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Paper 27

Multiple - Unit Train Equipments for Glasgow Suburban Lines (A.E.I. Manchester)

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1 Introduction

An order for the electrical equipments for 91 multiple unit trains to be used on the Glasgow suburban lines was placed with Metropolitan-Vickers Electrical Co., Ltd (now A.E.I. (Manchester) Ltd). This is the first electrification project undertaken in the Scottish Region of British Railways and embraces a number of dense traffic routes north and south of the River Clyde.

The electrical equipment was designed and built by the firm at its Manchester, Sheffield and Rugby works. The mechanical parts of the trains were built by the Pressed Steel Co., Ltd at their works at Paisley, near Glasgow, to the designs of the Chief Mechanical Engineer, British Transport Commission. A description of the mechanical parts will be found in Paper 4.

A photograph of the train unit is shown in fig.1.

Its composition is T-M-T, i.e. driving trailer; motor coach; driving trailer. The motor coach carries the pantograph and power equipments, and the trailers are driving trailers of which one, termed the battery driving trailer, carries the battery with its charging equipment and air compressor with its rectifier. The passenger doors are electro-pneumatically operated.

The performance specified was that set out in Paper 4.

2 Leading Particulars

These are tabulated below, the performance figures relating to 22·5 kV at pantograph and wheel treads worn to half the permitted amount.

Vehicle	*Unladen Weight*	*Laden Weight (all seats occupied)*
Battery driving trailer	37·5 tons	42·8 tons
Motor coach	55·6 ,,	60·1 ,,
Driving trailer	33·7 ,,	39·1 ,,
Total	126·8 tons	142·0 tons

Other principal data for the three-coach unit with all seats occupied (16 passengers taken as 1 ton), a line voltage of 22·5 kV, 100 per cent secondary tappings and half worn wheels, are as follows:—

Maximum axle load	15·0 tons
Maximum service speed	75 m.p.h.
Balancing speed on level tangent track	74 m.p.h.
Acceleration on level tangent track	1·35 m.p.h./sec.
Average accelerating tractive effort	21,800 lbs.
Continuous rating at wheel in weak field	
Tractive effort	6,600 lbs.
Speed	47 m.p.h.
Power	830 h.p.
Total weight of electrical equipment	19·9 tons

The performance curve for the equipment under the above conditions is shown in fig.2. The arrangement of the equipment on the motor coach is shown in fig.3.

3 Description of Circuits

3.1 *Power Equipment*

A schematic diagram of the power equipment is shown in fig.4.

Major considerations in the design of A.C. motive power units are the main transformer with associated tap changing gear, the type of rectifier unit and circuit used, and finally the traction motors with field control and provision for operating on an undulating current supply.

In the case of motor coach equipments, where all components in the power circuit are preferably roof-mounted or carried on the underframe, it is inconvenient to employ H.T. tap changing equipment. Furthermore, the comparatively small secondary load currents present no serious switching difficulties. On these coaches, therefore, an L.T. tap changer is used, working direct from a number of taps on the secondary winding. To cater for the dual overhead supply voltage, the primary winding consists of four sections which can be connected in series or parallel.

The four single anode mercury arc rectifiers are bridge connected and the four traction motors which form the D.C. load are permanently connected in a series-parallel arrangement. However, the mid-point between each pair of series-connected motors is connected to a centre tapping on the main transformer secondary winding. In this manner an effectively parallel connection of all motors is achieved, in a circuit arrangement combining the following well known advantages:

(*a*) Adhesion characteristics are improved.

(*b*) The whole of the transformer secondary winding is loaded throughout the A.C. cycle and therefore requires less kVA capacity than in the case of the alternating half-winding loading for the biphase circuit.

(*c*) The mercury arc rectifiers, which within wide voltage limits are rated solely on current, need be rated for the current of only two motors.

(*d*) A faulty pair of motors or rectifier tanks can readily be cut out of circuit, leaving half the equipment to work in biphase.

One end of the primary winding of the main transformer is connected to the rails through brushes running on the road wheel axles, and the L.T. power circuit is earthed at the transformer secondary mid-point through an earth fault relay.

3.2 *Control Equipment*

All control circuits operate at 110V D.C.

3.3 *Auxiliary Equipment*

A schematic diagram of the auxiliary equipment is shown in fig.5, and it will be seen that it falls into two categories in respect of electrical supply.

Most of the machines, the main rectifier excitation circuits and train heating circuits are operated at 240V A.C. supplied from the tertiary winding on the main transformer. The coach lighting, control circuits, and the auxiliary compressor are fed at a contant voltage of 110V D.C. from an automatic voltage regulator which has a 72 cell nickel-cadmium battery floating across it.

All of these circuits are earth connected to the structure of the coach in the interests of safety and simplicity of fusing.

The ignition and excitation gear for the mercury arc rectifiers is accommodated in a separate cubicle on the motor coach underframe. A diagram of the circuits appertaining to one rectifier is included in fig.5.

In normal operation the 80 Ah battery is kept charged from the voltage regulator, but in the event of overhead supply failure, the battery supplies the control and lighting load.

A small 'Bristol' air compressor with motor fed from the battery supplies air for initial raising of the pantograph and closing of the circuit breaker.

4 Description of Electrical Apparatus

4.1 *H.T. Equipment*

Pantograph

The Stone Faiveley pantograph, described in Paper 20, is mounted at one end of the motor coach roof.

Air Blast Circuit Breaker

Most of the train units are equipped with Brown Boveri circuit breakers and a few with A.E.I. breakers as described in Paper 3.

Potential Measuring Device for A.P.C.

This takes the form of a potential transformer mounted on the motor coach roof.

The voltage ratio is 25,000/400, with a rating of 200 VA.

4.2 *Main Transformer*

Fig.6 shows the main transformer.

A porcelain bushing forms the roof terminal of the H.T. cable, the other terminal being an oil-filled bushing at the H.T. end of the main transformer, which is centrally disposed on the underframe. The B.I.C.C. cable has vulcanised rubber insulation with a concentric earth sheath embedded in the rubber.

The main transformer is of the core type arranged for O.F.B. cooling, with the following ratings to I.E.C. 77:—

Primary	25/6·25 kV, 970 kVA
Secondary	2,770V, 10·4 per cent. reactance
Tertiary	273V, 78 kVA

The normal primary voltage is considered to be 22·5/5·625 kV.

The transformer tank is 24 in. wide and is divided by an internal partition into two compartments, one of which houses the core and windings with L.T. terminals at the tank end wall. In the other compartment is mounted the H.T. cable terminal and the 7-pole, 2-way primary changeover switch which is operated by an electrically controlled air engine, flange mounted on to the outside tank wall. The oil in this chamber is not circulated during normal operation having only an insulating function.

The oil in the main tank is circulated at a rate of 50 g.p.m. An oil conservator fitted with a silica gel breather is mounted in the guard's van.

4.3 *Tap Changer*

Fig.7 shows the tap changer.

The transformer secondary is provided with 7 intermediate tappings of which one is the mid-point; all are capable of carrying full load current. As will be seen from the schematic diagram in fig.4 the switching sequence of the tap changer is such that consecutive notches are obtained by gradually increasing the voltage from one or other half of the transformer secondary winding, moving outwards from the mid-point. During transition from one transformer tap to the next, an ohmic resistance is momentarily connected between the two taps to ensure continuity of supply to the motors. One or other of the two transition resistors, one for each transformer half, is also used to give intermediate output voltages by being connected in series with a transformer tap on alternate notches. The control circuits for the tap changer are so arranged that it is impossible to arrest its progression on a notch with resistance in circuit, so that the resistors need only be short time rated for the currents in question. Transition by resistance involves slightly greater losses than by reactance but the resistors are much smaller and lighter than reactors, and they provide for the heavy transition currents being interrupted at about unity power factor.

The tap changer itself takes the form of an electric motor driven camshaft; the 16 pairs of contact fingers have silver contact tips and are closed by powerful springs and opened by the cams, the actual cam followers being rollers with ball bearings. The contact fingers do not have to make or break currents, this duty being delegated to four electro-pneumatic air break contactors with laminated magnetic blowout circuit and arc splitters incorporated in the chutes. These contactors are mounted together with the camshaft unit inside a single switch group cubicle mounted on the underframe. The transition resistors comprise edgewound strip on ceramic formers and are arranged in an underframe mounted cubicle with natural air cooling.

4.4 *Rectifier Equipment*

Fig.8 shows a photograph of a rectifier.

Four single anode, pumpless, steel tank, air cooled mercury arc rectifiers are used. Rectifiers of this type were first used on the prototype 50 c/s. multiple unit train set commissioned by Metropolitan-Vickers Electrical Co., Ltd on the Lancaster – Morecambe – Heysham line in 1957, and the set of four tanks installed after the initial tests has since then given more than 130,000 miles of trouble-free running.

The tanks are of the continuously excited type, with an excitation power of approximately 200 watts. For the initial striking of the excitation arc, a silicon carbide ignitor dipping into the mercury pool is used. Ignition ceases automatically when the excitation arc has struck. A molybdenum honeycomb mesh acts as a mechanical stabiliser for the mercury, and immunity against backfires is increased by the provision of a grid surrounding the anode and excited with an A.C. voltage in phase with the anode voltage. The continuous rating of the four rectifiers is 700 kW at 1950V D.C. output.

The necessary preheating before the rectifiers are put on load when the ambient temperature is low, is achieved by connecting a resistor across the bridge output which circulates 100 amps. when supplied at Notch 1 voltage. The operation is governed by thermostats mounted on two of the tanks.

Each pair of rectifiers is resiliently mounted in a cubicle on the underframe which contains also the Keith Blackman cooling fan. Through ventilation is normally employed, but under cold weather and light load conditions thermostatically controlled, pneumatically operated shutters in the cubicle rear wall close so that the air recirculates.

4.5 *Smoothing Chokes*

Each pair of traction motors is fed through an iron-cored smoothing choke, which limits the A.C. ripple in the motor current to 30 per cent at the continuous rating. The two chokes are mounted together in a tank on the underframe and are oil cooled, utilising the same cooling circuit as the main transformer.

4.6 *Traction Motors*

Fig.9 shows a photograph of the traction motor.

The motors have been designed for operating on a rectified A.C. supply, to which end the damping of the interpole magnetic circuit has been effectively reduced by the provision of shallow laminated ring segments clamped to the inside of the main yoke casting and bridging the poles. Furthermore, a substantial portion of the ripple content in the motor current is bypassed from the main field windings by a non-inductive shunt. With full voltage on the motors, further speed increase is obtained by one step of field weakening.

The motors are designated type MV.148. They are insulated with Class B materials and have the following continuous ratings to B.S.S. 173/1941:—

Full field 975 volts, 165 amps, 190 S.H.P.
Weak field 975 volts, 180 amps, 210 S.H.P.

The machine has 4 poles, is wave-wound and designed for a maximum speed of 2,820 r.p.m. Field shunting down to 60 per cent. of full field is employed for normal running, but the more arduous duties are performed at full field.

The motor is axle mounted on Timken roller suspension bearings and the motor nose is supported from the bogie frame through a short vertical link incorporating resilient rubber bushes at both ends.

4.7 *Auxiliary Equipment*

Tabulated below are the essential particulars of the auxiliary machines.

No. per Unit	*Function*	*Output*	*Supply*	*Rating hp*	*Speed rpm*
1	Oil pump	50 gpm	246V A.C.	1·5	1430
2	Rectifier fan	1,500 cfm	246V A.C.	0·85	1430
1	Radiator fan	3,600 cfm	246V A.C.	0·95	1430
1	Main compressor	F.a.d.23 cfm	208V D.C.	6·4	1100
1	Auxiliary compressor	F.a.d. 3 cfm	110V D.C.	1·0	1450

A series wound D.C. driving motor is used for the main reciprocating Westinghouse air compressor to provide the required high starting torque and single phase capacitor induction motors are used for all fans and the centrifugal oil pump. These motors are of liberal size to ensure satisfactory operation over the wide voltage range specified.

The Pulsometer oil circulating pump is of the glandless type with oil immersed motor, and pumps the oil through a Serck radiator cooled by a 22 in. axial flow fan, capable of dissipating 26 kW.

A simplified circuit diagram of the automatic voltage regulator is shown in fig.10. The equipment basically comprises a germanium bridge rectifier with a flux resetting transductor inserted in each of two opposite phase legs of the bridge. The naturally air cooled rectifier cells and the control equipment are housed in a cubicle on the B.D.T. underframe, whilst the transductors are contained in an adjacent oil filled tank. To enable separate earthing of the D.C. output, a 1:1 ratio isolating transformer is inserted between the 240V supply and the regulator input.

4.8 *Driver's Controls*

The layout of the driver's controls follows standard practice on all new B.R. multiple unit stock, as described in Paper 4.

5 Protection

Protection against earth faults in the H.T. cable, changeover switch, or transformer primary winding is afforded by a differential relay which on tripping opens the air blast circuit breaker. Earth faults on the L.T. power circuits operate an earth leakage relay connected between the transformer secondary mid-point and earth, which trips the circuit breaker.

Transformer secondary circuit protection is by two overload relays, one in each output connection from the tap changer, and either, on tripping, opens the circuit breaker. Other contingencies acting on the circuit breaker are excessive transformer oil temperature, loss of transformer oil, and control air pressure becoming too low for safe operation of the breaker itself.

If the transformer oil pump should stop, a relay opens the transition contactors and removes the traction load from the transformers.

Should one of the two fans cooling a pair of rectifiers stop, the contactors for the corresponding pair of traction motors open. These contactors are also interlocked with the rectifier excitation proving relays so that they open on loss of excitation.

To protect against voltage surges originating from the overhead line or possibly generated by arc starvation phenomena in the rectifiers, Metrosil non-linear resistance units are connected across each section of the transformer secondary winding, across the rectifiers themselves, and finally in the excitation circuit.

6 Conclusions

The first train unit was completed and tested at the carriage builders' works in May, 1959, and commenced running on one of the new electrified sections shortly afterwards. Further details of the commissioning and inauguration of the Glasgow electrification scheme are given in Paper 2.

From the manufacturers' point of view these equipments are of particular interest since experience will be obtained with the type of transformer secondary tap changer used. A conventional scheme employing individual tapping contactors and transition reactors has been in successful operation for three years on the train unit operating on the Lancaster – Morecambe – Heysham line.

SUMMARY

This paper describes A.C. 50 cycle electrical equipment built for B.T.C. by A.E.I. (Manchester) Ltd (formerly Metropolitan-Vickers Electrical Co., Ltd).

The train units are of three coach formation with motor coach in the middle. They are geared for 75 m.p.h. maximum service speed, have a continuous rating of 830 h.p., can operate on 25 kV or 6·25 kV supply and weigh 142 tons when laden with 242 passengers, and of that weight the electrical equipment accounts for 20 tons.

Power conversion from 50 cycle single phase supply to an undulating unidirectional current for the substantially conventional D.C. traction motors is by means of a mercury arc rectifier comprising four single anode air cooled sealed steel tanks of the continuously excited type, working in bridge connection to feed the four traction motors. These motors are connected in a permanent series-parallel arrangement, with an inter-connection between their mid-point and the transformer secondary mid-point which endows the motors with all the adhesion stability associated with the parallel connection.

Motor voltage is stepped up during train acceleration in 11 steps, from 7 taps in the transformer secondary winding, by means of an electric motor driven cam switchgroup, four electro-pneumatic unit switches which perform all the current making and breaking, and transition resistors. The master controller permits sustained operation on three only of these steps and in weak field condition.

A tertiary winding of the main transformer provides auxiliary supplies including coach heating.

An air blast circuit breaker on the roof protects from the consequences of overloads on the transformer secondary and from earth faults on transformer primary and low tension power circuits.

The auxiliary pump and fans with low starting torque requirements are driven by single phase motors with capacitors for start and run, but the reciprocating compressor has a D.C. motor fed by a selenium rectifier.

The traction motors are axle mounted on roller suspension bearings and have a rubber resilient link suspension to the bogie frame.

The whole of the power equipment and most of the auxiliary equipment is mounted under the underframes except for roof mounted equipment.

RÉSUMÉ

Cet exposé décrit les équipements électriques à courant alternatif 50 Hz construits à la commande de la British Transport Commission par A.E.I. (Manchester) (anciennement Metropolitan-Vickers Electrical Co. Ltd).

Les rames unitaires sont composées de trois voitures avec la motrice au milieu. Le rapport d'engrenages est choisi pour la vitesse maximum de 75 m.p.h. Elles ont au régime continu, une puissance de 844 h.p. et fonctionnent à 25 kV ou à 6,25 kV. Le poids global de la rame avec sa charge de 242 passagers s'élève à 142 tons, l'équipement électrique pesant 20 tons.

A l'aide des redresseurs à vapeur de mercure on transforme le courant monophasé à 50 Hz de la caténaire en courant ondulé pour alimenter les moteurs de traction à courant continu essentiellement classiques. Les quatre cuves en acier scellées sont refroidies par air. Ces cuves à excitation continue, montées en pont de Graetz, alimentent les quatre moteurs de traction qui sont branchés en série et en parallèle avec une connection commune entre leur point milieu et le point milieu de l'enroulement secondaire du transformateur. De cette façon les moteurs possèdent toute la stabilité d'adhérence procurée par le couplage en parallèle.

On augmente la tension d'alimentation des moteurs en onze échelons à partir de 7 prises sur l'enroulement secondaire du transformateur, au moyen d'un groupe de commutateurs à cames commandé par electromoteur, quatre commutateurs électropneumatiques qui effectuent toutes les opérations de fermeture et de coupure et des résistances de passage. Le manipulateur permet le fonctionnement prolongé sur trois de ces échelons et au champ réduit.

Les auxiliaires et le chauffage des voitures sont alimentés à partir de l'enroulement tertiaire du transformateur principal.

On se sert d'un disjoncteur pneumatique sur la toiture pour assurer la protection contre les surcharges côté secondaire du transformateur et contre les défauts de terre côté primaire, ainsi que dans les circuits à basse tension.

Des moteurs asynchrones monophasés avec condensateurs pour le démarrage et la marche normale actionnent la pompe et les ventilateurs, ceux-ci nécessitant un faible couple de démarrage, mais le compresseur à mouvement alternatif a un moteur à courant continu alimenté par un redresseur au sélénium.

Les moteurs de traction sont suspendus par le nez à l'aide des paliers à rouleaux et sont liés au châssis de bogie au moyen d'un élément de suspension en caoutchouc. Une bielle semblable fixe latéralement la position du moteur.

La totalité de l'équipement de traction et la plupart des auxiliaires sont montés sous le châssis à l'exception des appareils montés sur la toiture.

ZUSAMMENFASSUNG

In diesem Bericht wird die für die " British Transport Commission " von der " Associated Electrical Industries (Manchester) Ltd " (ehemaligen " Metropolitan-Vickers Electrical Co. Ltd ") gebaute elektrische Ausrüstung für 50 Hz beschrieben.

Die Zugeinheiten sind dreiteilig ausgeführt mit dem Triebwagen in der Mitte. Sie sind mit Getrieben ausgerüstet, die eine Höchstdienstgeschwindigkeit von 75 m.p.h. ermöglichen. Mit einer Dauerleistung von 844 h.p. können sie an ein 25 kV und 6.25 kV Versorgungssystem geschaltet werden. Mit einer Belastung von 242 Personen haben sie ein Gewicht von 142 tons einschliesslich 20 tons für die elektrischen Apparate.

Die weitgehend klassischen Gleichstrom-Fahrmotoren werden mit gleichgerichtetem Wellenstrom gespeist, welcher durch Umwandlung des einphasigen 50-Hz-Stromes mittels eines Quecksilberdampf-Gleichrichters bestehend aus vier luftgekühlten, luftabgeschlossenen, dauererregten Einanoden-Stahlgefässen erhalten wird, letztere speisen die vier Fahrmotoren in Brückenschaltung. Der Mittelpunkt dieser Motoren, die dauernd reihen-parallel geschaltet sind, ist mit dem Mittelpunkt der Sekundärseite des Transformators verbunden. Durch diese Anordnung besitzen die Motoren, die mit der Parallelschaltung verbundene Haftreibungsstabilität.

Während der Zugbeschleunigung wird die Motorspannung in 11 Stufen gesteigert, und zwar mittels sieben Anzapfungen der Sekundär wicklung des Transformators, durch eine motorangetriebene Nockenschaltergruppe, mittels vier elektro-pneumatisch gesteuerte Schalter welche die Strom Zu-und Abschaltungen durchführen, sowie durch Uebergangswiderstände. Durch den Steuerschalter wird Dauerbetrieb nur auf drei von diesen Stufen, ausserdem bei geschwächtem Feld ermöglicht.

Die Hilfsapparate einschliesslich die Wagenheizung werden von einer Tertiärwicklung des Haupttransformators gespeist.

Ein auf dem Dach montierter Druckluftschalter schützt gegen Ueberlastung der Transformatorsekundärseite sowie gegen Erdschlüsse der Transformatorprimärseite und in den Niederspannungsstromkreisen.

Die Hilfspumpe und Ventilatoren, die ein nur niedriges Anzugsdrehmoment beanspruchen, sind mit einphasigen Motoren und Kondensatoren für Anlauf und Betrieb ausgerüstet, während der Kolbenkompressor von einem durch einen Selengleichrichter gespeisten Gleichstrommotor angetrieben wird.

Die auf den Achsen montierten Fahrmotoren sind auf Rollenhängelager gelagert und mit einem gummi-elastischen Aufhängeglied am Drehgestellrahmen befestigt.

Mit Ausnahme der auf dem Dach montierten Ausrüstung befinden sich die Stromversorgungsapparate und der Hauptteil der Hilfsapparate auf der Unterseite des Rahmens.

RESÚMEN

Este folleto describe equipo eléctrico para corriente alterna de 50 ciclos construido para la Comisión Británica del Transporte por A.E.I. (Manchester) Ltd (antiguamente Metropolitan-Vickers Electrical Co. Ltd).

Las unidades de trenes están compuestas de tres vagones con el vagón motriz en el medio. La relación de engranhaje está diseñada para una velocidad máxima en servicio de 75 m.p.h. y tienen una potencia en trabajo contínuo de 844 h.p.; operan en lineas de 25 kV o 6.25 kV y pesan 142 tons con 242 pasajeros. El equipo eléctrico pesa 20 tons.

La conversión de energía del sistema monofásico de 50 ciclos a la corriente unidireccional ondulante que alimenta los motores convencionales de tracción de corriente contínua, se efectua por medio de una batería de rectificadores de vapor de mercurio consistente de cuatro tanques herméticos de acero, enfriados por aire,

con un solo ánodo y del tipo continuamente excitado, trabajando en conexión de puente para alimentar los cuatro motores. Estes motores estan conectados en serie paralelo permanente, con una interconexión entre su punto medio y el punto medio del secundário del transformador, lo cual dota a los motores con la estabilidad de dahesión propia de la conexion en paralelo.

Durante la acceleración, la tensión del motor se aumenta en 11 etapas por medio de 7 tomas en el devenado secundário del transformador, por medio de un grupo de interruptores accionados por un eje de levas y movido por un motor eléctrico, por medio de cuatro disyuntores electro-neumáticos que efectuan los trabajos de interrupción y cierre del circuito cambiador, y por resistancias de transición. El regulador permite la operación contínua en solamento tres de estas etapas y en campo reducido.

Un devanado terciario en el transformador principal alimenta los servicios auxiliares, incluyendo calefacción.

Un disyuntor neumático montado sobre el techo protege el equipo contra las sobrecargas en el secundario del transformador, asi como contra las faltas a tierra en el primario y en los circuitos de fuerza de baja tensión.

La bomba auxiliar y los ventiladores, con las necesidades de un par de arranque reducido, son accionados por motores monofásicos con condensadores para el arranque y la marcha. En cambio, el compresor de acción recíproca tiene un motor de corriente contínua alimentado por un rectificador de selenio.

Los motores de tracción están montados sobre el eje por medio de cojinetes de suspensión de rodillos y tienen una suspensión de caucho resiliente al marco del bogie.

Todo el equipo de fuerza asi como la mayoría del auxiliar va montado bajo el bastidor inferior, excepción hecha del equipo montado en el techo.

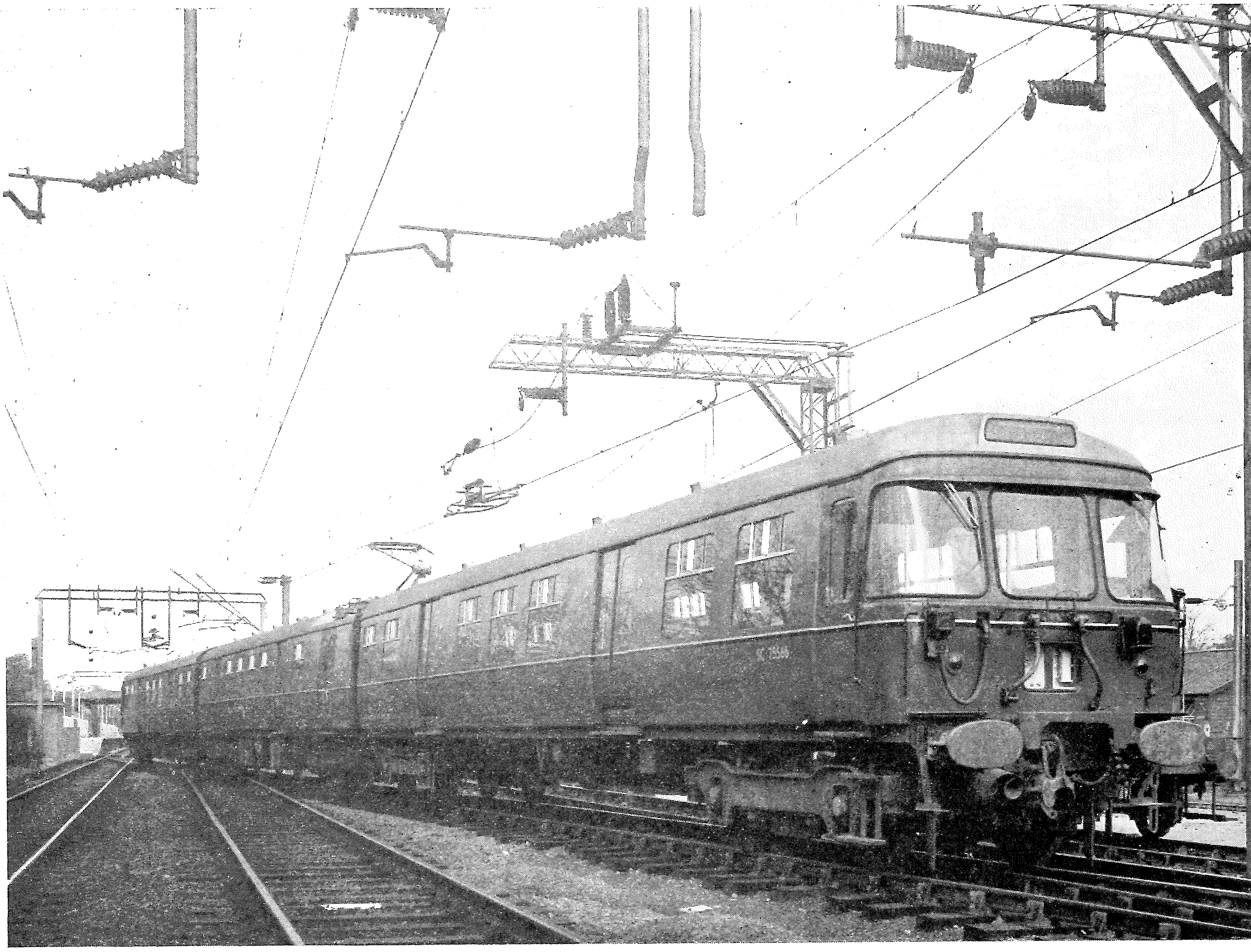


Fig.1 Complete train unit. Glasgow suburban lines

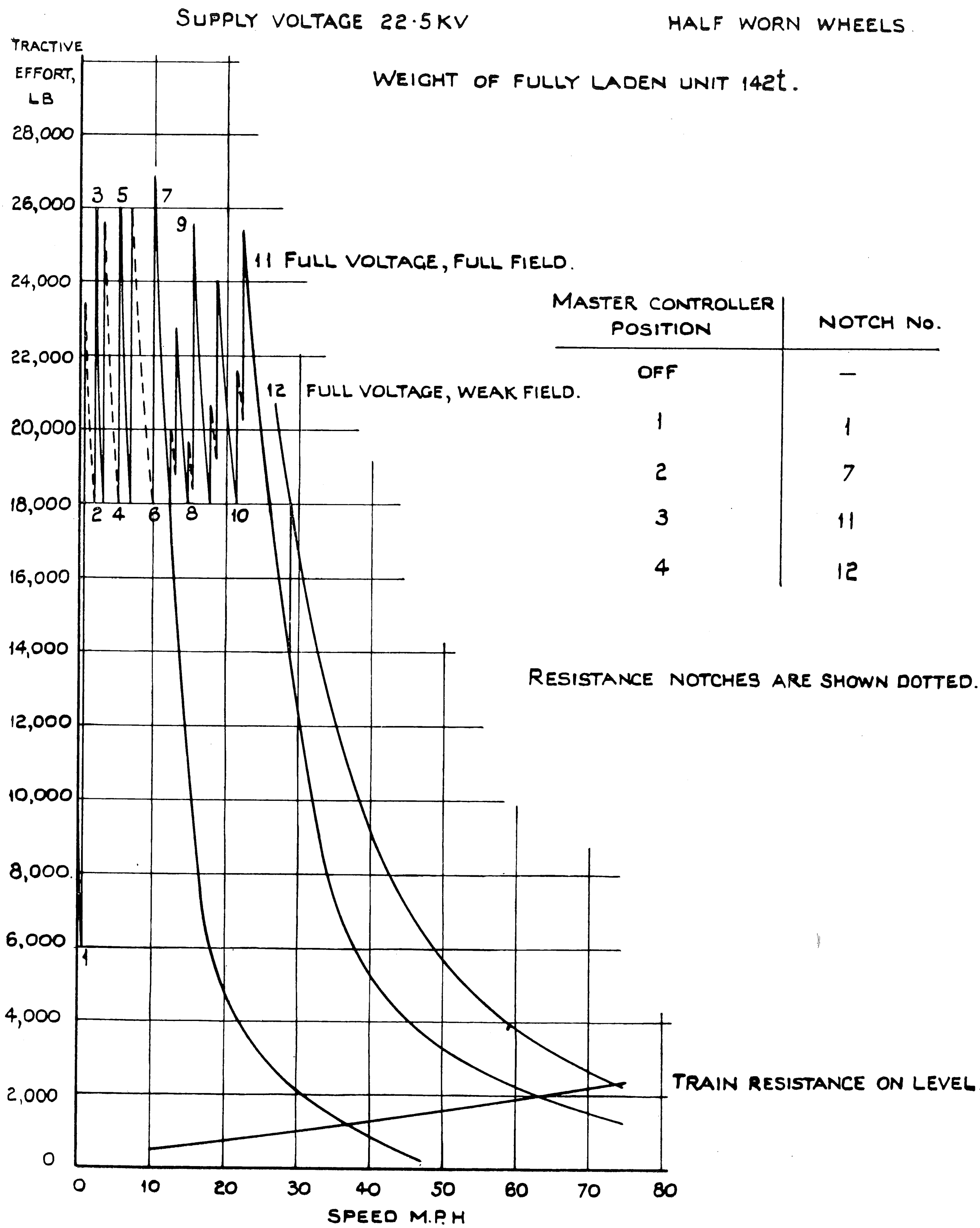
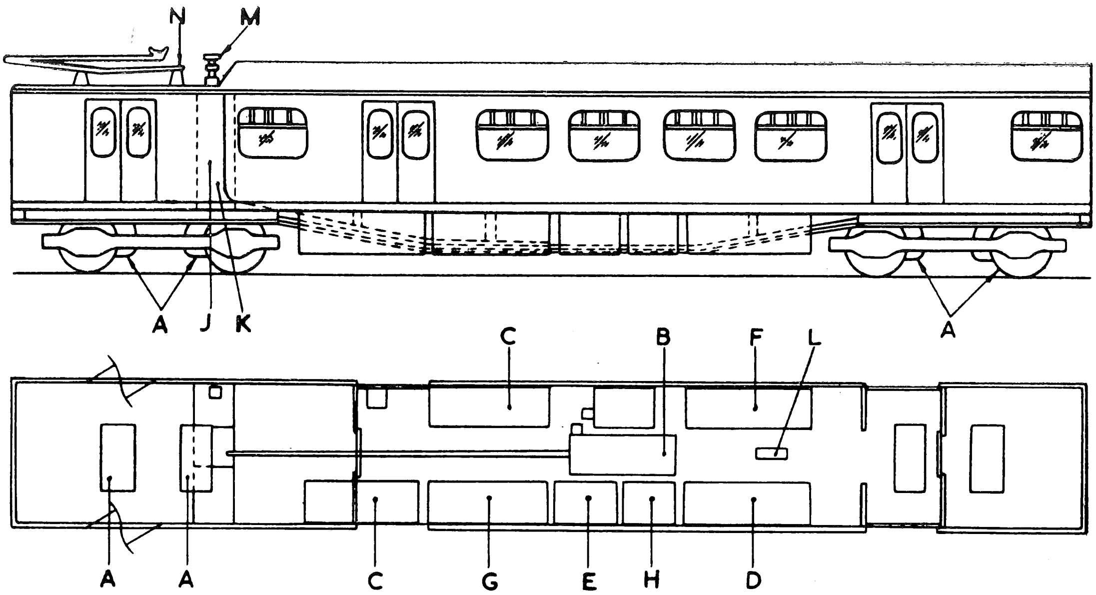
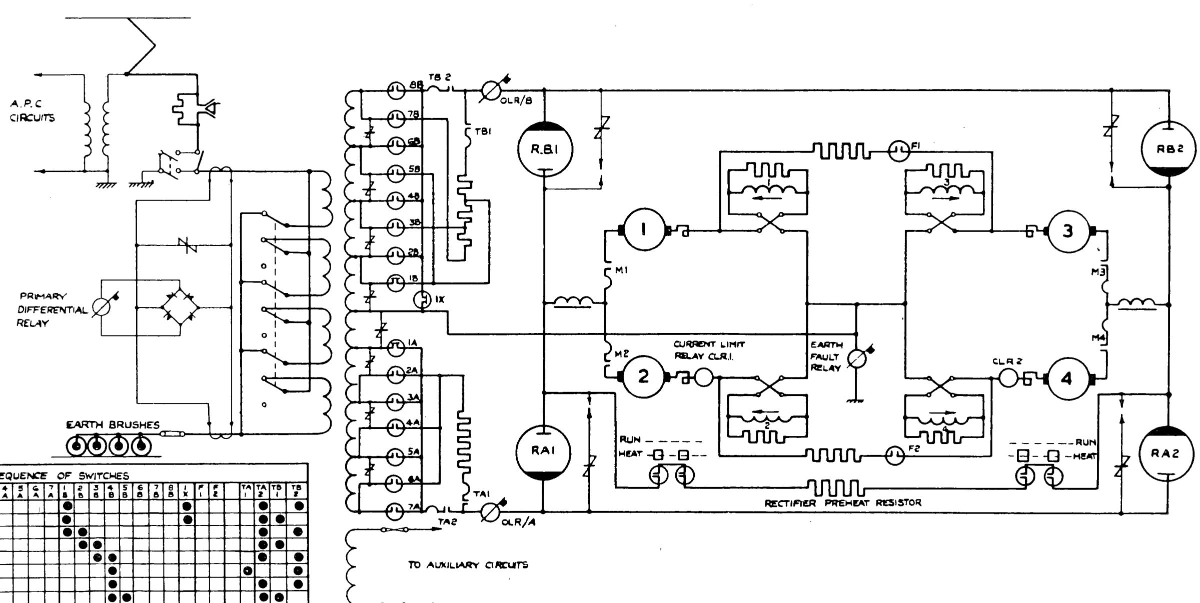


Fig.2 Performance curves for 3-coach unit. Glasgow suburban lines



A TRACTION MOTOR
B TRANSFORMER
C RECTIFIERS & FAN
D TAP-CHANGING SWITCHGROUP
E RADIATOR FAN & MOTOR
F MOTOR SWITCHGROUP
G RECTIFIER AUXILIARIES
H TRANSITION RESISTOR
J L.T. CUPBOARD
K PANTOGRAPH COMPRESSOR
L TERTIARY FUSES
M AIR-BLAST CIRCUIT-BREAKER
N POTENTIAL TRANSFORMER

Fig.3 Layout of equipment. Glasgow suburban lines



SEQUENCE OF SWITCHES

		1A	2A	3A	4A	5A	6A	7A	1B	2B	3B	4B	5B	6B	7B	8B	1X	F1	F2		TA1	TA2	TB1	TB2
SHUNT	1	●							●								●					●		●
	2	●							●								●					●	●	
	3	●							●	●												●		●
	4	●								●	●											●	●	
	5	●									●	●										●		●
	6	●	●									●									●			●
HALF POWER	7		●	●								●										●		●
	-			●								●	●									●	●	
	8			●									●	●								●		●
	-			●	●									●							●			●
	9				●	●								●								●		●
	-					●	●							●							●			●
	10						●	●						●								●		●
	-							●						●	●							●	●	
FULL POWER	11							●							●	●						●		●
WEAK FIELD	12							●								●		●	●			●		●
	-							●								●		●	●			●		●

Fig.4 Power schematic diagram. Glasgow suburban lines

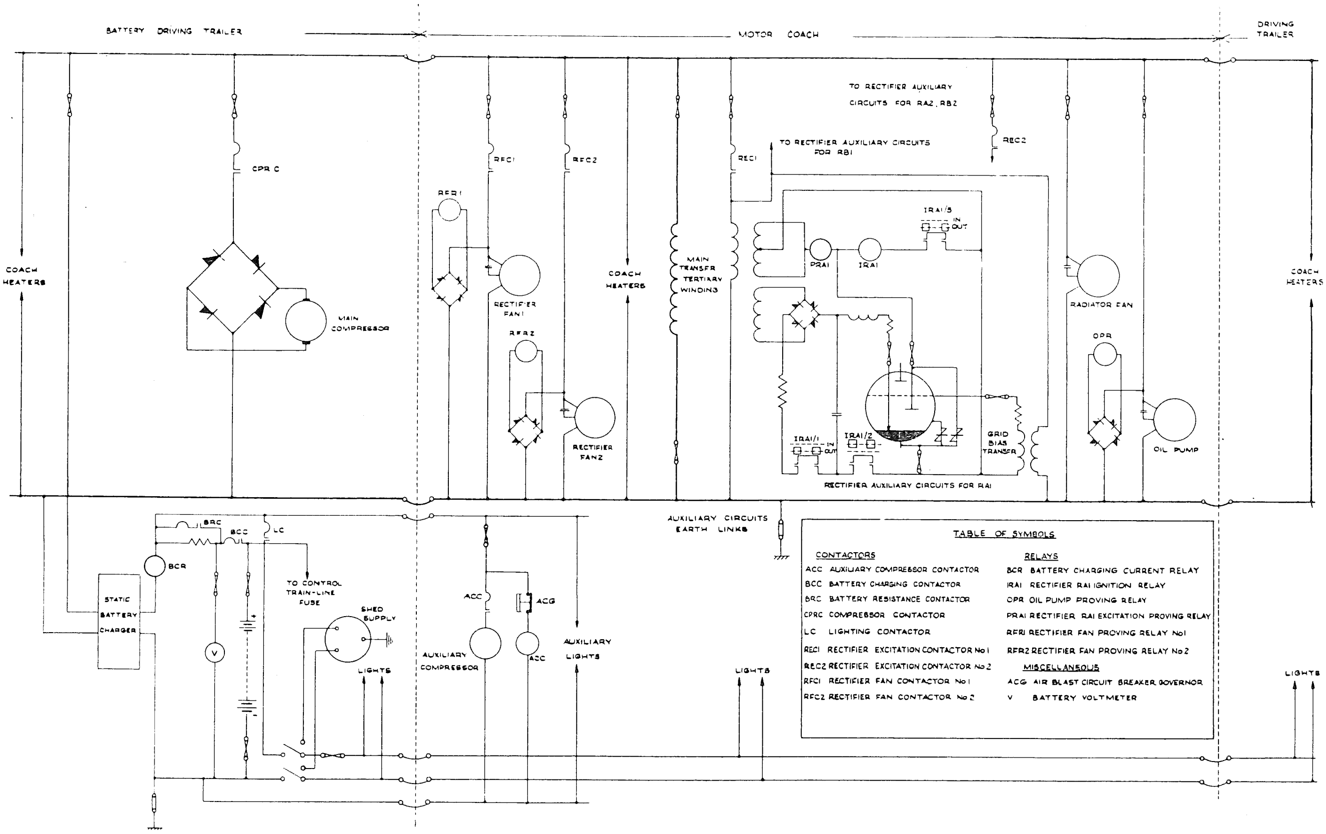


Fig.5 Auxiliary schematic diagram. Glasgow suburban lines

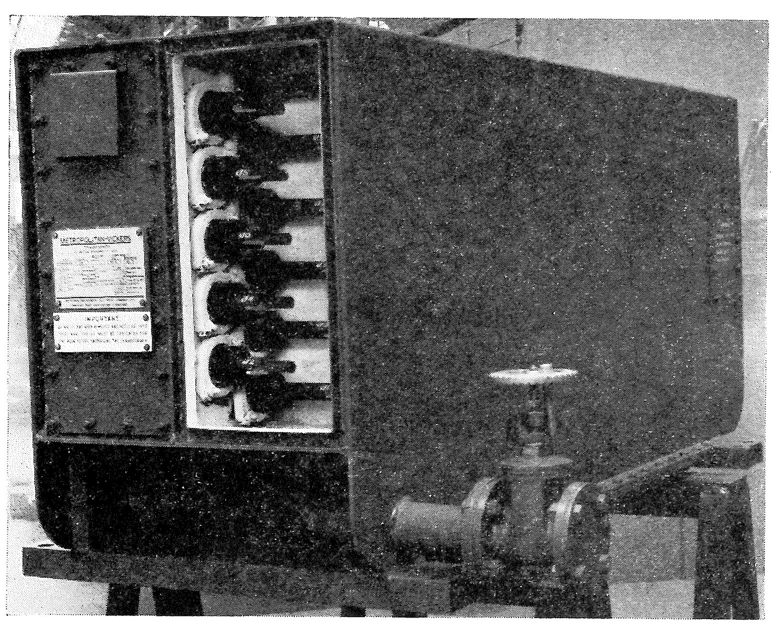


Fig.6 Main transformer seen from L.T. end. Glasgow suburban lines

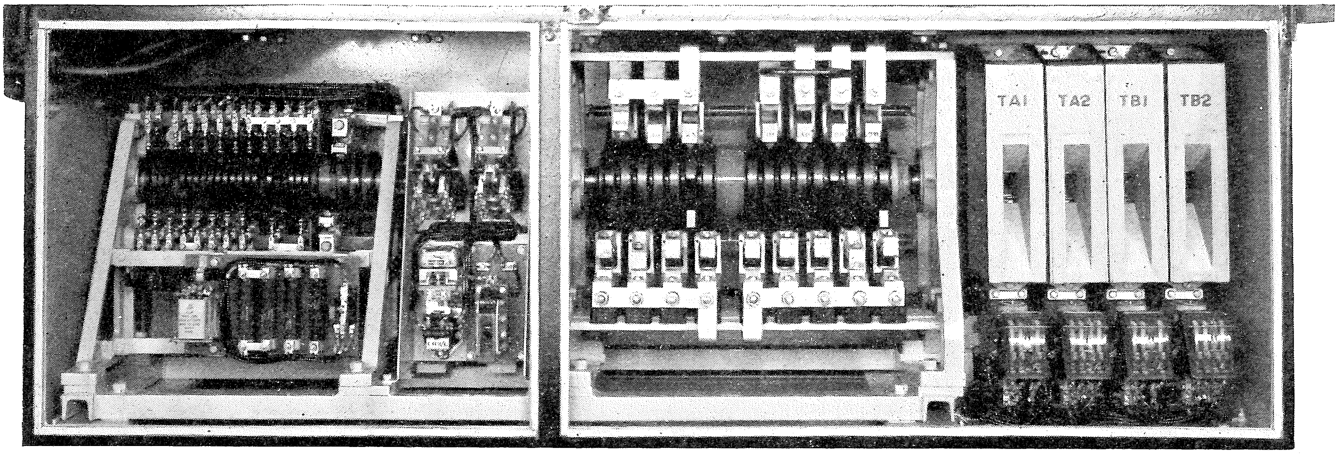


Fig.7 Tapchanger. Glasgow suburban lines

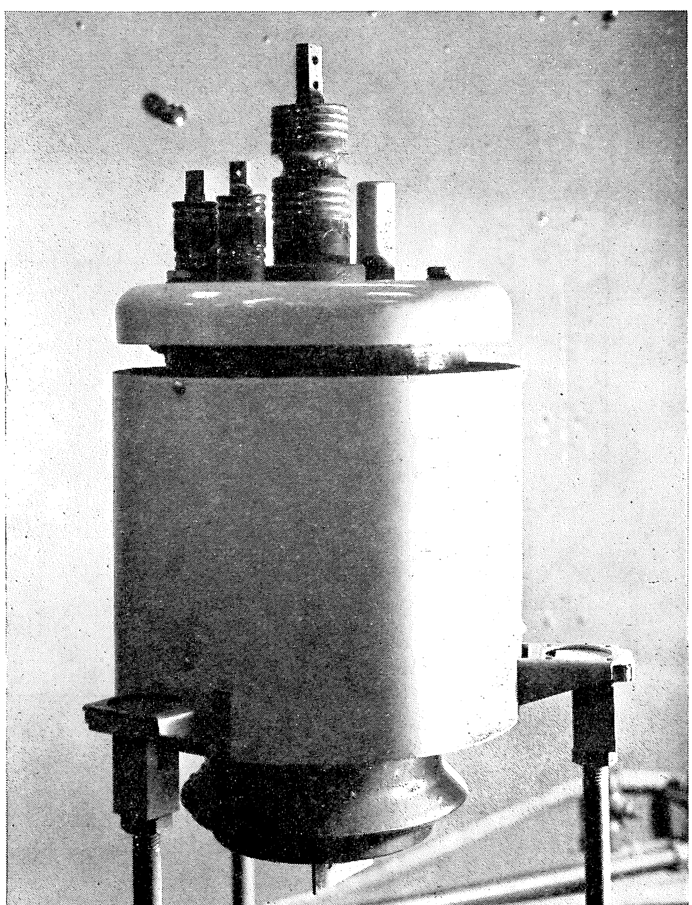


Fig.8 Single anode pumpless steel tank rectifier. Glasgow suburban lines

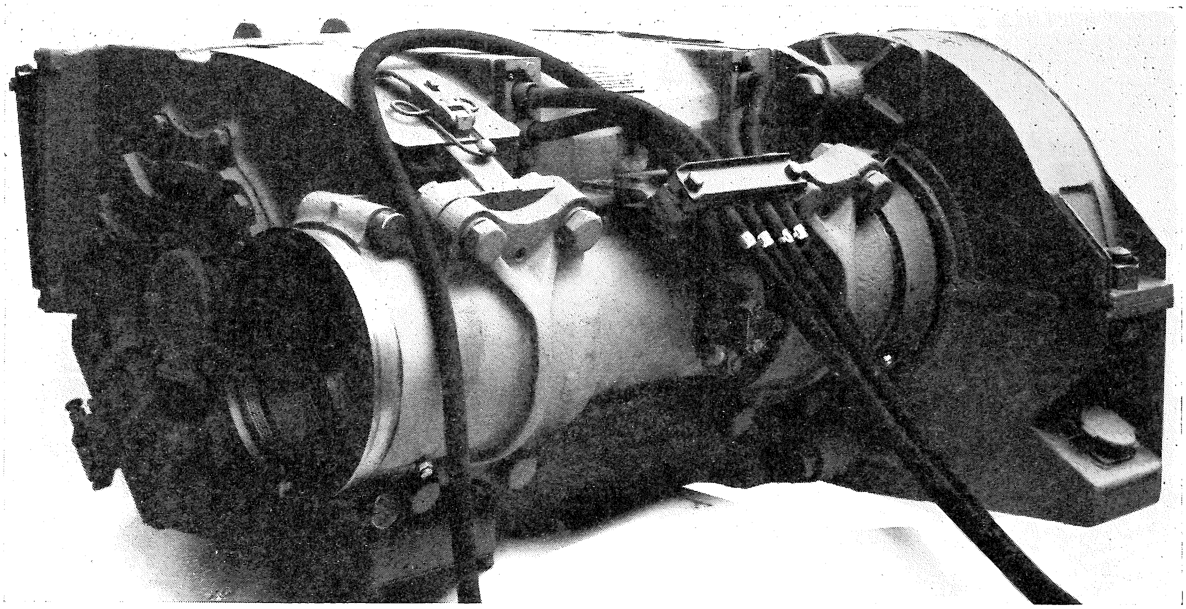


Fig.9 Traction motor with gearcase. Glasgow suburban lines

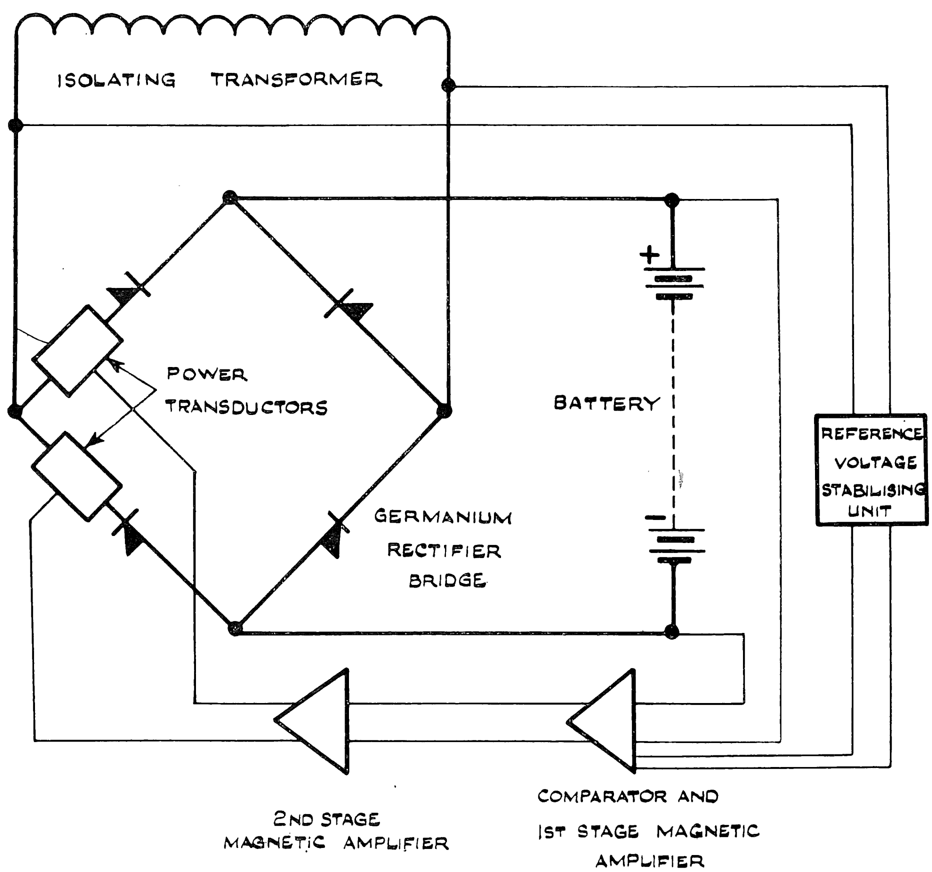


Fig.10 Automatic voltage regulator. Glasgow suburban lines

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