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Paper 24

Multiple - Unit Train Equipments for Manchester - Crewe Line (A.E.I.) Rugby

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1 Introduction

The equipment described in this paper is for 35 four-car train units, 15 units for service on the Manchester – Crewe and 20 for service on the Liverpool – Crewe suburban services of the London Midland Region. The coaches were built at the Wolverton Carriage Works of the London Midland Region.

Each four-car unit comprises:—
- Battery driving trailer,
- Motor coach,
- Plain trailer,
- Driving trailer,

of which details are given in Paper 4.

There are two design features peculiar to this stock:—

(*a*) The electrical equipment on the motor coach underframe has been mounted entirely in the side bays, keeping the centre section between the main longitudinals free for brakegear, pipework and cables.

(*b*) The stock is fitted with germanium main power and auxiliary rectifiers.

The equipments will operate in multiple with those provided by three other manufacturers, and a common driving procedure and layout of controls is used.

Photographs of the train unit are shown in figs.1 and 1*a*.

2 Leading Particulars

Vehicle	*Unladen Weight*	*Laden Weight (all seats occupied)*
Battery driving trailer	35·6 tons	40·6 tons
Motor coach	53·6 ,,	59·6 ,,
Non-driving trailer	31·3 ,,	36·3 ,,
Driving trailer	31·4 ,,	36·4 ,,
Total	151·9 tons	172·9 tons

Other principal data for the 4 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	14·8 tons
Maximum service speed	75 m.p.h.
Balancing speed on level tangent track	69 m.p.h.
Acceleration on level tangent track	1·1 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	19·2 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 underframe is shown in fig.3.

3 Description of Circuits

One of the advantages of the semi-conductor rectifier is that the efficiency is practically independent of voltage. It is therefore normally possible to design an efficient rectifier to suit any design of traction motor.

In the interests of standardisation it was decided to use the same motor as that for the Glasgow suburban services.

3.1 *Power circuits*. These are shown in fig.4

With a semi-conductor rectifier a bridge-connected rectifier scheme is the obvious choice as this gives useful weight and kVA savings in the transformer. The four traction motors are connected permanently in parallel in order to assist adhesion. The total RMS D.C. current is about 700 amps. It was decided to use low voltage tap changing with air break tap changing switches controlled by a motor driven camshaft. A tap changing reactor controls the inter-tap transformer circulating current by acting as a mid-point auto-transformer. In order to obtain a large number of notches from a fairly simple camshaft it was decided to use a buck-boost system of control. The motor voltage is stepped up during train acceleration in 17 steps from 5 transformer taps, using 10 camshaft operated contactors in conjunction with a tap-changing reactor. In this system an untapped secondary transformer winding is connected in series with the output from the camshaft contactors which in turn are supplied from another tapped winding. At first the two windings are in opposition and the full voltage of the tap winding is bucking the other winding. As the camshaft rotates, the output of the tap winding is reduced until the other winding only is supplying the motors at approximately half voltage. A pair of buck-boost contactors then changes over and the camshaft rotates in the opposite direction until the full voltage of the tap winding is boosting the other winding.

The master controller has running positions at half and full voltage but the progress of the camshaft can be arrested at any notch, and all are continuous running notches.

As the equipment has to be capable of giving its full output at 25 kV or 6·25 kV on the line, the primary is wound in four identical sections which are connected either in series or parallel by a changeover switch mounted under oil in the main transformer, and controlled automatically by the APC circuit, and the voltage selection circuit.

The roof mounted air blast circuit breaker cannot be closed until the switch has been proved to be in the position corresponding to the voltage on the line.

3.2 *Auxiliary circuits*. These are shown in fig.5.

The heating and auxiliary circuits for the whole unit are supplied from the tertiary winding of the main transformer. Most of the auxiliary motors are of the capacitor start and run type. For the main compressor, which calls for a high starting torque, a series D.C. motor is used, fed from the rectifier. The auxiliary compressor which provides air for the initial raising of the pantograph and closing of the air blast circuit breaker is driven by a D.C. motor fed from the battery. The battery is kept charged from a static battery charger. The lighting of the whole unit is supplied from the battery and battery charger operating in parallel.

4 Description of Electrical Apparatus

4.1 *H.T. Equipment*

The voltage selection circuit is fully described in Paper 3, and so is the air blast circuit breaker and the pantograph, in Paper 20.

Power is taken from the roof to the transformer via a rubber-insulated cable. This terminates at the roof in a porcelain-shedded bushing which is connected to the circuit breaker, and at the transformer end in a bushing which plugs into a garter-spring contact on the transformer. This bushing is subsequently filled with transformer oil, this oil being quite separate from the main oil circulation system so that the removal of the cable does not necessitate draining the transformer tank.

4.2 *The Transformer*

The transformer is a straightforward two-leg design, conventional electrically, but specially designed mechanically to mount in the side bay of B.R. standard underframe. In addition to the main windings it has a 240-volt 55-kW auxiliary winding for train heating and other auxiliaries.

The ratings of the transformer windings are as follows:—

Primary	945 kVA
Secondary winding	890 kVA
Auxiliary	55 kVA at 240 volts nominal

The 25/6·25 kV changeover switch is mounted at one end of the core and coil assembly, and is air-operated. The magnet valves and control gear are mounted on the transformer itself. This is illustrated in fig.6.

The transformer is forced oil cooled, and is resiliently mounted on rubber bushes, so that any racking of the underframe in service will not be transmitted to the transformer tank.

4.3 *Control Equipment*. See fig.7

The tap change camshaft and the motor contactors, with their associated control gear and relays, are mounted in two cases on the underframe of the motor coach. The camshaft is driven by a D.C. motor through a chain of reduction gears and Geneva mechanism. Accuracy of location is essential and is assured by a system of inter-notch interlocks which stop the shaft by dynamically braking the motor. A notching relay controls the automatic acceleration of the train.

There is an EP contactor in the positive and negative connection to each traction motor, and a motor cut out switch is provided operating on the coils of the magnet valves on the appropriate contactors. In addition there is an equipment cut out switch which can render the whole of the traction control equipment on the motor coach inoperative.

Two steps of traction motor field divert are provided under current limit control. The field divert resistors are underframe mounted and are of the edgewise-wound stainless steel strip type.

4.4 *Rectifiers*

The germanium rectifier consists of ten trays each having 48 cells. The trays are supported on rails inside a sheet steel cubicle, and by removing the polyester resin front cover, the trays can be pulled out on a special leg and are then fully accessible for maintainance purposes. Each tray carries two fuses, each fuse feeding two parallel strings of cells. A hole storage capacitor is mounted on the underframe. A rectifier with a tray pulled out is illustrated in fig.8.

Semi-conductor rectifiers require no heating or excitation equipment but adequate cooling is vital. The cells are mounted on aluminium fins and a fan blows approximately 3,500 cu. ft. of air per min. ducted from the outside of the coach, through the cubicle. This air is not filtered but is drawn from the sides of the coach above solebar level in order to avoid the very dirty air underneath the coach. It was, however, considered very much the lesser of two evils to accept unfiltered air rather than to risk blocked filters and subsequent air starvation leading to cell failure.

As this large quantity of cooling air was available, the transformer oil cooler, tap change reactor and D.C. smoothing chokes were mounted in the air stream on the opposite side of the rectifier cubicle from the fan. Thus the side on the coach opposite to the transformer has three bays occupied respectively by the fan and motor, rectifier cubicle, and transformer oil cooler plus tap change reactor plus D.C. smoothing chokes. Underframe members pass through the air stream at the end of each bay and special precautions have been taken to avoid air loss and to seal the gaps between items of equipment, using neoprene sealing pieces.

4.5 *Reactors*

The D.C. reactor is of dry type conventional construction with a two-limb air-gapped core. The windings on the legs are connected in parallel. They are of the disc type with copper conductors, insulated with glass braid, silicone impregnated, to class H standard. There is one reactor per motor coach connected in series with the motors and forced air cooled. The inductance of the reactor is 5·5 mH at 700 amps D.C. (continuous rating).

4.6 *Traction Motors*

The traction motors are described in Paper 27. They have a continuous rating of 190 H.P. in full field and 207 H.P. in weak field.

4.7 *Auxiliaries*

There are only four auxiliary motors on a four-car unit.

Auxiliary machines:—

Motors Duty	*How Supplied*	*Type of Motor*	*Nominal Voltage*	*H.P.*
Rectifier cooling fan	From Main transformer aux. winding	Single phase capacitor start and run squirrel cage induction motor	240 A.C.	3·1
Transformer circulating oil pump	From Main transformer aux. winding	Single phase capacitor start and run squirrel cage induction motor	240 A.C.	1·5
Main compressor	From Main transformer aux. winding	Series connected D.C. motor	210 D.C.	7
Auxiliary compressor	From Battery	Series connected D.C. motor	90/110 D.C.	1·2

The single phase squirrel cage induction motor driving the transformer oil pump runs in the circulating oil which cools it and lubricates its bearings. Thus no shaft glands are needed and the pump can be made oil proof with ease.

The battery is of the nickel-iron type. It normally floats across the battery charger which is a static type, which takes in an A.C. supply at a voltage between 192 and 310 according to the line voltage and gives a regulated D.C. output at 110 volts D.C. plus or minus 2 volts. This voltage is adjustable between about 105 and 116 volts. In addition a current limiting circuit prevents overloading of the battery charger, any overload being taken by the battery. The charger has a saturable reactor controlled by voltage and current sensing circuits and is expected to require no maintenance in service. The charger is illustrated in fig.9.

5 Protection

The transformer has three protective systems.

(*a*) A straight overload relay is connected to a current transformer in one primary winding section in such a manner that it operates with the appropriate current setting in the 6·25 and 25 kV transformer connections. This is set in service to give a reasonable measure of protection in the event of a short circuit on the primary or secondary side. It must be set fairly high because the inrush current to the transformer on closing the roof air blast circuit breaker can be several times full load according to the point on the cycle at which the breaker closes.

(*b*) The transformer tank is insulated on its rubber mountings and care is taken to ensure that it is not joined to earth by the circulating oil piping, etc. It is connected solidly to the underframe by a cable which passes through a current transformer. Thus any earth fault in this part of the circuit will cause current to flow through the current transformer which in turn will cause a relay to trip and open the air blast circuit breaker.

(*c*) A thermostat in the transformer oil opens the air blast circuit breaker if the oil temperature rises too high. This thermostat will also cover the failure of an oil pump or the blowing of its fuse since the oil temperature will rapidly rise.

The traction motor negative return is earthed through a current transformer. Any fault which occurs and causes an earth will cause this current transformer to trip a relay and open the air blast circuit breaker. This protection operates on A.C. or D.C. faults. The secondary of the current transformer is connected in series with a relay coil and an A.C. voltage is applied across the two in series. Normally this voltage appears almost entirely across the CT winding but the flow of fault current in the primary saturates the iron and causes the voltage to appear across the relay coil which trips the relay. On rectifier fed D.C. circuits the ripple component is sufficient to operate the system.

The traction motors are protected by conventional overload relays which open the appropriate motor contactors.

Rectifier Protection

The rectifier has fuses in each parallel pair of strings of cells. A cell failure is normally a short circuit and in due course probably leads to the failure of a string of cells and the blowing of a string fuse. A differential current transformer and relay system then operates indicating the position of the failure, but power is not removed and trains can continue to operate as the loss of one or even more strings is not sufficient to render the equipment useless.

If power is left on a semi-conductor rectifier after a cooling air failure, the rectifier will be destroyed in a very short time. A vane is therefore provided in the air circuit which will drop if the air supply fails and at once open the traction motor contactors.

Fault indication is provided as for the other M.U. train equipments as described in Paper 4.

6 Conclusion

This equipment incorporates several distinctive features and is noteworthy as being the first to be supplied in quantity to British Railways using germanium rectifiers for the main supply to the traction motors. The preliminary results available from the extended experiment of Lancaster – Morecambe – Heysham Line of the London Midland Region indicate that few difficulties should arise; the opinion of the authors is that semi-conductor rectifiers have already established themselves for multiple-unit practice.

SUMMARY

This paper describes the A.C. 50-cycle electrical equipment for undercar mounting on multiple-unit trains, built for B.T.C. by AEI (Rugby) Ltd (formerly The BTH Co. Ltd).

The train units, built at Wolverton Carriage Works of the L.M. Region, are of four coach formation with driving trailer at each end. They are geared for 75 m.p.h. max. service speed and have a continuous rating of 830 H.P. They can operate on a 25 kV or 6·25 kV supply and weigh 173 tons laden with all seats occupied. The weight of the electrical equipment is 19·2 tons.

Power conversion from 50-cycle single phase A.C. to undulating D.C. for the traction motors is by means of bridge connected air-cooled germanium rectifiers.

The motors are permanently connected in parallel. The tapped transformer secondary winding first bucks and then boosts an untapped winding in series with it to cover the full voltage range.

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

The transformer oil circulating pump and the main cooling fan are driven by single phase capacitor start and run motors while the compressor D.C. motor is supplied from a separate germanium rectifier.

RÉSUMÉ

Cet exposé décrit les équipements électriques à courant alternatif 50 Hz, montés sous les voitures des rames automotrices construites à la commande de la British Transport Commission par AEI (Rugby) (anciennement BTH Co. Ltd.).

Les rames automotrices construites aux ateliers de wagons de la Région London-Midland des Chemins de fer Britanniques à Wolverton se composent de quatre voitures avec une voiture-pilote à chaque extrémité. Le rapport d'engrenages est choisi pour la vitesse maximum de 75 m.p.h. Elles ont au régime continu une puissance de 830 H.P. et fonctionnent à 25 kV ou à 6,25 kV. Le poids global de la rame avec toutes les places occupées s'élève à 173 tons. L'équipement électrique pèse 19,2 tons.

Au moyen des redresseurs au germanium, refroidis par air on convertit le courant monophasé à 50 Hz en courant ondulé pour alimenter les moteurs de traction.

Les moteurs sont branchés constamment en parallèle. Pendant l'accélération de la rame, on augmente la tension en 17 échelons à partir de 5 prises du transformateur en se servant de 10 contacteurs commandés par cames, conjointement avec une réactance de transition.

L'enroulement secondaire à prises de réglage du transformateur diminue d'abord at augmente ensuite la tension d'un enroulement sans prises en série avec le premier, pour permettre le réglage complet de la tension.

Un enroulement tertiaire du transformateur principal alimente les circuits auxiliaires y compris ceux du chaffage des voitures.

Des moteurs asynchrones monophasés avec condensateur pour le démarrage et la marche normale entraînent la pompe à huile du transformateur et le ventilateur principal de refroidissement, tandis que le moteur à courant continu du compresseur est alimenté d'un redresseur au germanium indépendant.

ZUSAMMENFASSUNG

Dieser Bericht beschreibt die für die "British Transport Commission" von der "Associated Electrical Industries (Rugby) Ltd." (ehemalige "British Thomson-Houston Co. Ltd.") gebaute elektrische Ausrüstung für 50 Hz zur Montage auf der Unterseite des Rahmens von Triebwagenzügen.

Die in der bahneigenen ("London Midland Region") Eisenbahnwagenfabrik in Wolverton gebauten vierteiligen Triebwagenzüge haben an jedem Ende einen Steuerwagen. Die Getriebeausrüstung erlaubt eine Höchstdienstgeschwindigkeit von 75 m.p.h. Mit einer Dauerleisting von 830 h.p. können die Triebwagenzüge an ein 25 kV oder 6.25 kV Versorgungsstystem geschaltet werden. Mit vollbesetzten Sitzplätzen haben sie ein Gewicht von 173 tons einschliesslich 19.2 tons für die elektrischen Apparate.

Die Fahrmotoren werden mit gleichgerichtetem Wellenstrom gespeist, welcher durch Umwandlung des einphasigen 50 Hz Stromes mittels luftgekühlter Germanium-Gleichrichter in Brückenschaltung erhalten wird.

Die Fahrmotoren sind dauernd parallel geschaltet. Während der Zugbeschleunigung wird die Motorspannung in 17 Stufen gesteigert, und zwar von 5 Transformator-Anzapfungen unter Anwendung von 10 durch Nockenwelle betätigten Schützen sowie einer Schaltdrossel. Die mit Anzapfungen versehene Sekundär-Wicklung des Transformators verkleinert erst und erhöht dann die Spannung einer mit ihr in Reihe geschaltete Wicklung ohne Anzapfungen, um den ganzen Spannungsbereich zu decken.

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

Die Ölpumpe des Transformators sowie der Hauptventilator werden durch einphasige Motoren die mit den für den Anlauf bzw. Betrieb nötigen Kondensatoren versehen sind, angetrieben, während der Kompressor von einem Germanium-Gleichrichter gespeisten Gleichstrommotor angetrieben wird.

RESÚMEN

Este folleto describe los equipos eléctricos, tipo c.a. de 50 Hz, de colocarse debajo del bastidor de los trenes de unidades multiples, construidos a pedido de la Comisión Británica del Transporte por AEI (Rugby) Ltd. (antiguamente BTH Co. Ltd.).

Los trenes de unidades multiples construidos en los talleres de vagones en Wolverton, de la Region L/M de los Ferrocarriles Británicos, comprenden cuatro coches, con coche-piloto en cada fin. Tienen una transmisión a las velocidades hasta una máxima de marcha de 75 m.p.h., mientras el regimen continuo está de 830 h.p. Pueden funcionar ya con corriente de 25 kV o bien con 6,25 kV; el peso global es de 173 tons inclusive la carga total de pasajeros. El equipo eléctrico pesa 19·2 tons.

La conversión de energía del sistema monofásico de 50 Hz a la corriente unidireccional ondulante, que alimenta los motores de tracción, se efectua por medio de rectificadores de germanio enfriados por aire, y con conexiones en puente.

El arrollamiento secundario con puntos de toma reduce inicialmente y después aumenta el potencial en un devanado sin tomas en serie con el secundario, para permitir la utilización del alcance completo de voltajes.

Un devanado terciario del transformador principal suministra corrientes para circuitos auxiliares, inclusive los circuitors para calefacción de los coches.

La bomba para la circulación del aceite en el transformador y además el ventilador de enfriamiento principal están accionados por motores monofásicos con condensadores, para el arranque y la marcha; el motor de tipo c.c. para impulsar el compresor está alimentado de un rectificador de germanio independiente.

Fig.1 Complete train unit

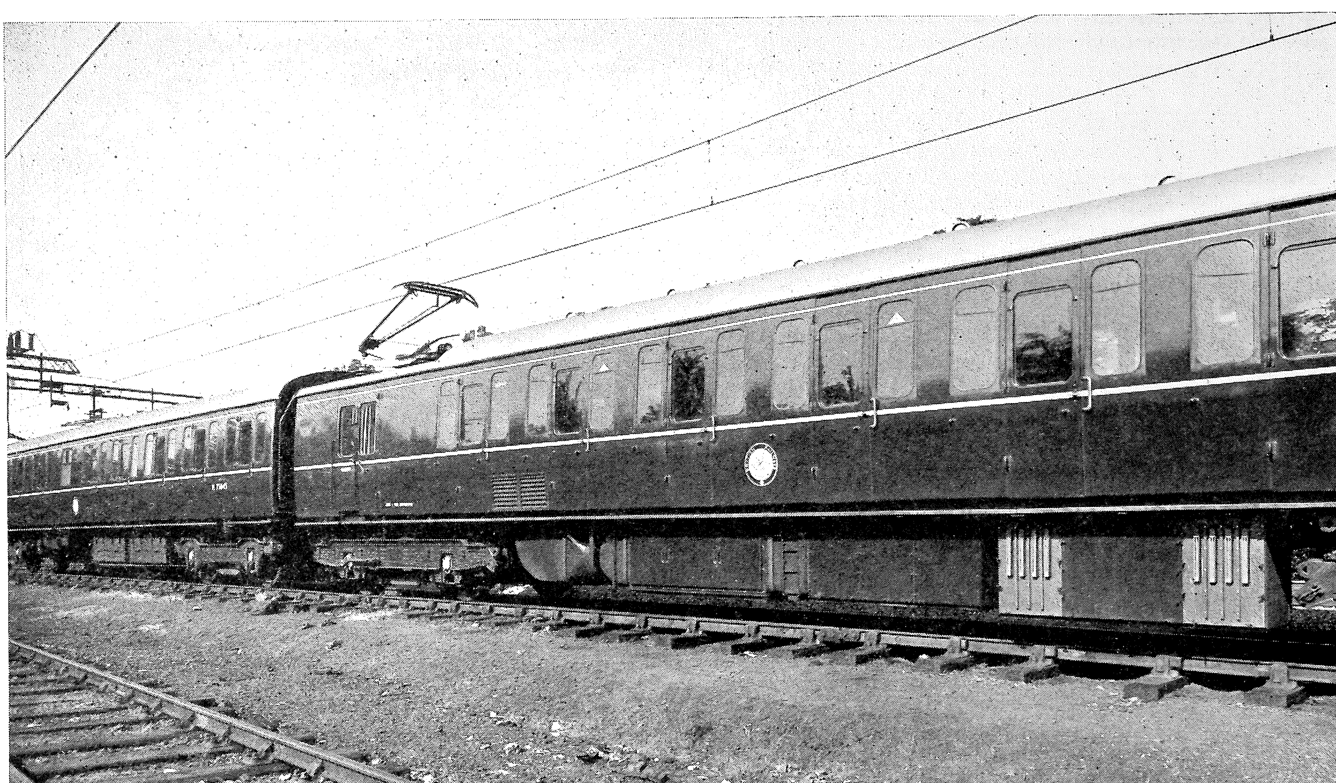

Fig.1a Motor coach. Manchester – Crewe line

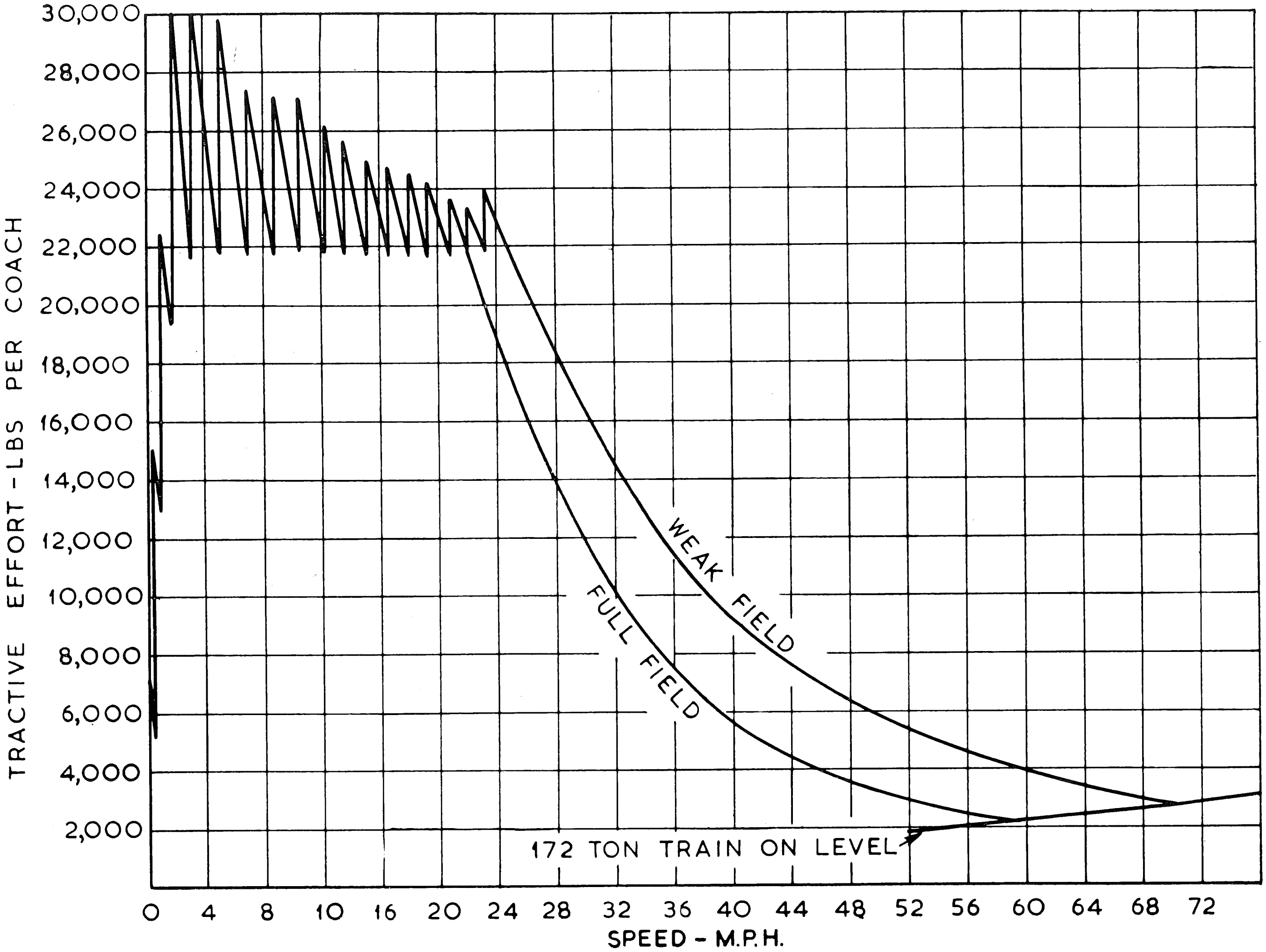

Fig.2 Performance curves for 4-coach unit

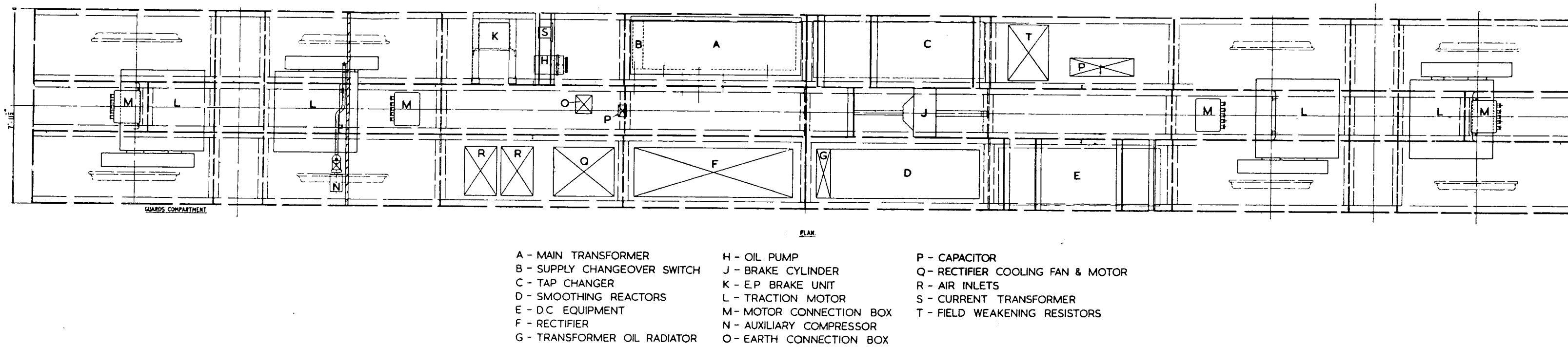

Fig.3 Motor coach underframe layout

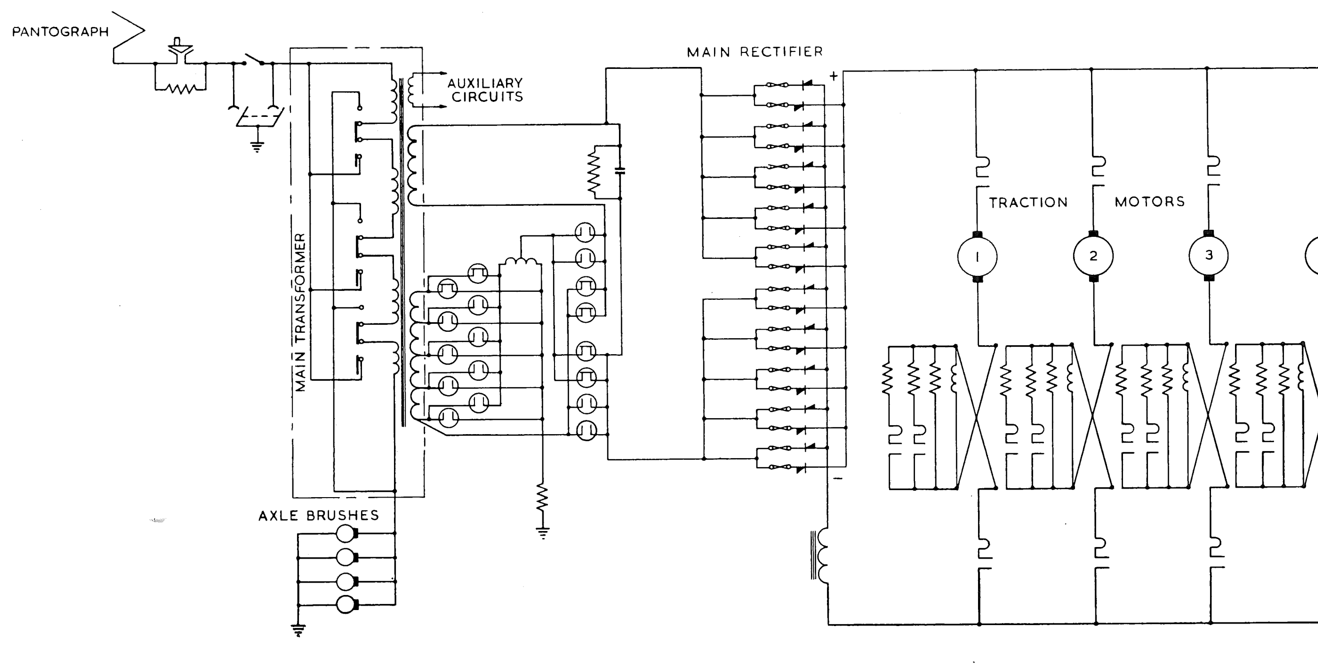

Fig.4 Power circuit

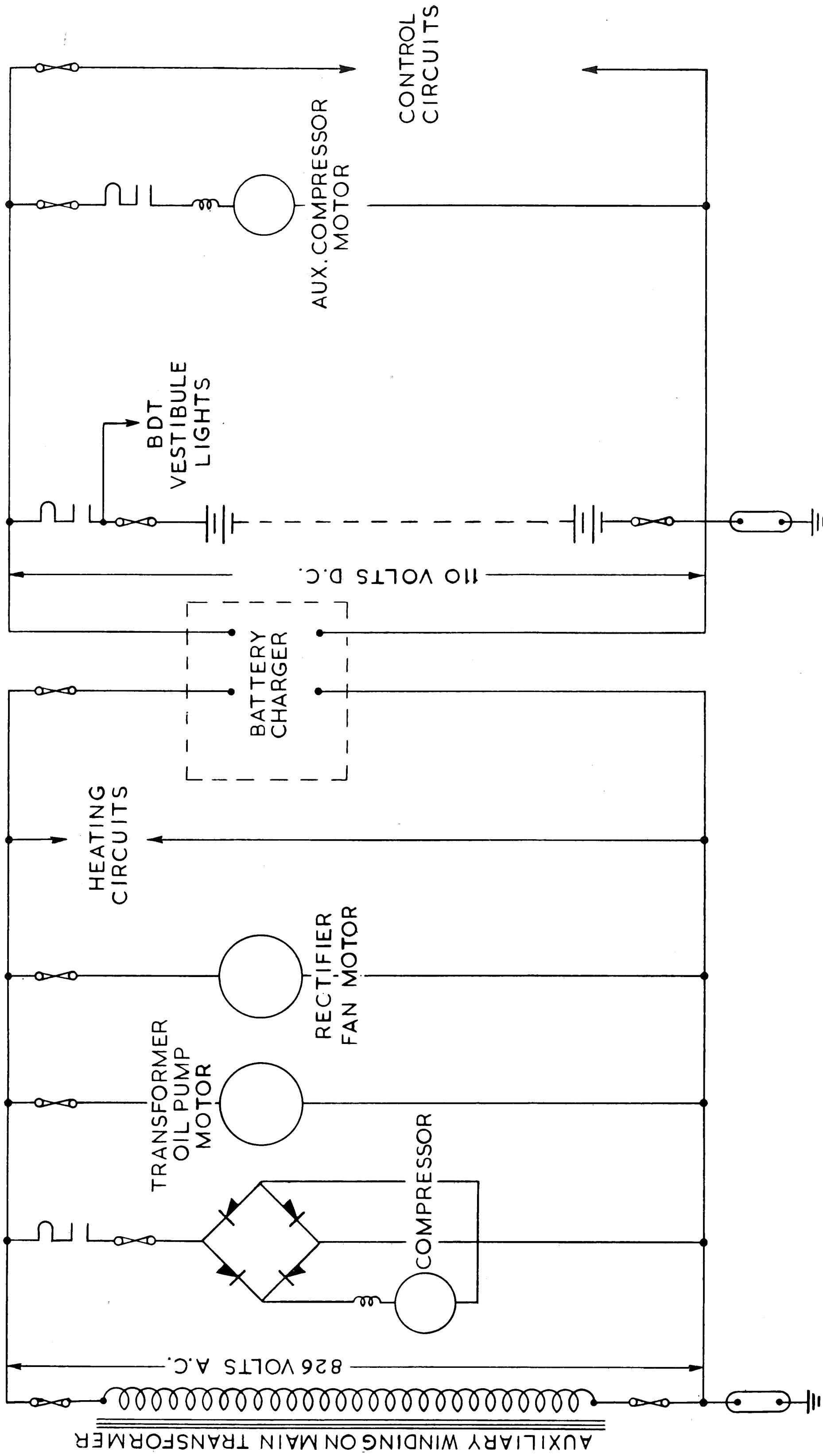

Fig.5 Auxiliary schematic diagram

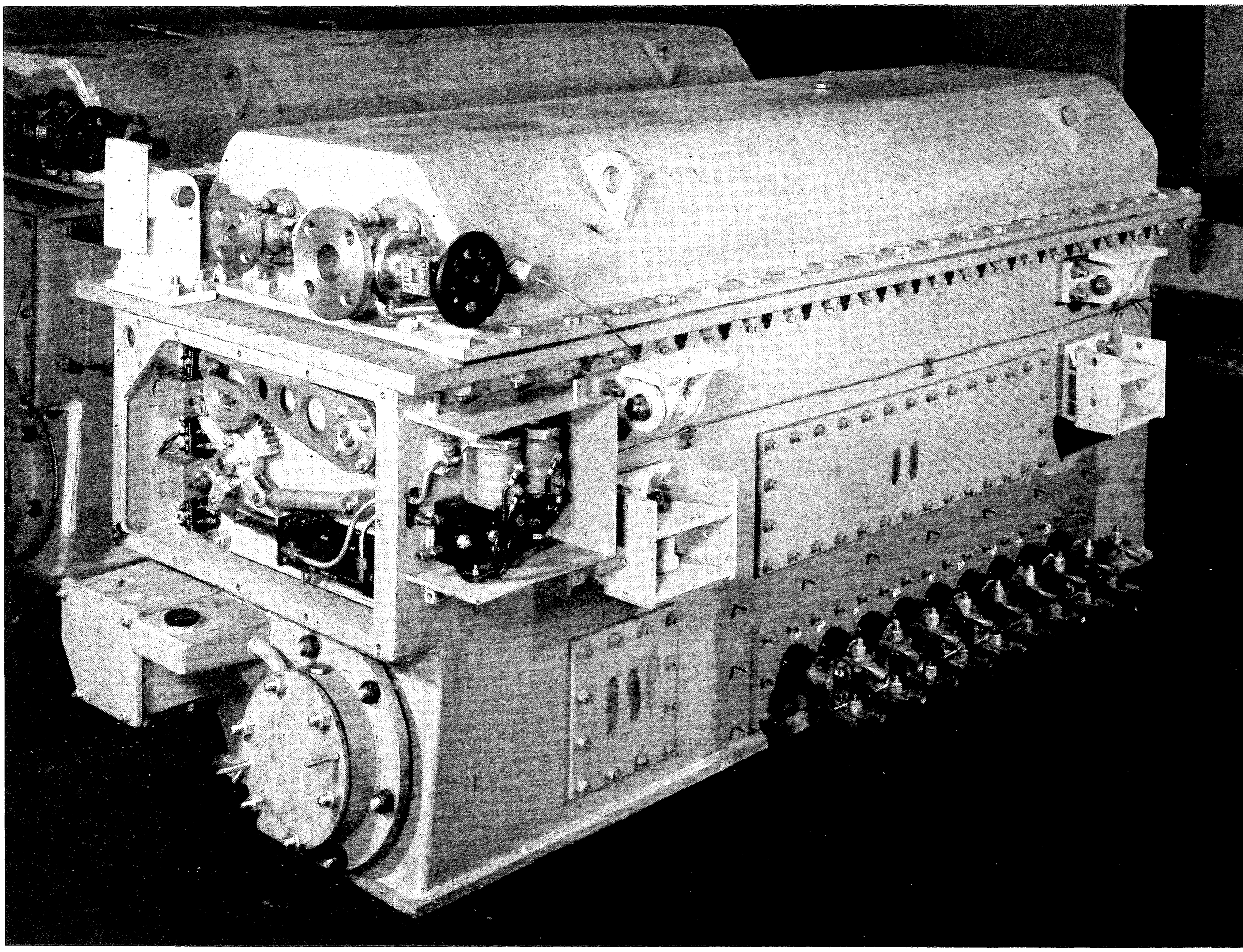

Fig.6 Main transformer. Manchester – Crewe line

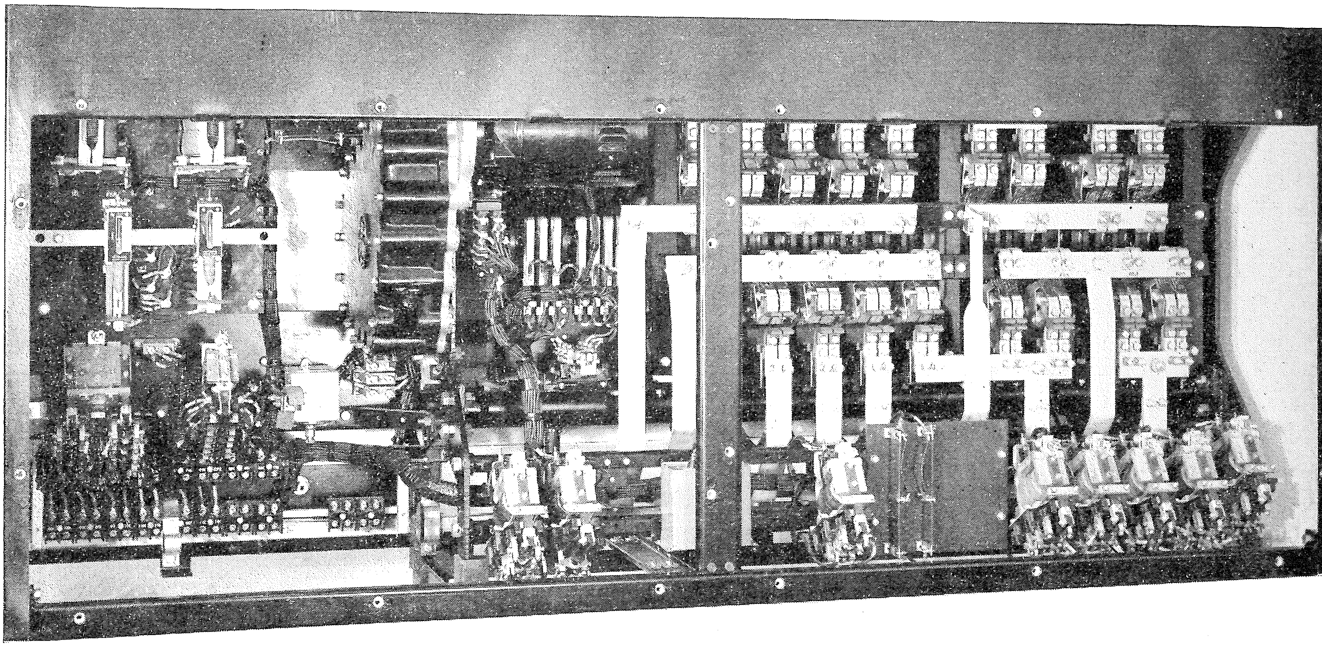

Fig.7a Control gear frame – camshaft unit

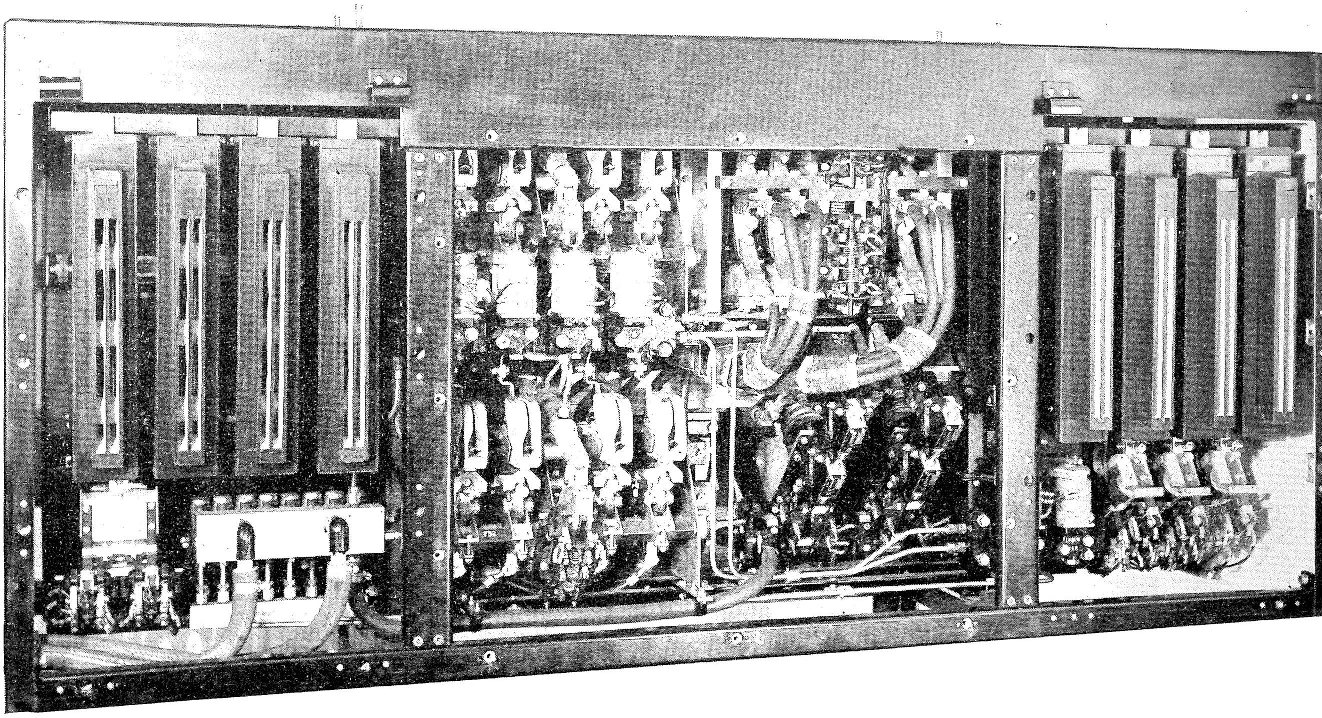

Fig.7b Control gear frame – motor contactors

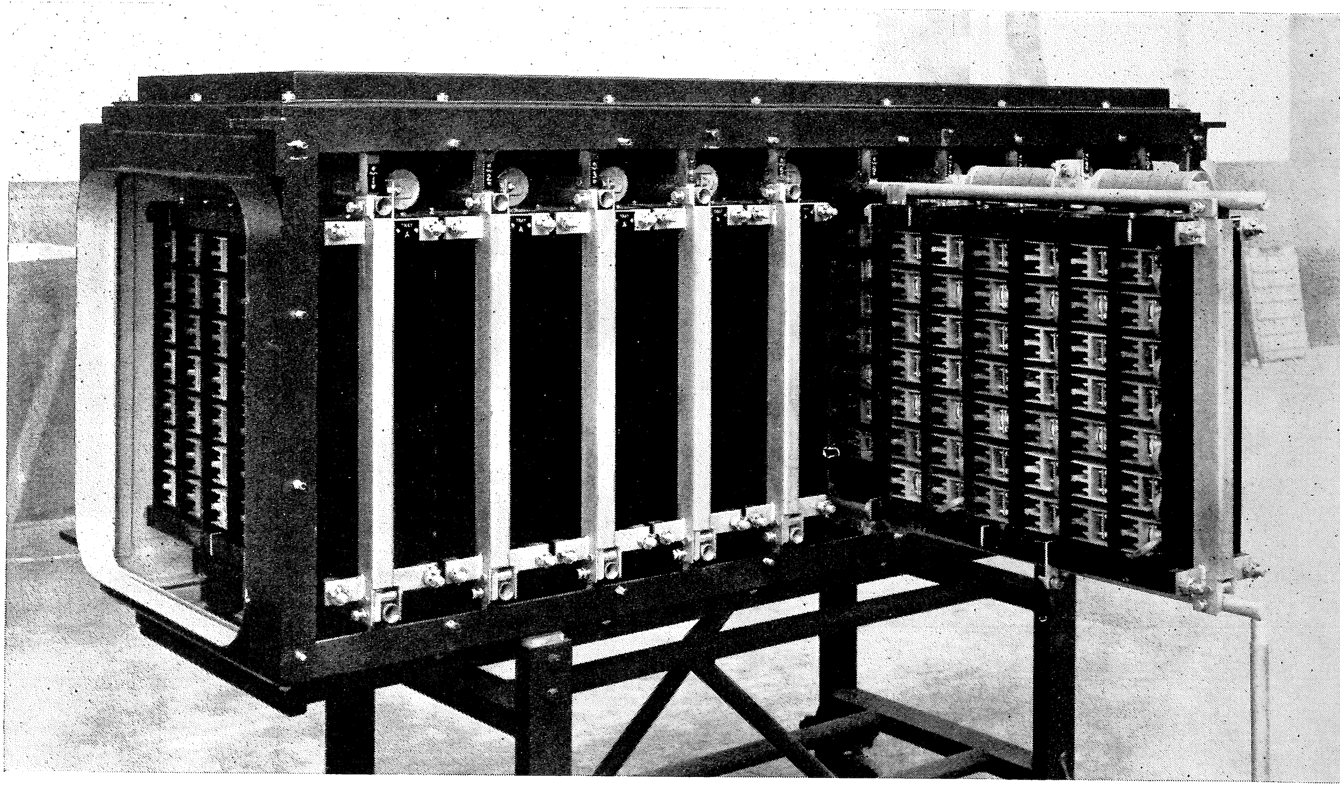

Fig.8 Main rectifier case. Manchester – Crewe line

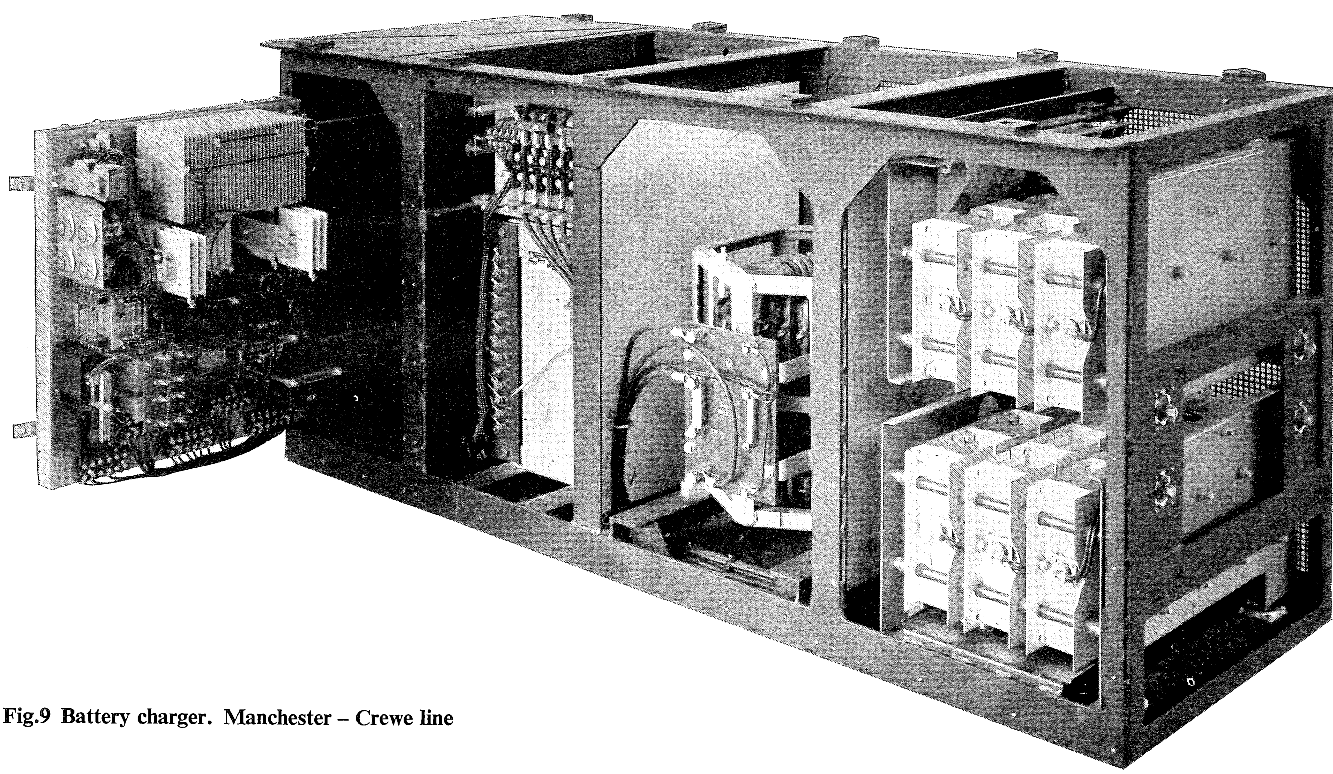

Fig.9 Battery charger. Manchester – Crewe line

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