# The Transactions of the South African Institute of Electrical Engineers

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Volume 45 JUNE 1954 Part 6

## PROCEEDINGS AT THE FOUR HUNDRED AND FORTY-FIFTH GENERAL MEETING

Held at Kelvin House, corner Marshall and Hollard Streets, Johannesburg

Thursday, 24th June 1954

R. W. KANE (Vice-President) was in the Chair and declared the meeting opened at 8 p.m.

There were present 80 members and visitors and the Secretary.

### ILLNESS OF THE PRESIDENT

The Chairman informed members that Mr J. P. Anderson, the Institute's President, had particularly asked that his apologies should be conveyed to them that evening. As members knew, he was still indisposed, but his health was improving. His apology was really because of the Railway paper to be read that evening and he was very sorry he could not be present.

### WELCOME TO MR A. J. ADAMS

The Chairman said that he would like to welcome the Secretary, Mr Adams, who had recently returned from Britain. He was the first of the two to return who had gone overseas to represent the Institute at the Commonwealth Engineering Conference.

### MINUTES

The minutes of the monthly general meeting held on the 19th May 1954, were taken as read and were confirmed.

### MEMBERSHIP

The Chairman announced that in terms of By-Law 5.2.4 the Council had elected the undermentioned candidates to membership of the Institute in the following grades:—

*Associate Member:* WILLIAM NORMAN BAILEY.
*Graduate:* RAYMOND CHARLES SHEWRY.
*Associates:* DOUGLAS HENRY FRAME, JOHN COLIN KIRK, EBEL CORNELIS LEUJES.
*Students:* THOMAS ALBERT COOK, S. J. DE BEER, LOURENS HUMAN, JOHANNES LOUIS JOUBERT, DENNIS FREDERICK KNEALE, DARRELL PAXTON SOBEY, ANTON MULLER.
*Transfer from Associate Member to Member:* WILLIAM MARTINUS ANDREW.
*Transfer from Student to Graduate:* WILLIAM WARREN BELL.

### GENERAL BUSINESS

The Chairman informed members that a cordial invitation had been extended to members of the Institute to attend a General Meeting of the Institution of Certificated Engineers, South Africa, to be held in the Main Hall, Kelvin House, on Thursday, 15th July 1954, at 8 p.m., when Mr E. R. Leeman would present a paper entitled 'Photo-elasticity—a means of "seeing" stresses in machine parts.' Members were also invited to contribute to the discussion on that paper. Galley proofs would be available for those who were interested.

### PAPER AND DISCUSSION

A paper entitled 'The main line electrification on the Cape Western System of the South African Railways' was presented by G. Williams (Member).

The Chairman proposed a vote of thanks and G. A. Dalton (Past President) and the Chairman contributed to the discussion.

The Chairman explained that it was intended that Mr Williams should give his paper later on in the year and, more or less, simultaneously read it at the Cape Western centre. Because of an unexpected alteration in the papers' programme, Mr Williams had been good enough to read it during the present month but would still read it at Cape Town in September next. It was hoped that, as the paper had been read and as it would have been published in the *Journal*, members would take the opportunity of preparing contributions to be presented at Cape Town. The Cape Town branch, who normally held their meeting on the third Thursday of the month, invited any Institute members visiting Cape Town to be present.

There being no discussion on the further items on the agenda, the Chairman thanked those present for their attendance, and declared the meeting closed at 9.15 p.m.

# Institute Notes

## Cape Western Local Centre

*Members of the Institute visiting Cape Town are cordially invited to attend general meetings of the Cape Western Local Centre which are held in Demonstration Theatre, Electricity House, Strand Street, Cape Town, on the second Thursday of each month.*

A general meeting of the Cape Western Local Centre was held in the Demonstration Theatre, Electricity House, Strand Street, Cape Town, on Thursday, 10th June 1954.

Mr C. N. Larkin (Vice-Chairman of the Centre) was in the Chair and declared the meeting opened at 8.10 p.m. 100 members and visitors were present.

Mr E. A. Sturman presented a paper entitled 'The Cape cable and wireless system,' which was supported by a number of slides, both diagrammatic and illustrative.

The author dealt very extensively with the subject matter of his paper and concluded by playing a recording of a telephone conversation, which took place the previous day with Mr J. A. Smale, Chairman of the Radio Section of The Institution of Electrical Engineers, and Engineer-in-Chief of Cables & Wireless, Ltd., London. The recording was followed by the showing of a film depicting a cable repair ship locating and repairing a faulty submarine cable.

Facsimile equipment (or picture telegraph) was demonstrated by means of a transmitter and a receiver situated on opposite sides of the hall and sundry items of equipment and a number of photographs were on display.

The Chairman proposed a vote of thanks to the author for his interesting paper and Messrs W. Charlton, G. W. Tudhope, G. A. Brickhill, M. N. B. Stephens, Dr L. Besseling, Lt. Louw, R.N., Messrs E. A. Sherlock, K. B. Sowman (Associate Member), G. H. S. Smith and H. M. Trainor (Associate Member) contributed to the discussion.

Mr Sturman replied to a number of the points raised by the contributors.

There being no further business, the Chairman declared the meeting closed at 10.55 p.m.

# THE MAIN LINE ELECTRIFICATION OF THE CAPE WESTERN SYSTEM OF THE SOUTH AFRICAN RAILWAYS

By G. WILLIAMS* (Member)

*Paper received on the 4th June 1954*

SUMMARY

The paper gives a brief description of the section and a history of the investigation leading up to the decision to electrify the section, and makes reference to some operating problems.

The substations and track equipment are described and some novel features referred to with reasons for their inclusion in the layout.

Construction methods adopted to reduce costs are discussed, and reference is made to some unsatisfactory items.

A full description of the locomotive is included and the alteration to the original design of the bogie frames is referred to and other modifications found to be necessary.

CONTENTS



## 1. HISTORY

From Bellville to Touws River, a distance by rail of 149 miles, the main line passes through one of the most intensively cultivated areas in the Union of South Africa and an area in which, of late years, industrial development has been rapid and continuous.

The mountainous nature of the country over the greater portion of the route necessitated numerous detours in order to take advantage of natural passes between the mountain barriers, the longest of these detours being that between Klapmuts and Chavonnes, a distance of 75·6 miles, the line traversing the pass between Elandskloof and Roodezands mountains at Gouda.

The main line rises to an altitude of 3 000 ft at Matroosberg, which is the highest point on the pass over the Hex River mountains.

Over the years, numerous investigations were carried out with a view to shortening and improving the existing main line and, in addition, a proposal was put forward to construct a new line from Wolseley via Ceres, a route that would avoid the existing heavy climb over the Hex River mountains. The most attractive of these proposals was the construction of a deviation through Du Toits Kloof, a route which offered a shortening of the main line by as much as 39 miles and it is of interest to note that this route was first surveyed as early as 1871.

Only during comparatively recent years, however, has it been demonstrated that the main line, as originally constructed, was approaching the limit of its carrying capacity and during 1943, a committee was set up to examine on a long-term basis, the improvements that would be necessary on this section, and the terms of reference included the following principal proposals—

- *i* the construction of a deviation between Klapmuts and Chavonnes via Du Toits Kloof
- *ii* the construction of a new route from Wolseley to Touws River via Ceres
- *iii* the electrification of the section Bellville to Touws River
- *iv* the electrification of the section De Doorns-Touws River.

The pass through the mountains offered by the Du Toits Kloof lies almost in a direct line between Klapmuts and Chavonnes and carries the new national road, but a detailed survey showed that it would not be possible to construct a railway with a gradient better than 1 in 50 and that it would be necessary to cut a tunnel of approximately 2½ miles

* Mr Williams is Chief Electrical Engineer, South African Railways.

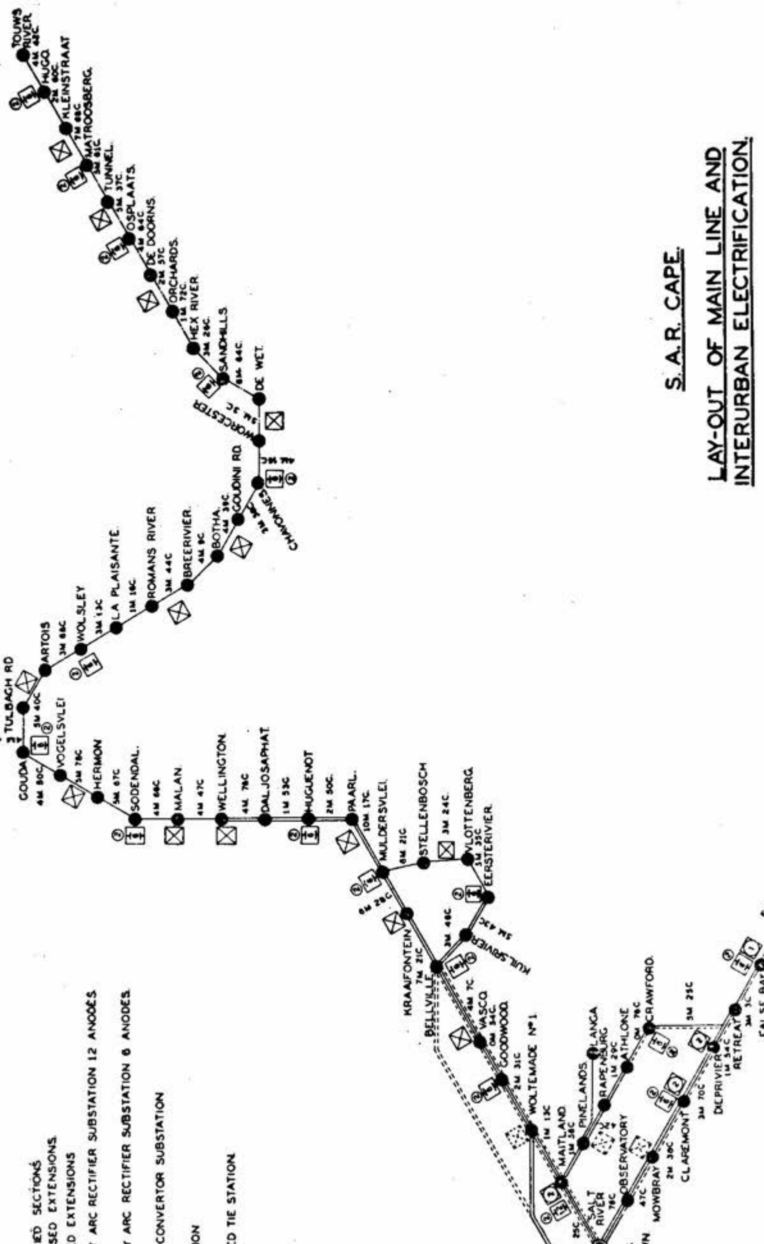


Fig. 1. Layout diagram

in length. As steam traction would not be practicable on a section of this nature, the possibility of operating the deviation by diesel or electric traction was also examined.

The cost of constructing the deviations was found to be very high, and a change in the form of traction, at a point only 20 miles from the principal marshalling yard at Bellville, would be uneconomic and introduce a number of undesirable features. A further objection to this proposal arose from the fact that it would not be possible to abandon the existing main line over the highly developed area between Klapmuts and Chavonnes, and the operation of both routes would be uneconomic.

The construction of a new line from Wolseley to Touws River via Ceres was also found to be costly and this proposal also suffered from the same disadvantage that only a portion of the traffic could be routed over the proposed new line, as it would not be possible to abandon the existing main line.

It was found that the electrification of the section from De Doorns to Touws River only, offered but a partial solution to the traffic problem and was not attractive economically necessitating the construction of a long transmission line from Cape Town, in order to furnish small power requirements, and in addition it would have been necessary to provide electrical repair and maintenance facilities at De Doorns or Touws River in addition to those required for the suburban electrification at Cape Town.

The yard facilities which would have to be provided at De Doorns, rest room accommodation for running staff and permanent housing for repair and maintenance staff, would also involve considerable expenditure.

A detailed examination of the proposal to electrify the whole section from Bellville to Touws River showed that the desired improvement in the working, and in the traffic capacity of the section, could be adequately provided for at an economic figure, offering a more rapid turn-round of trucks, a material reduction in the shift time of running staff, and in the haulage of locomotive coal, and permitting the abolition of the existing locomotive sub-depot at De Doorns.

The proposal to electrify this section brought about a review of the power supply position in the Cape area as a whole, and the Electricity Supply Commission decided that it would be necessary to construct a new power station at Worcester, and a new transmission system designed to meet the proposed traction and industrial requirements, to provide for industrial and general development over a large area.

During 1944 approval was given to the proposal to electrify the sections Bellville-Touws River, and Bellville-Muldersvlei via Eerste Rivier and Stellenbosch, and detailed survey and planning was commenced.

As a result of sharp rises in the cost of labour, equipment and material of late years, the total cost of the scheme, exclusive of locomotives, was £2 700 000.

The scheme embraces the electrification of 175 route miles of main line, with a total of 248 track miles and the construction of 11 traction substations. Fig. 1.

## 2. TRAIN OPERATION

Electric locomotives operate within speed ranges determined by design and number of motor combinations, and with given loads will perform to a somewhat rigid schedule over each section of track, and this fact has occasionally been quoted as one of the limitations of electric traction.

This feature has, in fact, a great deal to commend it, particularly when working single-track sections, for in these circumstances, it is desirable that crossings between up and down trains take place at the time and place arranged and the more rigid the locomotive performance the better is this requirement met.

It is also necessary that the section timing of up and down trains do not differ widely, and that there should be as little variation as possible in the average train speed over any section, in either direction.

Electric traction provides high sustained tractive effort on up gradients and regenerative braking permits higher speeds on down gradients as a result of automatic speed control and the fact that any mechanical brake power is held in reserve.

On the section under discussion, the foregoing considerations assume a great deal of importance, as in general, the ruling gradient of 1 in 66 is against the north-bound trains over a distance of 120 miles, with an almost continuous climb of 1 in 40 over the 16 miles from De Doorns to Matroosberg, this latter section forming the bottleneck limiting the capacity of the section as a whole.

Under steam traction, it was necessary to divide the section from the point of view of train crew shift working and to provide rest-room accommodation at De Doorns but, even with this arrangement and as a result of congestion, the duty periods were lengthy. The improved running times under electric traction, however, ensure that train crews complete the whole journey in a normal tour of duty, and electric operation permits the introduction of a change-over arrangement whereby the crews exchange trains approximately half way along the section, thus terminating all duty tours at the home depot.

Electric locomotives are serviced on a mileage basis, the time interval being from three weeks to one month and, during this period, are entirely at the disposal of the trains operators, who route the locomotives to meet the traffic requirements and stage them at any required point. They are completely pooled and are used to work any class of train.

The traffic requirements called for locomotives capable of hauling trains of 1 000 tons in the inland direction, and 1 200 to the coast. The locomotive provided will permit the working of trains of 1 200 tons in either direction, with one locomotive on all sections except between De Doorns and Matroosberg where an additional locomotive is attached.

The reduction in the train running times is as follows :—

Goods trains coastwise from 378 min to 284 min, saving 94 min.

Goods trains inland from 387 min to 292 min, saving 95 min.

Passenger trains coastwise from 270 min to 227 min, saving 43 min.

Passenger trains inland from 290 min to 238 min, saving 52 min.

It is the intention to transfer from Natal at a later date a number of the original Class 1E locomotives to work on the Cape main line, the intention being to use the smaller locomotives on inter-station and pick-up duty where the use of large locomotives becomes uneconomic.

## 3. LOCOMOTIVES

The type of locomotive provided for a section generally represents a compromise between a number of desirable operating and other features, financial considerations, both of first cost and of maintenance, being not the least of these.

From the operating point of view it is obviously desirable, if at all practicable, to have but one type of locomotive to form a pool of motive power from which to draw for any character of train, and from the maintenance point of view also, the advantage of such an arrangement requires no emphasis.

On a section such as the one under discussion where there are wide variations in the ruling gradients, in the weight and character of trains, and in the permissible speeds a solution can be found by the provision of a relatively large number of locomotives, each of modest tractive effort, designed to operate in multiple as required.

The provision of motive power in this manner, is, however, costly particularly under present-day conditions and better financial results are obtained by the employment of a smaller number of more powerful units.

The general specification of the locomotives purchased for this section is as follows :—

Wheel arrangement, $1 - C_0 + C_0 - 1$
Weight of locomotive, 155 tons (2 240 lb)
Overall length, 71 ft 9½ in.
Bogie fixed wheel base, 15 ft 2 in.
Distance between centre pivots, 35 ft 5 in.
Weight on driving wheels, 21·5 tons (2 240 lb)
H.P. at full field, 1 hour rating, 3 030 h.p.
Tractive effort at full field, one hour rating, 41 700 lb
Speed at full field, one hour rating, 26·7 m.p.h.
Maximum speed, 60 m.p.h.
Number of traction motors, 6
Gear ratio, 21/75
Diameter of driving wheels, 51 in.

The locomotives provided are capable of meeting the traffic requirements at satisfactory speeds, using one locomotive per train, on all portions of the line except between De Doorns and Matroosberg, where the gradient is 1 in 40, with almost continuous curvature, the minimum radius being 340 ft. Fig. 2.

Over this section an additional locomotive is attached, the two being driven in multiple by one driver, the attachment and detachment carried out by the train crew, the operation taking about five minutes, and the extra unit left unattended in short sidings strategically placed.

In order to prevent the lateral oscillation at speed experienced with previous designs of locomotives, particular attention has been given to the distribution of the locomotive weight. The body is supported by two spring-borne side bearers and two spring-borne end bearers on each bogie, no weight being carried on the bogie centre pivots, the tractive forces being transmitted by means of a link between the two driving bogies. The single-axle guiding trucks are laterally restrained on tangent track and the whole arrangement has resulted in good riding qualities at all speeds.

Weight compensation is provided between the guiding pair of wheels and the leading pair of driving wheels and between the second and third pair of driving wheels on each bogie. A spring restraining device is attached between the inner ends of the two driving bogies, designed to provide lateral forces to lead the rear driving bogie into curves, and minimize flange wear.

Due to design weaknesses this restraining device became displaced in service and was the subject of considerable modification.

All axles are carried in oil-lubricated tapered roller bearings of a type that has given excellent service on previous locomotives, the traction motors being fitted with conventional grease-packed roller and ball-bearings.

The driving motors are nose and axle suspended, the axle suspension bearings consisting of two white-metalled split bronze sleeves, and the nose carried from the bogie frame in rubber springs.

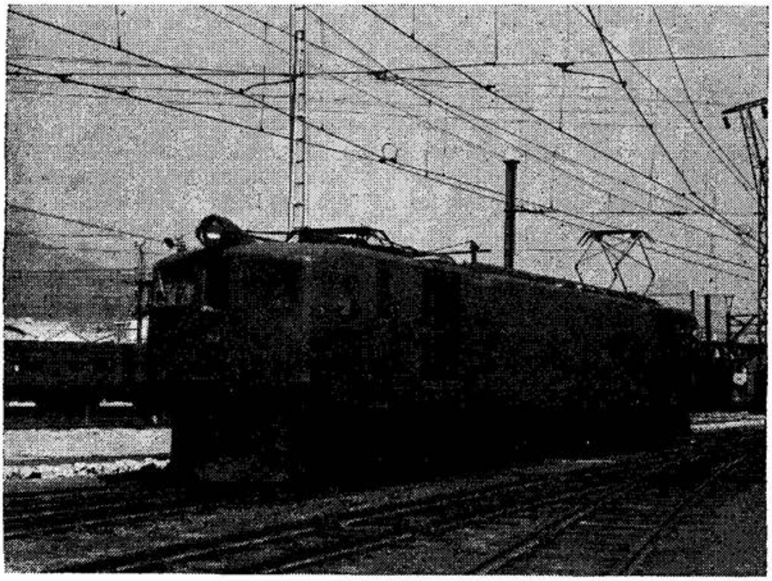

**Fig. 2. Class 4E locomotive**

Keys are not provided in the armature shafts and motor pinions, the pinions being shrunk on to a ground taper on the motor shaft. The drive to the wheels is taken through a gear wheel of the rubber-bushed resilient type.

In motoring or regeneration, the motors may be grouped in three combinations, i.e. :—

Series combination—all six motors in series

Series-parallel combination—two groups of three motors in series

Parallel combination—three groups of two motors in series

and field tapping is arranged to provide higher running speeds at light motor loads.

The regenerative braking system provides for the control of the full weight of the train and locomotive on all grades, all six traction motors being used as generators. Compressed air brakes are provided on driving wheels other than the intermediate drivers these being applied independently or in combination with the vacuum-operated train brakes.

Locomotive control is effected by means of electro-pneumatically operated unit switches and switch groups, the latter being used to arrange the motor groupings in motoring and generating sequences.

Particular attention has been paid to the cooling of the main resistances. These are installed in two separately ventilated chambers, the ventilation being carried out by a combination of induced and natural draught. The lighter sections are of the rustless strip metal type and the heavier resistances are of cast iron.

Two 3 000-V/110-V motor-generator sets are carried in the locomotive body, each set being provided with a fan delivering cooling air to three of the main driving motors.

One of the sets rated at 20 kW provides power for lighting and battery charging, for driving the compressor and the twin exhausters, and for control purposes, the second set rated at 42 kW provides for the excitation of the driving motor fields during regenerated braking, the generator voltage on this set being variable and controlled from the regeneration lever of the master controller. The exciter set in emergency can be used as 100-V supply motor-generator.

The use of h.v. cable in the h.v. compartment has been reduced to a minimum, bare copper bars on porcelain insulators used wherever possible. It has been shown that cable is more prone to fault under surge conditions and in addition, represents an avoidable fire hazard.

The control circuits on locomotives of this type are, of necessity, extremely complicated, incorporating a large number of interlocks. To ensure trouble-free service and long life, the interlocks have been carefully designed, are silver-tipped and enclosed in dust-tight cases.

Protection on the power circuits is provided by means of a main overcurrent trip relay connected in the incoming feeder from the pantograph, and an overcurrent relay in circuit with each pair of motors. An overvoltage relay is connected across the line and earth to protect the equipment when operating in regeneration and a 'no-current' relay to open the circuit in the event of voltage failure on the contact wire.

The master controllers are of the cam-operated type with three operating levers, the forward/reverse and combination lever is removable only in the off position, its removal locking the other levers. There are 14 resistance notches on the starting lever and 3 weak field notches. The regenerating lever has 16 notches for speed control in regeneration.

Entry into regenerative braking is made by voltage comparison, two edgewise voltmeters being mounted adjacent in the desk-type instrument panel for the purpose, one instrument indicating line voltage and the other the voltage across the main motors. When initiating regeneration the main resistances are left in circuit, and the regeneration lever notched up until the voltage generated by the motors in the selected combination, matches that of the line. The main resistances are then cut out by means of the accelerating lever and the train speed controlled thereafter by means of the regenerating lever.

Lightning protection is provided by means of a double horn gap connected between the pantograph and a surge absorber, and in addition a spark gap set at 0·11 inch in the high-voltage chamber. The spark gap, connected from line to earth through a non-linear resistance, is equipped with a separately excited blow-out coil and an arc-chute.

The bogie frames, originally fabricated by electric arc welding throughout, were re-designed, the thickness of the side frames being increased from 1½ in to 2½ in and attached by rivetting. The original flangeless wheels on the middle driving axle on each bogie were replaced by flanged wheels having side play to a total of 3½ in.

The driving motors on these wheels move laterally with the wheels, the motor suspension noses being carried in swing links.

Very little trouble was experienced with the electrical equipment, the principal difficulty being with the main motor brushes.

The brush boxes are of conventional design but the brushes are split laterally, each twin pair being held to the commutator by one pressure pad.

At the outset commutation was poor and the life of the brushes was short, but after some months of tests with different brush types and brush pressures a satisfactory arrangement was arrived at, and the life of the brushes is now about 60 000 miles and the commutation is good.

It was also necessary to make some minor alterations to the busbars in the h.v. compartment to eliminate vibration and the risk of fatigue fracture.

## 4. FOUNDATIONS

The masts are carried on concrete foundations, two cubic yards of concrete being required for the standard block, the bolt group illustrated in Fig. 3 providing adequate reinforcement.

In order to reduce the cost of foundations and at the same time to permit the work to proceed at a satisfactory rate, the handling of material and the mixing and pouring, was completely mechanized.

Ten petrol-engine-driven concrete-mixers, each of $4\frac{1}{2}$ cubic yard capacity, were mounted in pairs on flat trucks and marshalled as required on a construction train, which included a cabose for the staff and trucks to be used for the distribution of foundation groups, formers and miscellaneous materials.

Sand, stone and cement was delivered by rail to temporary depots established along the track, where material hoists were provided to charge the mobile concrete-mixers with dry material.

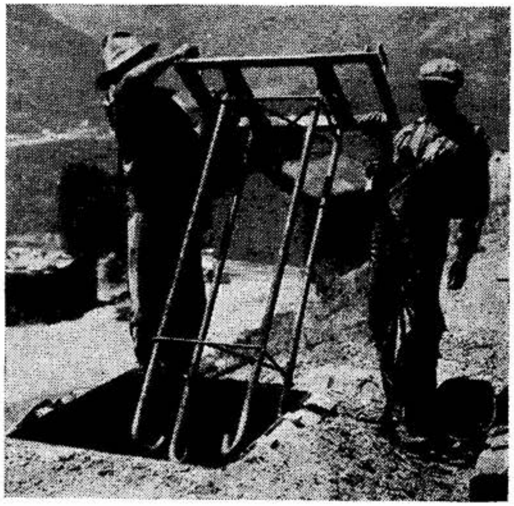

Fig. 3. Foundation group

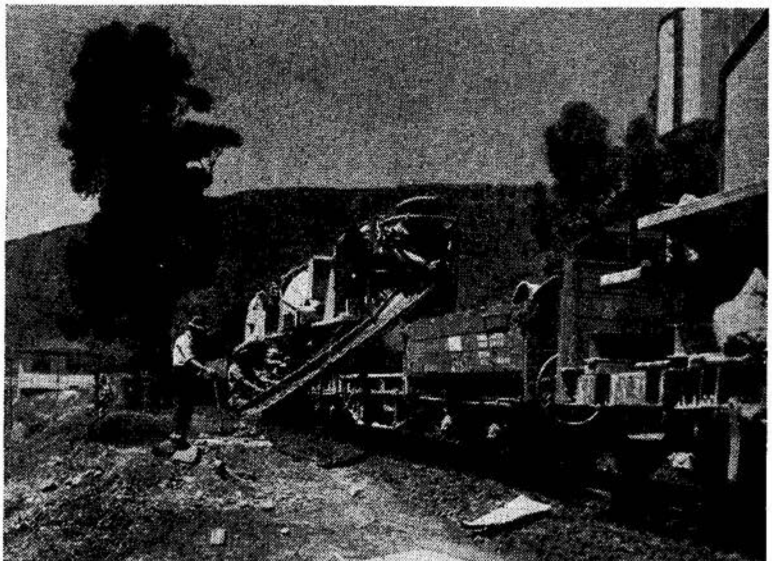

Fig. 4. Concrete train

The train conveying the loaded mixers entered the section at pre-arranged times between ordinary trains, and when approaching the foundation sites, the mixers were started up in rotation and water added to the dry contents. When all mixers had been emptied, the train returned to the depot for re-loading. Fig. 4.

With this method, the distribution of material and water along the track, a slow and wasteful procedure, was avoided, and the work proceeded with a minimum interference to normal traffic, standard foundations being cast at the rate of one every six minutes of track occupation, the actual time taken to pour the concrete being three minutes only.

The digging was done by hand, as self-propelled mechanical diggers could not be used alongside the track owing to the frequency of banks, cuttings, culverts, etc., and the use of mechanical diggers carried on the track would have seriously interfered with the working of normal traffic.

Accurately constructed steel moulds were provided to form the above ground portion of the foundation blocks and to locate the foundation bolt group. The top edges of the mould were machined and used as levels in the final screeding. The moulds were placed in position on short wooden sleepers and accurately adjusted by means of jack screws, in order to ensure that the top surface of the finished block is truly level, as no final adjustment, by wedging or grouting, is possible where mast base insulation is used.

The method of construction proved to be eminently satisfactory, requiring only a limited semi-skilled and unskilled labour force, and a consequent material reduction in cost.

A total of approximately 5 000 foundations were placed on the section.

## 5. TRACK EQUIPMENT STEELWORK

In order to reduce the cost of construction the designs adopted for steelwork were very simple, the number of different types was reduced to a minimum, and the manufacturing processes standardized to a high degree at a depot laid out and equipped for the purpose.

The masts were made from standard broad-flanged beams of four sizes, 6·7 inches by 7 inches, 7·5 inches by 7·8 inches, 8·3 inches by 8·5 inches, and 9 inches by 9·3 inches, the beams being ordered in the required length in order to avoid cutting, and the masts fabricated entirely by electric arc welding, all joints being completely sealed to prevent the ingress of water.

The use of broad-flanged beams provided a sturdy and inexpensive structure not easily damaged in handling and erection, and from the maintenance point of view the structures are easy and cheap to clean and paint and have a very long life.

The weight of this type of mast when compared to the weight of a lattice structure may appear to be disadvantageous during erection, but that the extra weight is of no consequence is illustrated by the fact that the actual lifting time by hand methods is only about three minutes each.

Masts of this type were stacked on top of one another in railway trucks to the full load of the vehicle and simply skidded to the ground when offloading on site.

The standard height of the catenary suspension point is 23 ft 3 inches, which with 220 ft normal spacing, provides a standard contact wire height of 16 ft 6 inches, and in yards and over public level crossings where 20 ft contact wire height is desirable the extra height is obtained by the use of standard length beams used in the type of structure illustrated in Fig. 5.

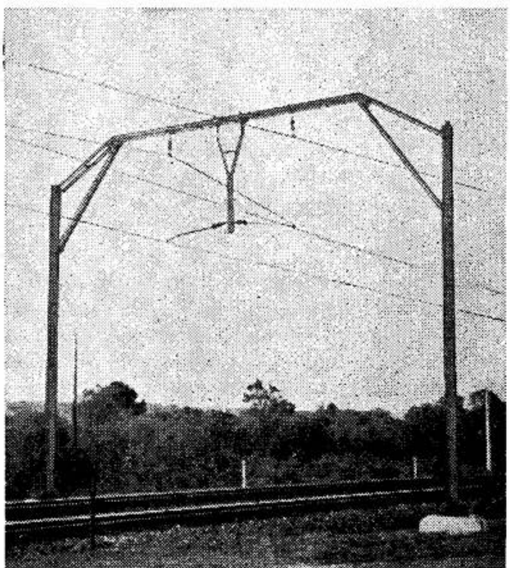

**Fig. 5. High-type structure**

Two standard beams of channel section in suitable sizes were used as bridge booms in two three and four-track structures, lattice-type booms being used only for spans in excess of four tracks.

All steelwork was designed to carry twice the normal loading under the worst recorded conditions of wind pressure, and in addition snow and ice loading was allowed for on the section north of De Doorns.

All masts are insulated from the concrete bases and holding-down bolts by means of insulation plates and bushes, hard fibre being used largely in the first stages of construction, tempered hardboard being introduced later.

The insulation of the mast bases is designed to prevent current leakage through the foundations, which frequently results in corrosion of the bolt group and cracking of the concrete blocks.

Mast-base insulation also permits direct bonding between the masts and the rails, eliminating the expensive and troublesome spark gap usually inserted in the mast-to-rail bonds and, on double and multiple track sections, it also permits the elimination of a large number of bonds between tracks, the bridge booms forming a metallic bond across the tracks.

Because of the high cost of copper and the fact that copper cross-bonds are readily pilfered, steel cross-bonds were used throughout, these being made up from ½-inch mild steel reinforcing rod with short flexible 'tails' for attachment to the rails, this method proved to be very satisfactory, the bonds being neat and strong.

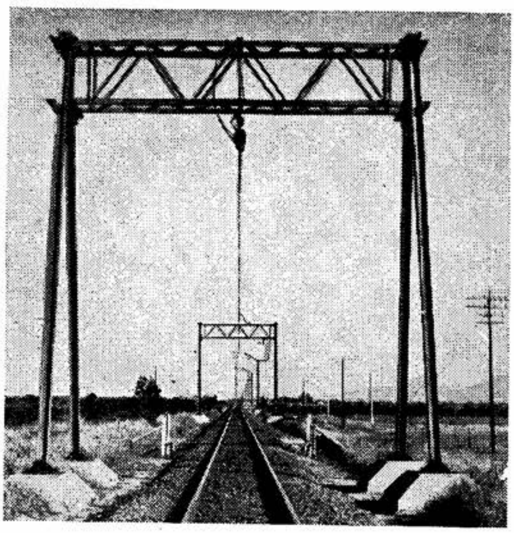

**Fig. 6. 'A' type tension structure**

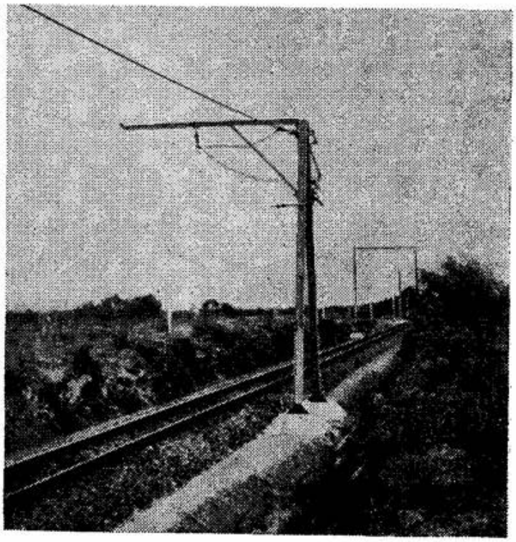

**Fig. 7. Single-track overlap**

Two types of tension structure were used, a simple 'A' structure as shown in Fig. 6 and a mast with raking leg as shown in Fig. 7 the make-off in this case being made over two spans as shown. This latter method proved satisfactory and inexpensive.

The steelwork was, in general, erected by means of simple hand tackle as illustrated in Fig. 8 and Fig. 9 in order to avoid the interference with traffic which results from the use of travelling cranes.

Hand erection not only facilitated train working, but proved to be cheaper than the operation of construction trains with the unavoidable waste of time which occurs when working on a busy section.

It is of interest to note that occupation of the track for construction purposes was limited to two periods per day, each period varying from a half hour to one hour.

## 6. OVERHEAD WIRES AND FITTINGS

On the double track section of 33·5 route miles south of Wellington, each track is equipped with copper conductors of

0·625 sq.in. total cross-section, made up of a 0·375-sq. in. catenary wire, and a 0·25-sq.in. contact wire, and on the 115·5 route miles of single track north of Wellington and on the section Bellville-Muldersvlei via Stellenbosch, a further 26 route miles, the total cross-section of the overhead conductors is 0·95 sq.in. copper equivalent, made up of 0·25-sq.in. contact wire, a 0·25-sq.in. catenary wire and a 0·45-sq.in. copper equivalent, stranded steel-cored aluminium feeder cable. On the section Chavonnes to Wolseley an additional feeder is provided

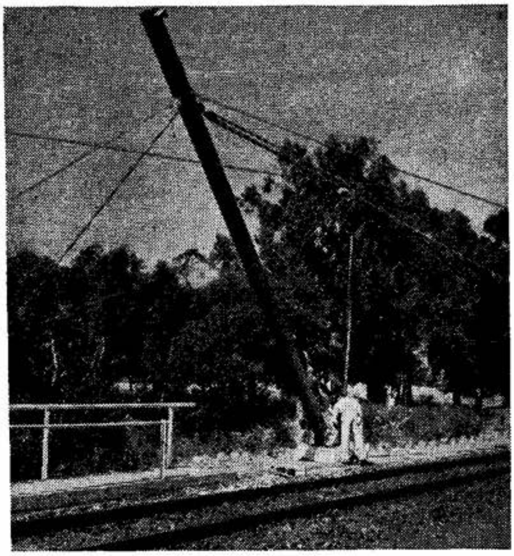

**Fig. 8. Erecting mast**

bringing the total cross-section up to 1·4 sq.in. copper equivalent.

The relatively large cross-section of the conductors was necessitated by the section loading and the distance between substations, and provides a satisfactory margin between load currents and substation circuit-breaker settings.

The omission of inverter equipment at substations on a section where full regenerative braking is in use, also affected the determination of conductor size, and this aspect of the matter is referred to later.

The overhead conductors are anchored at intervals of 6 000 ft, tension springs being incorporated at the anchor points in order to keep the tension in the conductors within prescribed limits under varying temperature conditions.

The steel-cored aluminium feeder cable and the copper catenary are both carried on one set of insulation by means of a specially designed double-suspension clamp, the feeder cable being supported on a trunnion in order to provide free movement with respect to the catenary wire. As the aluminium feeder is very large in diameter and tensioned only to 1 540 lb no vibration damping arrangement has been provided, special conducting clamps being installed, between the aluminium feeder and the copper catenary, at intervals of approximately 1 100 ft.

All conductors are carried and located by means of two porcelain suspension type insulators of 6 in. diameter at each point,

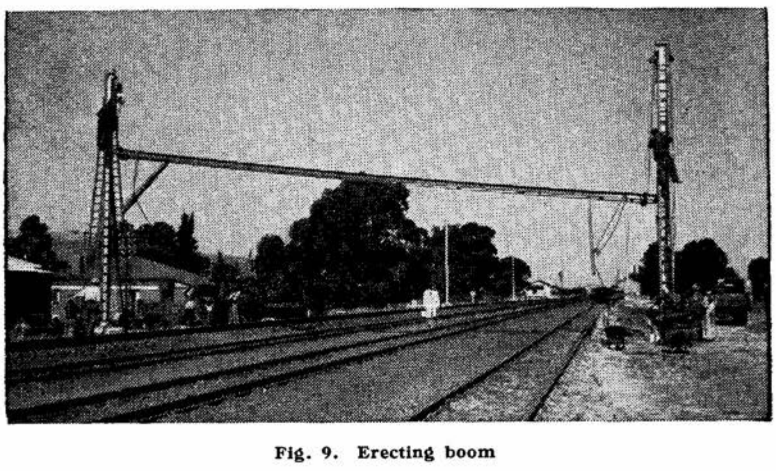

**Fig. 9. Erecting boom**

each insulator having a wet flashover rating of 30 kV.

Loop-type droppers of hard-drawn copper wire are used throughout and are designed so that they are adjustable for length.

An innovation of some interest was the use of section insulators on main running lines, which resulted from the development of a new design capable of permitting pantograph passes at high speed and fitted with arcing horns able to extinguish the arcs which are occasionally set up when pantographs pass from a healthy to a faulty circuit.

Some difficulty was experienced in constructing the insulator with sufficient mechanical strength to withstand the tension of the contact wire, but a solution was found in the use of fabric reinforced insulation.

In view of the high cost of conductors, consideration was given to the omission of the earth wire usually provided between all structures, the omission of this conductor being permissible only when all structures are individually bonded to the rails. There is, however, no appreciable saving in the omission of the earth wire, the cost of the additional mast-to-rail bonds approximating the cost of the earth wire, and in addition bonds require inspection and maintenance as they are liable to become damaged when work is done on the permanent way. An earth wire also has advantages in that it provides a shunt path for return currents in the event of damage to rail continuity bonds, and ensures that individual structures are not isolated in the event of the breaking of a mast-to-rail bond.

A steel-cored aluminium earth wire of 0·1-sq.in. copper equivalent was provided throughout, specially designed clamps being used at the point of attachment in order to prevent vibration fatigue. Rail-to-mast bonds were attached at intervals of 1 100 ft.

A 3-phase 11-kV transmission line was erected on extensions to the track equipment structures from Hugo substation to Touws River, a distance of four miles, to provide a supply to the steam locomotive depot and for the two townships of Touws River and Loganda previously supplied from an obsolete steam-driven plant at Touws River.

The bronze bolts and studs used for the fastenings on the overhead equipment were the source of considerable trouble. Non-ferrous material was initially employed in an attempt to eliminate corrosion problems. These bolts and studs, made locally, proved to be most unreliable, breakage occurring under normal loading and it was eventually necessary to replace them with steel bolts and studs throughout.

## 7. SUBSTATIONS

Each substation is equipped with two, six-anode, steel-tank mercury-arc rectifiers, with forced-air cooling, and fitted with vacuum pumping equipment. Each rectifier has a continuous full load rating of 3 000 kW (1 000 A) with overload capacities as follows :—

1 500 A for two hours
2 000 A for one hour
3 000 A for one minute
3 500 A for ten seconds.

All these overload capacities are available after continuous operation at full load, the ratings being calculated on a basis of 3 300 ft altitude and a 24-hour ambient temperature of 35°C with peaks of 40°C.

The anodes are provided with grids for arc suppression on reverse current and forward overload. The grids operate under normal conditions with a small positive bias in order to prevent the building up of a negative potential, blocking being applied under fault conditions.

Air-cooling for the rectifiers was adopted because of the simplification of the layout which results and to eliminate the problem of water-space corrosion which has been experienced in other areas.

Experience with 3 000-V air-cooled rectifiers on traction duty in this country has shown that very close temperature control is essential for trouble-free operation, the greatest instability being experienced at the lower temperatures. The rectifiers are, therefore, equipped with external and internal heaters.

External heating is provided by means of a wire-wound heater of 12·5 kW mounted in the air duct and the internal heater consists of steel strip bent into a non-inductive resistance of two turns, carried on porcelain insulators from the anode plate, Fig. 10. The internal heater is supplied with 550 amp at 6·5 volts, from an insulating transformer carried on the top of the rectifier.

The main cooling fan is driven by a 15-h.p. motor and runs continuously, the amount of air passing over the finned rectifier tank being thermostatically controlled and regulated by means of movable shutters over the air intake. Exhaust fans are fitted in the ceiling above the rectifiers, and are started up automatically under high-temperature conditions.

Each rectifier, complete with fan and air ducts is assembled as a unit on a steel frame, to which small wheels may be attached for handling. Lifting beams are provided at the door of the substations and the complete rectifier unit is readily transportable by rail or road, the total weight being 5 000 lb.

A 1·78-millihenry reactor is in circuit between each rectifier and the busbars, and consists of four aluminium rods of 0·587-inch diameter in parallel, wound into a helix of 32 turns of 5 foot 4 inches in diameter.

The turns are separated in air by means of hardboard spacers and mounted in a hardboard frame, and clamped together by steel tie bars. These reactors were locally made.

Resonant shunts are provided across the continuous current side of each rectifier and tuned to by-pass the 6th, 12th, 18th and 24th harmonic, the coils being wound of copper wire suitably stranded and arranged in two sections to permit accurate tuning. The condensers are of the paper-insulated oil-immersed type, enclosed in steel containers, a discharge resistance being permanently coupled across the filters, the whole being

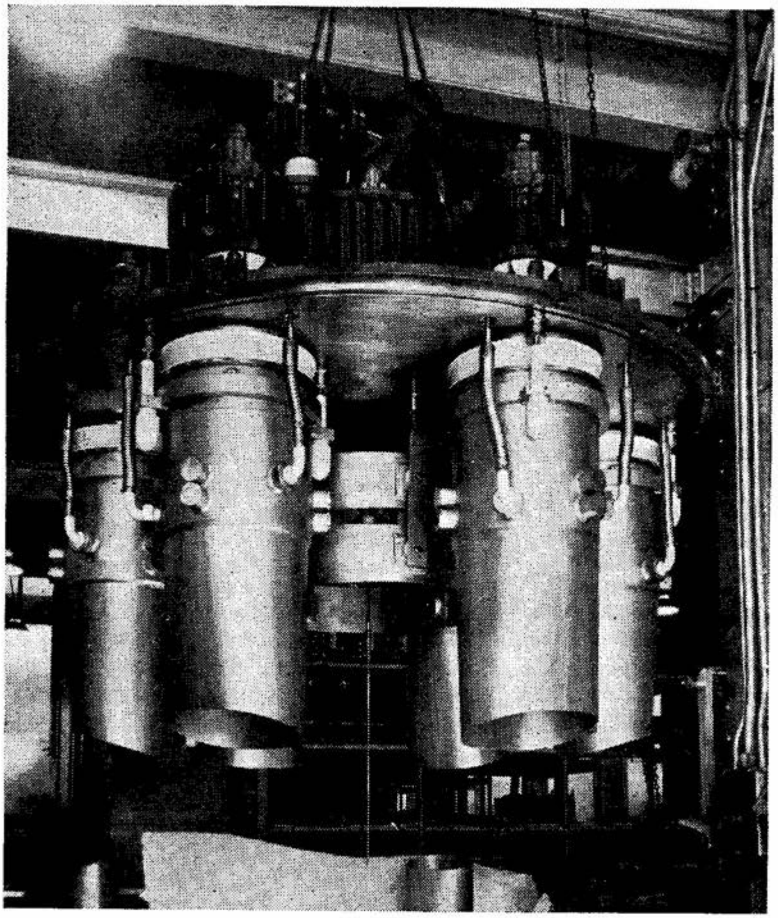

**Fig. 10. Rectifier anode plate**

protected by fuses and installed in separate brick cubicles.

The rectifiers are not arranged for voltage control in forward operation nor arranged for inverted operation, experience having indicated that voltage control is neither necessary nor desirable and a comprehensive study of the section loading has shown that the provision of inversion plant is not economically justified, in that the value of the energy passed back to the transmission system would not pay the capital and other costs of the equipment involved.

The provision of liberal conductivity in the track equipment in addition to providing good voltage conditions at the locomotive, also serves under normal traffic conditions to ensure the almost complete absorption of regenerated energy by direct interchange between trains on the section.

To prevent any undue rise of voltage on the contact wire during regeneration, resistance loading equipment is installed in a number of substations. The loading resistances are of three ratings, 900 A, 500 A and 400 A, and placed in accordance with local conditions.

During regeneration there is a rise of voltage in the contact wire at the locomotive, this rise being determined by the current drawn by other trains motoring on the section and their position, and in the event of this voltage being reflected at the substation to a value in excess of 90 V over the rectifier no-load voltage, the loading resistances are connected across the line by means of thyratron-controlled ignitrons, the delay between the excess voltage rise and the firing of the first ignitron being only one millisecond, other ignitrons being fired in succession at 5-millisecond intervals, the

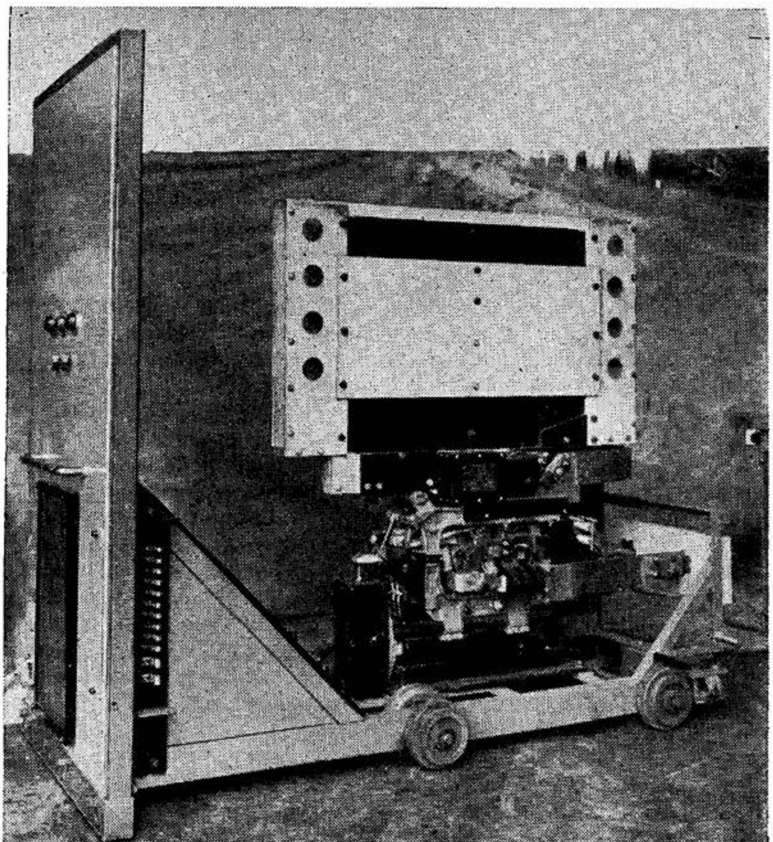

**Fig. 11. Truck -type circuit-breaker**

ignitrons being subsequently short-circuited by relay operated contactors, these having a delayed drop-out of 2 to 3 seconds in order to prevent chattering due to rapid voltage fluctuations which may arise from various operations of the locomotive controllers.

The loading resistances are mounted outside the substation buildings, in steel waterproofed shelters and are self-ventilated.

High-speed circuit-breakers are provided for the protection of all circuits on the overhead equipment, and a bi-directional circuit-breaker is connected between the cathode of each rectifier and the d.c. busbars, to protect the rectifier against d.c. back feed under fault conditions.

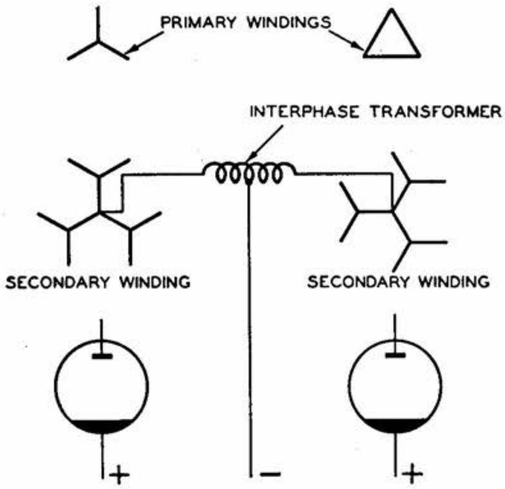


**Fig. 12. Main transformer connection**

The rate of rise of current reduces the tripping value of the circuit-breakers, and the control circuit is arranged to permit three automatic reclosures at time intervals of 5 seconds before lock-out takes place.

The circuit-breakers are mounted on S.A.R. standard type draw-out trucks and housed in pre-cast concrete cubicles, all circuit-breakers on the system being interchangeable. Fig. 11.

The two main transformers at each substation have a voltage ratio of 66 kV/2 350-V anode to neutral, except at Eersterivier, where the incoming voltage is 33 kV. On the primary side one of the transformers is star-connected, the other delta-connected, each substation thus operating as a 12-phase rectifying unit.

The secondary windings are 6-phase fork-connected, the neutral points being brought out for connection to an interphase transformer as shown in Fig. 12.

The rectifier transformers have a reactance of approximately 6 per cent and off-load tappings of plus or minus $2\frac{1}{2}$ per cent and 5 per cent are provided.

Bushing type transformers, Buchholz relays and temperature alarms are fitted, and the windings are specially designed to withstand the very severe mechanical stresses set up under short circuit and back-fire conditions. The coil stack clamps are spring-loaded and fitted with oil dash-pot dampers.

A.C. and d.c. earth-leakage protection has been provided throughout, and in addition the d.c. protection system includes a 50-cycle per second detector relay, arranged to shut down any rectifier passing 50-cycle per second impulses to the line, as it has been established that such impulses can be sent out if faulty grid circuits give rise to erratic anode firing, and under certain circumstances may cause interference with signals track circuits operating at 50-cycles per second.

The d.c. negative is not earthed, in fact precautions have been taken to ensure that the substation negative is substantially insulated from earth and earthed conductors.

The conventional substation d.c. earth bar is replaced by a lightly insulated 'common return bar' which is connected to the negative and rail but not to the earthing system.

All steelwork associated with d.c. equipment is connected to the common return and all steelwork associated with the a.c. system, as well as the a.c. transmission earth wire and lightning arrester ground wires is connected to a conventional earth system, the d.c. common return and the a.c. earth system being quite separate, and operating with a difference of potential between them. This arrangement has been adopted as a result of experience gained in the Transvaal and is designed to prevent the flow of traction currents in earthed conductors such as a.c. earth wires, water mains and cables.

The substations are fully automatic and operate unattended, starting up or closing down of equipment being initiated by remote control from the nearest signal cabin, at which point indication is provided to show rectifiers on or off load, circuit-breaker position and lock-out. The signalman on duty at the cabin acts only on instructions from the central control office, communication being effected by selector telephone.

8. ACKNOWLEDGMENT

The author wishes to acknowledge with thanks the permission of the South African Railways to the publication of this paper.

## DISCUSSION

G. A. Dalton (Past President): It is becoming quite a habit for Mr Williams to give of his time and leisure and come here to regale us with the results of enterprises and engineering accomplishments of the department over which he presides. In this we are indeed fortunate.

In the historical prelude to his paper he made mention that the Cape Western Main Line passes through a valley of intense cultivation, the progenitor of which was that great lover of the grape, van der Stel, and, in more recent times, spectacular industrial development. With such growth the single line traversing this valley showed signs of approaching saturation, resulting in the establishment of a Committee during 1943 to find means for effecting improvements. Detailed surveys were made over protracted periods, and proposals viewed, discussed, and investigated from every conceivable angle, but eventually it was decided to electrify. The question may be asked as to why electrification was not accepted in the first instance ? It seems to be a generally accepted fact that electric traction replaces steam traction once the latter form has reached the ultimate in capacity. The Natal Main Line is an instance of this. The costs of investigation, surveys, etc., must have been appreciable, but the main point is that the system of working now introduced would have become a higher revenue earning proposition at an earlier date. On the face of things it can be assumed that the electric locomotive only triumphed over its old steam counterpart after a very severe and trying struggle. However, the first reading is over, the steam engine, like its brother in the United States, has retired into obscurity, and the electric locomotive is hauling its loads to Touws Rivier.

The author has concisely, yet clearly, brought out the preponderance in every particular, except availability, of the electric locomotive in his review of 'Trains operation,' not only for inland bound traffic, but also for that coastwise. The reduction in train running times is revealing. With regard to 'availability,' it is appreciated that the steam engine is in depot for requirements for much of its time, but it would be interesting to have the relative times these divergent types of locomotives are available for traffic. Whilst the author has not, quite naturally, touched on the economics of the undertaking to any extent, yet it is possible to discern from his observations on 'Trains operation,' to mention one facet only, that a very appreciable reduction in the number of train crews will be possible when the whole scheme has settled down, with all that this entails in terms of housing, allowances, etc.

The author makes mention of the review of the power position in the Cape area consequent on the decision to electrify the section of line to Touws Rivier, and the decision of the Electricity Supply Commission to construct a power station at Worcester to meet this contingency, but is it not a fact that the Commission's original intention was to furnish a tail ended supply from an enlarged Salt River Power Station, at a tariff which was not altogether attractive, and incidentally involving the additional mileage for hauling of coal ? Was it not the Railway Administration's declared intention to build its own power station at Touws Rivier that proved the deterrent, hence the Hex Power Station at Worcester ?

It is noted that the all-in cost of the scheme under review, exclusive of locomotives, amounted to £2 700 000, and when one considers the very wide field of application which this money represents, it reflects great credit on the engineering and organizing abilities of those responsible for bringing the undertaking to fruition. The mileage figures are given as 175 route miles, with the single track equivalent of 248 miles, but in order to reduce the abovementioned costs to a cost per mile basis, some confusion is likely to arise as it is difficult to reconcile the figure of 175 route miles from Bellville with the distance quoted from Cape Town of 149 miles. Would it be that the Stellenbosch Loop is included as an integral part of the route mileage ?

In a paper of this nature the locomotive most always provides the central feature or theme, and usually takes pride of place over substations and overhead equipment of track, both of which require a great deal of thought, planning and engineering. To meet this popular appeal the author has devoted more space to the locomotive and the highlights of its design. It is most pleasing to note, and must be a source of great gratification to those responsible for the preparation of the specification, that the finished locomotive possesses, in the words of the author, 'good riding qualities at all speeds,' and that 'very little trouble has been experienced with the electrical equipment.' Innovations such as the partial elimination of cable in the high-voltage compartment; hermetically sealing of the silver-tipped interlocks; the protection afforded the power circuits using overcurrent and overvoltage relays, and the means adopted for obviating 'bad shots' when effecting transition from motoring to regeneration, are of very great import and interest. It is also of interest to note that adequate protection against the vagaries of lightning has been legislated for, and it might be asked by some whether the Cape is subject to such visitations. Certainly, thereabouts, lightning is a rarity, but freak storms do eventuate, and it is on record that in one of these damage was caused to the Muizenberg Traction Substation.

The only instance of trouble on the electrical equipment recorded by the author concerns the main motor brushes, split brushes being used in a conventional type of brush box, apparently resulting in poor commutation and short brush life. It is interesting to know that following some experimentation with brush types and pressures satisfactory mileage and commutation has been achieved. Can the author state if it is possible to discern at this early stage in the life of the locomotives, whether any ulterior effect is noticeable on the commutator as a result of using the split brush ? With the inordinate wear which must surely arise on six faces, due to chafing, instead of the four faces of the solid brush, and the resultant play in the box, would there not be a greater tendency — using split brushes — for the brushes to follow the rotation of the armature, and the tip of the second brush in the line of rotation becoming jammed between the box and the commutator, resulting in chipping and scoring of the commutator ? This tendency, perhaps, would only show up after some considerable mileage, but the author's views would be welcomed.

There is just another query before leaving the locomotive. Has there been any radical departure from the design of pantograph as used on other classes of electric locomotives, and if so, in what respect ? What practice is pursued in pantograph pan lubrication, and does this fulfil a dual purpose in prolonging the life of the collector strips, and minimizing wear on the contact wire ?

In his survey of the overhead equipment of track the author, whilst providing in broad outline a mental picture of this fundamental link between the substations and the locomotive, has been unduly modest. The greatest departure from comparatively recent practice has been in this particular sphere of activity, not so much in so far as fittings, fastenings, and insulation are concerned, these being substantially standardized, but in general layout, methods of tackling the work, and particularly respecting steelwork and steelwork design. The original pattern set by the consulting engineers for the first electrification undertaking, viz. from Pietermaritzburg to Glencoe Junction in Natal, consisted of solid foundations with steelwork designed to meet every contingency and with lasting qualities, all in keeping with a first class job. This pattern was not always lived up to in subsequent ventures carried out departmentally, recourse being had to second-hand rails and boiler tubes, with foundations composed of pre-cast concrete sleepers. With a return to solid engineering design and construction, the author could quite readily have 'gilded the lily' without reproach. The method of pouring concrete for the foundations from the specially equipped train was not only ingenious but the acme of efficaciousness, the speed of pouring at each location being a revelation. With the very limited times available for track occupation methods had to be evolved for speed, not only for foundation work, but also for steelwork erection, and the means described by the author deserve the highest commendation. Such methods are an indication of how the costs of such a major undertaking were kept within the bounds of £2 700 000.

Another departure, brought about this time by the price of copper, is the increasing use of aluminium for augmenting cross section, in terms of copper, and thereby providing the required margin between load currents and substation circuit-breaker settings.

Concomitant with the adoption of solid foundations and robust steelwork, spring tensioning of the overhead equipment has again been resorted to, which is all to the good, and a symbol of faith in structural design.

Some ingenuity has been displayed in the design of special clamps to accommodate the aluminium feeder on the same set of insulation as the copper catenary. It is noted that special clamps parallel this feeder with the catenary at intervals of 1 100 feet. A description of this clamp would be appreciated, detailing the means to overcome electrolytic corrosion.

Traction engineers will be especially interested in the novel design of the section insulator permitting the passage of the pantograph from a healthy section to a faulty without bringing the overhead equipment down. This is probably unique and either a more detailed description, or an illustration, would be especially welcomed.

As an Institute we are fortunate in the number of papers presented in which the electrical engineers of the South African Railways have furnished us with the knowledge and experience they have gained in the installation, operation, and maintenance of mercury arc rectifiers which has long been their speciality, in preference to other forms of conversion, for providing direct current for trains working. With each presentation reference has been made to some new method of application, or some particular innovation to improve efficiency or widen the scope of their usage, and in this instance the author has not failed to maintain this interest. I am sure there are many present who will endorse my statement that the electrical engineers of the S.A. Railways have reached a state of proficiency in mercury arc rectifier technique which places them in the forefront as authorities on the subject. The author in his modesty would not readily claim this distinction, but on being pressed he could tell quite a story of the enquiries which reach him from many parts of the world.

One aspect of the rectifiers which have been installed on this latest undertaking, and which must perforce command some attention, are the phenomenal overloads which they are capable of handling. Where inordinate demands are at times made on substations due to bunching of trains following an accident, such as a derailment, this capacity to meet such peaks must have a very marked economic value on the planning, operation, and maintenance of such a large undertaking.

To eliminate the troubles experienced with water-space corrosion and at the same time achieve simplification of layout to facilitate handling, whilst maintaining the outputs to which reference has just been made, air-cooled rectifiers were decided on, and the wisdom of this is instanced in the author's reference to the complete assembly of these rectifiers on the unit basis, each unit weighing 5 000 lb, making them extremely mobile, and easily transportable. From the maintenance angle, and to preserve continuity of supply, this is a radical departure of considerable importance.

The author makes mention of the fact that experience has shown that air-cooled rectifiers are temperamental, particularly when the frost is on the ground, and that to cajole them back to trouble-free operation, internal, as well as external heating has to be resorted to, and then very close temperature control is essential. It would be interesting to know whether this control is any closer than that applicable to water cooled rectifiers under similar conditions. The methods adopted for the application of internal heat are distinctly novel, a system no doubt proprietary, and associated with the rectifier manufacturers.

The author's reference to the disposal of excess energy resulting from regenerative braking of trains is replete with interest. In Natal the integration of inverted energy has definitely proved of considerable economic and monetary value, and this is the first instance on the S.A. Railways where regenerative braking is definitely essential, and it has been shown that dissipation of the resulting energy through resistances is economically justifiable. The use of ignitrons to secure automatic operation of this feature, read in conjunction with the ancillary equipment to make it feasible, are points of design worthy of note.

It has been pointed out in the paper that from experience, regulation on a traction undertaking is not of such vital importance, which obviously permits of transformers having a comparatively high reactance, and, as such, better able to cope with back-fire conditions.

With regard to the incorporation of a 50-cycle per second detector relay in the d.c. protection system for isolating a rectifier passing 50-cycle per second impulses to the line, will the author quell inquisitiveness by telling us why the signals track circuits cannot be operated on a frequency other than standard, keeping the question of safety, for signalling, in mind ? Is it not possible for stray currents at 50 cycles per second from systems adjacent to the railways affecting such circuits ?

Finally, it is interesting to note that the author, in his coverage of the substation section of his paper, has taken the precaution of vouchsafing to himself and his engineers, mental peace, and some relaxation in leisure hours, by successfully applying the knowledge and technique so hardly won on the Witwatersrand, and so ensuring to themselves the absence of complaints about stray traction currents attacking Paarl Rock, or the effect of such currents contaminating Mr Williams' favourite Nederburg, not to say very strange happenings in the trout hatchery at Stellenbosch.

In conclusion Mr Williams has made another valuable contribution to the Institute's literature for which the membership is grateful. It has served to whet the appetite, and we can look forward to one or more of his engineers giving us, at no distant date, further details of the scheme, as well as the economic and other results of operating this interesting venture.

THE CHAIRMAN : We have listened to a very interesting paper, and in some of its aspects there were items hinted at but not really developed. It occurred to me that there are problems associated with public transport that most of us take for granted.

I was rather intrigued with the remark about the material saving in the shift times of running staffs. I was wondering how these shifts were arranged and exactly how you paid for such shifts.

You also referred to the £2·7 millions and the fact that it appeared that that was somewhat in excess of the original estimates. I wondered if steam or perhaps some of the other routes would have been re-considered if you knew that there was going to be that final cost of £2·7 millions ? Against that, of course, your answer may be that the deciding factor was the development in the country alongside your existing routes.

There is another little curiosity which I do not think the members heard or had the advantage of seeing in the paper. The wheel arrangements are put down as $1 - C_0 + C_0 - 1$ ; it sounds like some type of cocktail formula. It is something new to me and probably to quite a few of us, and I wonder if you will explain it ? It might be something peculiar to electrical traction.

I had another point to mention, but I think Mr Dalton has covered most of it, that was the question of these laterally split brushes. To me, the paper is not entirely clear when the author referred to the alteration to the brushes, the pressures and the grades, and he doesn't make it really clear whether he continued with the laterally split brush.

G. WILLIAMS (*in reply*) : Mr Dalton mentioned the availability of the electric units, and I think most of us know that steam locomotives must return to depot at least once daily, they are double shifted these days, but must be returned to depot for fire cleaning, fuelling, watering, oiling, etc.

The new electric units are at the moment working for three weeks, available 24 hours per day, with four hours in the sheds thereafter, when they are returned for duty for a further three weeks. They are otherwise unattended except for minor attention at the terminals, and the provision of sand.

As a result of the improvements in designs to give long periods of availability, particularly air filtering and the enclosure of relays and interlocks, we hope to be able to extend this service period to one month on the road and four hours in the shed. We are actually getting three weeks at present.

The route mileage referred to by Mr Dalton includes the Stellenbosch Loop, which is an auxiliary main line from Bellville via Eerste Rivier to Muldersvlei.

Standard lightning protection was adopted because a number of these locomotives are working in Natal and may continue to do so for a period and we aimed at flexibility so that these locomotives may be used on any system. As referred to in the paper there will be some re-distribution of motive power later.

As regards the split brushes in the main motors, I am sorry that I was not clear enough. The designers were emphatic that we would not get good commutation with a solid brush and, whilst we had a preference for solid brushes, we persevered with brush types and pressures, and I am glad to say that the commutation is now good with no sparking and we are getting 60 000 miles per set of brushes and we hope to improve on that.

The pantographs are very different from earlier designs. It is necessary to ensure even pressure on both pans under all circumstances and the pan springing has to be somewhat complicated in order to avoid pantograph pan flutter.

The problem of pantograph lubrication is one of interest, but one of operation rather than one within the scope of this paper. The line was opened using a solidified graphite paste on the pans and no oil or grease. What happened is what from previous experience I expected to happen. The results were excellent in the dry season but when the rains set in we experienced poor performance, bad sparking, rough wire and the other usual pantograph troubles and had to revert to grease lubrication.

The double suspension clamp supporting the aluminium feeder and the copper catenary is simple, it is of malleable iron heavily galvanized, and a mild steel slip is inserted underneath the aluminium conductor in its cradle. The same type of clamp has been up on the Welverdiend section since its opening, a long time, and there is no sign of electrolytic action anywhere. We are satisfied that even where steam traction operates, it is a satisfactory arrangement.

Referring to the temperature control of the air-cooled rectifiers, Mr Dalton asked whether or not they were more temperamental than water-cooled rectifiers. They are, very much so, a water-cooled rectifier has a heat soak capacity which takes care of rapid fluctuations in air temperature. Using air-cooled rectifiers, when the air suddenly cools after a hail storm on a very hot day for instance, unequal cooling takes place due to the blast of ice-cold air at the bottom of the rectifier at a time when the rectifier in general is hot, and it is not only the ultimate temperature but the temperature gradient that interferes with the stability, in other words, if you have hot anodes and a cool cathode or *vice versa*, the rectifier becomes unstable and flash-backs result.

The temperature control is critical and requires the use of a large number of thermostats, but they give very little trouble and we are satisfied that the advantages outweigh the disadvantages, particularly the advantage mentioned by Mr Dalton that an air-cooled rectifier can be made as a unit which can be readily changed and transported by lorry.

Mr Dalton referred to the use of 50 cycles per second for signalling; there are good reasons why 50 cycles per second should not be used for signalling but it is a question of economics, the use of any other frequency entails the use of frequency converters and it becomes very expensive.

Mr Kane mentioned the question of train crew payments, one of the economies to be expected is in the reduction of shift periods which under steam traction were extremely long, and in addition there were out-of-depot expenses, rest room facilities and so on, whereas electric working provides for normal shift periods and permits a system of change-over working whereby the north-bound crews change-over trains with south-bound crews at some point on the run and both crews spend each rest period at the home depot. This is the system worked in Natal.

# Committee's reply to discussion on

# Code of practice for earth-leakage protection on mines for a.c. circuits up to 660 volts

*Transactions*, November 1953

The Committee wishes to thank all those people who spent their valuable time in preparing contributions to the discussion on the Code of Practice for earth-leakage protection on Mines for a.c. circuits up to 660 volts.

All contributors appear to have overlooked the fact that the Code was designed for the help and guidance of people on the mines, many of whom have had no previous experience of the operation of earth-leakage protection. The Code was also intended to explain the purpose of introducing earth-leakage protection to that section of the mining community which can be classified laymen so far as electrical engineering is concerned.

The Committee also had to bear in mind that the Code should cater for the application of earth-leakage protection to old mines in which the electrical reticulation already exists, as well as to new installations. For these reasons the Code was kept as simple as possible and no rigid course of action was laid down. It was felt that giving the advantages and disadvantages of the two principal methods of installing earth-leakage protection would be of more use and would be more likely to lead to the adoption by all mines of some type of earth-leakage protection. If the practical application of this type of protection shows that one particular method has outstanding advantages the Code can then be revised to give details of this method.

Several contributors criticise the use of the word ' earth ' in the Code. The frequent use of this word by these contributors emphasises its value. It is a term with a distinctive meaning to electrical engineers, referring to a conductor which is maintained at a basic electrical potential common to all unenergized conductors or bodies. The recommended method of obtaining an earth-return path is described in Section 9 of the Code.

The notion that ' there is no such thing as a good or effective earth underground ' is distinctly dangerous. For instance, if Mr Allan's ' extended neutral ' were at a voltage considerably above ' earth ' it could constitute a danger to persons standing on a wet foot wall near it. What the Committee wants to emphasise is that the rock underground cannot be relied on to be either an insulator or a conductor and for this reason a reliable metallic earth-return circuit must be established. This circuit should always be as near as possible to ' earth ' potential.

### *In reply to Mr Lackey*

The Committee would point out that bonding of cable sheaths and glands, and cross bonding at metalwork of electrical equipment is sufficiently stressed in Section 9 of the Code which deals with bonding and earthing for both current- and voltage-operated systems.

The Code states it is not practicable to cater for fault currents of less than 10 amperes or 10 per cent as experience underground has proved that hardly any visible damage is caused by a fault when cleared at lower current values. This makes fault location a difficult and lengthy procedure. It is, therefore, felt that, if a more sensitive system is required, a voltage-operated system should be selected. Mr Lackey advocates the use of continuously rated coils for voltage-operated systems but the Committee feels that no useful purpose would be served by safeguarding the operating coil of the relay if a fault on the system is not cleared.

The Code merely points out that the danger of gas or flammable material being ignited by fault currents will be *less* when using voltage-operated systems but it does not exclude the possibility of such ignition taking place.

It has been found that leakage currents in a damp motor could cause a complete failure of the winding. It is, therefore, an advantage to protect against such a contingency by adopting a voltage-operated system.

Mr Lackey further states that a severe distortion of the phase-to-earth voltage will result in overstressing of the insulation which might cause a more serious breakdown. From the practical aspect, however, the difference in insulation stress caused by a phase-to-phase or phase-to-neutral voltage is negligible, within the voltage limits applicable to this Code.

*In reply to Mr Allan*

The Committee would like to draw attention to the fact that in his Fig. E the current flowing in $Z_F$ (which may be the body of a victim) is that flowing in $Z_N$ plus the resultant current in the three capacities (or impedances) $C_{AS}$, $C_{BS}$ and $C_{CS}$. A person may be killed on an isolated-neutral system for which $Z_N$ is infinity.

Of the four types of fault discussed by Mr Allan the second and fourth fall outside the scope of the Code. A fault on two phases which also goes to earth does not differ materially from a single earth fault so far as earth-leakage protection is concerned except in the very important case of the faults to earth occurring at two points some distance apart on the same system. In the latter case the earth-return circuit between the two faults will be called upon to carry heavy phase fault current in addition to any neutral current. A low earth-return circuit impedance is therefore important if dangerous voltages are to be avoided under double earth-fault conditions.

The size of current transformer that should be used in a three-phase circuit depends on the load and on the short-circuit current rating of the circuit. On the low-voltage circuits considered in the Code the range of earth-fault currents encountered is nothing like that suggested in Mr Allan's Table B. A total supply plus fault plus earth-return impedance of only 0·1 ohms would limit the earth-fault current to about 3 000 amps. If a low-ratio current transformer is used in the transformer neutral its own impedance would be by no means negligible.

The Committee does not agree that Fig. 6 of the Code is a current-operated system. It differs from Figs. 7 and 8 only in the way in which the zero-sequence voltage is measured. Mr Allan is correct in saying that there is no difference between Figs. 7 and 8 in the Code. The iron circuit of Fig. 8 which would make it distinctive has inadvertently been omitted.

In connection with Mr Allan's deductions regarding his Figs. F and G, if the fault on one phase in (*a*) was through a person's body it would be most unhealthy. The large voltage difference under (*c*) will be across the fault, and not in the fault area. The voltage difference between $N$ and $S$ under (*d*) depends on the value of the impedance and on the value on the transformer impedances. It is not correct to say that the voltage across the relay and across the victim are unrelated.

In reviewing the Code Mr Allan states that with one exception the schemes proposed in the Code, which he calls expensive, are designed to protect apparatus and not personnel. In this he completely misses the point that the most effective way, and on most systems the only way of protecting personnel against the dangers of earth faults is to protect the system against earth faults or against earth faults being sustained. The means for this proposed in the Code are not expensive when the benefits derived are counted. It is always difficult to measure the value of protection in hard cash. Mr Martin's paper, read before this Institute in 1950, emphasises how many lives could have been saved by correct protection of apparatus.

The Committee wants to draw attention to the fact that the 'economical' schemes shown in Mr Allan's Figs. I(*a*) and I(*b*) are *not* earth -leakage protection schemes but are for monitoring the earth return continuity. An earth fault with scheme I(*a*) and possibly also with I(*b*) will prevent the starter from tripping by keeping the holding coil energized.

A code should never be considered as final but should be revised from time to time as new materials, methods and equipment become available and as experience dictates. The present Code has been well received in the sphere for which it was drawn up and the

Committee feels is should stand as it is until experience with it indicates that a revision is necessary.

*In reply to Mr Jobling*

In connection with Mr Jobling's discussion, the lack of suitable earth-leakage protection on many mines and the lack of knowledge of the methods and characteristics of earth-leakage protection were among the main reasons for drawing up the Code. The Committee had no wish to condemn one successful method in favour of any other equipment; operating conditions and methods are so diversified that latitude for choosing the scheme best suited to the need had to be allowed.

# Discussion on

# Electrical services in modern civil aircraft

By J. A. BOSCH (Associate Member)

*Transactions*, May 1954

V. A. HIGGS (*contributed*): In his paper Mr Bosch has undertaken to cover a very wide field of specialized electro-technology, and because this subject is so vast the paper can only deal briefly with the various problems involved. Mr Bosch is to be congratulated on his industry and research into this subject, but has made several positive statements on matters which are very controversial and by no means as simple as he seems to think.

Firstly, in his introduction he stated that 'due to the lack of reliability of the old-type magneto a change was made to ignition coil and battery.' So far as I know there has never been any aircraft fitted with coil ignition, certainly no British aircraft; coil ignition was introduced on automobiles not because of any difficulty with magnetos but because the coil is considerably cheaper than a magneto. There are ample statistics available on the servicing of automobile equipment to indicate that the coil ignition system is not 100 per cent reliable, and certainly quite unacceptable for aircraft application.

The d.c. power system, shown in Fig. 6, is a typical American system not unlike the system used in British aircraft, but the description of the system operation is not made very clear. Any power system involving the use of d.c. generators in parallel with batteries must include a battery cut-out relay to prevent the batteries discharging through the generators. The cut-out used in Fig. 6 is a differential relay connected across the main contactor, and this is polarized so as to measure the difference between the generator volts and the busbar volts. The relay operates so that it will connect the generator to the line only when the generator voltage is greater than the line voltage. This type of relay prevents cut-out chatter, which can occur if the conventional type of automobile battery cut-out is used. The differential relay therefore closes the main contactor when the generator is fitted to provide power to the line, and opens the main contactor when reverse current flows through the current coil. In this section mention is also made of automatic overvoltage protection, but so far no one has developed and manufactured a satisfactory automatic overvoltage protection device for use on 28-volt d.c. power systems. However, considerable development is in hand both in America and in Britain to develop overvoltage systems, and it is confidentially expected that a satisfactory system will be available shortly.

In paragraph 3.1 a comparison is made between the electrical systems in the *Brabazon* and the *Princess* aircraft, but the author fails to point out that in the *Brabazon* the total of 180 kVA is available only at the maximum engine speeds, and the total power available is reduced as engine speed is reduced, whereas in the case of the *Princess* the full power is available over the entire engine speed range. The two aircraft systems, however, are not readily comparable because the engines and their speed ranges are different. In general terms the alternator/rectifier combination should weigh less than the corresponding d.c. generator, but this fact alone does not necessarily mean that the complete power system will be lighter when using alternators and rectifiers. Neither of the disadvantages quoted in this section apply to an aircraft system in which the a.c. power is rectified to d.c. The main disadvantages of alternator/rectifier combinations are :—

*a* Alternators are not self-exciting, require large field currents compared with d.c. generators, and are difficult to control over wide speed ranges

*b* Rectifiers are bulky in volume, and require a large volume of cooling air and this means that there are considerable installational difficulties

*c* Rectifiers are very vulnerable against high temperature and in the case of military aircraft against shrapnel and machine-gun attack.

In Section 4 a very brief and rather inaccurate mention is made of a.c. power systems. There have been two British aircraft built using a.c. power systems, the *Shetland* and the *Seagull*. Both of these aircraft were flying boats and neither were produced in quantity. However, in both cases the a.c. power system was selected after very careful consideration was given to alternative systems, and in each case the a.c. system showed many advantages, including a saving in overall weight. The *Shetland* aircraft used two separate auxiliary generating plants and the *Seagull*, which was a single-engine aircraft, used one main engine-driven alternator.

In Section 6 Mr Bosch comments on the rotational speeds of a.c. motors, but ignores the fact that modern d.c. aircraft motors run at speeds from 8 000 to 12 000 r.p.m. The British standard speed for main engine starter motors is 10 000 r.p.m., and this is a very convenient speed for a 4-pole 400-cycle per second a.c. motor.

In Section 8 I gather the impression that Mr Bosch is in favour of the use of electrical power rather than hydraulic power, not only for the operation of propellers but for the operation of any power services. Since I represent one of the major suppliers of British aircraft electrical equipment I must commend Mr Bosch for this attitude of mind, but I would like to warn him against over-enthusiastic application of electrical power. Electrical motors provide their power best in the form of a rotating shaft and as he stated in his paper the rotational speeds must be high to keep down the weight. Many aircraft services require power in the form of a thrust in a straight line, and there is no doubt whatever that this is best achieved by a hydraulic or pneumatic ram. Unfortunately, hydraulic and pneumatic power is difficult to distribute about the aircraft, and the best compromise for such requirements is to transmit the power throughout the aircraft electrically and to convert that power to hydraulic or pneumatic power locally with motor-driven pumps or compressors.

Finally, the tabulation of the details of typical heavy-current relays is meaningless without more information concerning the exact duties of the relays listed.

# Discussion on

# The electrical uses of aluminium

By F. G. McDONALD (Member)

*Transactions*, February 1954

H. L. DAWE (Companion): Having read through Mr McDonald's interesting paper again, I would like to make a further contribution mainly from the insulated-cable aspect, where aluminium is not only being used for conductors but also for mechanical protection.

Although the use of aluminium for conductors of insulated cables had been thought of from time to time in the past, it was not seriously considered since there was no economic advantage to be gained, but interest was once again aroused when during and after the war the price of copper began steadily to increase.

From the technical point of view there is no advantage to be gained with aluminium conductors since their use involves an increase in cross-section with a resultant increase in cable dimensions and cable materials. With lead-sheathed and armoured cable the increase in material discounts to a large extent the saving gained by using aluminium for the conductors. However, the development of aluminium-sheathed cables in 1948 brought to the fore the use of all-aluminium cable, since in a large number of cases armouring can be dispensed with when aluminium is the sheathing material.

Apart from economic advantages the saving in weight of the all-aluminium cable—a saving of 66 per cent can be shown despite the increased size—has advantages where particular installations are concerned. One that comes immediately to mind is where cables are required to be installed vertically such as rising feeders in buildings, etc. Furthermore it has attractive features for industrial applications, particularly where cables are required to be installed along roof trusses or at some distance above floor level.

The jointing of such cables presents no problems since a satisfactory method for the making of wiped joints has been developed and invariably joint boxes and sleeves as used for lead-sheathed cables are employed.

For the jointing of the conductors a soft-soldering technique has been evolved which closely follows the practice established for copper joints and requires no special skill or elaborate apparatus for making the joint. The temperatures during jointing do not usually exceed those attained in copper joints, the pouring temperature of the metal being of the same order for the same sizes of conductor. This technique can also be applied to the jointing of aluminium to copper conductors. Here again no change in the normal construction of joints or terminations is entailed.

Referring now to the corrosion of aluminium when laid in the ground, I should like to be more specific than the author (Reference 2.3.3 of the paper) and state that in no circumstances should aluminium-sheathed cables be laid direct in the ground without protection. This also applies when cables are drawn into ducts.

The type of protection recommended should incorporate an impermeable layer and the company with which I am associated pioneered the use of p.v.c. tapes backed by glass fibre and hessian tapes to that end.

Atmospheric corrosion of aluminium-sheathed cables is negligible under normal conditions and in this respect they have an advantage over the stranded aluminium overhead line, since the serrated surface of the latter lends itself to the so-called 'crevice attack.' Precautions should, however, be taken to avoid contact of the bare sheath with walls and dissimilar metals in damp situations.

In conclusion, the use of aluminium not only for sheaths but for the conductors of insulated cables will no doubt find an increasing application in the future, particularly where advantage can be taken of their saving in weight.

There are no problems associated with their manufacture and experience to date suggests that the main problem of jointing has been overcome.

F. G. McDonald (*in reply*) : Mr Dawe's remarks have considerably strengthened that chapter of the paper which deals with underground cables, and the author agrees with each of the points he has made. On one point, the author would like to comment further.

Aluminium is not often considered for the conductor cores of insulated cables except when aluminium has already been decided on for the sheath. The reason, as stated by Mr Dawe, is that 'with lead-sheathed and armoured cable the increase in material discounts to a large extent the saving gained by using aluminium for the conductors.'

This is a general statement ; on heavy cables the saving made by leaving out copper can be very substantial, and is not much affected by the extra cost of paper and lead.

As an example, the author would mention a recent job in his own works in Pietermaritzburg. About 1 500 ft of heavy single-core cable was required to connect a new induction furnace, and the first estimates were based on the use of 0·3-sq.in. copper conductor, paper insulated and lead sheathed. The following table shows the comparative cost of alternative aluminium-cored cables.

| *Conductor* | *Current rating—amp* | *Price per cent* |
|---|---|---|
| 0·3-sq.in. copper ... | 592 | 100 |
| 0·4-sq.in. aluminium ... | 554 | 78 |
| 0·5-sq.in. aluminium ... | 633 | 88·5 |

In this particular instance, the only connections to be made were indoors, and heavy 4-bolt clamps were available at each terminal. There would seem to be no reason at all, except only force of habit, why copper should ever have been considered for this job.

The author suggests that force of habit is resulting at the present time in a lot of unnecessary expenditure by electrical engineers in this country.

For cables having conductors of 0·1 sq.in. and larger, the cost of copper cables is much higher than the cost of aluminium cables of equivalent current-carrying capacity, and except perhaps for low-voltage distributor cables, what jointing problems are introduced by aluminium are more imaginary than real.

The extent of the savings that are possible would soon be realized if enquiries for cables invited prices, as alternatives, for aluminium cables of equivalent rating. The savings are so important that it is absurd that they should be ignored, as they are at present being ignored, by users and manufacturers alike.

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