

# Multiple - Unit Train Equipments for Liverpool Street - Enfield - Chingford - Hertford - Bishop's Stortford Lines (G.E.C.)

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## 1. Introduction

This multiple-unit stock ordered by the British Transport Commission from The General Electric Co., Ltd is of two types designed for routes having different service requirements.

Fifty-two three-coach units, each comprising a battery driving trailer, motor coach and driving trailer, will operate from Liverpool Street to Enfield Town and Chingford. This is a high density suburban service with, in the case of the Enfield Town route, a scheduled speed of 22·2 m.p.h. and an average of only  $\frac{3}{4}$  mile between stops. The equipment must, therefore, be designed for a high frequency of operation and for handling the heavy currents at short intervals characteristic of this type of service.

Nineteen four-coach units, similar to the three-coach ones but with a trailer coach added, will operate an outer suburban service with an average speed of approximately 34 m.p.h. from Liverpool Street to Hertford and Bishop's Stortford. This service consists of a non-stop run of approximately  $8\frac{1}{2}$  miles followed by  $22\frac{1}{2}$  miles with an average of 2 miles between stops, and as it involves a considerable amount of running near the maximum service speed the equipments must be designed for a high standard of performance in this region.

The equipments are also required to operate in multiple with ones produced by three other manufacturers and described in Papers 24, 25 and 27. A common driving procedure and layout

of controls is used and the general disposition of the different makes of equipment on the coaches also follows a common plan.

The coaches were designed and built by British Railways, the three-car sets at York and the four-car sets at Doncaster.

Fig. (1) is a photograph of a 3 car set.

## 2. Leading Particulars

### 4 Coach Unit

Vehicle	Unladen Weight	Laden Weight (all seats occupied)
Battery driving trailer	35·9 tons	40·9 tons
Motor coach	54·9 „	60·9 „
Non-driving trailer	31·0 „	36·0 „
Driving trailer	32·2 „	39·0 „
Total	154 tons	176·8 tons

### 3 Coach Unit

Battery driving trailer	34·1 tons	39·1 tons
Motor coach	54·2 „	60·2 „
Driving trailer	30·8 „	37·6 „
Total	119·1 tons	136·9 tons

Other principal data for the 3 and 4 coach units 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:—

	<i>3 coach unit</i>	<i>4 coach unit</i>
Maximum axle load	16.7 tons	16.7 tons
Maximum service speed	75 m.p.h.	75 m.p.h.
Balancing speed on level tangent track	72.3 m.p.h.	67 m.p.h.
Acceleration on level tangent track	1.35 m.p.h./sec.	1.1 m.p.h./sec.
Average accelerating tractive effort	21,600 lbs.	22,200 lbs.
Continuous rating at wheel in weak field		
Tractive effort	7,000 lbs.	
Speed		43 m.p.h.
Power		800 H.P.
Total weight of electrical equipment	23.4 tons	23.5 tons

The performance curves for the equipments under the above conditions are shown in fig.2.

The arrangement of the equipment on the motor coach underframe is shown in fig.3.

### 3. Description of Circuits

#### 3.1 Power Circuits

Fig.4 shows the power circuits in schematic form.

Current is fed from the pantograph through an air blast circuit breaker to the voltage changeover switch, which connects the four sections of the transformer primary in series for 25 kV operation and in parallel for 6.25 kV operation. The return current is fed from the transformer to the wheels through brushes on each axle of the motor coach.

The transformer secondary supplies two bridge mercury arc rectifier circuits, each feeding two traction motors in series. An equalising connection between the mid-points of each pair of motors reduces the rise in voltage on a motor which develops slip, and thus assists recovery of adhesion.

The motor voltage is controlled by tapping switches on the transformer secondary using two contacts per tap in conjunction with series resistances and a centre tapped choke.

By these means 20 steps are provided from nine taps, two of these being running steps with no series resistance in circuit. Two further steps are provided by motor field weakening, of which the second is a running step. The motor field is permanently diverted for smoothing purposes, and the final step is obtained by a tapping on the field in conjunction with a proportionate tapping on the smoothing divert.

The earth connection in the motor circuit is at the mid-point of the transformer secondary, thus limiting the potential to earth of all parts of this circuit to a maximum of half the full secondary voltage.

This scheme was adopted for the following reasons:

(a) The restricted space available for underframe mounted equipment and the desirability of using a minimum

amount of oil immersed apparatus made low tension tapping essential.

- (b) The most economical arrangement of rectifiers and transformer is obtained with bridge connection at an output voltage such that it is desirable to connect two motors permanently in series. Use of the bi-phase circuit could halve the number of rectifiers, but the advantages of this would be outweighed by the larger transformer and duplication of the tapping switch contacts and choke which would result from its adoption. The further alternative of a single bridge circuit using four rectifiers with four motors in series is unacceptable because of its poor adhesion characteristics, inability to operate with half the motors cut out in the case of a defect developing, and high secondary voltage.
- (c) The scheme incorporates the following features considered essential for service on multiple unit stock of this nature.
  - (i) Speedy operation through the sequence, particularly when returning to the off position.
  - (ii) Avoidance of backward tapping when switching off.
  - (iii) A small number of transformer tappings.
  - (iv) Reduction of momentary voltage drops during notching to negligible proportions.

- (d) The scheme is a compromise between the simplicity of resistance control at constant voltage and the complete elimination of resistance steps, in that the introduction of some series resistance and reactance into the circuits during notching improves current distribution between motors and reduces the number of taps and steps required, without making the adhesion characteristics unacceptable for multiple unit service.

#### 3.2 Control Circuits

Control of the direct current circuits follows established D.C. practice, with the addition that isolation of a pair of motors also cuts out the associated rectifiers by opening their excitation circuits.

Movement of the master controller causes the tapping switch to progress step by step to the appropriate position under the control of a current limit relay which regulates the lifting of the pawls, the operation being described in more detail in section 4.3.

#### 3.3 Auxiliary Circuits

A 240V tertiary winding on the main transformer supplies the train heaters, battery charger and auxiliary machines with the exception of the auxiliary compressor, which, together with the lighting and control circuits, is fed from a 110V alkaline battery.

The battery charger is a transductor controlled rectifier unit with voltage regulation by a closed loop control.

The main compressor is driven by a D.C. series motor supplied through a selenium rectifier and the transformer and rectifier pumps and fans by single phase capacitor motors.

Fig.5 shows the auxiliary circuits.

## 4. Description of Electrical Apparatus

### 4.1 H.T. Equipment

#### Circuit Breaker and Pantograph

These are common to all types of rolling stock and have been described elsewhere.

#### H.T. Lead in

The 25 kV feed from the pantograph is by bare conductor to the circuit breaker and thence to the through insulator on the roof. A continuous cable goes from the insulator to a compound filled connection box formed in the voltage changeover switch housing.

#### Voltage Changeover Switch

This is a 9-pole oil filled switch with contactor type elements operated by insulated links from a common shaft which is rotated to either of two positions by an external air engine. The switch, illustrated in fig.5(a) is flange mounted on the transformer but has a separate oil supply to avoid any contamination of the transformer oil.

### 4.2 Transformer

The transformer rating to I.E.C. 77 is as follows:—

Primary	25/6.25 kV	1,000 kVA
Secondary	1,875 V	910 kVA
Tertiary	269 V	90 kVA

The oil cooled transformer, fig.6, is the heaviest single item on the underframe and it is therefore logical to mount it in the centre bay, which necessitates a long narrow shape.

This requirement is best met by a two limb design with the coil axis horizontal, and, because this type of construction does not allow oil circulation by thermo-syphon action, forced circulation with a very high rate of flow is used in conjunction with a separate fan cooled radiator, the oil being directed into the transformer winding by a system of baffles.

The core is, in effect, clamped between two frames with the weight and shock loads carried on key bars at each corner, thus avoiding heavy stresses on the core bolt insulation. The complete transformer is suspended from resilient mountings on the underframe by extensions of these frames, thus permitting slight relative movement between it and the underframe. The majority of the oil piping is rigidly mounted on the transformer, only short lengths of flexible hose being used for the radiator connections.

The impulse level for the 25 kV connection was specified as 170 kV peak. It was not considered necessary to maintain this level for the 6.25 kV connection and a useful weight saving was effected by reducing the level to 75 kV peak under these conditions.

### 4.3 Tapping Switch

This is an electro-pneumatic camshaft operated switch with cam opened, spring closed, contacts; a design which provides the necessary number of steps with the minimum of electrical interlocks. Adequate mechanical spacing between steps is obtained by using two camshafts, each with its own air engine,

which, when notching up, move alternately under the control of a common escapement mechanism, shown diagrammatically in fig.7.

Lifting of a pawl by energising its control valve operates pawl interlocks, causing rotation of the camshaft by exhausting one cylinder of its air engine. Dropping of the pawl cushions the stopping of the shaft by re-admitting air to the cylinder. Starting and stopping is therefore without trigger action or undue impact. The pawl drop position is determined mechanically by the notch wheel and accurate setting of the electrical interlocks which de-energise its valve is unnecessary.

The interlocks controlling switch operation and providing safety features are cam operated by extensions of the main shafts and have silver butt type contacts.

Return to the lowest tap position is made without going through the tapping sequence by using contactors to break the circulating current path. This allows a very quick reset time, as both camshafts run back simultaneously.

The complete switch is illustrated in fig.8.

### 4.4 Rectifiers

Eight Compak single anode rectifiers arranged in two bridge circuits are fitted to each motor coach. They are a somewhat smaller version of the rectifiers described in Paper 17 and have a simpler cooling system consisting of a single circuit from the radiator through the cathode, tank and anode in series. Fig.9 shows the rectifiers mounted in their case.

### 4.5 Chokes

The smoothing and tapping switch chokes are naturally oil cooled air gap reactors. Two smoothing chokes, each of 0.016 H inductance at 230 amps. D.C. are used and are designed to limit the motor current ripple to 30 per cent. at any current between half and twice the continuous rating.

### 4.6 Traction Motors

The axle hung motors follow conventional D.C. practice except for the following features:

- (a) They are approximately 5 per cent. heavier than an equivalent D.C. motor, having been made 7 per cent. larger in diameter and somewhat shorter in length in order to improve commutating conditions.
- (b) A permanent field divert of 10 per cent. is used to reduce flux pulsation to approximately 2 per cent., which eliminates its harmful effect on commutation and losses.
- (c) Eddy currents are reduced to a minimum by using thin pole stampings and by designing the coil springs and washers to give the maximum resistance to circulating currents produced by the pulsating armature and interpole fields.

Class B insulation is used because the advantages of a smaller motor resulting from operation at Class H temperatures are outweighed by its increased cost and more difficult commutating conditions.

#### 4.7 Auxiliaries

The following are the principal particulars of the auxiliary machines.

Function	No./ Unit	Output	Supply	Motor Data		
				<i>h.p.</i>	<i>r.p.m.</i>	Type
Main compressor ..	1	38 c.f.m. swept vol.	240V A.C. 110V D.C. 240V A.C.	7·0	1,200	D.C. series with rectifier
Auxiliary compressor ..	1	5 c.f.m. swept vol.		0·75	1,080	D.C. series
Transformer coolant pump	1	50 g.p.m. against 20' hd.		1·5	1,450	
Transformer radiator fan ..	1	2,500 c.f.m.		0·4	1,450	Single phase induction,
Rectifier coolant pump ..	1	9 g.p.m.		0·75	2,900	capacity start and run.
Rectifier radiator fan ..	1	2,500 c.f.m.		0·4	1,450	
Battery charger .. ..	1	8·0 kW at 110V D.C.				Westinghouse Type 1285

#### 4.8 D.C. Control Equipment

This follows established D.C. traction practice but incorporates modifications to those relays which operate on pulsating current. The equipment, shown in fig.10, is electro-pneumatically operated, camshafts being used for the reverser and field control group with individual contactors elsewhere.

#### 4.9 Master Controller

Silver butt contacts, spring closed and cam opened, are operated by a rocking dead man's handle and interlocked reverse handle freed for operation by a removable key. The controller is shown in fig.11.

#### 5. Protection

The circuit breaker cannot be closed unless its operating air pressure and the transformer oil level are correct, the voltage changeover switch and measuring relays are in corresponding positions, and the motor circuits are open.

The breaker is tripped by low air pressure, low transformer oil level operation of the primary overload relay or loss of line voltage.

The motor contactors cannot be closed unless the rectifier coolant pressure and temperature, and the transformer oil temperature are correct.

The contactors are opened if the rectifier coolant pressure becomes too low, or its temperature either too high or too low, or if the transformer oil becomes over-heated, or by operation of the motor overload relays. The latter protect the motor circuits against overload or limited short circuit, major faults on the motor circuits and all faults on the rest of the secondary circuit being cleared by the primary overload relay.

Protection of the auxiliary circuits is by H.R.C. fuses, except for the rectifier ignition circuit where a combination of automatic and manually closed thermal relays prevents damage to the ignition solenoid should a rectifier fail to ignite.

No-voltage protection on the primary circuits is provided by the voltage measuring relays opening the circuit breaker. The traction motor circuits are protected by a combined no-voltage, no-current relay energised and retained up to the half voltage tapping by the closing of the circuit breaker. Beyond

half voltage the relay is retained by motor current only.

The voltage measuring scheme is protected against failure of the D.C. supply to the slave relays by a no-voltage relay with contacts in the feed to the A.C. measuring relays.

Wheel slip protection is provided by means of a relay in the equalising connection between the pairs of motors. Operation of the relay prevents further progression of the tapping switch.

#### 6. Conclusions

These electrical equipments have been designed to give reliable operation on two widely differing types of service, and in addition they have met the requirements laid down by the B.T.C. for multiple working with other multiple-unit stock, and for the general design of the equipments.

In order to do this much development work was necessary, particularly as regards the rectifiers and tapping switch, which it has been quite impossible to describe fully in the necessarily brief confines of this paper. Satisfactory trial running of which further details are given in Paper 2 confirms the correctness of the decisions taken and promises successful operation under full service conditions.

#### SUMMARY

Identical underframe mounted equipments are fitted to two types of train, a three-car unit for suburban service with frequent stops, and a four-car unit for semi-fast outer suburban service.

Two bridge rectifier circuits each supply two motors in series, the mid-points of the motor circuits being joined by an equalising connection.

Control of motor voltage is on the secondary side of the transformer by means of an electro-pneumatic camshaft operated switch controlled by a current limit relay.

The transformer primary windings are connected in series for operation on 25 kV, and in parallel for operation on 6·25 kV. Space restrictions necessitate forced oil cooling.

The single anode Compak rectifiers are liquid cooled steel tank

excitrons considerably smaller in size than rectifiers of conventional design.

The Class B insulated traction motors are basically D.C. series machines with slightly modified field systems to improve commutation and reduce losses. They operate in conjunction with a permanent field divert and a naturally oil-cooled series reactor.

The auxiliaries are supplied from a 240 volt tertiary winding, via a battery in the case of the lighting, control circuits and auxiliary compressor. Fans and pumps are driven by single-phase capacitor motors.

Overload relays provide protection against power circuit faults, and other protective devices guard against loss or overheating of transformer oil, overheating or overcooling of rectifiers or loss of coolant, and loss of air pressure or line voltage.

The equipments have operated satisfactorily and no major changes to the basic design appear necessary.

## RÉSUMÉ

Des équipements identiques montés sous le châssis sont utilisés pour deux types de rames, unités de trois voitures pour le service de banlieue avec arrêts fréquents et unités de quatre voitures pour le service demi-rapide destiné à la banlieue extérieure.

Deux ponts de redresseurs alimentent chacun deux moteurs en série, les points milieux des circuits moteur étant reliés par une connexion d'équilibre.

Le réglage de la tension des moteurs s'effectue sur le côté secondaire du transformateur au moyen des contacteurs actionné par un arbre à cames électro-pneumatique et contrôlés par un relais limiteur de courant.

Les enroulements primaires du transformateur sont connectés en série pour 25 kV et en parallèle pour 6,25 kV. Les restrictions d'espace nécessitent l'emploi du refroidissement par circulation d'huile forcée.

Les redresseurs Compak à anode unique sont des excitrons à cuves en acier, refroidis au liquide et de dimensions fort réduites par rapport aux redresseurs de conception classique.

Les moteurs de traction à isolement classe B sont, en principe, des moteurs série à courant continu qui comportent toutefois des champs légèrement modifiés dans le but d'améliorer la commutation et de réduire les pertes. Ils fonctionnent conjointement avec un shuntage permanent et une self de lissage en série, refroidie par circulation d'huile naturelle.

Les appareils auxiliaires sont alimentés à partir d'un enroulement tertiaire à 240V. Dans le cas des circuits d'éclairage, de contrôle et du compresseur auxiliaire, cette alimentation est fournie par une batterie. Les pompes et les ventilateurs sont entraînés par des moteurs monophasés à condensateur.

Les relais à maximum de courant protègent contre des défauts éventuels dans le circuit de puissance et d'autres dispositifs protègent contre la perte ou l'échauffement exagéré de l'huile du transformateur, l'échauffement ou le refroidissement excessif des redresseurs, la perte de liquide réfrigérant, la baisse de la pression d'air comprimé ou le manque de la tension de la caténaire.

Les équipements ont fonctionné d'une façon satisfaisante. Aucune modification importante de leur construction de base ne semble être nécessaire.

## ZUSAMMENFASSUNG

Der Bericht beschreibt zwei verschiedene, jedoch mit gleichartigen Untergestell-Ausrüstungen versehene Zugtypen, einen Dreiwagenzug für Vorstadtbetrieb bei dem mit häufigen Halten zu rechnen ist, und einen Vierwagenzug für den halbschnellen Aussenvorortsbetrieb.

Zwei Gleichrichterstromkreise in Brückenschaltung speisen je zwei Motoren in Serieschaltung, wobei die Mittelpunkte der Motorstromkreise durch eine Ausgleichsverbindung miteinander verbunden sind.

Die Steuerung der Motorspannung erfolgt auf der Sekundärseite des Transformators, und zwar mittels eines elektropneumatischen, durch Nockenwelle betätigten Schalters, welcher von einem Maximalstromrelais überwacht wird.

Die Primärwicklungen des Transformators sind für 25 kV Speisung in Serie – und für 6,25 kV Speisung in Parallel geschaltet. Infolge Raummangels musste Druckölkühlung vorgesehen werden.

Die Einanoden "Compak" Gleichrichter, welche sich im Vergleich zuden herkömmlichen Gleichrichtern durch ihre äußerst gedrängte Bauart auszeichnen, sind flüssigkeitsgekühlte Excitron-Gleichrichter in Stahlgefäßen.

Die nach Klasse "B" isolierten Fahrmotoren sind im Wesentlichen Gleichstrom-Reihenschlussmotoren mit leicht abgeändertem Feldsystem um die Kommutation zu verbessern und die Verluste zu verkleinern. Diese Motoren arbeiten mit einem Dauerfeld enbenschluss sowie mit einer in Serie geschalteten, öulumlaufgekühlten Drossel zusammen.

Eine Batterie speist die Beleuchtungsanlage, Steuerstromkreise und den Hilfskompressor. Der Antrieb der Ventilatoren und Pumpen erfolgt durch einphasige Kondensatormotoren; die übrigen Hilfsgeräte sind an eine 240V Tertiärwicklung geschaltet.

Die Starkstromanlage wird durch Höchststromrelais geschützt. Weitere Schutzaufnahmen zur Verhütung von Transformatorenölverlusten oder übermäßiger Erwärmung des Oels, Unterkühlung oder zu starker Erwärmung der Gleichrichter, zur Verhütung von Kühlmittelverlusten sowie Luftdruck- und Netzspannungsabfall sind vorgesehen.

Diese Ausrüstungen haben bisher zufriedenstellend gearbeitet, sodass sich an ihrer Grundkonstruktion keinerlei Änderungen als notwendig erweisen.

## RESÚMEN

Se han instalado idénticos equipos montados sobre bastidores inferiores en dos tipos de trenes, uno de ellos formado por tres vagones para el servicio suburbano con frecuentes paradas, y el otro compuesto de cuatro vagones, para el servicio semirrápido suburbano exterior.

Dos circuitos rectificadores en puente alimentan a dos motores en serie, y en los puntos intermedios de los circuitos del motor se ha hecho una conexión de compensación.

La regulación de la tensión del motor se efectúa por el lado secundario del transformador por medio de un interruptor accionado por un árbol de levas electro-neumático controlado por un relé limitador de corriente.

Los devanados primarios del transformador se hallan conectados en serie para servicio con corriente de 25 kV, y en paralelo con corriente de 6,25 kV. Debido al reducido espacio disponible ha

sido preciso recurrir al sistema de enfriamiento forzado por circulación de aceite.

Los rectificadores Compak de un sólo ánodo ofrecen la forma de "excitrones" montados en el interior de tanques de acero y enfriados por agua, con un tamaño mucho más reducido que el de los rectificadores de tipo convencional.

Los motores de tracción, con aislamiento de Clase B, son fundamentalmente máquinas de c.c. en serie consistentes en sistemas de campo ligeramente modificados para mejorar la commutación y reducir las pérdidas. Funcionan conjuntamente con un derivador de campo permanente y un reactor en serie de enfriamiento natural por circulación de aceite.

En el caso del alumbrado, los circuitos de control y el compresor auxiliar, los aparatos auxiliares son alimentados por un devanado terciario de 240 voltios, através de una batería. Los ventiladores y las bombas son actuados por motores monofásicos con condensador.

El sistema se halla protegido por relés de sobrecarga contra las fallas en los circuitos de fuerza, y otros dispositivos de protección impiden la pérdida o el sobrecalentamiento del aceite del transformador, sobrecalentamiento o enfriamiento excesivo de los rectificadores o pérdida del agente refrigerante, y pérdida de la presión del aire o caídas en la tensión de la línea.

Los equipos han funcionado con absoluta satisfacción y no parece que sea necesario efectuar cambio alguno en el diseño básico.

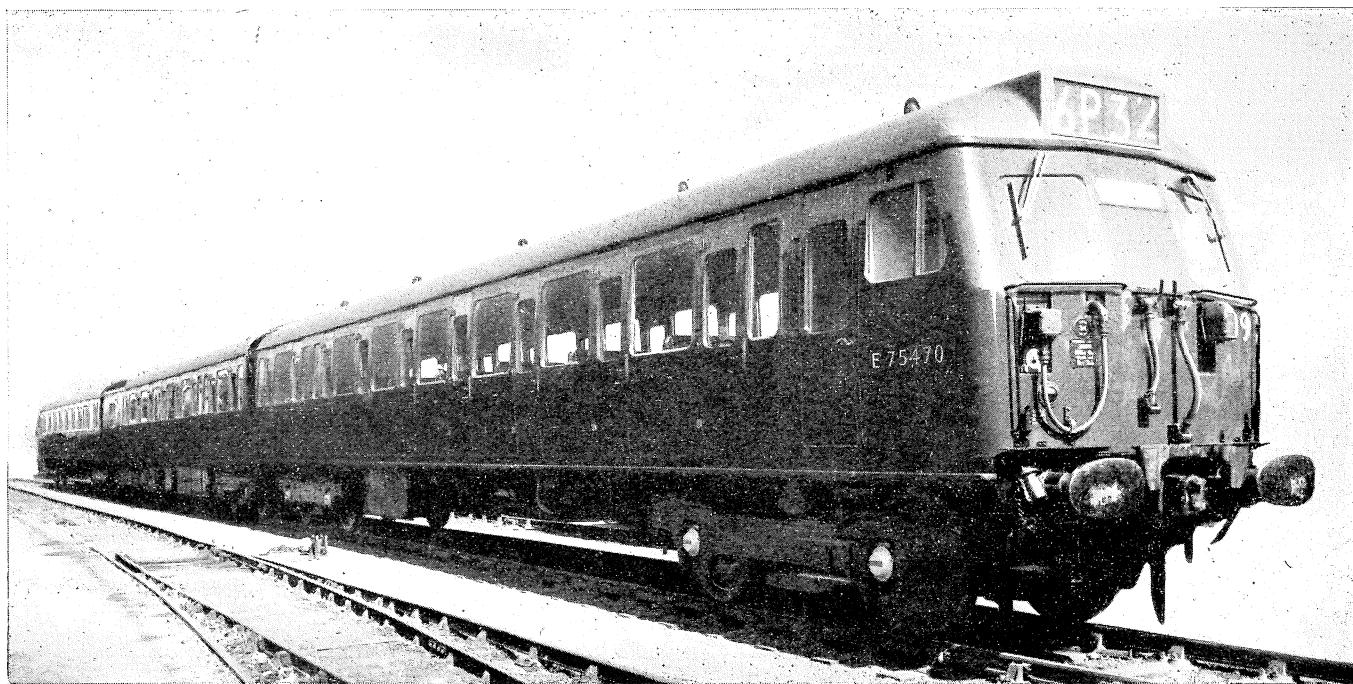


Fig.1 3 Coach train unit

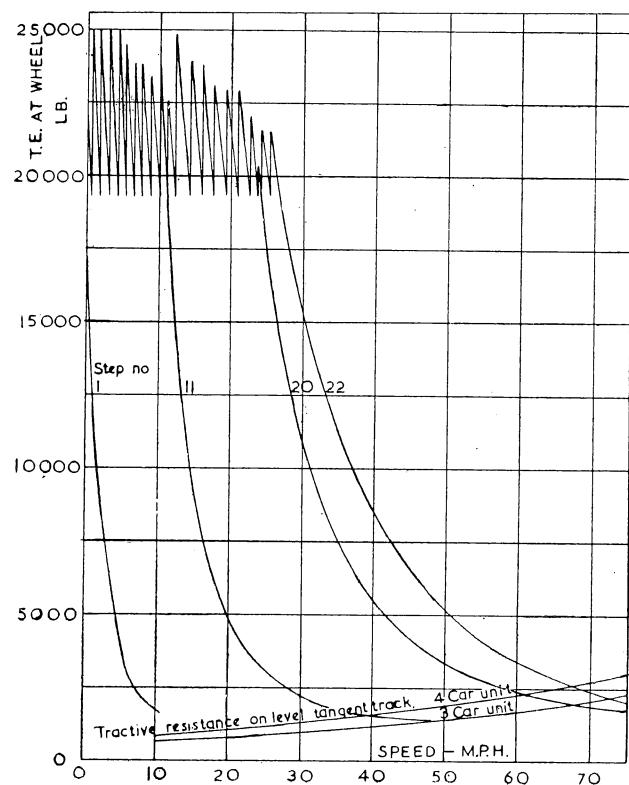
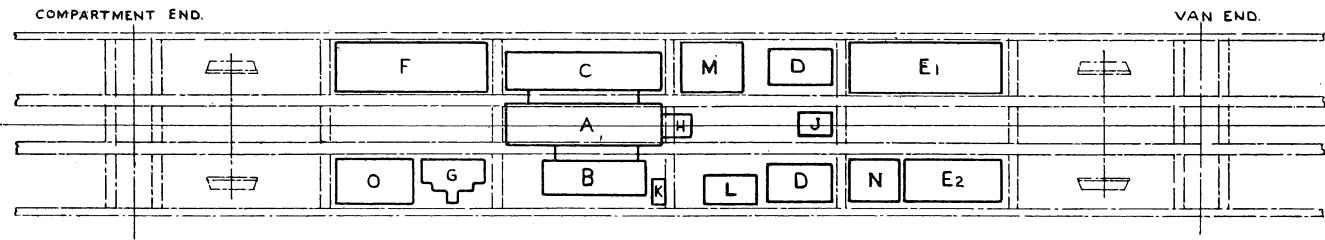
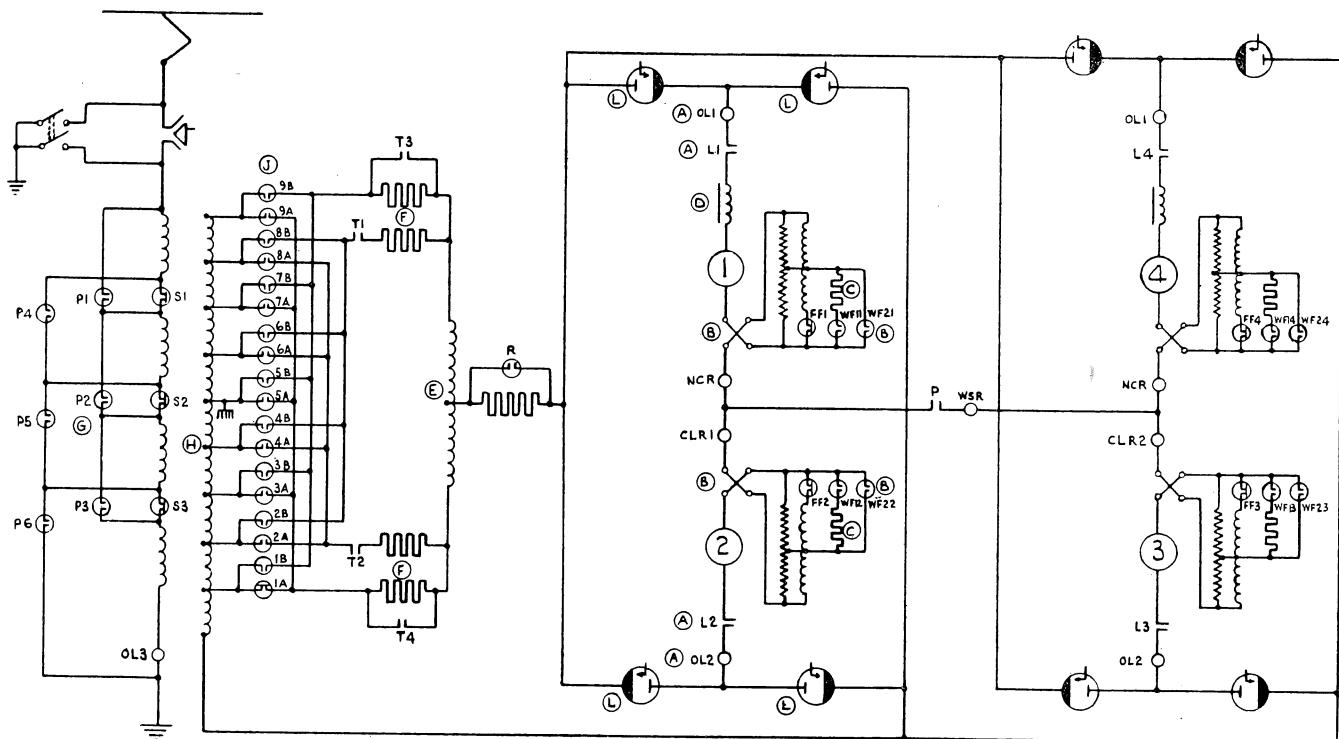


Fig.2 Speed-tractive effort characteristics



ITEM NO.	DESCRIPTION
A	MAIN TRANSFORMER.
B	SUPPLY CHANGE-OVER SWITCH.
C	TAP CHANGER.
D	SMOOTHING REACTORS.
E1	D.C. EQUIPMENT. LINE SWITCHES & %/L RELAYS.
E2	D.C. EQUIPMENT. REVERSER & W.F. CAM GROUPS.
F	RECTIFIER.
G	TRANSFORMER OIL RADIATOR.
H	OIL PUMP.
J	Brake cylinder.
K	E.P. BRAKE UNIT.
L	TAPPING SWITCH REACTOR.
M	TAPPING RESISTANCE.
N	WEAK FIELD RESISTANCE.
O	RECTIFIER IGNITION EQUIPMENT

**Fig.3 Plan layout of equipment on underframe motor coach**



**Fig.4 Diagram of main power circuits**

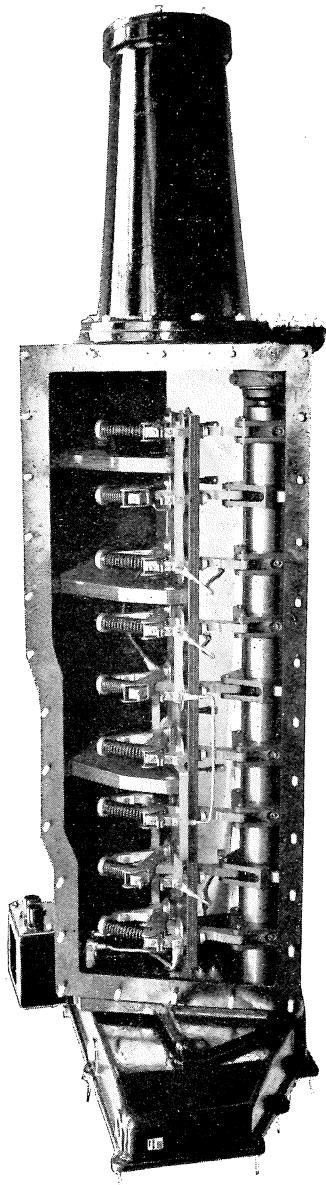


Fig.5a Power change-over switch

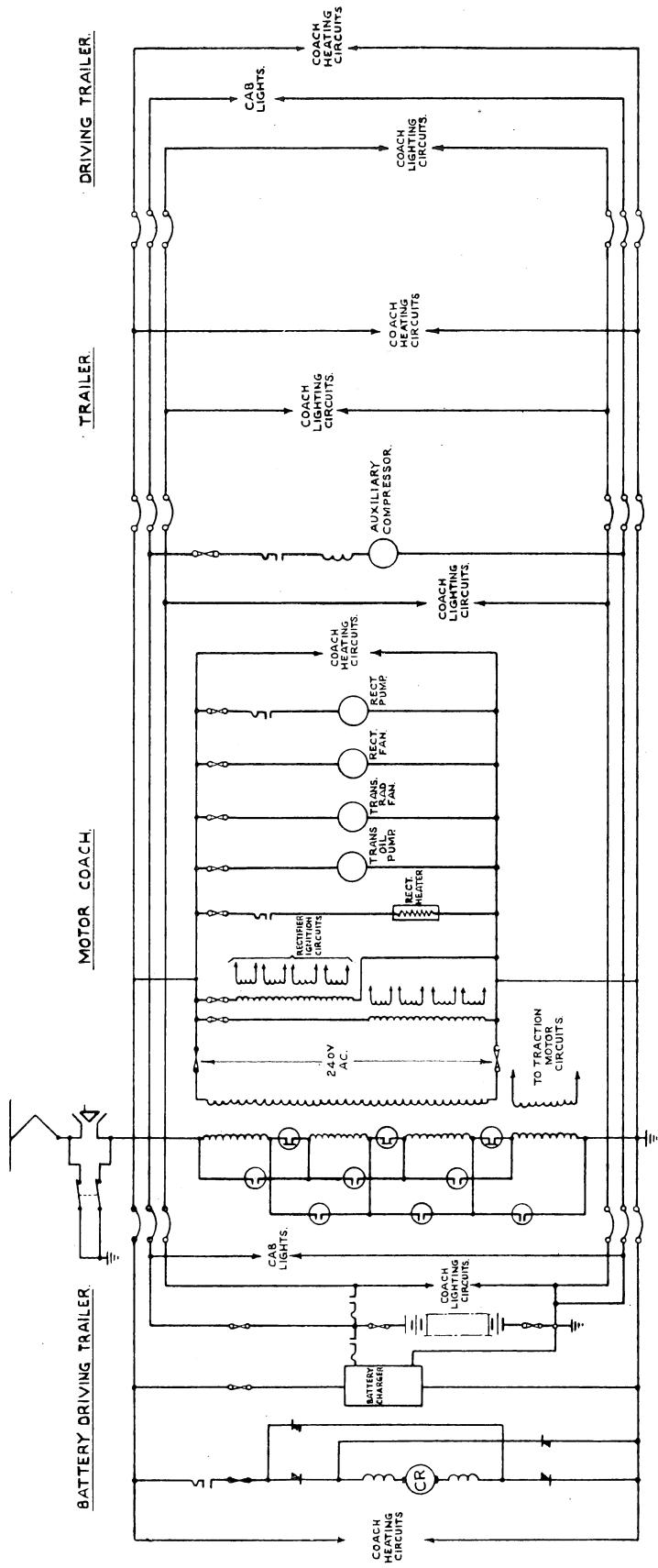


Fig.5 Diagram of auxiliary circuits (4 car train)

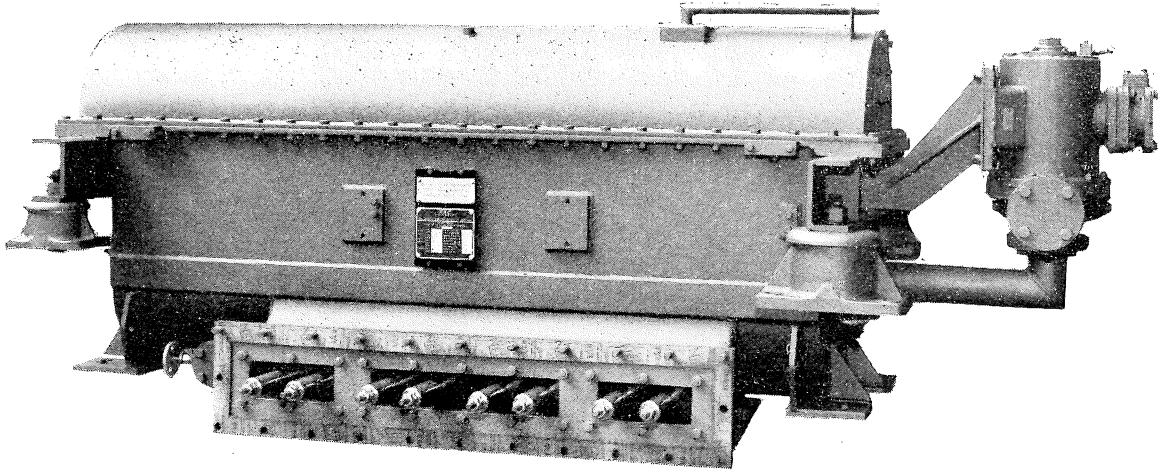


Fig.6 Transformer

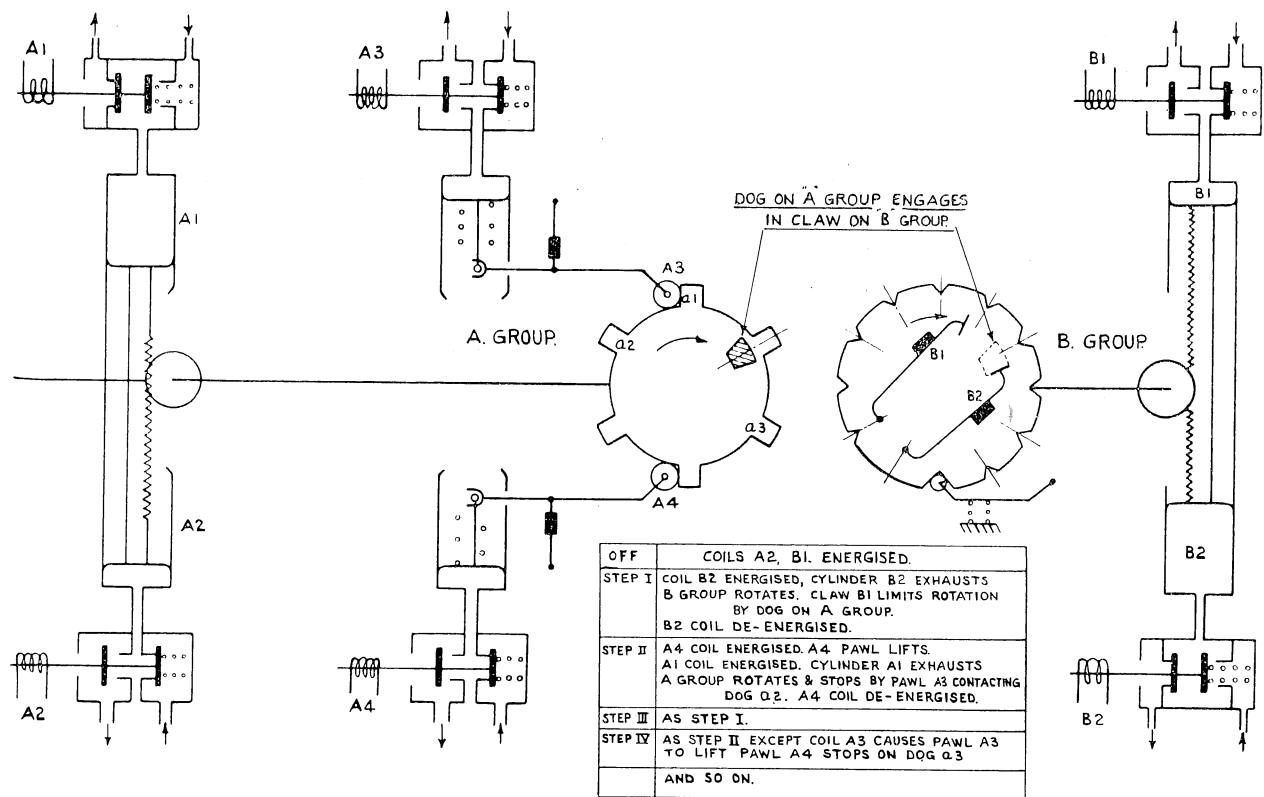
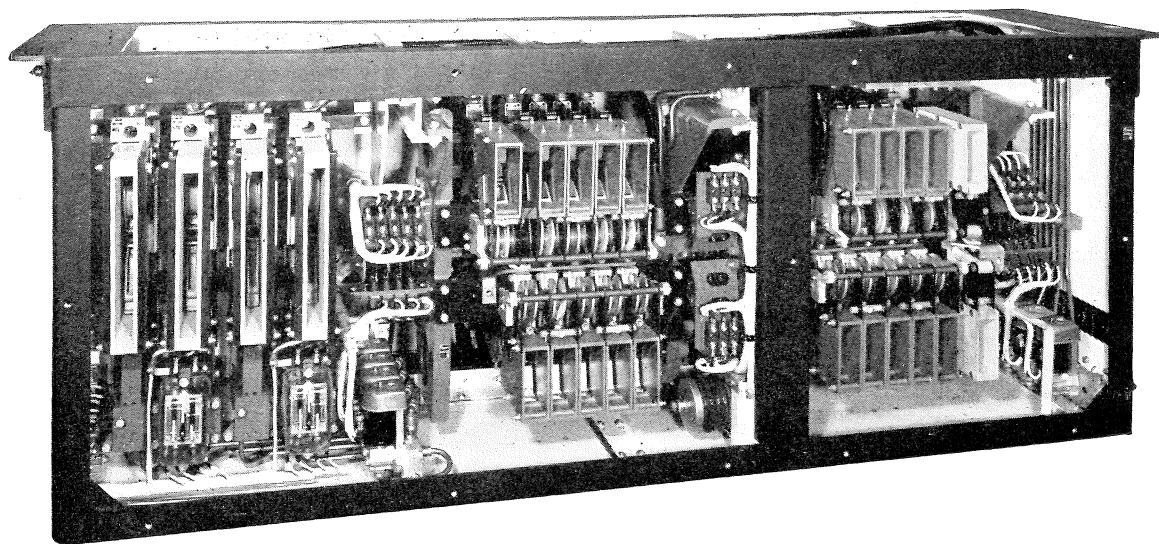
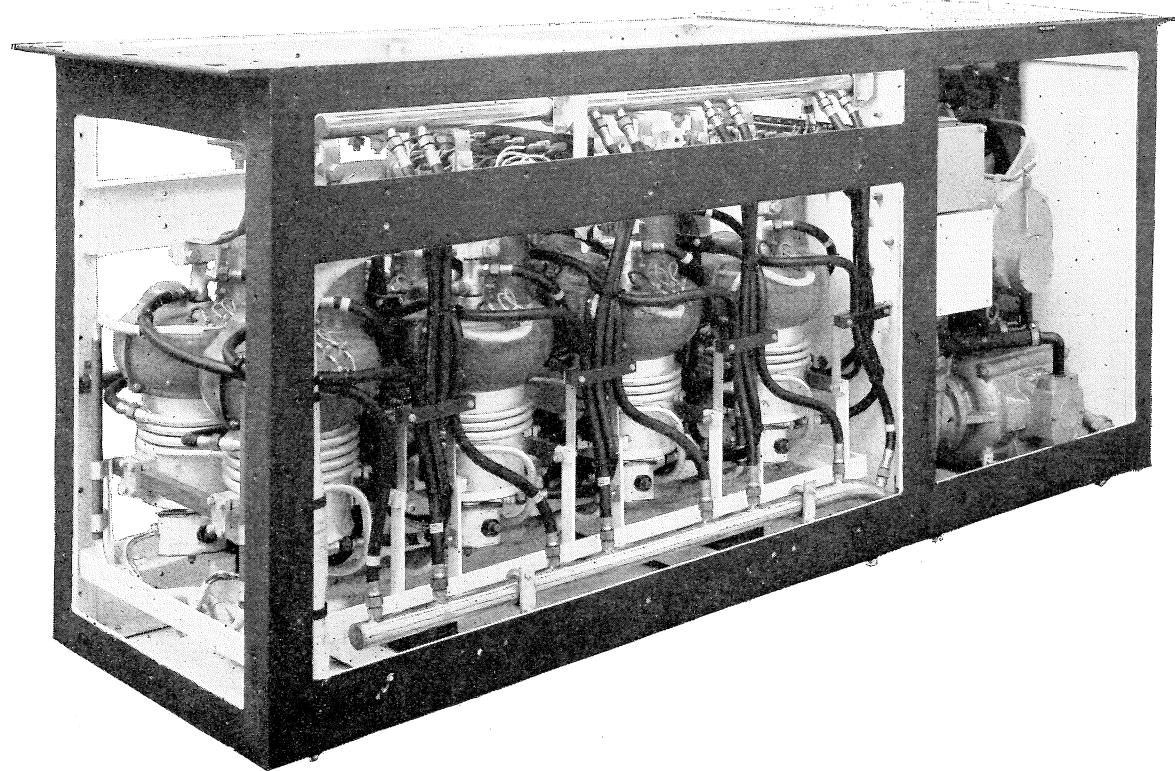


Fig.7 Diagram of tap switch mechanism



**Fig.8** Tapping switch in case



**Fig.9** Rectifier case

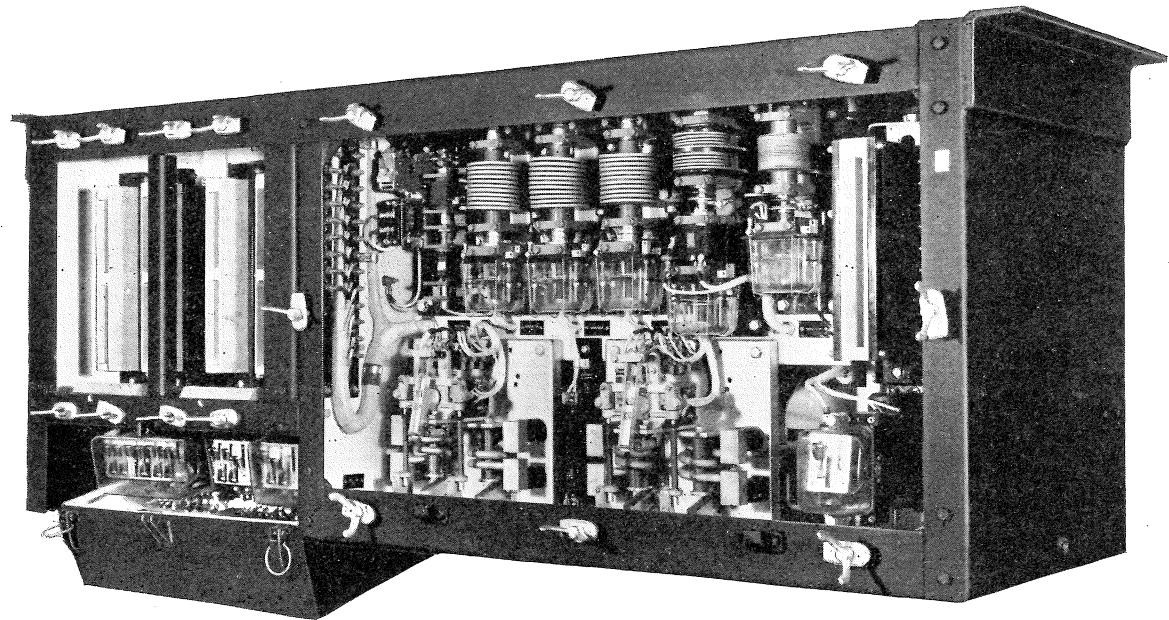


Fig.10 D.C. equipment case

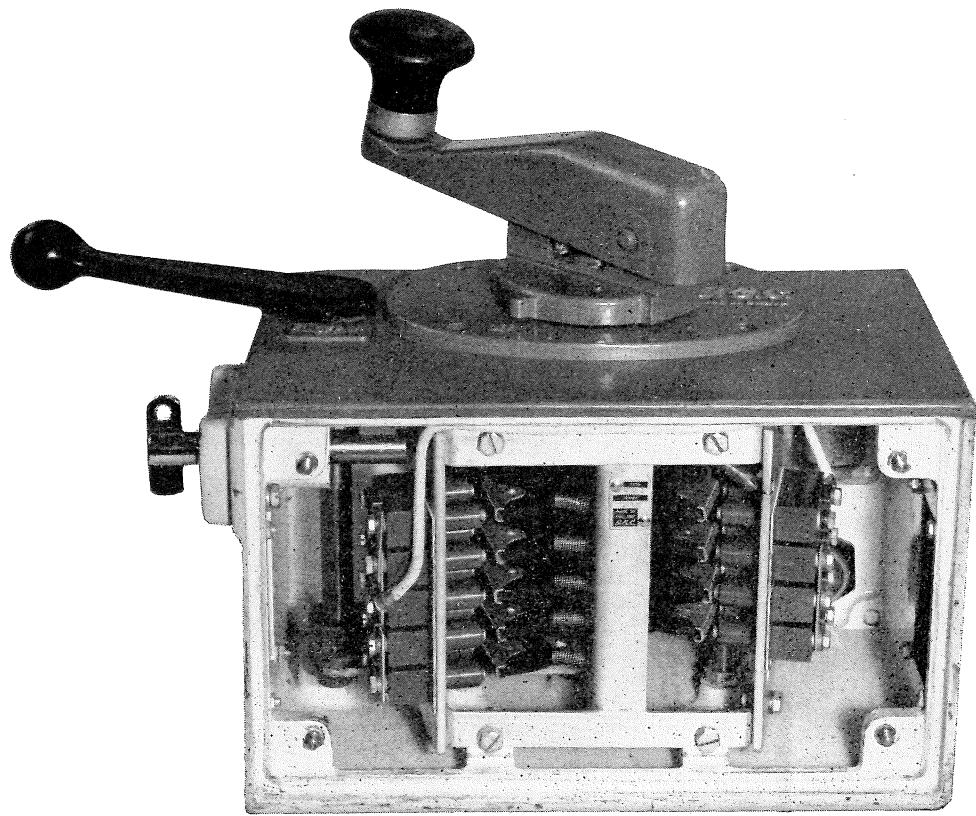


Fig.11 Master controller