621.335.2(42)

Paper 3

The Locomotives

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1. Introduction

The purpose of this paper is to explain the basis underlying the choice of the types of locomotive forming the initial fleet of 100 A.C. locomotives, and to describe the principal features of the locomotives of which detailed particulars are given in Papers 15 to 19 inclusive. The study of these considerations goes a long way to explain both the similarities and the differences between them and leads naturally to such comparisons as are at present permissible.

2. Specification of Locomotives

When the specification for these locomotives was drawn up and when the orders were placed, the British Transport Commission's Modernisation Plan was in its early stages and it was expected that locomotives would be required for service both on the London Midland Region Main Line from Euston to Manchester and Liverpool and on the Eastern Region Main Line from King's Cross to Leeds or York. These two lines differ considerably in character. For the former it was decided that a mixed traffic locomotive would be the most suitable as the maximum locomotive availability could be obtained by using the same locomotive on both passenger and freight duties. On the Eastern Region Main Line, certain special considerations permit or even demand the use of multiple-unit trains for much of the main line passenger working and the schedules are such that a very high annual mileage can be obtained. On this line, therefore, the locomotives would be required mainly for freight working.

Circumstances have prevented the electrification of the Eastern Region Main Line concurrently with that of the London Midland Region. For reasons which are outside the scope of this paper and are mentioned in Paper 1, the anticipation regarding the fitting of power brakes to all classes of freight trains has not, in fact, been realised and some of the freight duties for which the locomotives were designed will not arise in the immediate future. The effect of these factors is that the fleet as built comprises mainly mixed traffic locomotives, referred to as type A, whilst five have been built with a different gear ratio, referred to as type B, so as to obtain early experience of a locomotive with a bigger draw-bar pull such as will ultimately be required for working high speed fully braked freight and mineral trains.

The specification did not stipulate a particular rating but gave a number of duties among which the following are considered to be those which determine the design of the locomotives:—

(*a*) The locomotive to be capable of hauling a 475 ton express passenger trailing load from Manchester (London Road) to London (Euston) with a balancing speed of 90 m.p.h. on level tangent track and a maximum running speed of 100 m.p.h. The average speed is 67 m.p.h. with 1 stop of 1 minute and 4 miles at 15 m.p.h.

additional speed restrictions for track maintenance.

(*b*) The locomotive to be capable of hauling a 950 ton freight train between Manchester (Longsight) and London (Willesden) at an average speed of 42 m.p.h. with a maximum speed of 55 m.p.h. The locomotive will also have to work 500 ton express freight trains (fully fitted) at a maximum speed of 60 m.p.h. over this section. The locomotive to be capable of making three consecutive starts with the 950 ton train up to 20 m.p.h. on a 1 in 100 gradient, and to be capable of working without damage to the equipment with this train for 10 miles at 10 m.p.h. on any part of this route.

The last of these requirements reflects the desire to ensure that no harm would come to the locomotive under dense fog conditions which still occasionally prevails for several days together, and may be regarded as a typically British requirement.

The type B locomotives to be capable of hauling a 1,250 ton mineral or freight train between Manchester (Longsight) and London (Willesden) at an average speed of 42 m.p.h. with a maximum speed of 55 m.p.h. with the same conditions as specified for type A.

The duties specified reflect the intention of the Modernisation Plan to give a marked increase in the speed of both passenger and mineral trains. The former were required to be suitable for running at a maximum speed of 100 m.p.h., although for some years to come the maximum speed may be restricted to 90 m.p.h. In spite of a very large programme for improving the permanent way, there are still, particularly on the London Midland Region, many sections of main line where speed restrictions below this are necessary because of curvature, junctions, etc. So far as the main line from Euston to Manchester is concerned, the effect of these speed restrictions is such that if no account is taken of acceleration and retardation, the maximum attainable speed of running non-stop and observing the same speed restrictions specified under 2a is only 75 m.p.h.

The actual average speed of 67 m.p.h. gives an improvement of 9 per cent. over the timing of a 475 ton coach passenger train hauled by a steam locomotive with the same track and other limitations, including 4 per cent. make up time.

3. Limitations on Locomotive Design

Parallel with these considerations, it must be mentioned that at the time these orders were placed, the Civil Engineer attached great importance not only to the maximum axle load, but also to the wheel diameter in relation to that load. The maximum axle load permitted was 20 tons and the minimum wheel diameter 48 in., and these two parameters were stipulated as a rigid requirement. In addition, it was decided to use a flexible drive to reduce the unsprung weight on the axles to a minimum.

The problem for the manufacturers was, as is usual in this country, made more difficult by the requirement for rigid compliance with the British loading gauge which is specially restrictive in association with the wheel diameter stipulated above and is smaller in all dimensions, and particularly in its lower parts than the gauges normally encountered on 4 ft $8\frac{1}{2}$ in. gauge lines in other countries.

4. Development of Designs

Before comparing the various solutions adopted by the manufacturers, it is useful to recall that at the time the orders were placed, there was no experience in this country of building A.C. locomotive equipments and only a very limited experience on the part of some manufacturers with multiple-unit trains. The Commission took a firm decision to adopt D.C. motors with conversion by rectifiers and circumstances have indicated this decision was correct. The decision was taken at a time when the semi-conductor rectifier was making rapid progress but it was not considered that there had been sufficient experience to warrant its use for locomotives where operating conditions may frequently depart considerably from those stipulated. The initial designs therefore included for various types of mercury arc rectifier. The contractors were given complete freedom to propose either high or low voltage tap changing for speed control and they were also given a considerable measure of freedom as regards mechanical design of both the bogies and frames.

Investigation as to the probable weight, undertaken during the course of the development of designs, disclosed that there was a likelihood of infringing the permissible axle load. As this could not be permitted, a considerable measure of re-design was undertaken which has both delayed the production of the locomotives and, as events have shown, has in some cases involved the use of necessarily expensive types of construction, which should be avoidable in the future. Whilst this is regrettable in one sense, it has in fact led to the production of some locomotives, exceptionally low in weight for their performance, to which further reference is made in Paper 23, as it has important consequences for the future.

Whilst the freedom mentioned above was given, equally important stipulations were enforced in three directions—(*a*) it was required that all the cabs should be substantially similar, and that the driving technique be the same for all types of locomotive. The essentials of this technique were specified and all the contractors concerned co-operated excellently in achieving the desired result; (*b*) the use of certain standard mechanical components; (*c*) the Commission bought under separate contracts and issued to the manufacturers concerned certain components, principally the pantographs and air blast circuit breaker, and made certain stipulations as regards the arrangement of those parts of the circuits with which the drivers and maintenance staff will be principally concerned.

Against this background of the general objectives of the Commission in the first fleet of locomotives, the way and the extent to which they have been achieved in the initial fleet, may now be considered.

5. Leading Particulars

Fig.1 is a photograph of the first locomotive delivered and fig.2 gives the principal dimensions of the B.R. built locomotive. The leading particulars for the type 'A' locomotive are as follows:—

Table 1

		A.E.I. Rugby	*A.E.I. Manchester*	*B.R./A.E.I.*	*G.E.C.*	*E.E.Co.*
Loco. Nos.		E3001–23	E3046–3055	E3056–3095	E3036–3045	E3024–35
Total Weight	Tons	80·0	78·4	79·0	77·0	73·0
Maximum Axle Loading	Tons	20·0	19·6	19·25	19·4	18·3
Weight of Electrical Equipment (including drive)	Tons	39·6	37·7	39·0	38·0	37·0
Weight of two bogies (excluding motors and drives)	Tons	21·0	21·0	21·0	21·0	19·5
Weight of underframe and body	Tons	19·4	19·7	19·0	18·0	16·5
Length over Buffers	ft	56·5	56·0	56·5	53·5	52·5
Bogie Wheelbase	ft	10·75	10·0	10·75	10·0	10·0
Bogie Centres	ft	31·5	30·75	31·5	29·5	30·0
Gear ratio		29/76	29/76	29/76	25/74	25/76
Tractive Effort for acceleration	lbs.	48,000	48,000	48,000	48,000	40,000
Continuous ratings at wheel tread at 22·5 kV and half worn-wheels						
Tractive Effort—						
Full Field	lbs.	20,000	20,000	20,000	21,000	20,000
Weak Field	lbs.	17,000	17,000	17,000	17,500	15,260
Speed—						
Full Field	m.p.h.	60	62	60	54	55
Weak Field	m.p.h.	71	73	71	66	73
Power—						
Full Field	h.p.	3,200	3,320	3,200	3,000	2,940
Weak Field	h.p.	3,200	3,310	3,200	3,080	2,950
U.I.C. Rating: (1 Hr. S.H.P.)		4,260	4,260	4,260	4,270	3,735

Fig.3 shows the B.R./A.E.I. locomotive performance curve for both motoring and braking. Curves for the other locomotives are given in Papers 15 to 18. It should be noted that this curve is drawn for a line voltage of 22·5 kV with half worn wheels and that ratings in Table 1 are of locomotive wheel output. The rating of locomotives in accordance with U.I.C. Code 614.0 is based on the one hour test bed rating of the traction motor and the nominal line voltage of 25 kV, i.e.

$$\text{S.H.P. Pr} = \frac{n\,U\,I}{736} \times P$$

where n = No. of motors
U = Nominal Voltage
I = Motor Current
P = Efficiency excluding gears

6. Circuits

The circuits for the five types of locomotives are fully described in the individual papers but a basic diagram showing the circuits for comparison is given in fig.4. The major differences of these circuits are discussed below. The method of operation of the locomotive is described in detail under para.8.4. The driver's controls are completely standardised giving him full control over 38 running notches on full field and two further running notches with field weakening of the motors.

7. Standardised (Roof Mounted) H.T. Equipment

The roof mounted equipment is standard for all locomotives except for the potential divider used for voltage measurement when changing from 25 to 6·25 kV and *vice versa*. The standard items are as follows:—

(*a*) *Pantograph*. All locomotives are fitted with the Stone-Faiveley pantograph, described in Paper 20, which is a modified version of the Faiveley/S.N.C.F. design. This pantograph occupies a minimum area of roof space. Two pantographs per locomotive have been fitted, although under normal conditions, only the trailing pantograph is used in spite of the fact that full power must be collected at both 25 kV and 6·25 kV. From the commencement, carbon strips have been successfully used in spite of heavy pollution of the contact wire by steam and diesel locomotives prior to electrification.

(*b*) *Circuit Breakers*. The Brown-Boveri circuit breaker was adopted for the initial batch of locomotives as it was fully developed. The principle is well known and the circuit breakers differ from the standard design only in having an additional air reservoir. A.E.I. have recently produced an alternative of very similar design which has been incorporated on some locomotives and multiple units so that comparative performance can be established under service conditions. The air blast breakers have a very onerous duty as they have to open at each neutral section to ensure that the transition from 25 kV to 6·25 kV and *vice versa* is made.

(*c*) *Earthing Switch*. The earthing switch on all vehicles, together with the principles of interlocking mechanism have been standardised so that there are no differences in method of protection to cause errors. Any individual closing the earthing switch on the locomotive can lock it into the safe position by a personal padlock before entering the H.T. compartment.

(*d*) *Voltage Changeover*. The method of voltage detection and the automatic setting of the transformer to either 25 kV or 6·25 kV has been standardised for both locomotives and multiple unit trains.

At points of the overhead line where changes in phase or voltage occur, neutral sections are introduced consisting of three successive short sections of wire, insulated from earth but not energised.

In order to avoid damage to the overhead wire and pantographs when passing from the live wire into the neutral section, automatic power control is used. This also enables multiple unit trains to negotiate neutral sections without the motormen shutting off, as although it would be practicable to arrange for the driver to take power off a locomotive at the appropriate place it is considered impracticable to expect him to do so for a multiple unit train.

Permanent magnet inductors of the type used for the B.R. Automatic Warning System (A.W.S.) are mounted on the sleeper ends outside the running rails and approximately 100 ft before reaching and after leaving the neutral section.

Each power equipment carries a receiver, of the type used for the B.R. Automatic Warning System, which is mounted on the bogie and is operated by the magnetic field of the inductors. The receiver is a polarised latched relay fitted with a reset coil.

Contacts on the receiver armature operate a counting circuit formed of traction type relays; a contact of one of these relays interrupts the closing and holding circuits of the air blast circuit breaker. The relays are APR.1, 2 and 3 in fig.5.

The operation of the circuit is such that on approaching a neutral section the circuit breaker is automatically opened before the pantograph reaches the dead section of overhead line: after leaving the neutral section the circuit breaker is automatically released and closes under the control of the voltage selection equipment.

The voltage selection feature of the Automatic Power Control must measure the line voltage (25 kV or 6·25 kV), provide 'no voltage' protection, and set the changeover switch appropriately before permitting the air blast circuit breaker to close.

A connection is taken directly from the pantograph to a voltage measuring device, which is either a potential transformer, a capacitor divider or a series capacitor. The output voltage is taken to a group of calibrated relays, operating between the following limits:—

Low voltage 4·1 kV to 6·9 kV.
High Voltage 16·7 kV to 27·5 kV and above.

Within these limits of voltage the supply changeover switch is operated to the appropriate position and when proved to be correctly operated the air blast circuit breaker is closed.

The relays open the circuit breaker when the line volts drop to 3·5 kV and 15 kV respectively. The circuit is arranged to prevent the voltage changeover switch operating in the event of a fault on the 25 kV system lowering the voltage temporarily to within the 3·5/6·9 zone.

8. Main Electrical Equipment

The equipment now to be described has been designed by the individual contractors to give a wide range of variations to enable a comparison of their merits to be made.

8.1 *Main Transformers*

Two methods of approach to the design of the main transformer have been made. Two types of locomotive (A.E.I., Manchester, and G.E.C.) have an H.T. tapping switch together with an auto-transformer feeding into a fixed ratio secondary transformer winding or windings to supply the rectifiers. The other three types of locomotive (A.E.I. (Rugby), E.E. Co. and B.R./A.E.I.) have tapping on the secondary winding.

In the two H.T. schemes, the changeover from 25 kV to 6·25 kV is effected by tapping the primary winding, but where secondary tap changing is used, the primary winding is in four sections connected in series or parallel as necessary. The H.T. scheme of tapping the primary winding means that when on 6·25 kV tapping, the open end of the transformer can set up high transient voltages under surge conditions and special precautions have to be taken to ensure that these induced voltages do not exceed the 170 kV impulse level for which all transformers are designed.

8.2 *Tap Changer*

The A.E.I., Manchester, and G.E.C. high voltage tapping contacts are incorporated in the main transformer tank under oil with external load breaking contactors for the transition currents. Geneva mechanisms ensure synchronisation of these contactors and the tapping contacts. The G.E.C. tap changer operates at up to 12·5 kV, the A.E.I. (Manchester) up to 25 kV and both use resistance switching, but the former provides 20 voltage tappings with intermediate notches by series resistance and the latter provides 40 voltage tappings. The current rupturing switches are air insulated and the tap selecting switches are incorporated in the main transformer tank under oil. Geneva mechanisms ensure synchronisation of the selecting and rupturing switches.

Secondary tap changing is used on the B.R./A.E.I., A.E.I. (Rugby) and the E.E. Co. locomotives. The first two use a buck/boost scheme, involving a double wound transformer and a mid-point auto-transformer. Tap changing is at intermediate potential by cam-operated air insulated current rupturing switches. The E.E. Co. locomotives use a tap changer directly in the output circuit and each tapping is used twice during the accelerating cycle; the inter-tap current is limited mainly by resistance and mid-tap notches are obtained by series inductance; the tap selection is by cam-operated air insulated contacts and current rupturing by electro-pneumatic contactors. The A.E.I. (Rugby) and B.R./A.E.I. locomotives have air break secondary tapping cam groups. E.E. Co. have off load tapping cam groups with contactors for load breaking.

8.3 *Rectifiers*

Both the A.E.I. locomotives use three multi-anode air cooled steel tank mercury arc rectifiers developed from industrial designs. The output from the rectifiers is fed directly to the traction motors which are connected in parallel. On the A.E.I. Rugby locomotives only, high speed breakers are fitted in the D.C. output leads from the rectifier banks but the size and complication of these high speed breakers is an undesirable feature.

The E.E. Co. have used eight ignitron liquid cooled rectifiers in two groups of bridge connections; each bridge supplies two motors in series but the centre point is connected back to the transformer to maintain a stabilised voltage in the event of wheel slip.

The G.E.C. have used excitron liquid cooled rectifiers; two secondary windings each feed eight rectifiers arranged in bridge with again the two motors in series with a centre point linked back to the transformer forming a common earth point.

The railway-built locomotives are fitted with A.E.I., Rugby, equipment, similar to that supplied on their complete locomotives, but the rectifiers are semi-conductor type, 10 locomotives with silicon and 30 with germanium to give a comparison with mercury arc rectifiers. The saving in weight and space compared with the three air-cooled mercury arc tanks has made it possible to incorporate a rheostatic brake on the B.R. locomotives. This rheostatic brake is described in Paper 19. This possibility and the avoidance of the complicated auxiliaries of the mercury arc rectifier gives the semi-conductor rectifier an advantage even for locomotive duties.

8.4 *Driver's Controls*

The driver's controls have been completely standardised for all locomotives. Fig.6 shows the diagrammatic layout of all controls, and fig.7 the driver seated at the desk.

The master controller has a reversing lever (forward, off and reverse) which can be returned to the 'off' position only when the main control handle is in the 'off' position. The main control handle has six positions: 'off', run back, notch back, hold, notch up, and run up. This last position is spring loaded so that if the driver releases the pressure, it will stop forward notching. This controller operates the motor driving the tap changing mechanism.

Each notch is a running notch and the driver has 38 notches on full field and 2 with field weakening. The notch indicator shows approximately the position of the transformer tapping switch by measuring the secondary voltage as a percentage of its full value. There is a separate zone to indicate when the locomotive is in operation under weak field conditions.

The four motor currents are individually indicated on two double ammeters. The scales are shown by coloured sectors as the actual current value differs slightly between the various types of locomotives. The lower green zone is from zero to the approximate continuous rating equivalent to 20,000 lbs. tractive effort. The next amber zone terminates at 50,000 lbs. and the red zone is above this value. The drivers are trained to operate the locomotives during acceleration in the amber zone and to see that under running conditions, except for limited periods, the locomotives operate in the green zone.

Some indication of wheel slip is given by these ammeters. The motor voltage being controlled by the transformer tap, the danger from over-speed is reduced and the recovery from wheel slip by notching back made simple and effective. It will be noticed, however, that on the left hand side immediately below the brake valve lever a push button has been provided to give an anti-slip brake application equivalent to 5,000 lbs. braking effort to assist in stopping wheel slip.

The train and locomotive are normally controlled by the vacuum brake handle, the air brakes on the locomotive being applied through a proportional valve. In addition, a straight air brake valve is provided for light locomotive working when backing up to a train and when operating unfitted stock. The locomotives are equipped with the standard A.W.S. system and a foot operated 'dead man' device. A 'dead man's' push button is provided on the right hand side to enable the driver to cross the cab. All locomotives have been fitted with sanding gear but it is not being used until operating experience has been obtained to prove, or otherwise, its necessity.

Three indicator lights normally dim are provided; one white with a black 'L' to indicate that the overhead line is alive; one amber to indicate certain faults on the locomotive; one white with a black 'H' to indicate that the heating circuit is on. A standard form of fault indication panel is provided in the body of the locomotive at number 1 end, visible through the length of the corridor. In the event of the locomotive failing and the amber indicator light on the driver's desk showing a fault this panel will inform the driver what circuit is in trouble so that he can take the necessary action.

On these locomotives fitted with a rheostatic brake, a changeover switch is added to the master controller for selecting motoring or braking as required.

8.5 *Traction Motors*

The traction motors have been designed by the three contractors to suit their particular equipment and to meet the performance specified. The A.E.I. have standardised their two designs which are also used for the B.R. built locomotives. These have been designed to work with the Alsthom drive and the E.E. Co. and G.E.C. with the Brown-Boveri drive.

In order to provide a basis for traction motor design, it was agreed that the reactors should be such that the amount of ripple at the continuous rating would be 30 per cent. The method of calculating this ripple has been $\frac{\text{I max.} - \text{I min.}}{2 \times \text{I average}} \times 100$. This formula was adopted because the average current is proportional to the tractive effort and is measured by D.C. meters on the locomotives. The U.I.C. formula of $2\,\frac{(\text{I max.} - \text{I min.})}{\text{I max.} + \text{I min.}} \times 100$ can give a different value. The A.E.I. motor operates with a series choke which allows this 30 per cent. ripple at the continuous rating on the Rugby design, but with a smaller choke allows a 40 per cent. ripple on the Manchester design.

The traction motors are continuously rated but a one hour rating is used for routine test. Prototype tests were made on all types of traction motors on both D.C. and on rectified A.C. with the appropriate reactor. The standard of commutation on rectified A.C. is checked by reference to fig.8.

The worst commutation point accepted has been $1\frac{1}{2}$ on rectified A.C. and $1\frac{1}{4}$ on D.C. The maximum commutation point observed on all motors has been at twice full load and 22·5 kV, full load at 27·5 kV and maximum speed of motor at 27·5 kV. The standard achieved has been most satisfactory and encouraging. The production routine tests are made on D.C. to the standards achieved on the comparative tests.

8.6 *Auxiliaries*

Four variations of auxiliary circuits have been used to enable a clear comparison to be made to guide future policy on this matter. The A.E.I. (Rugby) scheme has all auxiliaries fed from the 137 volt auxiliary winding on the main transformer, this voltage being chosen as providing the most suitable voltage supply for the static 110 volt battery charger. A.E.I. (Manchester) use a 240 volt supply for their auxiliary circuits obtained from a tapping on the main transformer primary with special protection against over voltage should the winding or the earth connection become open circuited. The E.E. Co. auxiliary power is provided by a 70 kW Arno converter supplied at 415 volts from the tertiary winding. The auxiliary machines are thus of the three phase type which gives a good starting characteristic under low voltage conditions.

The G.E.C. design uses only two combined blowers and generator sets each driven by a single phase 510 volt motor. These two blower sets provide all the air required by the locomotive and thus the number of auxiliary motors has been reduced.

9. Protection

An important problem in designing these locomotives has been to give adequate protection without increasing the risk of failure due to the protection equipment itself. Table 2 shows the range of protection given in the various designs. All transformers except 10 are protected by gas relays. The 10 exceptions are on A.E.I. locomotives equipped with differential current protection. Service running will indicate the most simple yet effective overall form of protection for use in the future. A similar arrangement of fault indication panel has been provided by all manufacturers so that in spite of differences of the equipment, the action taken by the driver in response to each of the fault lights is similar.

The fault lamp on the driver's desk becomes bright when any protective circuit operates. If the lamp remains bright, he will look at the fault indication panel which will give clear indication of the circuit involved. Individual motors and rectifier equipments can be cut out and fuses changed in the event of cooling fans and other auxiliaries failing. In the event of a major fault on the transformer, no fault light will show on the indicating panel as the matter is beyond the driver's control and the locomotive must remain out of service.

Table 2

A. Protection provided for A.C. Locomotives

	A.E.I. Rugby	*A.E.I. Manchester*	*B.R./A.E.I. Equip.*	*G.E.C.*	*E.E. Co.*
I. TRACTION MOTORS					
Overcurrent	Yes	Yes	Yes	Yes	Yes
II. RECTIFIERS					
Overload	Yes	Yes	Yes	No	Yes
Under-temperature	Yes	Yes	—	Yes	Yes
Over-temperature	Yes	Yes	Yes	Yes	Yes
III. TRANSFORMERS					
Power Regulating Tapping System	Secondary Taps	Primary Taps	Secondary Taps	Primary Taps	Secondary Taps
Primary overload	No	—	No	Yes	No
Primary differential protection	—	Yes	—	—	—
Secondary overload	Yes	Yes	No	No	No
Secondary earth-fault	Yes	Yes	Yes	No	Yes
Gas relay	Yes	No	Yes	Yes	Yes
Oil level	No	Yes	No	No	Yes
Oil flow	No	Yes	No	Yes	Yes
Over-temperature	Yes	No	Yes	No	Yes

B. Indicating Only

	A.E.I. Rugby	*A.E.I. Manchester*	*B.R./A.E.I. Equip.*	*G.E.C.*	*E.E. Co.*
I. TRACTION MOTORS					
Blower failure	Yes	Yes	Yes	Yes	Yes
II. RECTIFIERS					
Back fire	Yes	Yes	—	No	No
Fan failure	Yes	Yes	Yes	No	No

10. Mechanical Parts

Just as in the case of the electrical equipment where each manufacturer was given freedom to propose his own solution, so for the mechanical parts wide freedom was given to draw upon his experience and design skill subject to certain essential provisions. It was essential, for example, that the locomotives should pass the universal B.R. loading gauge, that they should traverse a minimum radius curve of $4\frac{1}{2}$ chains and that they should use certain standard parts such as tyres, buffers and drawgear, hose and cable connections, brake-blocks, etc. The Chief Civil Engineer had laid down an absolute maximum axle load for these locomotives of 20 tons, making 80 tons for the complete locomotive.

He required, moreover, that regard be paid to Hertzan stresses between wheel and rail and in the present state of knowledge of this matter requested that a P/D value of 5 be not exceeded, which led to the adoption of 4 ft 0 in. diameter wheels.

Apart from these and certain other detailed requirements referred to later, it was desired within these first 100 locomotives to encourage the widest range of mechanical development, with the thought that the proven best features might be adapted in a single standard design for future quantity production. In the outcome there are five different designs of underframe and body and four bogie designs, and these are now described as follows.

10.1 *Bogies*

At the time of ordering these locomotives, British Railways had experience of locomotive bogies having three axles for use at speeds up to 90 m.p.h., and no two-axled bogie of proved suitability existed. Opportunity was, therefore, taken to approach the problem afresh, and each of the manufacturers was invited to submit designs and in the outcome four new bogies were accepted for comparative trial. These are illustrated in fig.9.

The development of these bogies was in each case a co-operative effort between the manufacturers and British Railways and Table 3 sets out the relevant data.

Table 3

BOGIE DESIGN DATA

Locomotive	*A.E.I. Rugby*	*A.E.I. Manchester*	*B.R.*	*G.E.C.*	*E.E. Co.*
Estimated Data—					
Service Weight (t)	80	78·4	79	77	73
Body Weight (t)	41·9	40·3	40·9	40·8	38·3
$1x$(t.ft.sec^2)	16·7	13	16·7	14·6	16·4
$1y$(t.ft.sec^2)	212	168	212	192	186
$1z$(t.ft.sec^2)	212	166	212	192	186
Bogie Weight less Motors (t)	21	21	21	21	19·5
Weight of Motors (t)	17·1	17·1	17·1	15·2	15·2
Type of Drive	Alsthom	Alsthom	Alsthom	BBC	BBC
Spring Characteristics					
Primary—					
Static Deflection (in.)	3	2·25	3	2·275	1·75
Stiffness per Bogie (t.per in.)	11·3	15·1	11·3	14·75 (28·8)	18 (32·2)
Static Stress (t.per sq.in.)	32	33	32	30·6	26·3
Secondary—					
Static Deflection (in.)	1	2·75	1	3·2	2·75
Stiffness per Bogie (t. per in.)	16·3	6·9	16·3	6·3	7·01
Static stress (t.per sq.in.)	31	32	31	31	33·1

NOTE: The values in brackets refer to the total stiffness due to bogie springs and the vertical component of the quill drive.

Swing Links					
Actual Length (in.)	—	24	—	20	18,22,26
Angle	—	4° 45′	—	0°	7° 15′
Effective Length (in.)	—	19·6	—	20	12·4,15,18

Natural Frequencies of Locomotive Body (Calculated) (Cycles per sec.)					
Bouncing	1·5	1·5	1·5	1·57	1·69
Pitching	1·5	1·86	1·5	1·83	2·07
Nosing	—	0·9	—	0·83	1
Lateral	—	0·7	—	0·7	0·72
Lower swaying	—	0·7	—	0·62	0·65
Higher swaying	—	1·46	—	2·2	2·25
Resonance Speeds (M.P.H. (Calculated))					
Bouncing	31	31	31	32	35
Pitching	31	39	31	38	42
Nosing	—	45–50	—	40–45	50–55
Lateral	—	35–40	—	35–40	35–40
Lower Swaying	—	35–40	—	30–35	34–38
Higher Swaying	—	75–80	—	110–120	117–126

NOTE: Vertical resonance speeds are estimated for excitation impulses at 30 ft intervals. Lateral resonance speeds are estimated for 1 in 20 tyres.

Lateral Displacement of Locomotive					
At Cantrail (10 ft 6 in. above rail) (in.)	2·75	2·8	2·75	2·4	3·1
At Pantograph (14 ft above rail) (in.)	3·5	3·5	3·5	2·94	3·61

NOTE: The above values are valid for a lateral force equivalent to 10 per cent of the locomotive body weight applied at its centre of gravity.

Due to special design features, certain values are omitted for A.E.I., Rugby, and B.R. bogies.

The general requirements were as under:—

(*a*) To come within the British loading gauge which is particularly restrictive in the width available below 4 ft 0 in. above rail level.

(*b*) That in general only steel springs would be used as the principal suspension elements, in view of the incomplete results obtained up to that time with all rubber suspensions.

Rubber was, however, fully acceptable for auxiliary purposes.

(*c*) Total vertical spring deflection of 6 in. was aimed at and damping values in the vertical plane of the order of ·2 to ·25 of the critical value were proposed and in the lateral plane of ·3 to ·4 of the critical value.

In order that such values could be clearly identified and maintained constant, hydraulic dampers were specified and the use of laminated springs was ruled out.

(*d*) The disposition of bogie centres and traction points to be such as to effect minimum weight transfer between axles.

(*e*) The lateral sway at pantograph level (14 ft) was required to be limited to less than 5 in. each way under all circumstances.

(*f*) Within the above parameters, and allowing for the supplementary vertical effect of flexible drive between traction motors and road wheels, optimum riding qualities were sought. These were considered to involve:—

(i) Low oscillation acceleration values both vertical and lateral.

(ii) Resonance speeds for the different effects of Bouncing, Pitching, nosing and lateral swaying which are either well below or well above the habitual running speed of the locomotives.

(iii) Minimum change in the above due to the effects of wear, not only of tyres but of all other bogie parts subject to relative movement.

These requirements have been met in principle by all four bogie designs, but to a varying degree in detail.

Final choice for a future standard will depend upon minimum ride deterioration over large mileages, and minimum maintenance costs. Subject to these considerations, least weight, greatest simplicity and lowest first cost will influence the choice. Each bogie is now briefly considered in its main design characteristics, and as to how these approach the desired conditions. Reference again to Table 3 indicates the calculated values of frequencies, resonance speeds and displacement.

The A.E.I. (Rugby) bogie derives from the Alsthom Co.'s design development. A fabricated frame is supported upon S.K.F. roller axleboxes located by Alsthom suspension links. The ends of the spring beams are attached to the underside of the axleboxes through rubber pads which contribute $\frac{3}{8}$ in. out of the total of 3 in. spring deflection of the primary suspension. Total vertical spring deflection is 4 in. The major part of the body weight is carried by the double rubber cone assembly which also acts as a swing link of indefinite length with lateral spring control. There is no bolster as such. The total deflection of the two rubber cones under load is 1 in. A smaller proportion of the load is carried through four rubber pads disposed over the bogie side frames through the intermediary of light coil springs and these also supply some rotational damping. Traction forces are applied from the bogie frame to a point on the underframe $3\frac{5}{32}$ in. 'below the centre line of the wheels'.

This bogie is also used without significant modification on the Railway built locomotives with A.E.I., Rugby, electrical equipment.

The A.E.I., Manchester, bogie derives from a novel system of body suspension first applied to the gas turbine locomotive built by this firm for British Railways and now converted to 50 cycle traction and in use on the electrified section. As applied to the new A.C. locomotives, body weight is carried direct by the lower ends of rubber bushed swinglinks of 19·6 in. effective length. Originally, use of primary suspension only was proposed by the manufacturers as in the case of the gas turbine locomotive but the limitation imposed by the flexible drives made secondary suspension essential. For this, helical springs deal with both vertical and lateral deflections and in the latter connection, the sideways spring deflection of up to $\frac{1}{2}$ in. is added to the lateral displacement of the body due to the swinglinks. Total vertical spring deflection is 5 in. Traction is taken by rubber bushed links at the bogie centre disposed in the same horizontal plane as that of the axles. The bolster is located fore and aft by additional traction bars. The Timken axleboxes are guided fore and aft by horn guides but short links, one assembly to each axle, are used to locate the axle sideways and control the axle lateral motion The bogie frame is a steel casting.

The E.E. Co. bogie is conventional in principle, of fabricated construction and with S.K.F. roller bearings in normal horn guides. Total nominal spring deflection is 5·25 in., but it will be seen from the table that the stiffness of the primary springing is considerably increased by the vertical component of the springing in the Brown-Boveri flexible drive. A wide lateral secondary spring base of 7 ft 0 in. is provided. Vertical body weight is carried on a centre having a rubber cone with $\frac{3}{4}$ in. vertical deflection and the effective point of application of the traction force is at axle level. A small proportion of body weight is taken by body side supports, arranged between upper bolster beam and body frame. Provision has been made for trials with alternative swinglinks having 12·4 in., 15 in. or 18 in. effective lengths.

The G.E.C. bogie is of conventional layout having S.K.F. roller bearings in normal horn guides and fabricated frame. Total vertical spring deflection is 6 in., and vertical swinglinks 20 in. long are associated with secondary coil springs at 7 ft $5\frac{3}{4}$ in. centres across the locomotive. The weight of the locomotive body is taken solely by lateral side bearing pads working in an oilbath placed directly over the bolster springs on each side of the locomotive, thus providing a measure of rotational damping. Traction forces are transmitted through a bogie centre pin and traction links set $1\frac{3}{4}$ in. below the centre line of the axles. Rubber elements are used for traction bar bushes, swinglink supports, at the centre pin, and to ensure non-linear lateral centering characteristics.

10·2 *Bodies aud Underframe*

Each manufacturer as well as British Railways' design office at Doncaster was allowed to develop his own body layout appropriate to the electrical equipment to work and be maintained therein, and was left free to propose any combination of design and material for body and underframe, subject to the following:—

(*a*) A standard cab was required to be worked out between manufacturers and British Railways which was to be applied to all the locomotives.

(*b*) Provision to be made for standard pantograph and circuit breaker on the body roof.

(*c*) Underframe/body structure to be capable of withstanding end load of not less than 200 tons without permanent deflection.

Each designer had about 40 tons available for the mechanical parts, some rather more, some rather less, according to how the weight of the electrical equipment came out, and this condition called for very special attention to be paid to weight saving in each case.

Fig.10 illustrates the different designs and a brief comparative description is set out below.

A.E.I. (*Rugby*) design is of conventional semi-integral welded construction having substantial underframe portion in Cor-ten steel with trussed body sides welded to it, the whole following closely the design developed by Messrs. B.R.C.W. and in successful use on Type 2 and 3 Diesel Electric locomotives on B.R. As a weight saving measure, wide use is made of resin-bonded glass fibre construction.

A.E.I. (*Manchester*) This is an extreme example of separate body and underframe construction in which an exceptionally robust mild steel welded underframe portion is capable of carrying all horizontal and vertical loads, whilst the super-structure is mainly of light construction in aluminium alloy.

B.R. Here is the development of an idea originally from the S.N.C.F. in which the underframe and lower halves of the body sides combine into a trough sectioned structure in mild steel built up in sections which carries all the loads. The upper halves of the body side and the roof are of very light mild steel construction. The two halves of the assembly are bolted together. With the upper half removed, ready access to the electrical equipment is available for assembly or repair purposes.

E.E. Co. An integral structure includes a box sectioned underframe with portions built up in sections. The body side frame portion is of girder design, the vertical pillars being rectangular tubes in Cor-ten steel. Considerable use is made of resin-bonded glass fibre construction for fittings.

G.E.C. An integral combined underframe and body is built up from mild steel plate, the design being of the Veerendeel Truss Type. Wide rectangular openings in the basic framework facilitate assembly during erection and these are closed by thin external sheeting welded on to complete the construction.

These different forms of construction cover the majority of the design methods which are available using steel and there is no reason to think they will not all last the lives of the locomotives. Merit between them will, apart from the obvious considerations of cost and weight, depend upon freedom from corrosion, the cheapness and facility with which repairs can be carried out after minor collisions and the readiness with which essential maintenance work within the body casing can be effected. The majority of these factors will emerge soon after the locomotives are put into service which will give a lead on the choice to be made for future bulk production of locomotives of this kind.

Other Mechanical Features

Here again, reference should be made to the general descriptions elsewhere for details, but the following may be of interest:—

Cabs

The somewhat generous cab space is based upon the need under British operating conditions for ready egress from either side of the cab at any time of the second man who, when he is provided under the manning agreement, has traffic duties to perform.

Available Space in Body

This is undoubtedly reduced by the combination of large wheels and a low roof occasioned by the presence of pantograph equipment within the available structure gauges. Should continued electrical and mechanical development lead to still lower weights of components in future, use of a smaller wheel diameter would bring much relief.

Styling

There is a limit to what can be achieved by way of attractive appearance in what is in effect a rectangular box. By dealing with all five designs as a whole from this point of view, by the careful development of a uniform frontal design and by the greatest attention to all external detail, it is possible that an appearance both distinctive and agreeable has been achieved.

Valuable advice and assistance on this point was given by the B.T.C. Design Panel, and by the Design Research Unit.

10·3 *Brake*

Because the vacuum brake is standard for all British locomotive-hauled rolling stock on the one hand and it was desired to obtain the advantages of the air brake so far as the locomotive itself is concerned, the normal B.R. system of dual brake is fitted in which the driver operates a vacuum brake valve acting direct upon the train and controlling the air brake on the locomotive through proportional valves. A straight air brake with separate control is also provided for light locomotive working or for use where unbraked freight trains are worked.

11. Conclusion

These locomotives incorporate a variety of both electrical and mechanical designs and a series of tests has been initiated with a view to making comparisons on each item of equipment. The tests on the riding of the locomotives will:—

(*a*) record accelerations, frequencies and displacements, and allow adjustments to damping and other characteristics to obtain optimum riding performance for each bogie design;

(*b*) obtain complete comparative riding records of each locomotive in its optimum condition;

(*c*) study and record the interaction of the vehicle and track with each design; also the interaction between the pantograph and the overhead catenary.

The tests on the equipment will record effects of normal acceleration, short circuit and wheel slip conditions.

SUMMARY

While ordered to a common specification, the first 100 locomotives have been deliberately built to combine the available experience of the Railway and Manufacturers as regards both the electrical and mechanical parts, and to provide an initial range of variables in matters where operational and maintenance experience is desirable before deciding upon overall standards for bulk production.

The locomotives are within 80 tons total weight with a wheel diameter of 48 in. new and are capable of handling all classes of traffic for the Euston – Manchester – Liverpool electrification. Five of the locomotives are fitted for experimental purposes with a different gear ratio to give an increased T.E. with a maximum speed of 80 m.p.h.

This paper deals with the features which it was decided to standardise for all the locomotives. These include cab layout and all controls, instruments, fault indications, so that drivers are not concerned with the make of locomotive. Pantographs, circuit breakers, protection and earthing arrangements, and voltage changeover devices have also been standardised. Comments are also made upon Rectifiers, Transformers and Traction Motors where manufacturers have supplied differing solutions as described in papers 15 to 19. Reference is made to locomotives fitted with rheostatic braking to reduce brake gear and tyre maintenance.

Differences in design of the mechanical parts are commented upon, and in particular details are tabulated of the suspension characteristics of the four different bogies.

RÉSUMÉ

Bien que les 100 premières locomotives aient été toutes commandées conformément à la même spécification on a incorporé exprès dans leur construction électrique et mécanique les résultats conjoints de l'expérience des Chemins de Fer et des fabricants. On s'est arrangé pour qu'elles varient entre elles en ce qui concerne les aspects de l'exploitation et de l'entretien où il est souhaitable d'avoir encore de l'expérience avant d'établir définitivement des normes pour la fabrication en gros.

Le poids total d'une locomotive ne dépasse pas 80 ton. Le diamètre des roues neuves est de 48in. Elles conviennent pour toutes les catégories de trafic de la ligne Euston–Manchester – Liverpool. Le rapport d'engrenages de cinq locomotives est différent de celui des autres et donne un plus grand effort de traction avec une vitesse maximum de 80 m.p.h.

Cet exposé traite les aspects que l'on a décidés de normaliser pour toutes les locomotives. Ces aspects comprennent la disposition de la cabine, tous les appareils de commande et de mesures, et les indicateurs de défauts, de telle façon que la commande des locomotives ne diffère pas de l'une à l'autre. Les pantographes, les disjoncteurs, les appareils de protection et de mise à terre et les dispositifs de changement de tension électrique (de 25 kV à 6,25 kV et inversement) ont également été normalisés. Les auteurs commentent les redresseurs, les transformateurs et les moteurs de traction dans les cas où les fabricants ont adopté des solutions différentes aux problèmes posés par cet équipement, lesquelles sont décrites dans les exposés 15 à 19. Ils mentionnent les locomotives qui sont munies d'un système de freinage rhéostatique dans le but de réduire au minimum l'entretien exigé par la timonerie de frein et les bandages.

Ils commentent les différences entre les constructions adoptées pour les parties mécaniques, et, particulièrement, ils donnent sous forme de tableau les caractéristiques des systèmes de suspension adoptés pour les quatre différents bogies.

ZUSAMMENFASSUNG

Die ersten 100 Lokomotiven wurden, obwohl nach einer gemeinsamen Spezifikation bestellt, mit der Absicht gebaut, die von der Eisenbahn und den Herstellern gemachten Erfahrungen hinsichtlich der elektrischen- und mechanischen Teile auszunützen, und zunächst eine Reihe von Variationen in Komponenten zuzulassen, in denen Bedienungs- und Unterhaltungserfahrungen wünschenswert sind, bevor man sich über Gesamtnormen für die Massenherstellung entschliesst.

Das Gesamtgewicht einer Lokomotive liegt innerhalb 80 tons, der Raddurchmesser im Neuzustande beträgt 48 inches. Die Lokomotiven sind imstande alle Arten von Zügen auf der Linie Euston – Manchester – Liverpool zu fördern. Fünf dieser Lokomotiven sind für Versuchszwecke mit einem andern Ubersetzungverhältnis ausgerüstet, um eine erhöhte Zugkraft mit einer Maximalgeschwindigkeit von 80 m.p.h. zu erhalten.

Dieser Bericht erörtert ebenfalls die Hauptmerkmale in denen alle Lokomotiven übereinstimmen sollen. Diese schliessen ein: Führerstandanlage und alle Steuerungen, Instrumente und Fehleranzeigungen, sodass die Führer nicht mit verschieden Bauweisen vertraut sein müssen. Die Stromabnehmer, Schalter, Schutz- und Erdungsanordnungen und Spannungsumschaltvorrichtungen wurden ebenfalls genormt. Anmerkungen über Gleichrichter, Transformatoren und Fahrmotoren werden in jenen Fällen gemacht, in denen die Hersteller verschiedene Ausführungen geliefert haben, wie sie in den Berichten 15 bis 19 beschrieben sind. Es wird auf die Lokomotiven verwiesen die mit Widerstandsbremse versehen sind, um die Bremsgetriebe – und Radreifenwartung zu reduzieren.

Die Unterschiede in der Konstruktion der mechanischen Teile sind erläutert. Besondere Einzelheiten der Aufhängungscharakteristiken der vier verschiedenen Drehgestelle sind tabelliert.

RESÚMEN

Aunque el pedido de las primeras 100 locomotoras sigue una especificación común, su construcción se ha realizado a propósito de forma a combinar la experiencia disponible por los Ferrocarriles y por los Constructores tanto en las partes eléctricas como mecánicas y de forma a dar, inicialmente, un margen de variedad en materias donde experiencia de explotación y mantenimiento es deseable antes de tomar la decisión de normalización completa para la producción en masa.

Las locomotoras son de un peso total por debajo de 80 toneladas con un diámetro de rueda nueva de 48 ins. y capaces de trabajar toda clase de tráfico en la línea electrificada Euston-Manchester-Liverpool. Cinco de las locomotoras llevan, experimentalmente, una razón de engrane diferente para dar una fuerza tractiva mayor con una velocidad máxima de 80 m.p.h.

Este folleto explica los rasgos que se decidió normalizar para todas las locomotoras. Son estos, disposición de cabina de control, instrumentos, indicaciones de faltas, de manera que los conductores no se preocupan de la marca de la locomotora. Tambien se han normalizado pantógrafos, disyuntores, dispositivos de protección, puesta a tierra y cambio de tensión. Se comentan tambien rectificadores, transformadores y motores de tracción para los cuales los constructores han sometido soluciones diferentes descritas en los folletos 15 a 19. Se refiere a locomotoras dotadas con frenos reostáticos para reducir desgaste y mantenimiento de frenos y llantas.

Se comentan las diferencias de diseño de las partes mecánicas y en particular se han tabulado los detalles de las características de suspensión de los cuatro bogies diferentes.

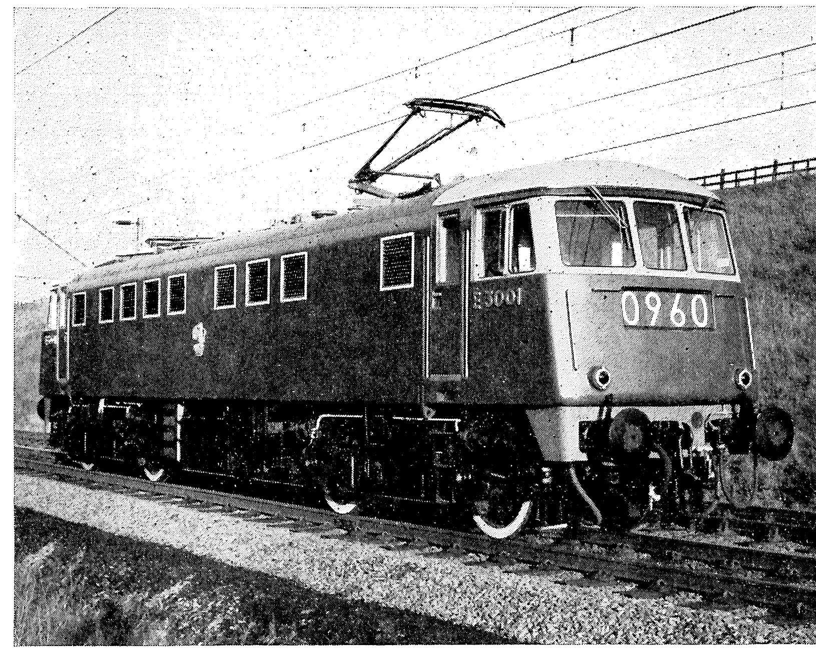


Fig.1 The first locomotive

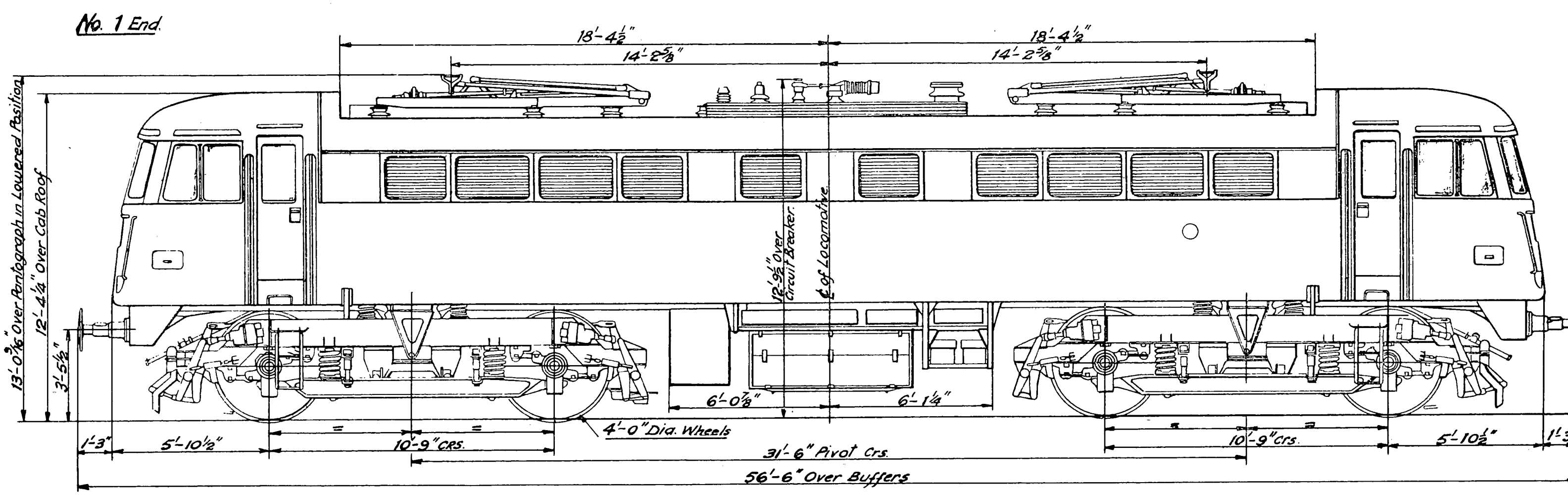
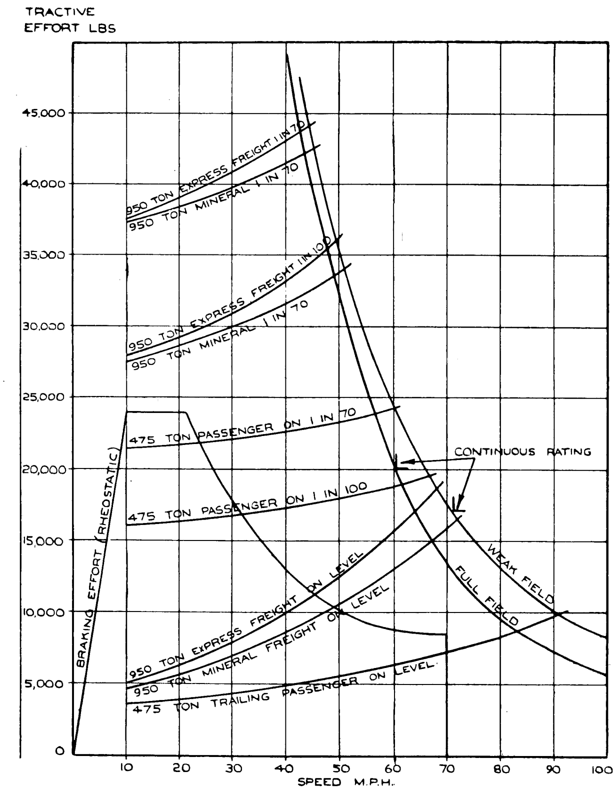


Fig.2 Outline of B.R. locomotive

Fig.3 Performance of A.C. locomotives.
Typical tractive effort/speed characteristic at 22·5 kV



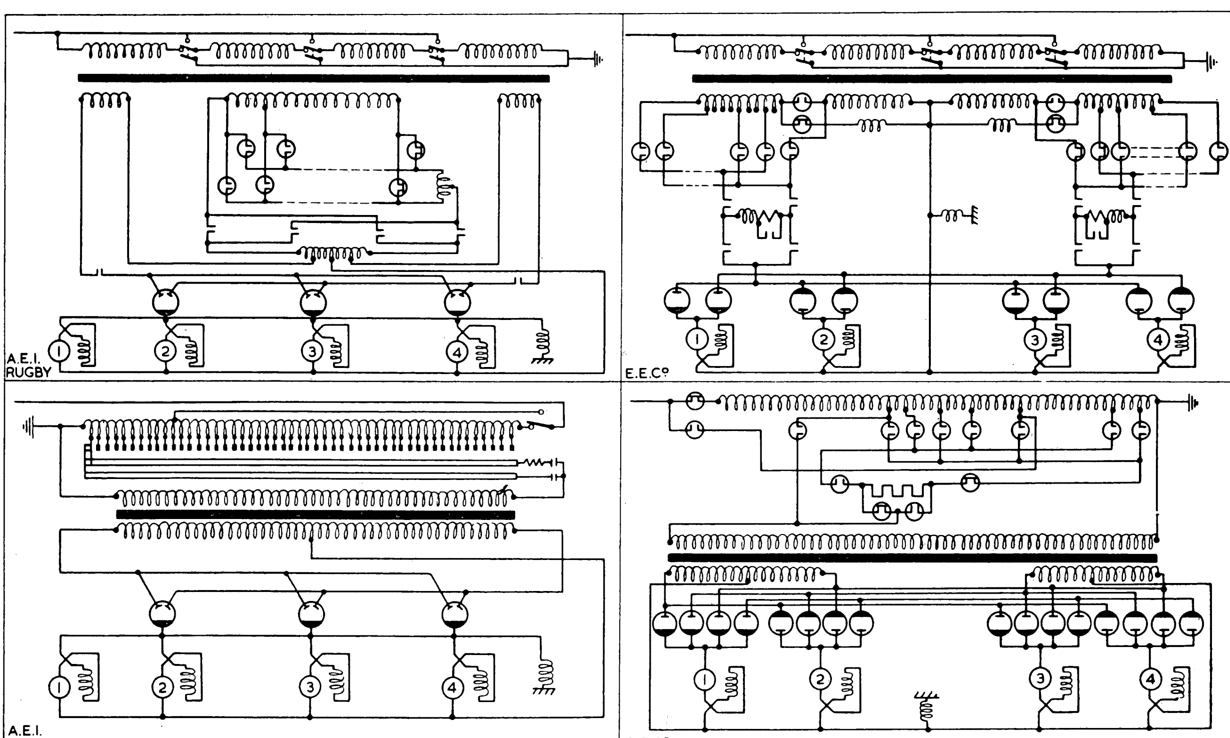
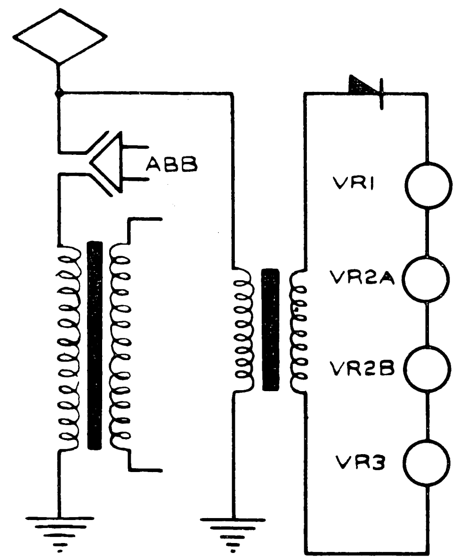


Fig.4 Schematic power circuits



SYMBOL	DESCRIPTION	CALIBRATION	
		DROP OUT	PICK UP
VR1	VOLTAGE RELAY		4·1kV
VR2A	VOLTAGE RELAY	6·9kV	
VR2B	VOLTAGE RELAY	6·9kV	
VR3	VOLTAGE RELAY		16·5kV
SCS	SUPPLY CHANGE-OVER SWITCH		
ABB	AIR BLAST CIRCUIT BREAKER		
APD	APC RECEIVER (MAGNETY LATCHED)		
APD RESET	APC RECEIVER RESET COIL		
AR1	APC RELAY		
AR2	APC RELAY		
AR3	APC RELAY		
ABR	AIR BLAST C.B. RELAY (TRIP & SET)		
OLR	OVERLOAD RELAY		
ARR	APC RESET RELAY		
ABG	ACB GOVERNOR		
PV	PANTOGRAPH VALVE		

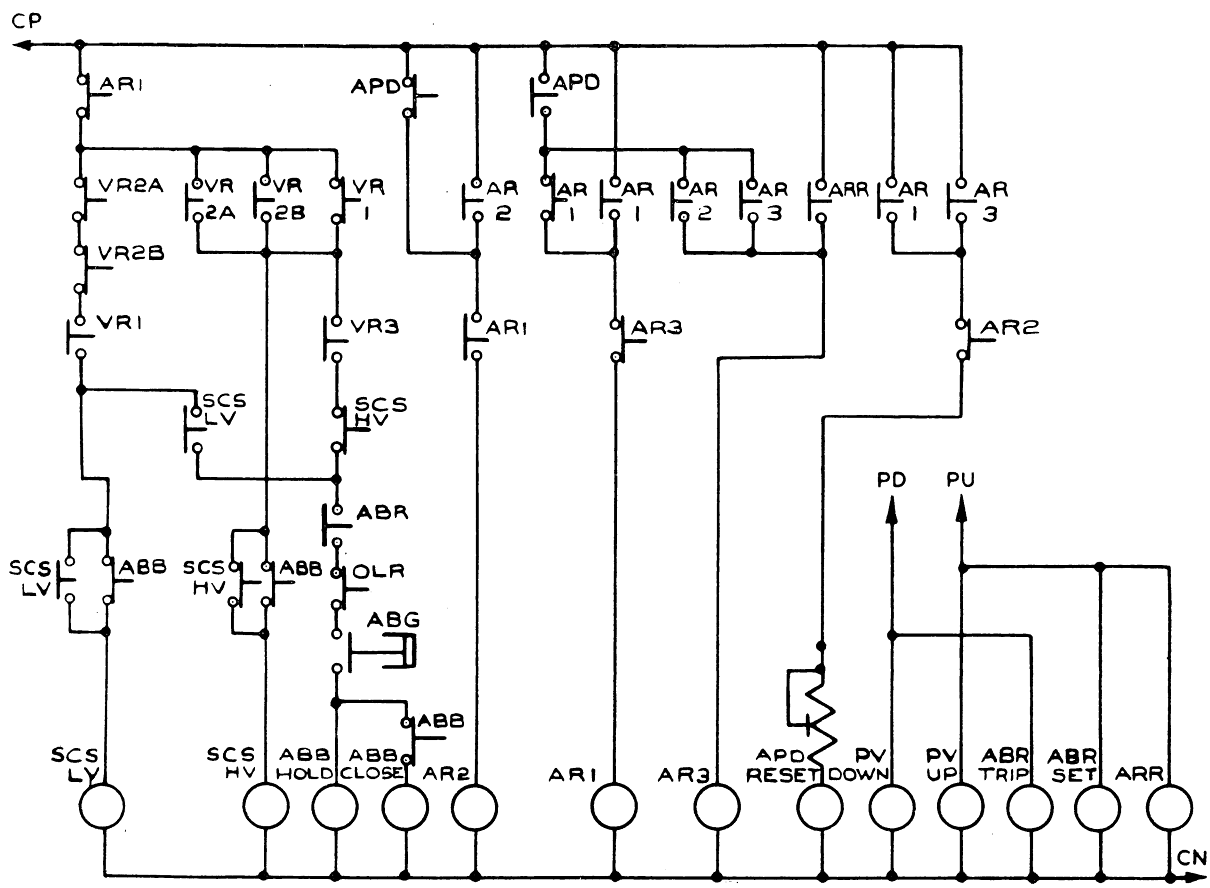
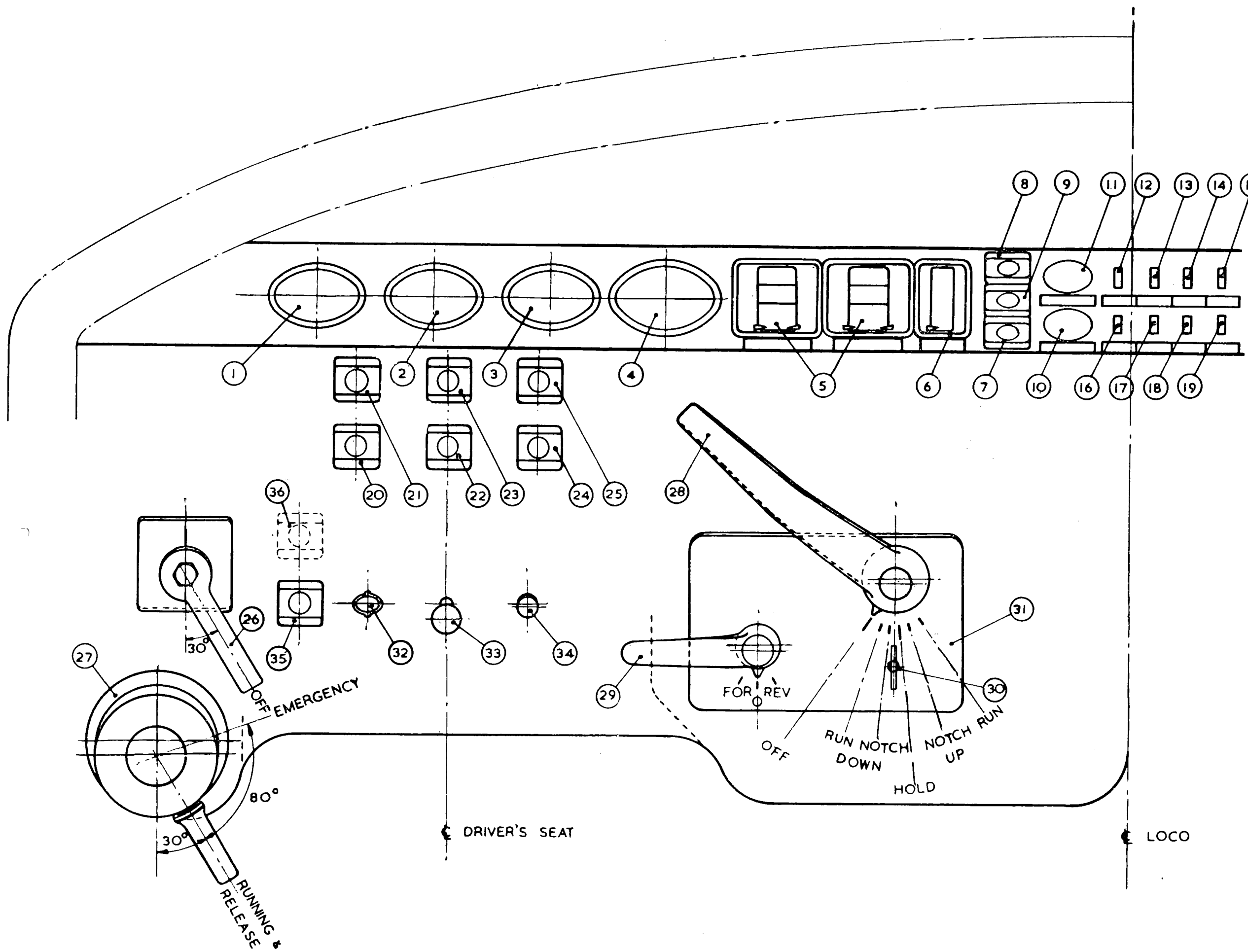


Fig.5 Voltage change-over schematic diagram



REFERENCE TABLE	
1	4" SINGLE PRESS. GAUGE (MAIN RESERVOIR)
2	4" DUPLEX PRESS. GAUGE (BRAKE CYL - BOGIE 1 & 2)
3	4" DUPLEX VACUUM GAUGE (VC-TP)
4	5" DIA. SPEED INDICATOR
5	MOTOR AMMETERS
6	NOTCH INDICATOR
7	TRAIN HEATING LAMP (WHITE)
8	LINE INDICATOR LAMP (WHITE)
9	FAULT INDICATOR LAMP (AMBER)
10	INSTRUMENT LIGHT DIMMER
11	INDICATOR LIGHT DIMMER
12	DEMISTER SWITCH
13	FOOT WARMER SWITCH
14	CAB HEAT SWITCH
15	CAB PREHEAT SWITCH
16	INSTRUMENT LIGHT SWITCH
17	ROUTE INDICATOR SWITCH
18	TAIL LIGHT SWITCH
19	CAB LIGHT SWITCH
20	EXHAUSTER STOP
21	EXHAUSTER START
22	PANTOGRAPH DOWN
23	PANTOGRAPH UP
24	TRAIN HEAT ON
25	TRAIN HEAT OFF
26	STRAIGHT AIR BRAKE VALVE
27	DRIVER'S VACUUM BRAKE VALVE
28	MAIN CONTROLLER HANDLE
29	REVERSING HANDLE
30	CONTROL KEY
31	MASTER CONTROLLER PLATE
32	WINDSCREEN WIPER
33	HORN CONTROL
34	A.T.C. RESET SWITCH
35	ANTI-SLIP BRAKE
36	LOCO BRAKE RELEASE (IF FITTED)

Fig.6 Arrangement of driver's desk

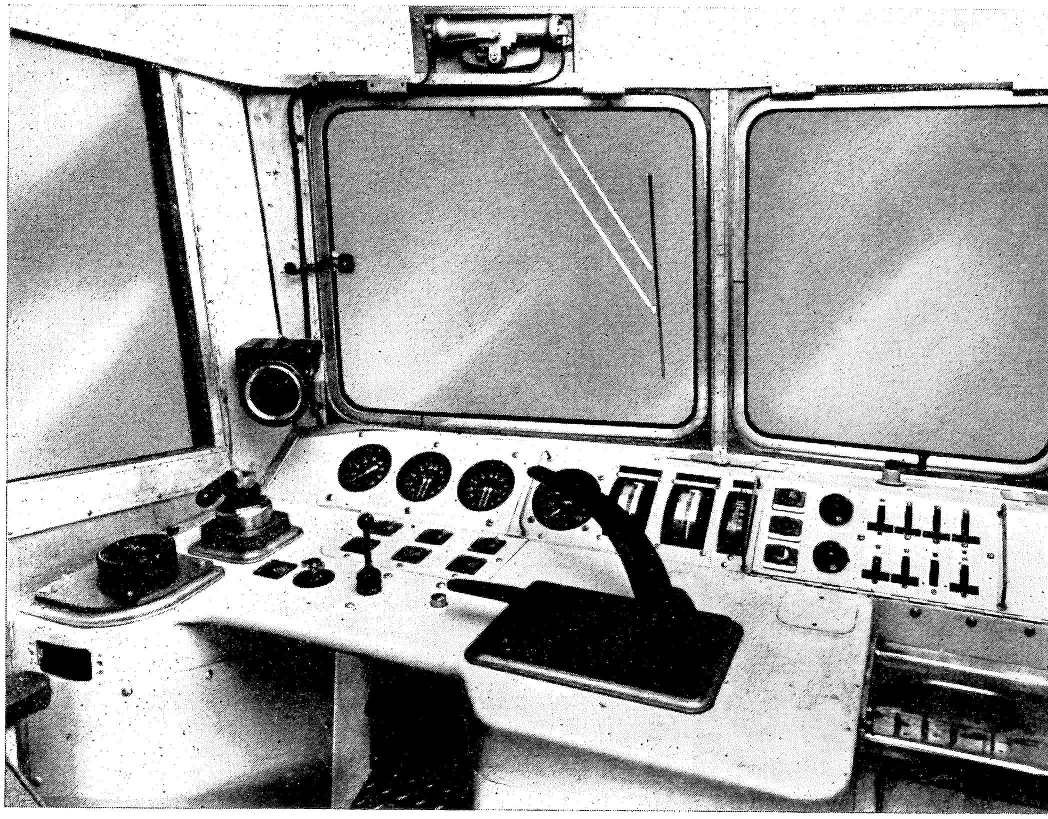


Fig.7 Driver's controls

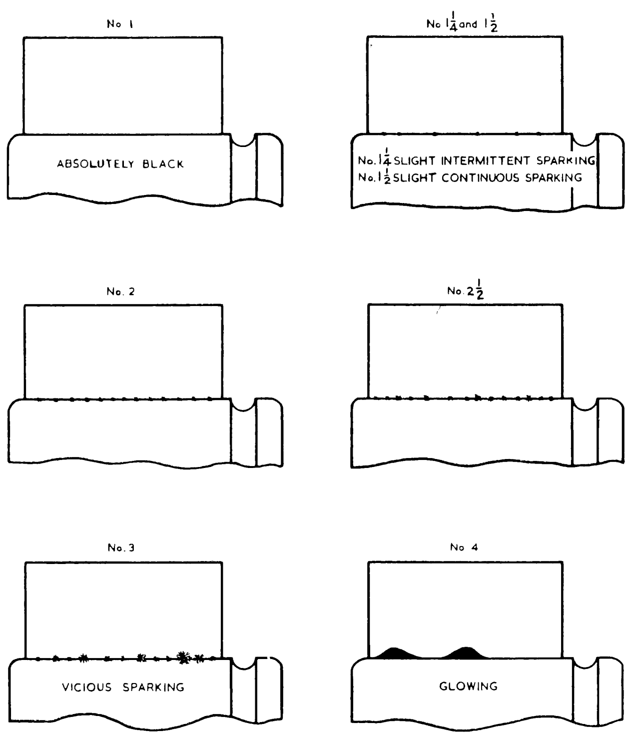


Fig.8 Commutation chart

Bogie Constructions

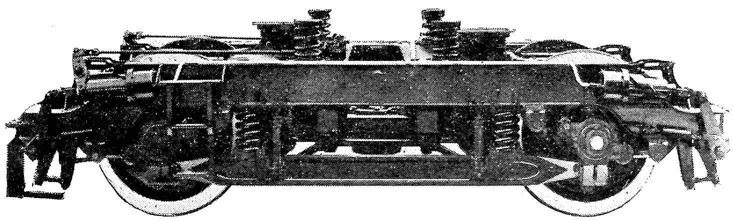


Fig.9a Nos.E.3001/23, E3.301/2

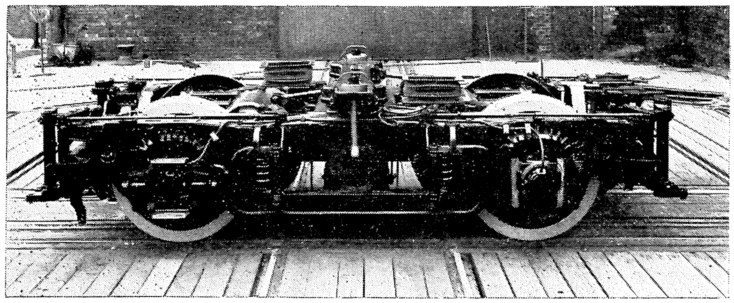


Fig.9b Nos.E.3046/55

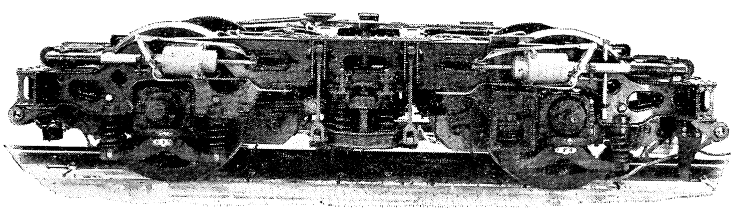


Fig.9c Nos.E.3024/35, E.3303/5

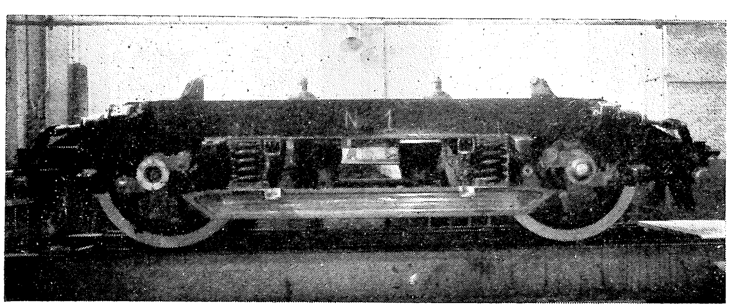


Fig.9d Nos.E.3056/95

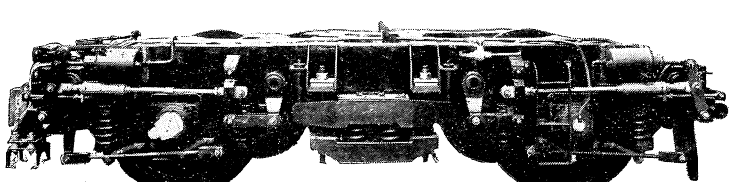


Fig.9e Nos.E.3036/45

Locomotive Superstructures

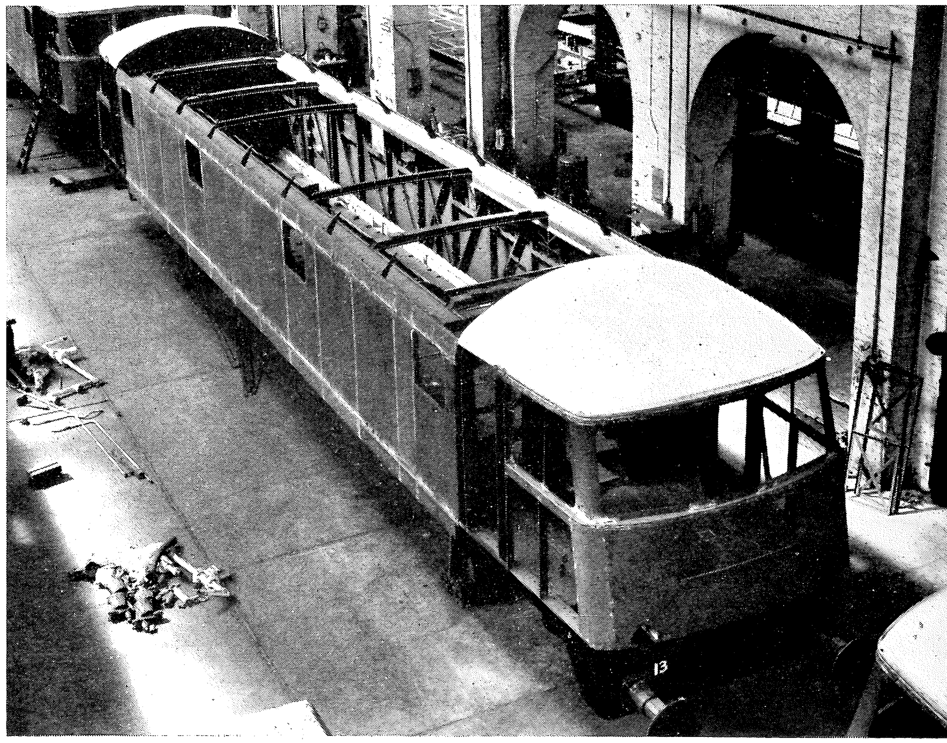
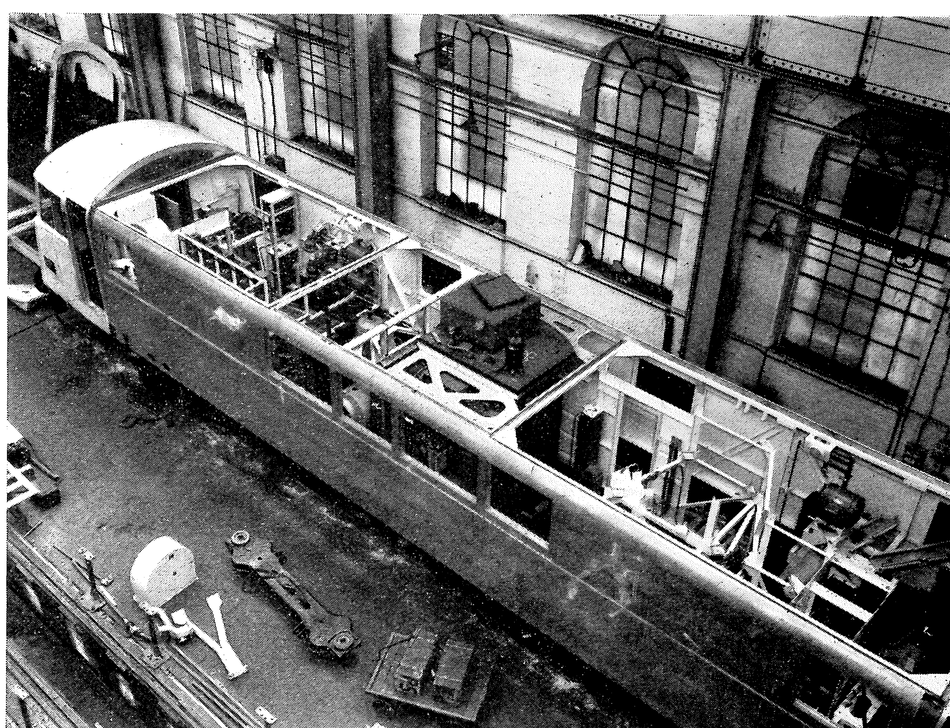


Fig.10a Nos.E.3001/23, E.3301/2



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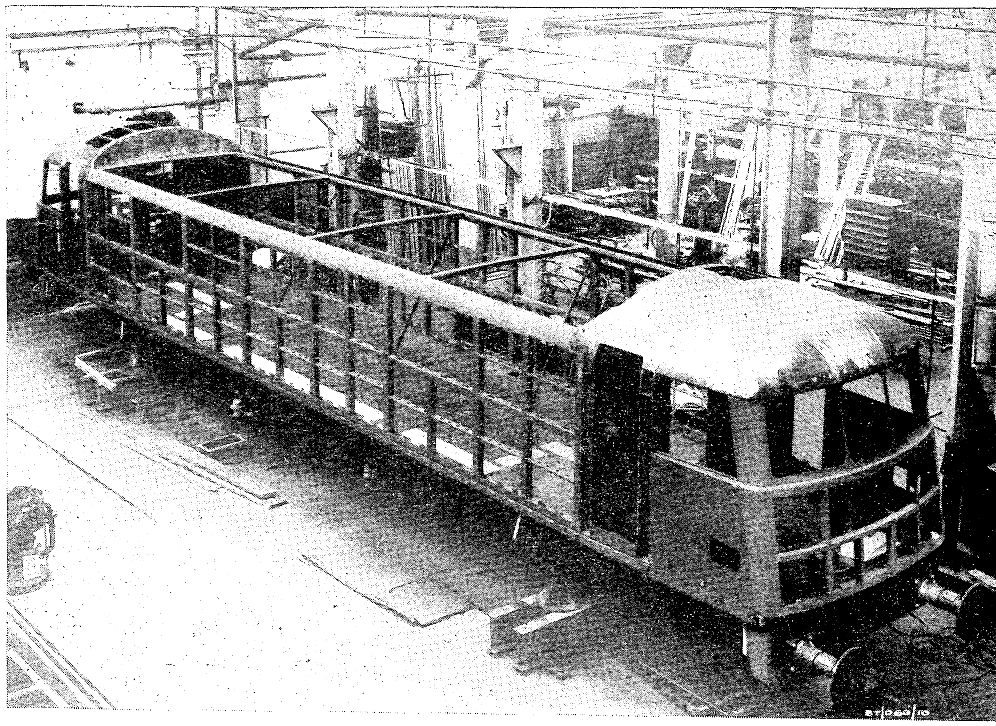

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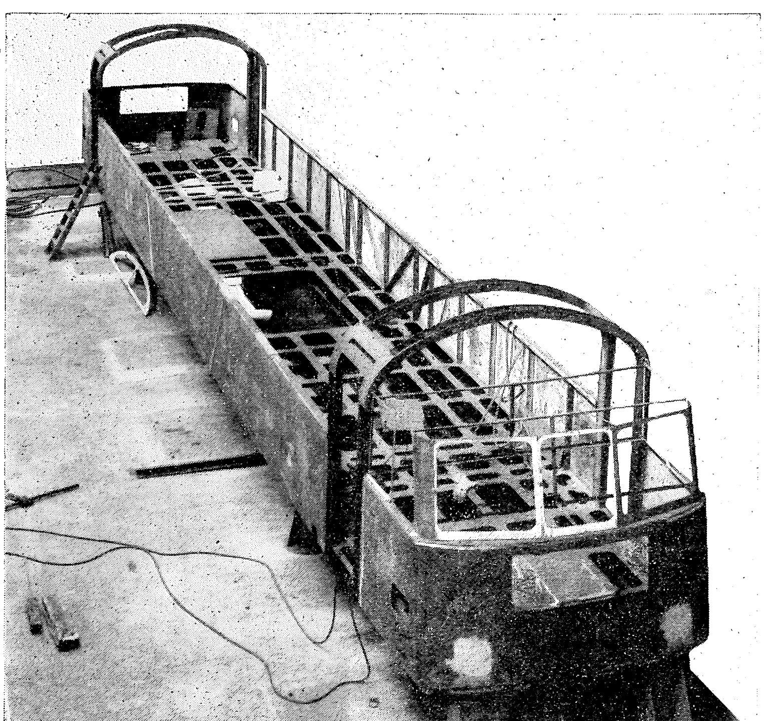

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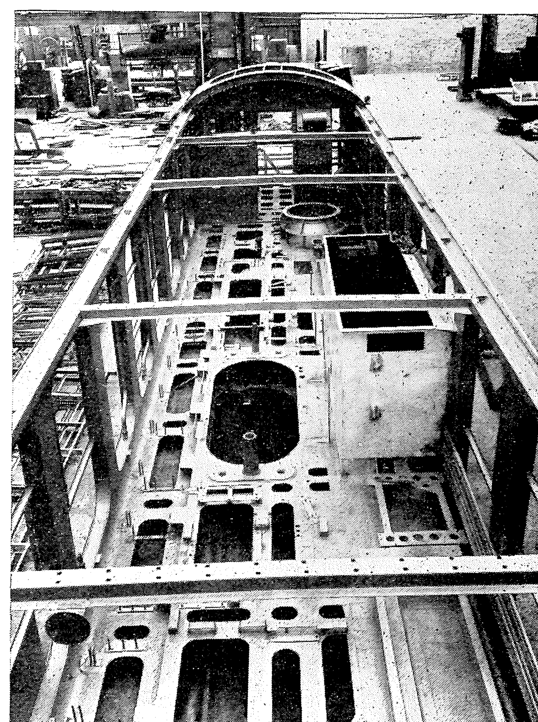

Fig.10e Nos.E.3036/45

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