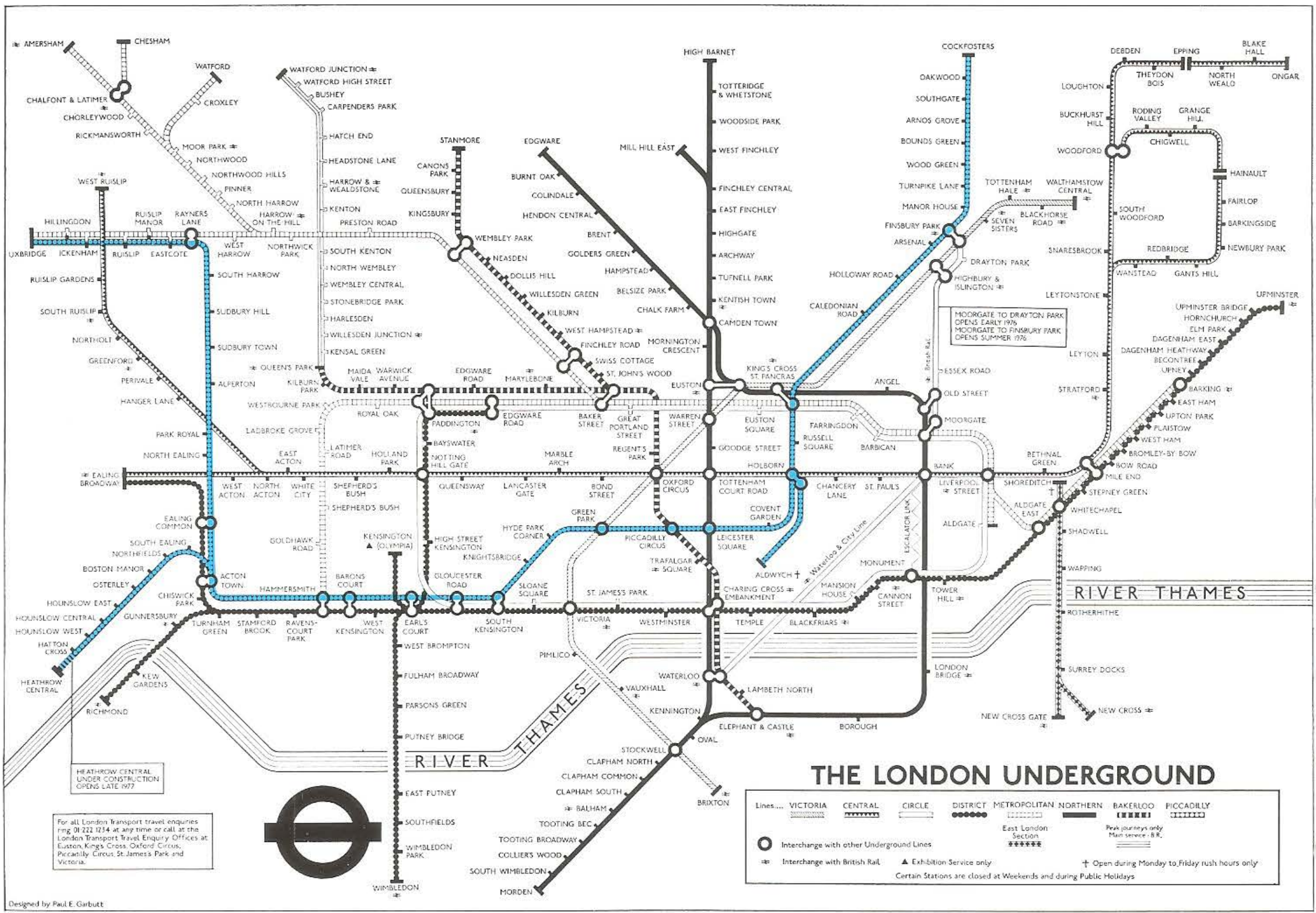
Vehicles for
LONDON TRANSPORT'S DEEP TUBE LINES
equipped by

GEC
TRACTION



For all London Transport travel enquiries ring 01-222 1234 at any time or call at the London Transport Travel Enquiry Offices at Euston, King's Cross, Oxford Circus, Piccadilly Circus, St. James's Park and Victoria.

Designed by Paul E. Garbutt

GEC and its predecessors have met London's Tube and Underground Railway requirements since the earliest electrification in the 1890's. Whilst present day designs embody conventional techniques, chopper-equipped sets are under service trials. Robust low-maintenance philosophy perpetuated in design development of equipment for LTE.

LT latest deep-tube line stock designed for London Airport metro service

London Transport's latest stock to enter service for its 'deep Tube' lines is the '1973 Tube Stock' working on the Piccadilly Line.
It is presently terminating at Hatton Cross on the perimeter of Heathrow Airport but next year (1977), on completion of the Heathrow Extension (1), it will run through to Heathrow Central and service the airport for which the new line has been built. The new fleet will comprise 77 six-car trains and 21 three-car trains.

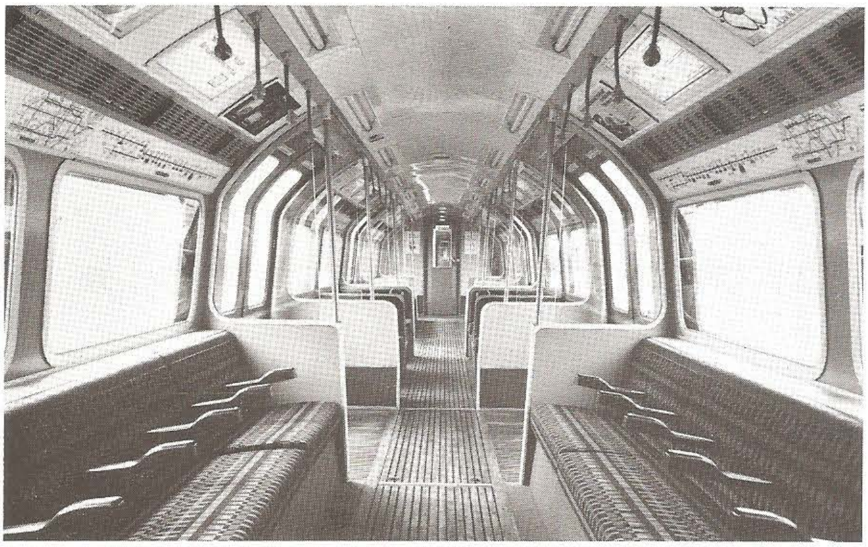
The LT railway system includes the world's first underground urban passenger railway and parts have been electrified since 1890, and since 1960 the whole of the network. GEC Traction Limited (and its predecessors) supplied locomotives for that first electrification and have been equipping LT multiple unit trains and electric locomotives almost continuously since then. The extent of this will be appreciated from the Table on page 6.

The extent of present day London Transport system will be seen from Fig. 1 and is divided into 'Surface' lines and 'deep Tube' lines, the former constructed largely by cut-and-cover techniques. The deep Tube lines, however, are not constrained by surface contours and extend to considerable depths below the surface—maximum depth 67 m (221 ft) below ground level—including passing under the River Thames in several places. Much of the below ground part of the Tube network was constructed in the early part of the 20th century and at that time a tunnel diameter of 3.6 m (12 ft) was the largest considered practical. In addition, and despite the fact that the tunnels were usually

Fig. 1. *London Transport Underground railway system, the inner network of which runs in tunnel, either deep-bore tube or cut-and-cover.*

(1) Cut-and-cover and bored tunnel construction adopted for L T tube extension to London airport. Rail Engineering International, April/May 1975.

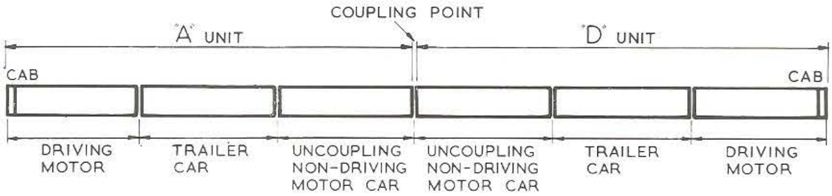
Derived from an article originally printed in Rail Engineering 1976.



Interior of a 1973 Tube stock trailer car.

London Transport railways—general particulars

Total route	401 km
comprising:	
Cut-and-cover tunnel	38 km
Deep Tube tunnel	119 km
Surface lines	224 km
Number of stations served	278
Passengers carried	
weekday	2.1 million
annual	636 million
Annual passenger-km	5140 million
Annual car-km	306 million
Rolling stock:	
Power cars	2952
Trailer cars	1366



▲ **Fig. 3.** *Piccadilly Line '1973 Tube stock' train formation made up of two three-car sets with intermediate semi-permanent coupling.*

General particulars of six-car set

Length	10 700 mm
Tare weight	152 tonne
Crush loaded	229 tonne
Seated passengers	264
Total passengers	1210 crush loaded
Maximum speed	100 km/h
Maximum demand	3800 ampere—crush loaded train

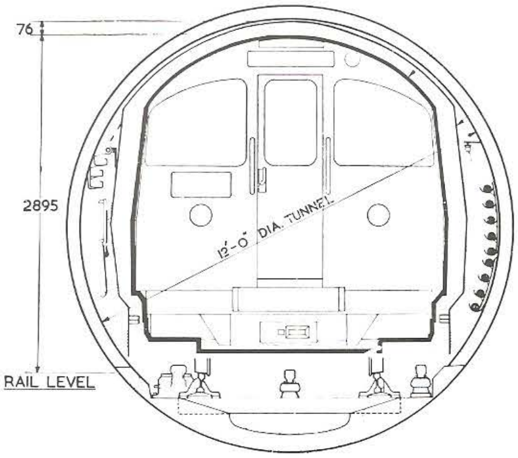


Fig. 2. *Structure and loading gauge for London Transport Tube stock.*

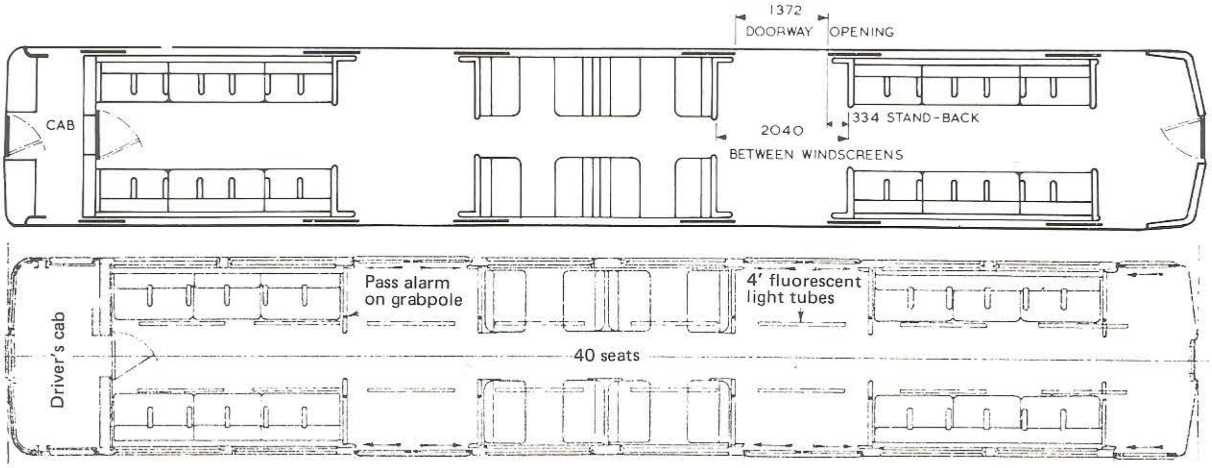


Fig. 4. *Seating layouts:*
(top) '1973 Tube stock'
Between windscreens 1973 mm
Standback 334 mm
Door opening 1372 mm
(bottom) Victoria Line STOCK
Between windscreens 1818 mm
Standback 222 mm
Door opening 1372 mm

well below the foundation level of existing buildings, it was felt prudent to follow the plan of the street network above (a policy which is now known to be unnecessary and no longer applies to present day Tube constructions). These twin constraints of a very small tunnel diameter and sharp curvature, however, resulted in rolling stock of unique construction and characteristics—the small loading gauge and the tight fit of the stock being well illustrated in Fig. 2.

The power supply is at a nominal 600 V dc, a common voltage for rapid transit/metro operators but London Transport is unusual in adopting a fourth-rail system whereby the electrical supply is separate from the running rail. This system was originally introduced to avoid the effects which might result from earth-return currents passing along the cast-iron tunnel segments. The nominal voltages are + 450 V (side conductor rail) and —150 V (centre return rail), but the system is floating electrically and, in the extreme, either rail can be the full 600-V potential relative to earth. This facility is used in some parts of the system where inter-running with third-rail British Railways electric multiple-units occurs and in these cases, although LTE trains use the centre rail, it is as effectively earthed as the running rails themselves. A further advantage of the 'floating' system is that a fault to earth from one pole still permits a train to be taken out of service whilst other trains continue to operate normally.

Because of the depth of the Tube tunnels below ground level, it has always been a Government requirement and LTE policy to adopt more stringent safety precautions than those for normal surface railways. Two features which illustrate these precautions are:

(a) no intercar power jumpers are permitted;
(b) there must be emergency lighting from batteries.

Reliability also is of paramount importance and is largely achieved by designing equipment with ample overload margins—an anticipated service life of 40 years is an additional benefit from this policy. The reliability of the PCM camshaft equipment (which has been progressively developed since its introduction to LTE in 1935) illustrates this point in that in 1974 (the last year for which figures are available) the recorded rate of failure was one per 2·7 million operations. With such a small average failure rate, a particular driver may only experience one once in many years, and to assist him in speedily identifying the problem a fault annunciator is fitted to the latest trains. With many types of faults it is permissible to move the train, but only at low speed—in these cases a sealed switch can be operated to permit the train to move and thus clear the track.

1973 Tube stock

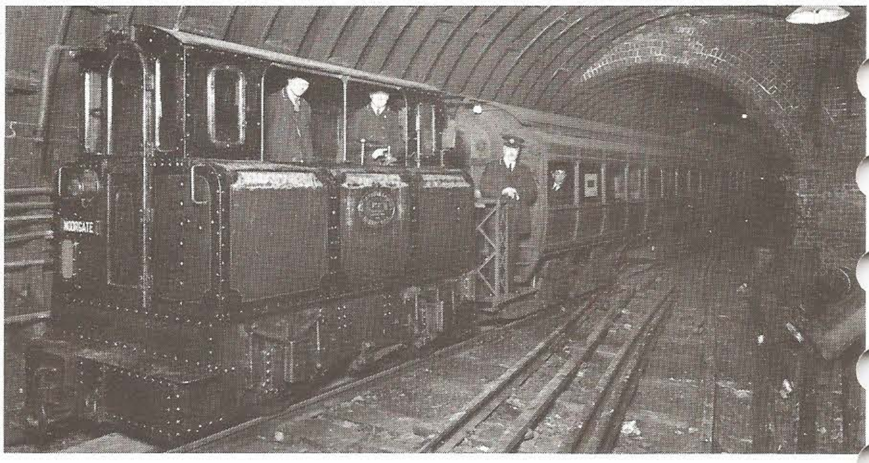
The trains consist of two similar three-car units with semi-permanent couplings between cars of a unit, the majority of which are equipped only with one cab at the outer end. However, to give greater flexibility of operation, 21 of the units have a second cab and all the 'non-driving' ends have a shunters' driving position for manouvering in depots.

The bodies are of aluminium with steel underframes. Seats are provided for 264 passengers and there is standing room for about 950 more giving a total of 1210 in a six-car train. Because these trains are designed to serve Heathrow Airport passengers with hand baggage must be provided for. However, it is clear from the loading gauge (Fig. 2) and interior view of the car that there is no room for conventional overhead luggage racks and large 'standbacks' have been provided therefore at each doorway. Standbacks have been common practice on LTE Tube trains for many years but those on this latest stock are much deeper than previously and total 20 m^2 of floor area per train which is available for luggage, without impeding the doorways, or additional standing room.

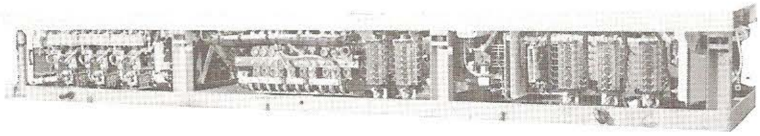
Performance

The Piccadilly Line from Cockfosters to Uxbridge or Heathrow Central presently serves a total of 50 stations in a route length of 63 km and this new fleet is expected to travel 53 million km annually or about 100,000 km/car which is a most impressive figure for a rapid transit/metro service. The performance required from these 1973 trains is higher than previous generations of tube stock and, to provide this, two-thirds of the axles are motored, as compared with half axles motored on other recent tube stock, and less than 36% on the oldest tube stock still in service. The 1973 stock power cars, however, account for 75% of the adhesive weight of an empty train.

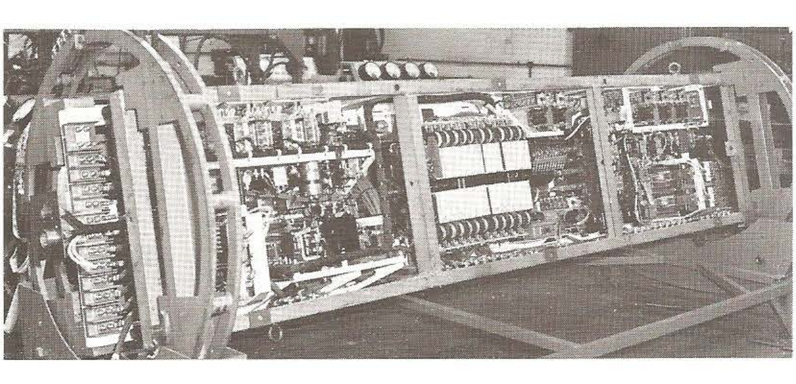
Load weighing sensed by the suspension deflection is applied both in motoring and braking and thus the desired rate of acceleration can be maintained at all conditions between tare and crush loaded. If there is a failure of the load-weighing device the system reverts to the equivalent of tare weight. Because of the different adhesion conditions in tunnel (central area) and open track (out of town sections) provision is made to select different rates of acceleration to suit prevailing conditions. The rates



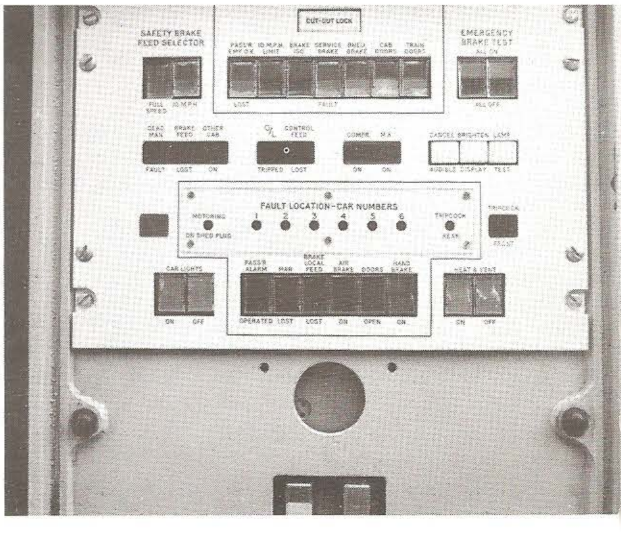
(Above) An early electric locomotive on London's first tube railway. Locomotives similar to this were supplied by GEC in 1890 and continued in service until the 1920s.



(Top left) Main equipment case showing the very shallow height. These have been mounted on cars with only 400 mm clearance between the underframe and the loading gauge.



(Bottom left) Equipment case on its manufacturing trolley showing the compact arrangement of the equipment.



(Bottom) Train Equipment Indicator Panel in the off-side console in the driver's cab whereby a fault can be located and remedial action taken to avoid delay.

are 1·15 m/sec² (2·6 mile/h/sec) 'high' and 0·7 m/sec² 'low' corresponding to 20% and 12% adhesion respectively.

The trains are also designed with different performance characteristics for 'in-town' sections, with lower speed restrictions and stations at close intervals, and 'out-of-town' sections, where higher speeds are permitted and stations are located further apart. Another complication arises in that initially the new trains must operate with the existing 1959 Piccadilly Tube stock which has a much lower performance capability and until the entire service is operated by 1973 stock the performance will be deliberately restricted. The four levels of performance:
initial 'in-town'—full field;
initial 'out-of-town'—weak field, 1st stage (75%);
future 'in-town'—weak field, 2nd stage (57%);
future 'out-of-town'—weak field, 3rd stage (42%).

Fig. 5 shows typical train resistances (both in tunnel and on the surface) for existing London Transport rolling stock, and the resulting speed/distance performance curves for 1973 Tube stock trains are shown in Fig. 6. In establishing the schedule, a provision has been allowed for 'make-up' or recovery time of 5 sec/km whilst station stops are scheduled as 15-20 seconds with layover times of 4 minutes at each end of the line.

In emergencies the train can operate with half the equipment cut out and in these circumstances two successive starts can be made with a crush load on a 3·33% grade without overloading the equipment. Alternatively, one train can propel another which has become totally disabled. In addition, a crush loaded train can be braked rheostatically from 100 km/h without any forced ventilation of the braking resistances. They are designed for operation on a nominal 600 V system but in practice surges can occur up to + 4·5 kV and –1·6 kV, such as when a sub-station breaker opens under fault conditions and the equipment has ample insulation to cope with such conditions.

Rheostatic braking

Rheostatic braking is used on the 1973 Tube stock as it has been on all new London Transport stock since the Victoria Line but waste heat recovery is not used because of lack of space for the air ducting, etc. When braking, the motor cars are automatically switched over to rheostatic braking reverting to the air brake if the rheostatic braking current falls below the required effort or at the end of the stop. In addition, trailer cars contribute their share of braking effort by air operated block braking.

The 1967 Victoria Line trains with a lower proportion of motored axles, have a different system of progressive stages of braking effort. Initially, and again entirely automatically, the entire braking effort for an empty train is provided rheostatically but if this is insufficient then the friction brakes on the trailer cars only are progressively applied and only when these are fully applied are the friction brakes on the motor car applied. This system has been extremely effective but was felt to be unnecessarily complicated on the 1973 stock where only 25% of the adhesive weight is accounted for by non-motored axles.

The introduction of rheostatic braking on LTE has produced dramatic improvements in stock utilisation and tyre wear, and as a result the 'programme lift' maintenance intervals—which are largely fixed by the need to change wheel sets—have been increased. The 1938 stock, without rheostatic braking, required wheel changes at approximately eight-month intervals, whereas for the Victoria Line stock, with half axles motored but rather more than 50% of the braking energy dissipated electrically, the interval has increased to 18-20 months. The even greater proportion of motored axles in the 1973 stock should increase this interval even further.

Rheostatic braking can be used from the maximum service speed (100 km/h) but in normal service it is not used at speeds above 90 km/h, nor set up below 32 km/h although, if already in use, braking effort is maintained down to 20 km/h, below which block braking takes over. Normal service braking is 1·0 m/sec² but the equipment caters for the maximum braking rate of 1·15 m/sec² with a crush-loaded train. Emergency braking, friction only, is 1·3 m/sec².

Automatic operation

The 1973 Tube stock will initially be operated with a two-man crew — a driver (known as 'motorman') and guard, but the trains themselves are designed for one-man operation in

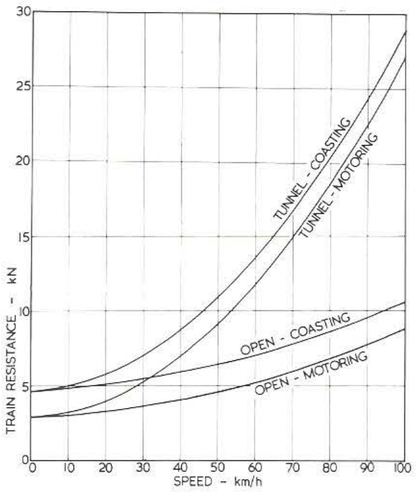


Fig. 5. *Train Resistance for a six-car train of '1973 Tube stock'. (left).*

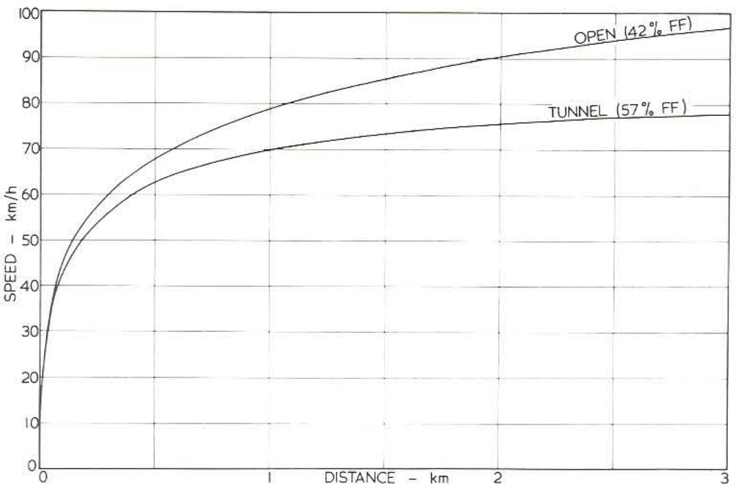


Fig. 6. *Performance of '1973 Tube stock' in tunnel and on the surface. (right).*

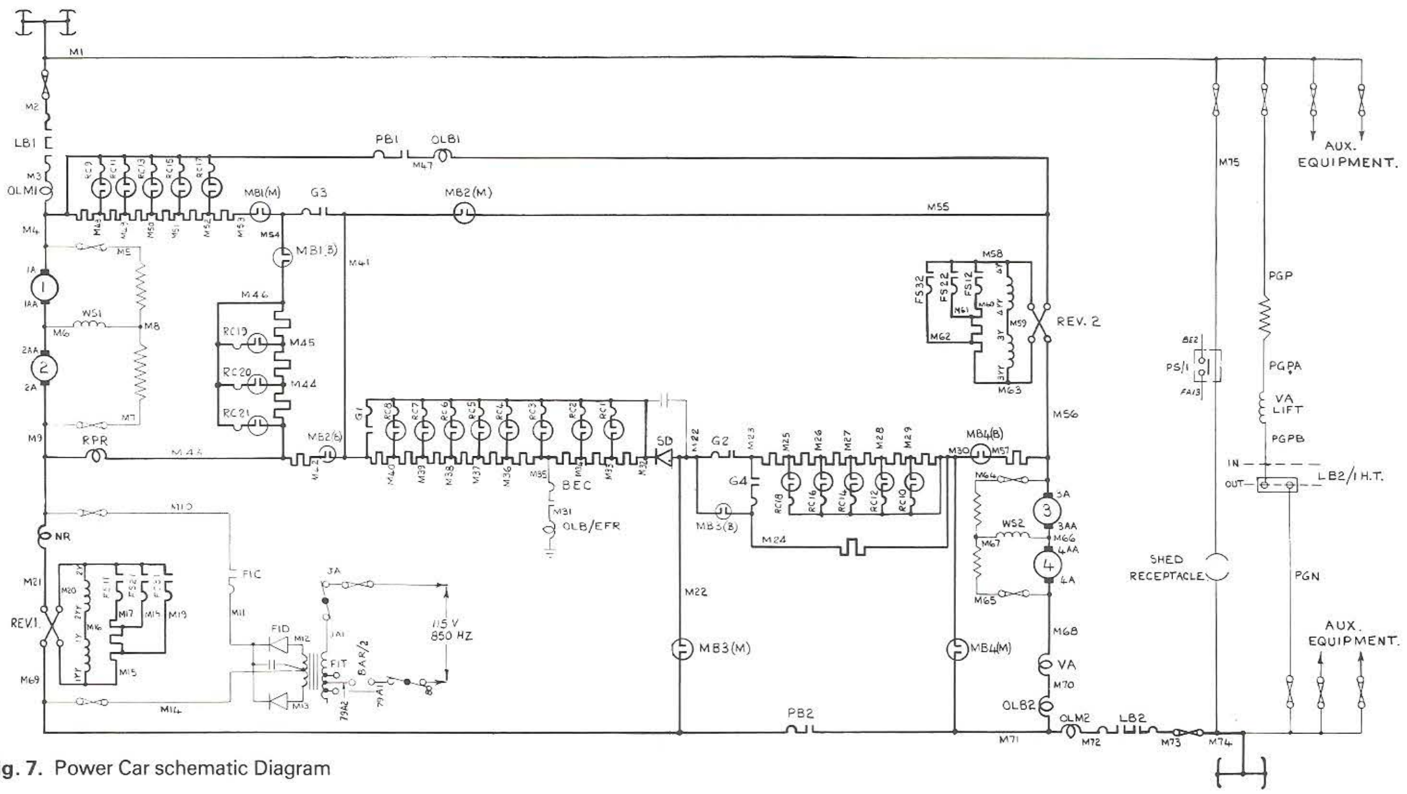


Fig. 7. Power Car schematic Diagram

London Transport Electric Rolling Stock Fleets Equipped by GEC Traction

Equipments for Multiple Unit Trains

Quantity	*Stock and Service*	*Date Ordered*
797	Various tube lines—now withdrawn	1901—1936
1021	Various surface lines—now withdrawn	1902—1937
941	1938 Tube Stock—Northern and Bakerloo Lines	1938—1948
371	R Stock—District Line	1938—1959
246	Surface stock refurbishing	1955—1959
380	1959 Tube Stock—Piccadilly Line	1957
12	**1960 Tube Stock—Central Line (Woodford-Hainault)	1959
232	A60 and A62 Surface stock—Metropolitan Line	1959—1961
527	1962 Tube Stock—Central Line	1960
158	**1967 Tube Stock—Victoria Line	1965
5	Chopper equipments	1965 & 1968
106	*C69 surface stock—Metropolitan and Circle Lines	1968
252	*1972 Tube Stock—Northern Line	1971
350	*1973 Tube Stock— Piccadilly Line	1972
2	*Chopper equipments—Fleet Line prototypes	1975
33	*C77 Stock—Circle Line	1975
5433		

Equipments for Locomotives

62	Various locomotives—now withdrawn	1890—1926
32	Battery/Line maintenance locomotives	1938—1969
11	Battery/Line maintenance locomotives	1972
105		

Total 5538 continuously since 1890.

**Automatic operation
*One man operation

the future. Automatic train operation (ATO) has been used by LTE since 1964 (on the Woodford-Hainault branch of the Central Line) and has been used on the Victoria Line from its inception. On the Victoria Line the train operator is responsible for closing the doors and giving a start signal to the train which then automatically accelerates up to the permitted speed indicated by coded signals transmitted from the trackside to the train and stops entirely automatically at the next station; the train operator then opens the doors. A very high degree of stopping accuracy has been achieved on this line from the beginning: ± 1·5 m under all conditions of train load, gradient, etc. Non-automatic one-man operation (OMO) has been used on London Transport since the introduction of the C69 surface stock.

Control equipment

The previous stock on the Piccadilly Line comprised seven-car trains. In the initial design stages of the new stock it was appreciated that a considerable capital cost economy could be achieved if the car length was increased so that six cars approximate to the length of seven cars of the older type. To accommodate the longer cars the width had to be reduced slightly to provide structural clearance on tight track curvatures. The resulting further reduction of the already very restricted space on the underframe available for mounting the control equipment was a major design problem, particularly as access for maintenance had to be provided to the various pieces of equipment.

With the co-operation of the car-builder, Metro-Cammell Limited, it was agreed that major pieces of equipment such as the camshaft, reverser, power/brake switch, field shunt and grouping contactors, etc, would be supplied to them ready wired and mounted in an open framework. This framework is mounted between one of the longitudes and solebar and is enclosed by dustproof fibre-glass covers. Similarly placed on the opposite side are the other major apparatus such as the line breakers, braking contactors, transition diode, main positive and negative fuse boxes, shed receptacle, etc, all mounted, pre-wired, in an enclosed equipment case.

For convenience of shipping and erection, the main resistor elements are divided in three individual frames which are mounted between the longitudes and incorporate secondary insulation. The resistance elements are force ventilated by air drawn over them by a fan on the adjacent motor alternator set. Previous LTE practice was natural ventilation and the change has been made because of the increased braking duty and lack of space. An overtemperature device is provided to detect overheating of the resistors.

Traction current is collected on each bogie by three collector shoes, two positive and one negative. The appropriate shoes on each car are connected by a bus line but not those on adjacent cars because of deep level Tube line operating safety regulations. In locations where live conductor rails are not permitted, such as in maintenance sheds—power supply is by the shed receptacles to enable line-fed electrical devices to be checked and for the train to be moved at low speed within the depot.

Power circuits

The six-car formations comprise four motor cars and two trailer cars, and each motor car has its own self-contained propulsion equipment with all axles motored. The power circuit, in which the four traction motors are connected in permanent series pairs is shown in Fig. 7. The notching sequence is essentially a conventional resistance starting equipment using a series/parallel bridge transition and a series diode in place of the normal 'S' contactor to reduce wearing parts. Rheostatic braking is also obtained by connecting the motors in a conventional stabilised figure-of-eight, self-excited braking circuit.

To assist the build up of braking current, field injection into one pair of motor fields is provided. The changeover from the motoring to the braking circuit is by a pneumatic linear power brake switch to avoid interlocking of individual contactors. Control in both motoring and braking is by resistance switching in the motor armature circuits, under control of the notching relay. A total of 20 notches are provided in motoring and 19 in braking. Grouping contactors are used so that in braking, camshaft contacts can be isolated to prevent unwanted interference with the ohmic resistance of the power circuit.

The series diode also carries the common leg rheostatic braking current. As the direction of the build up of the braking current is thus controlled the opportunity was taken to use field reversing, rather than armature switching as in earlier tube and surface stock. This saves space because a smaller reverser is possible but the diode itself is somewhat larger than would otherwise be necessary.

'Soft notch' starting is by starting in the weakest field with all resistance in series and progressively increasing the field strength until full field is used in notch 4. The three top notches, with all resistance out, again are achieved in weak field. The jerk limit is limited to 0·6 m/sec^3 and a further feature to improve passenger comfort is the provision of faded brake release by reinserting the braking resistances. Notching is by a single camshaft unit, the operating mechanism of which comprises a hydraulically damped, electro-pneumatically operated piston-actuated rack-and-pinion. The camshaft is controlled by three coils, the two camshaft magnet valves (U) and the stop coils (S) which are referred to respectively in the typical diagram Fig. 8.

With the camshaft in the "off" position and power as yet shut off, to notch up, the magnet valves (U) are energised and the camshaft rotates through the ten 'notching up' positions. The speed of notching is controlled by a needle valve which regulates the oil flow moving the rack-and-pinion piston group across. On the latter having moved its full stroke, and the equipment now in 'full series', an interlock prepares the circuit for parallel operation.

On throwing over the master controller to 'parallel', the parallel starting resistance is inserted and the magnet valve (U) is de-energised by an interlock on the grouping contactor. Air can then feed into the rack-and-pinion piston group to bring about its return stroke, so rotating the camshaft back through parallel acceleration closing and opening the contact units in sequence exactly the reverse of that for the series acceleration operation. During parallel notching, resister sections are cut out of the two motor circuits simultaneously.

The final movement during full-field parallel acceleration is used to short out the camshaft contacts for operation on the full motor characteristics. Weak-field operation is by closing the field shunting contactors sequenced from control contacts on the camshaft running back under the control of the notching relay. The accelerating group position is the same for motors in series with all resistors in circuit and motors in parallel with resistors cut out. Considerable time is saved therefore when passing over rail gaps which are long enough to cause operation of the volt-amp relay and disconnect the equipment because the camshaft does not need to return to the 'off' position.

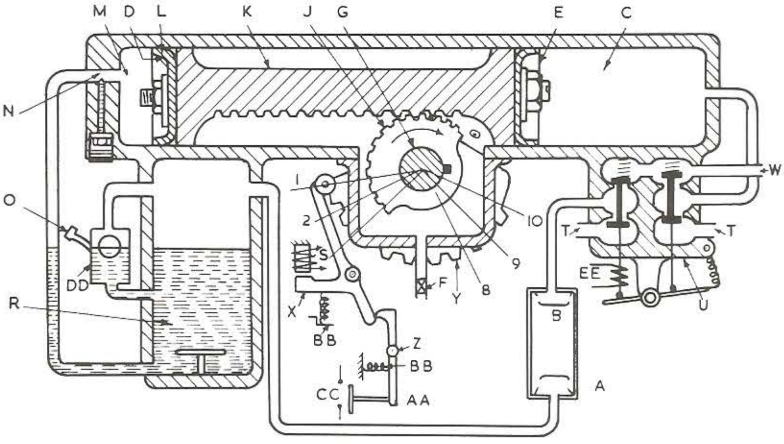
Protection

The 'volt-amp' relay provides protection when line volts are too low and also opens the line breakers if the main current flow is interrupted such as by a gap in the conductor rails. The 'lift coil' closes the relay when the minimum voltage is exceeded and this permits the line breakers to close under overall control from the master controller. Immediately power is taken, current flows through the 'series coil' which holds the relay because an interlock interrupts simultaneously the supply to the lift coil. An interruption of main current through the series coil opens the relay automatically and the line breakers are tripped.

The trains operate under a wide range of adhesion conditions varying from those consistently good in the tunnel to the potentially very poor in wet rail conditions above ground. To some extent this is catered for by selecting a lower rate of acceleration when running above ground but for optimum performance under 'normal' conditions wheelspin must be anticipated under poor conditions. Initially, therefore, the starting resistance can be progressively reinserted and if insufficient to restore normal operation, the line breakers are opened and reclosed with acceleration at the lower rate. If wheel-slide occurs during rheostatic braking the braking effort is reduced gradually before the braking contactors are opened.

Auxiliary supplies

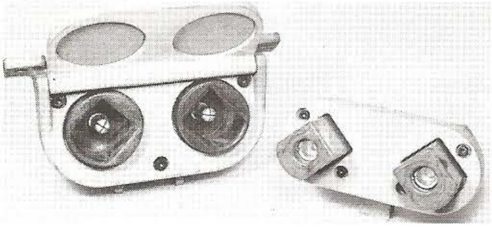
The motor alternator set provides a high-frequency supply for fluorescent lighting at 115 V 850 Hz and through a rectifier, low tension 52 V dc for battery charging and the auxiliary circuits. The alternating current is produced by an inductor type alternator, driven by a 600-V dc motor, this type of alternator consisting of a solid rotor, a homopolar field and a stator winding and hence no slip rings or rotating



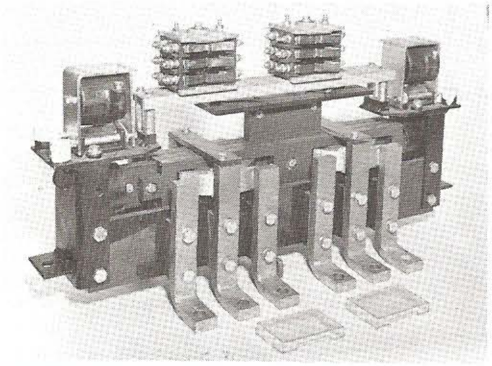
A	EXPANSION CHAMBER.	R	OIL RESERVOIR.
B	BAFFLE.	S	STOP COIL.
C	CYLINDER. (AIR END.)	T	EXHAUST.
D	EXPANDER.	U	MAGNET VALVE.
E	PISTON PACKING (AIR)	W	TO AIR RESERVOIR.
F	DRAIN COCK.	X	STOP MAGNET. (SPRING BIASED TO CLOSED POSITION.)
G	CAM SHAFT.	Y	STARWHEEL.
J	PINION.	Z	FULCRUM.
K	AIR ENGINE PISTON.	AA	INTER INTERLOCK LEVER.
L	PISTON PACKING (OIL)	BB	SPRING.
M	CYLINDER (OIL END)	CC	INTER-INTERLOCK.
N	TIMING ADJUSTMENT. (NEEDLE VALVE.)	DD	WINDONUT TYPE OIL-LEVEL INDICATOR.
O	OIL FILLER PLUG.	EE	MAGNET VALVE COIL.

Fig. 8. *Rotary camshaft notching-up unit schematic showing air-operated piston/rack-and-pinion group LKEE-JG controlled by magnetic valve U and solenoid EE.*

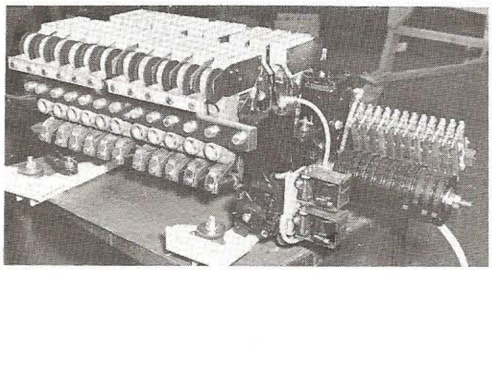
Operation: With the magnet valves 'U' de-energised, compressed air is admitted from 'W' via the right-hand valve to the air cylinder 'C', thus holding the camshaft in the OFF position. When 'U' is energised the left-hand valve moves to close the exhaust port 'T' and to admit air via the expansion chamber 'A' to the oil reservoir 'R'. Simultaneously, the right-hand valve opens the air cylinder to exhaust. The piston then moves towards the right, rotating the camshaft clockwise, through pinion 'J'. As the camshaft moves from position '1' to '2' the PC internotch device closes, thus energising the stop coil 'S' and also the lift coil of the notching relay. If there is no main current in the series coil of the notching relay, its contact will open as the internotch device opens, thus de-energising the stop coil 'S' and allowing the camshaft to proceed. Under these conditions the camshaft should rotate from position '1' to '10' in 1½ to 2 seconds. The rate can be adjusted by the needle valve 'N' in the inlet of the oil cylinder 'M'.



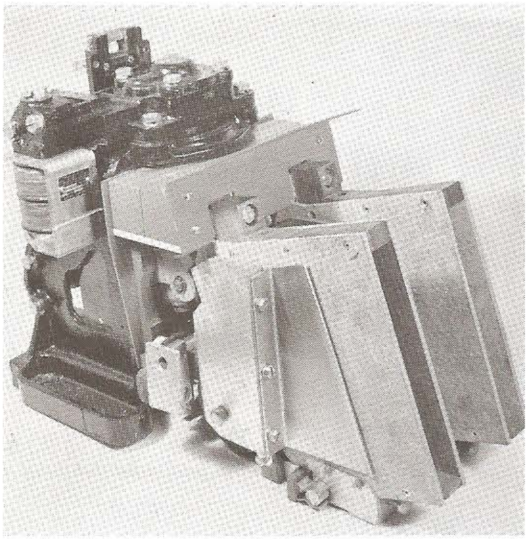
Shed jumper plug and receptacle.



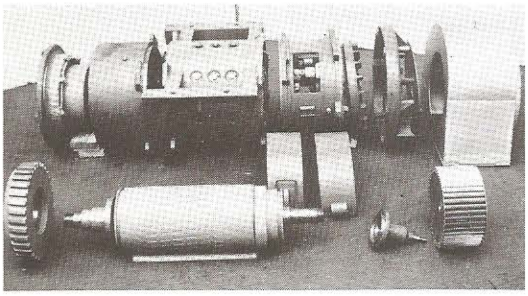
Linear power brake switch (the reverser is similar)



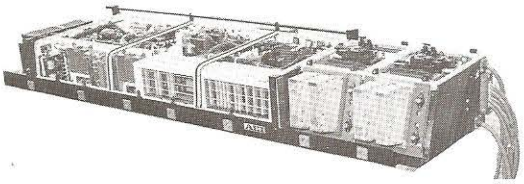
Camshaft unit



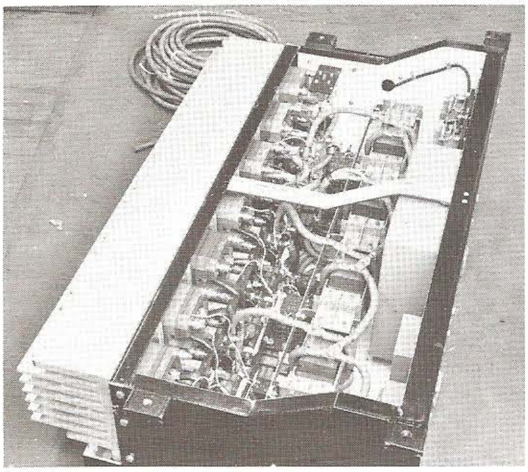
Line breaker for conventional and chopper controlled cars.



Component parts of the motor alternator



Chopper main equipment case



Details of thyristors in chopper equipment case.

Choke for chopper equipment (left).

parts to require maintenance. The complete motor alternator set is totally enclosed.

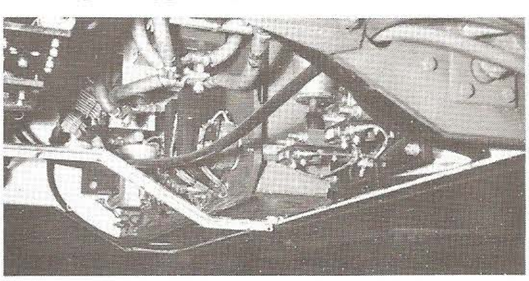
With the permanent series resistor in circuit, the motor is designed to withstand the voltage disturbances frequently encountered on traction systems. It can also be short circuited without flashover when running at normal speed and voltage and be started from rest, direct on line, without damage.

The alternator supplies a constant voltage to the low tension circuits via the transformer, rectifier and regulator equipment. The alternator voltage is maintained constant by a static regulator which controls the separately-excited motor field current. If the alternator voltage should rise slightly above the required value due, for example, to a supply voltage change and a corresponding increase in motor speed, the regulator increases the motor-field current which reduces the speed and corrects the error. Conversely, if the alternator voltage should fall below the required level, the motor field current will be reduced to increase the speed and restore the generated voltage. The alternator set is also level compounded which compensates both load and line voltage variations and the speed is therefore maintained; it is resiliently mounted below the coach.

A centrifugal double-sided type fan on the motor end of the shaft blows cooling air over the machine frame. It also circulates the air within the machine but a running seal with centrifugal thrower of the fan periphery prevents the external air from being drawn into it. An additional centrifugal fan is mounted on a shaft extension at the motor end to ventilate the accelerating and braking resistances. The motor armature and alternator rotor are both mounted on a common shaft. Class F insulation systems are used throughout including epoxy bonded poles and coils in the alternator field. Resistance to creepage on the four brush arms on the motor is provided by a PTFE sleeve. The motor armature core, main poles and alternator stator are of laminated construction but the motor compoles are solid.

Chopper experience extends over ten years

GEC Traction first started work with choppers on LT railways in 1965 and in subsequent years much valuable development work has taken place. Two four-car trains have operated on the Woodford-Hainault branch of the Central Line (which was the first on LTE to use automatic train control) to check that the equipments do not interfere with existing signalling and train control circuits. The latest equipments which have been ordered are intended as prototypes to demonstrate the advan-



Undercar view of the gate-firing power supply (right).

LT Chopper equipped train on the Central Line

Battery locomotive on a Victoria Line works train

tages (and disadvantages) for future rolling stock and incorporate regenerative/rheostatic braking whereby the receptivity of the supply is continually monitored and the maximum possible amount of braking energy is returned to the supply rather than being wasted in resistances.

The Central Line equipment also incorporates a GEC developed on-board interference monitor (the first time, it is believed, that such a device has been used with chopper-control equipment). This feature is part of the control electronics and will trip out the equipment if any of the following four interference checks operate:

- —incorrect chopper frequency detected from the power circuits;
- —excessive peak inrush line current;
- —excessive alternating current components measured over a finite time;
- —excessive alternating current components at or near LTE's basic signalling frequency of 125 Hz.

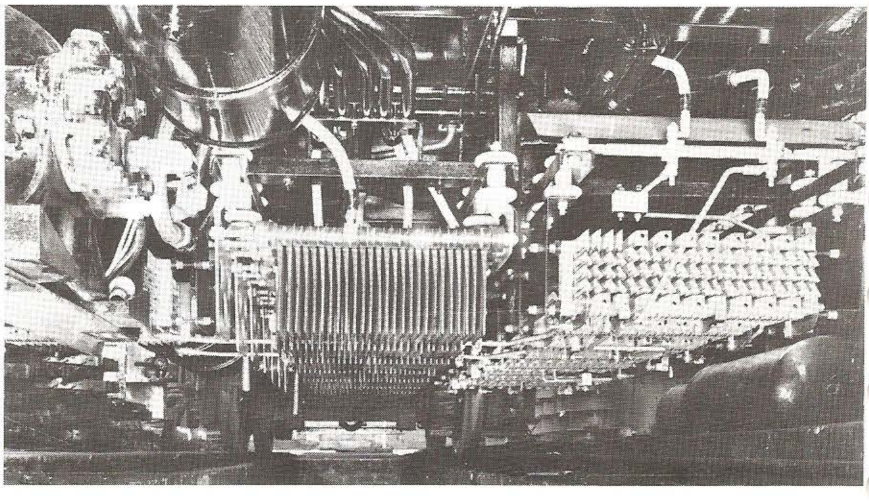
The latter one has the lowest current setting and also includes a narrow band filter circuit. The circuit can be calibrated to detect a 125 Hz component less than 1 ampere when the train is drawing line currents up to 1000 A dc.

Battery locomotives

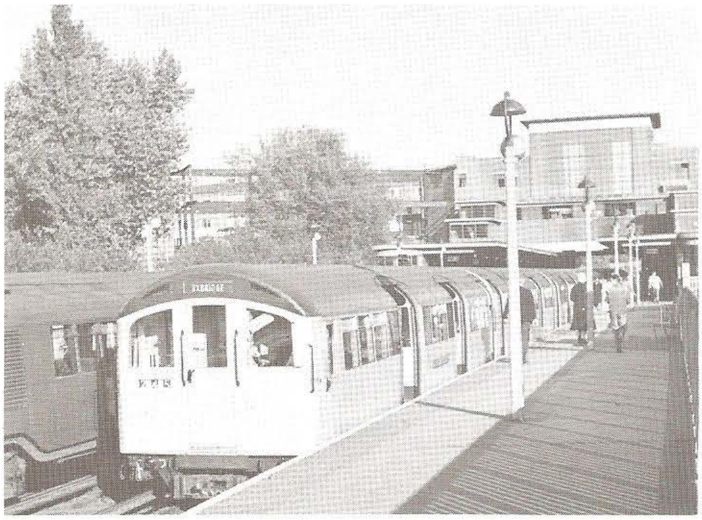
London Transport operate a number of locomotives for ballast and works train haulage for new extensions and maintenance. These operate normally from the 600-V conductor rails supply but are used often when this power is not available. At such times they take power from their on-board storage batteries which can be charged direct from the 600 V dc supply when it is available. The latest order for 11 Bo-Bo locomotives built by British Rail Engineering Limited in 1974 were again equipped by GEC, and can operate anywhere on LTE lines being built to the tube loading gauge.

Duties vary considerably. Two locomotives working in multiple might typically be required to take a 200-tonne works train several kilometres partly on line and partly on battery power. Once there they might have to inch it forward up a 3·3% grade whilst unloading and then return light to the depot. Alternatively, when laying cable a single locomotive could be operating for a long period at some 5 km/h with 100-tonne trailing load. Such wide ranging duties require a flexible control scheme and this is provided by a total of 28 operating notches in three motor combinations. They weigh 60 tonne, are 16 076 mm overall and the continuously rated tractive effort is 52·5 kN.

Equipment layout beneath underframe viewed from below



Other recent tube stock


1959 Piccadilly and Central Lines.


1967 Victoria Line—fully automatic operation.


1972 Northern Line.


Cab of 1973 Tube Stock


Equipment layout in battery/electric locomotive

Electric traction facts — Equipments from GEC Traction

London Transport

600V dc

Total motor coaches equipped in period 1890 — 1976 . . .
5,523

Motor coach fleet in 1976 . . .
3,000

World Wide

27 countries

600, 750, 1500, 3000V dc
6.25 kV, 25 kV, 50 kV
50 Hz, 60 Hz
dual mode ac/ac ac/dc

16,500

Electric Multiple Units

3,400

Electric Locomotives

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