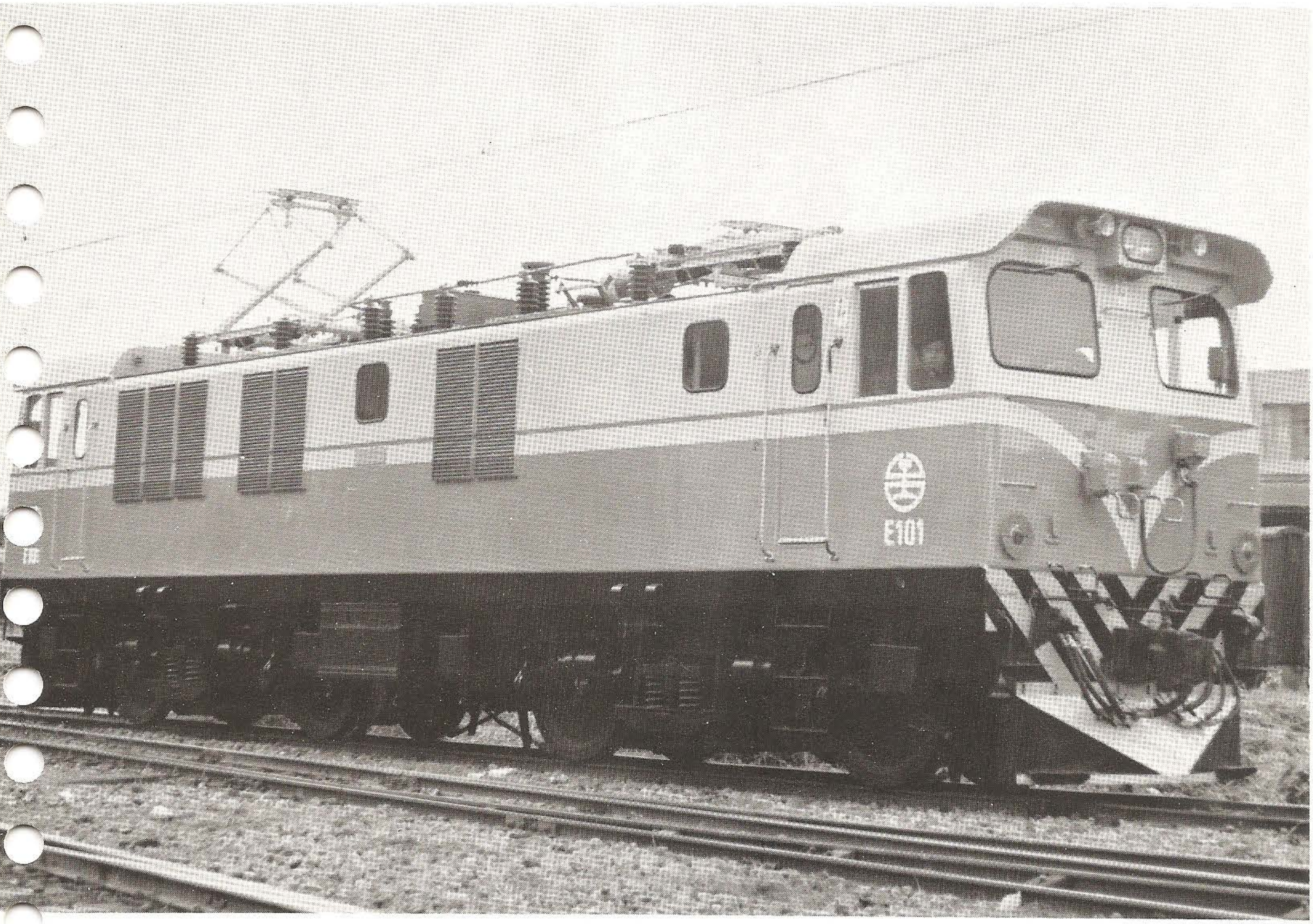


25kV 60Hz light weight thyristor locomotives for Taiwan

GEC Traction Limited

Thyristor locomotives for Taiwan

Supply begins of GEC Traction 2100 kW mixed-traffic locomotives for 25 kV 60 Hz electrification scheme

GEC Traction's order for twenty 25 kV 60 Hz locomotives for the Taiwan Railway Administration (TRA) is their second export order for a fleet of ac thyristor-controlled locomotives. When the ISCOR (Iron and Steel Corporation of South Africa) thyristor locomotives, on order from GEC, are commissioned in 1978 they will complete the spectrum of standard industrial frequencies and voltages, viz 25 kV at 50 and 60 Hz and 50 kV at 50 Hz.

The 25 kV Bo-Bo locomotives for Taiwan are part of an electrification scheme being co-ordinated by GEC Transportation Projects Ltd. GEC Traction are also supplying 13 luxury electric multiple-unit trains (also with thyristor control) as part of the programme. The electrification became necessary because of heavy and increasing traffic between the northern port of Kee-lung and the southern port of Kao-Hsiung. At the same time, track on the 400 km, 1067-mm gauge trunk line is being renewed and upgraded to take heavier axle loads, while new signalling is also being installed.

The new mixed traffic locomotives, rated at 2100 kW, are at present being delivered to Taiwan where they will be used for crew training purposes on a 20 km test track until the electrified service itself starts in 1978. Designed by GEC Traction in the UK, the locomotives are being built in South Africa by Union Carriage and Wagon Co, under the direction of GEC staff.

Locomotive utilisation

The locomotives will be used on both the coast and mountain lines. The coast line has only modest gradients (10‰ ruling) so single locomotives will haul trailing loads up to 1250 t, while pairs of locomotives will haul 2000 t (limited by existing drawgear). The limiting grade on the mountain line is 2.5% and here single locomotives will be hauling 525 t passenger trains. The temperature in which the trains operate ranges between zero and 40°C, with humidity often close to 100%. The altitude varies between 30 and 400 m, with some snow in the mountain section during the winter.

The locomotives represent a considerable technical achievement in that although designed for a buffing load of 2950 kN (300 t), the gross weight is within 72 t whilst meeting the axle-load tolerances. Thyristor control eliminates the need for the high-voltage tap-changer (and associated auto transformer) and this makes a large contribution to weight reduction, but there are many other detailed ways in which weight has been saved, such as the use of aluminium alloy in conduits, air reservoirs and the transformer tank.

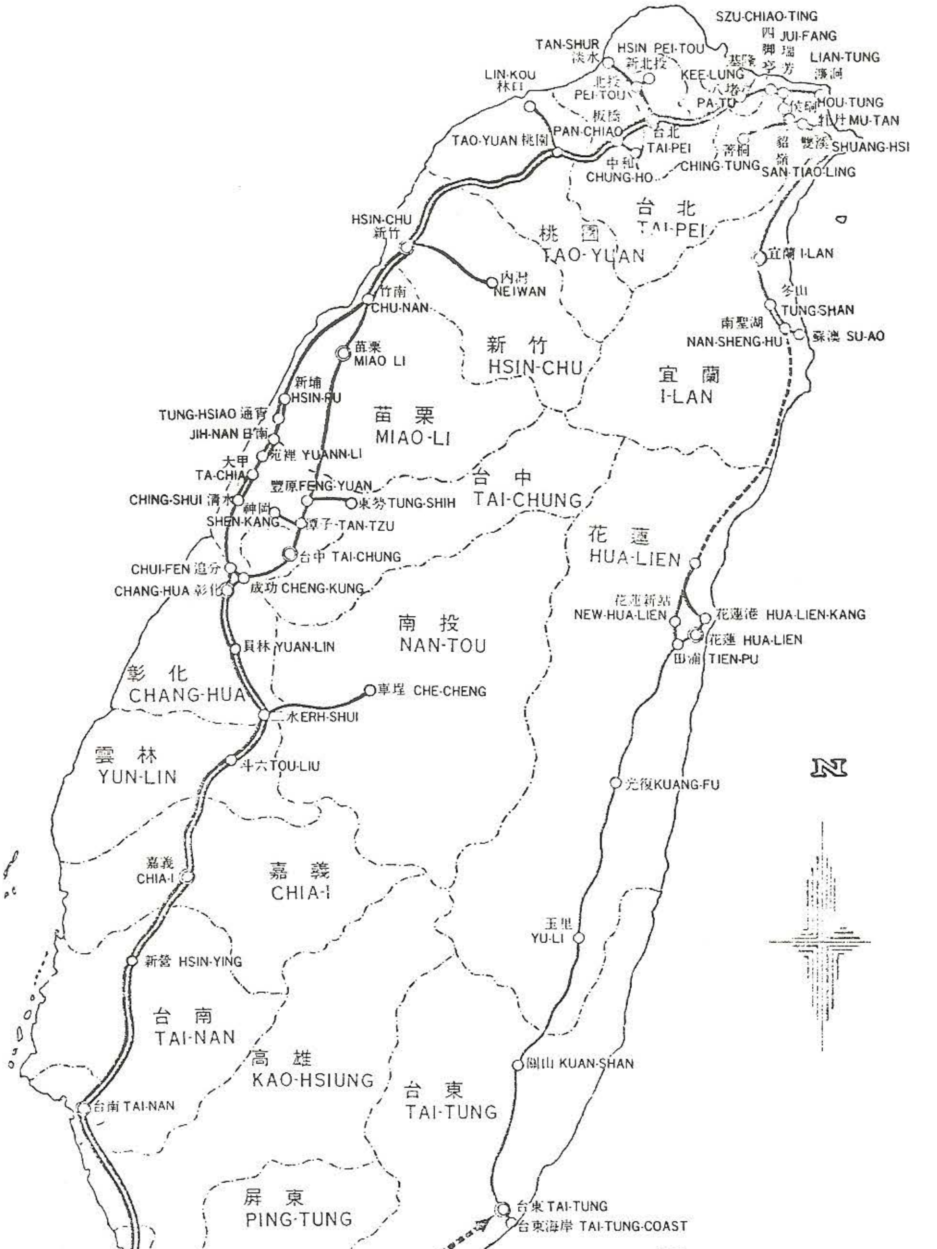
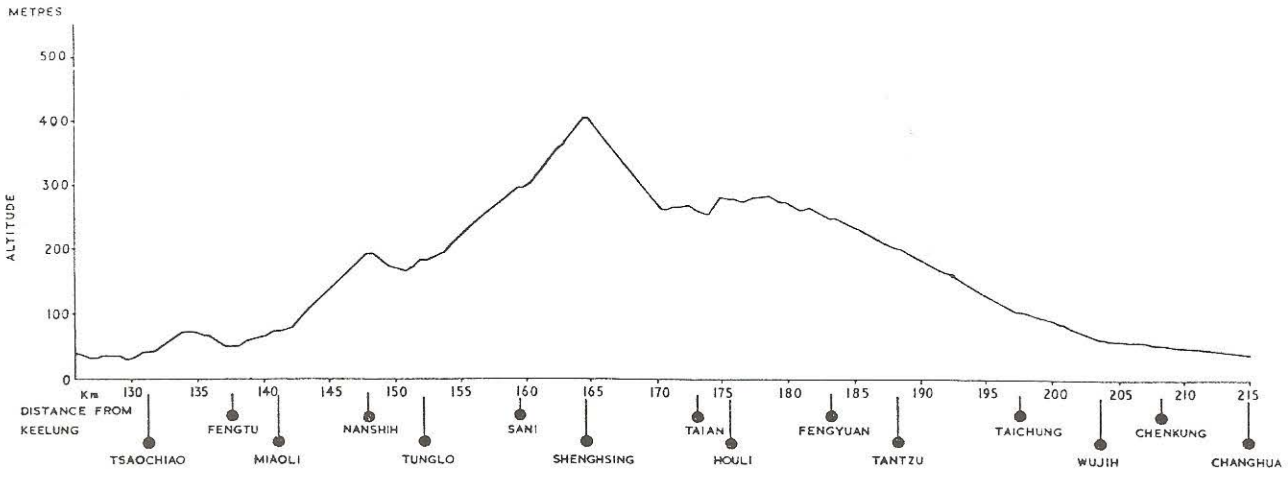


Fig 1. Existing railway lines in Taiwan and proposed extensions

Performance

The locomotive performance is shown in Fig 3 for nominal line voltage, together with computed tractive resistances for specimen trains. The

Derived from an article in Railway Engineer, January/February 1977



ROUTE PROFILE CHU NAN TO CHANG HUA VIA TAI CHUNG

maximum tractive effort, which is limited by the permitted maximum armature current, is available up to the 'base speed' of about 40 km/h. Above this speed further increases in speed are obtained by reducing the motor excitation. Any point below the performance curve can, of course, be chosen as an operating point up to the permitted maximum speed of 110 km/h.

During acceleration the locomotives can exert a tractive effort of 275 kN (equivalent to a nominal 39% adhesion). Separately excited traction motors help to make the maximum use of such high adhesion factors together with bogies designed to minimise weight transfer.

General arrangement

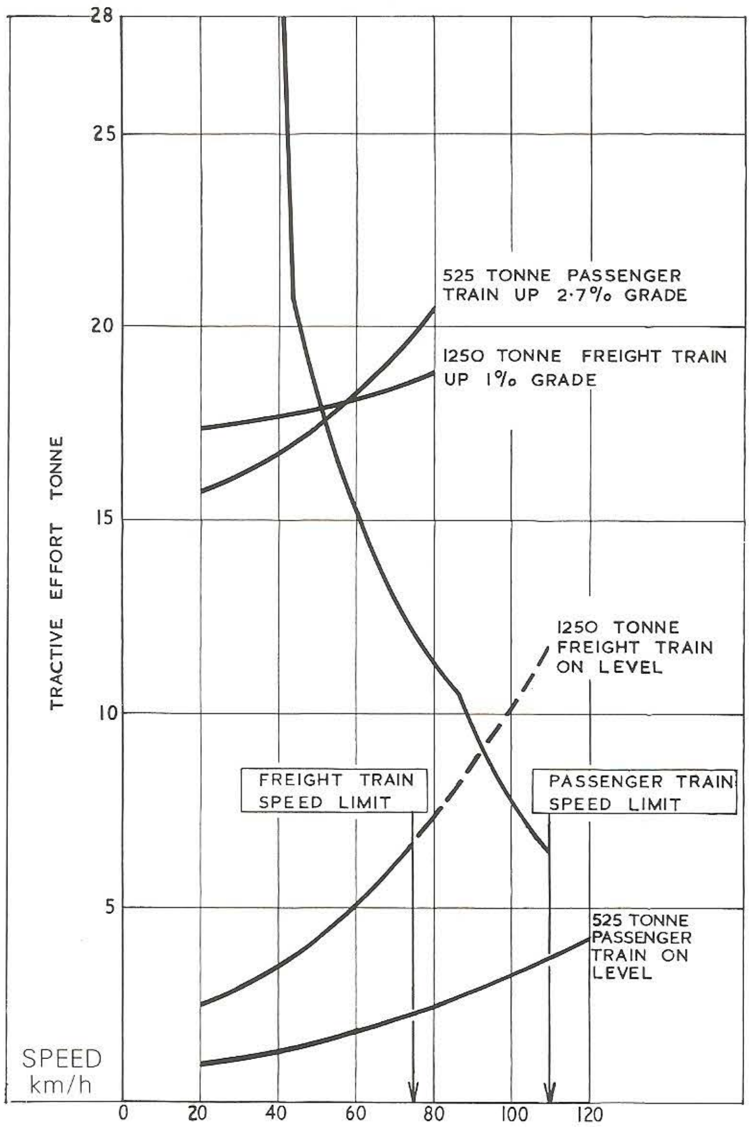
The transformer is located in the centre of the locomotive with the radiator between the transformer tank and the body side, while the two main rectifier frames are immediately adjacent. Cooling air is drawn from within the body of the locomotive, through the rectifiers and the transformer radiator, being expelled through the locomotive roof. The traction motor blowers and the compressors also draw their air from within the body, ensuring cleanliness and coolness within the body. The traction motor blowers and smoothing chokes are at diagonally opposite corners and each serves the motors on the adjacent bogie. Opposite these items are the high tension chambers. These can only be reached from doors in the cab and are mechanically and pneumatically interlocked so that unsafe access is impossible. A full-width cab at each end of the locomotive accommodates a driver and assistant. The driver sits in the left-hand seat with the master controller and brake handles by his right hand. Instruments, however, are located in front of the driver for ease of visibility and have indirect illumination at night. Crew comfort is assisted by cab heaters, sun vizors and cab fans. Boiling rings are provided in both cabs and a water cooler in one.

Fig. 2. Route profile of the Mountain Line. Altitude varies between 30 and 400 m. The longest gradient is approximately 35 km in length and averaging 1.05%, but it includes a maximum of 2.5% for some 6 km.

Advanced electrical equipment

The ability to make maximum use of the available adhesion is vital with a lightweight locomotive. An obvious advantage of thyristor control is that it gives smooth, notchless control of tractive effort and enables the locomotives to be worked at the peak of the notches which would be associated with a tapchanger locomotive. A further advantage is that infinitely variable control of the field current independent of armature current is practicable and this is most advantageous when operating close to the limit of adhesion. The characteristic of a separately excited motor is as

Fig 3. Performance curve for the locomotives at 25 kV line voltage, showing tractive resistances for typical trains and speed limits



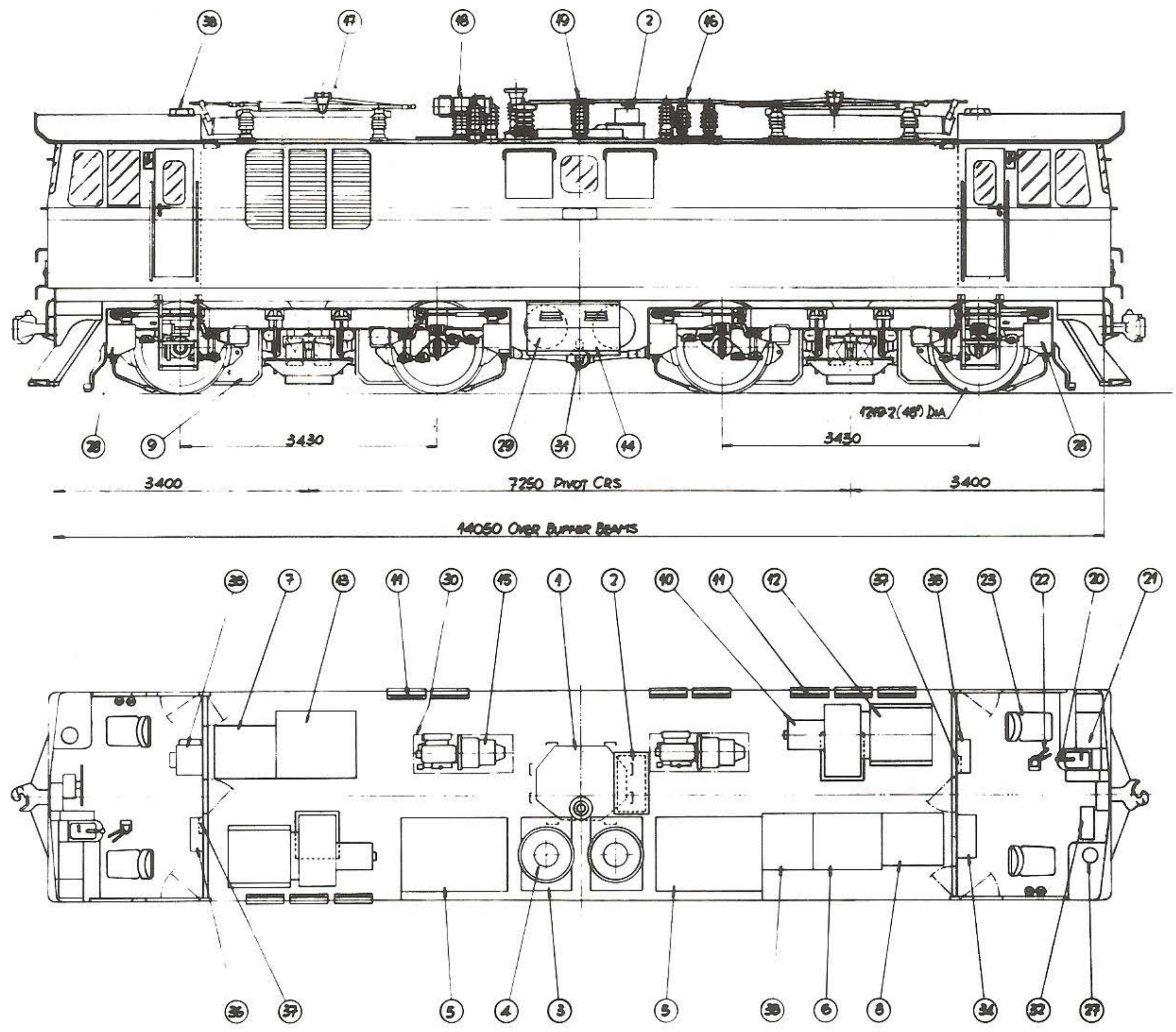


Fig 4. General arrangement of the Taiwan Railways 2100 kW thyristor-controlled locomotive: 1. Transformer; 2 Conservator; 3. Radiator; 4. Fan & Motor; 5. Main rectifier; 6. Electronics control cubicle; 7. Equipment frame No 1 end HT; 8. Equipment frame No 2 end HT; 9. Traction motor; 10. Traction motor blower; 11. Air filters; 12. Smoothing choke; 13. LT equipment frame; 14. Battery; 15. Air compressor; 16. Isolating switch; 17. Pantograph; 18. Vacuum circuit breaker; 19. Input bushing; 20. Master controller; 21. Instrument panel; 22. Brake valves; 23. Seat; 27. Boiling ring; 28. Sandbox; 29. Air reservoirs; 30. Brake equipment; 31. Inter-bogie spring coupling; 32. ATC equipment; 33. Aux & battery charger; 34. Clothes locker; 35. Cupboard; 36. Water cooler; 37. Cab heater 1 kW, and 38. Cab roof ventilator.

shown on curve 1 in Fig 5, while that for a similar series field motor is shown in curve 2.

The most simple arrangement of thyristors is to have a single bridge controlling the armature supply, but this gives a poor power factor during the acceleration period. Multiple bridges in series, each phasing forward in turn, can result in a good power factor, but at the expense of extra thyristor stacks, etc. The GEC locomotive supplied to Pakistan in 1969, in fact, had four circuits in series, effectively providing four series bridges, but with the thyristor bridge mechanically switched between as the voltage progressed. Two bridges in series give the optimum return as regards high power factor over the full notching range at minimum cost in thyristor modules, so this arrangement was chosen for Taiwan.

Form of control

The basic control parameter set by the position of the driver's master controller is motor armature current. With over-riding exceptions described later, this is maintained automatically by a closed-loop control system to the level demanded by the driver, irrespective of train speed or line voltage variations.

Over the speed range the motor is controlled in three different modes (see Fig 6):

1. Up to a speed of approximately 40 km/h the motor field is maintained at a fixed high level and armature current is controlled by varying the motor armature voltage through phase control of the armature thyristor bridges. In this operating area, the setting of the driver's controller corresponds to a fixed tractive effort level.

2. At speeds above base speed armature current is maintained by progressively weakening the motor field with the armature voltages maintained at the maximum level. This corresponds to constant power operation, and in this area the setting of the driver's controller corresponds to a fixed power level. Motor armature current in this area is limited to a maximum value of 400 A. At higher demanded armature currents the motor is allowed to run down the full-field, full-voltage motor characteristic until the armature current reaches 400 A before field weakening is permitted. The armature current is then controlled to this value.

At controller settings corresponding to motor armature currents of less than 400 A, the armature current is controlled to the demanded level.

3. At high speeds and currents operation is transferred to a series motor characteristic to ensure satisfactory motor commutation.

At all speeds, traction motor powers are maintained equal by individual control of motor field strengths; thus the tractive effort generated at the rail by each axle is maintained equal, irrespective of wheel diameter differences or variations in motor characteristic.

Mechanical parts

The underframe comprises main longitudinal side members interconnected by cross members at the bogie pivots,

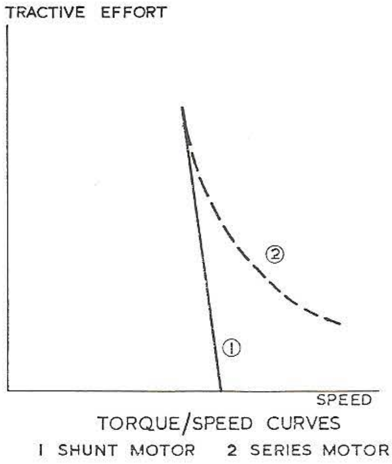


Fig 5. Speed/tractive effort curves for a separately-excited traction motor (curve 1) and a series-connected motor (curve 2)

transformer and equipment mountings, buffer beams and drag boxes. Insulated bulkheads are provided between the equipment compartments and the cabs. The complete structure is covered with steel panels welded to the framing and butt-welded together. The roof is in three removable sections, one below each pantograph and one above the transformer. The underframe, side frames, bulkheads and fixed roof members form a unit load-bearing structure.

Provision is made for the structure to be jacked at four locations adjacent to the bogie pivot centres. In addition it can be lifted or jacked from one end with the other end resting on its bogie and with the bogie at the end being jacked still attached to the body. Rubber cushioned draft gear is fitted together with central automatic couplers, AAR type E, and steel panelled cowcatchers. The bogie frame is of fully welded box-frame construction, made from steel plate. Axleboxes are fitted with SKF spherical roller-bearings.

The superstructure load is carried on a flat centre pivot. The top half of the pivot casting is spigotted and bolted to the underframe, while the bottom half is integral with the fabricated-steel swing bolster.

The swing links and secondary coil springs are external to the bogie frame and to eliminate lateral loading on the secondary suspension the spring seats are anchored to the swing bolster by long arms with pin joints. Friction dampers are provided on the primary and hydraulic dampers on the secondary suspension systems, while lateral hydraulic-dampers are also provided between the bogie frame and the swing bolster.

An inter-bogie spring control unit in the form of a transverse spring-loaded plunger is fitted between the inner headstocks of the two bogies to provide inter-action between bogies on curved track, thereby reducing both flange forces and flange and rail wear.

The rolled-steel disc wheels are fitted with tyres. Because of the limited space available within the 1067-mm gauge the resilient gearwheel is shrunk on to the road wheel hub.

Fig 6 (below). Locomotive performance curve showing the effect of selecting levels of performance on the driver's master controller

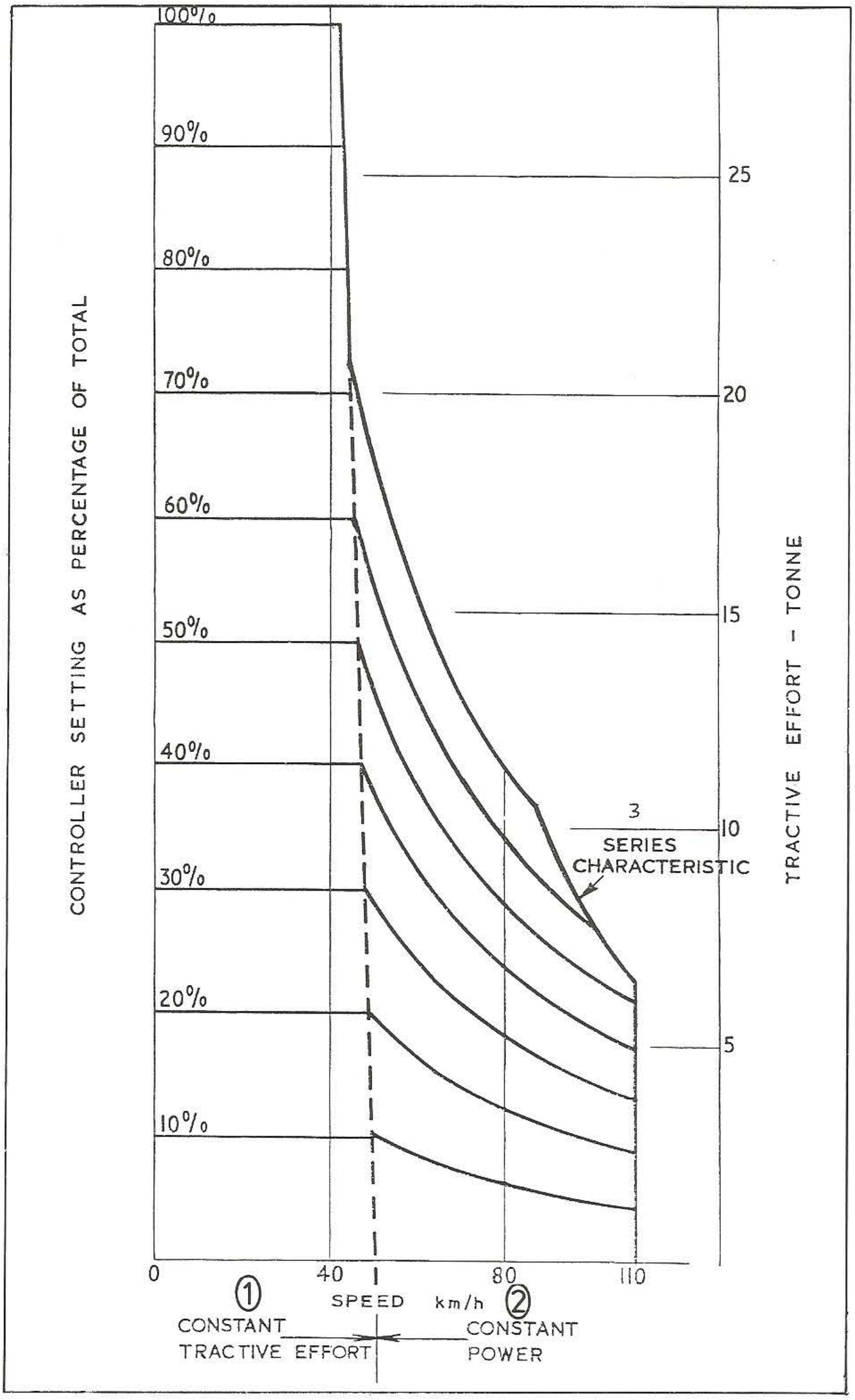
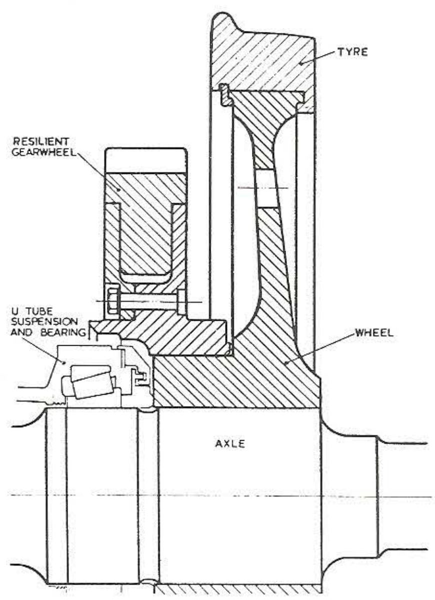


Fig 7. Arrangement whereby the gearwheel is shrunk onto the road wheel hub



One 200-mm (8-in) diameter brake cylinder, mounted on the bogie frame adjacent to each wheel, applies clasp brakes on the wheel. Four sand boxes (each of 30 litres capacity) are provided on each bogie and an air-operated ejector on the base of each sands the rail at the outer side of each wheel. Separate automatic and independent air brakes are provided at each driving position, the former acting on the locomotive and train, while the latter acts on the locomotive only. The brakes are Wabco type 26–LA. Air for the brakes, and other auxiliaries, is provided by electrically driven compressors.

Rectifiers and electronic control

There are two rectifier cubicles, each of which contains the two armature bridges and the separate field bridge for each of the two motors on one bogie set. The devices are of the capsule type and are clamped to separate heat sinks with cooling fins. Modules for the armature circuits contain one device clamped between two heat sinks, while the devices for the fields use single heat sinks. The heat sinks are mounted individually in separate glass fibre modules.

Both thyristor and diode modules contain snubber circuits for transient voltage suppression, while the thyristor modules also include a firing transformer for the thyristors together with a choke and fuse for the thyristor in that module.

The modules are mounted in vertical columns on supports in the cubicles and arranged for simple disconnection from the bus bars and horizontal withdrawal, enabling rapid replacement of a module.

The electronic control system is constructed on a modular plug-in basis. Each individual electronic circuit is built on a single glass fibre printed circuit card which itself is mounted on a protective metal chassis to form the plug-in module. The construction of a typical module is shown in Fig 9 while Fig 10 shows a number of modules in a typical single tier mounting rack.

All circuitry, including plugs and sockets, is mounted on the printed card and no electrical wiring is necessary when adding its protective frame. Outgoing connections are made at the rear of the card by way of a multi-way plug fitted with gold-plated pins. A similar, but smaller, socket is mounted at the front of the card to allow access to monitoring points when the module is plugged into its mounting rack. No adjustable controls are fitted to the module, all setting and calibration being made by fixed resistors soldered to turret pins. On the rear plate of the module polarising pins are fitted which mate with appropriately positioned holes in the socket mounting plate to ensure that modules cannot be plugged into the wrong positions.

The equipment is designed for a minimum life of 20 years. Special attention has been paid to the mechanical design to ensure that deterioration will not result from the vibration and shock. To ensure that the design is adequate all electronic equipment is tested for vibration and shock resistance as laid down in IEC Specification No 77.

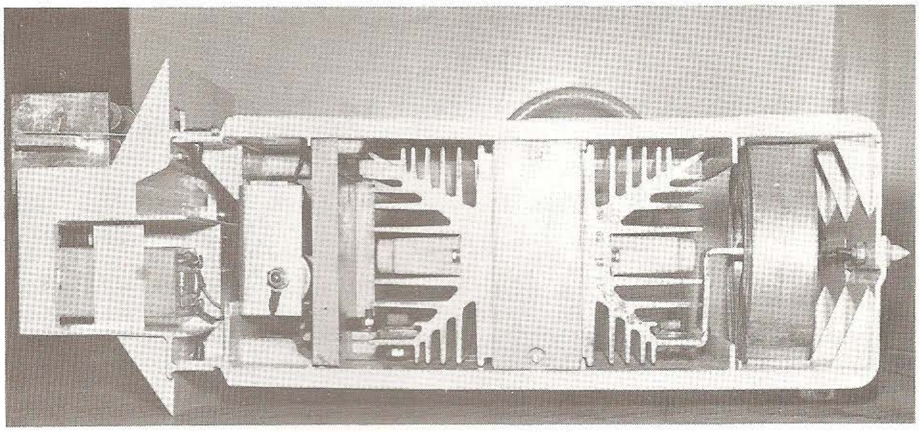
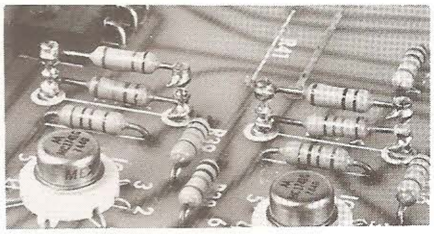


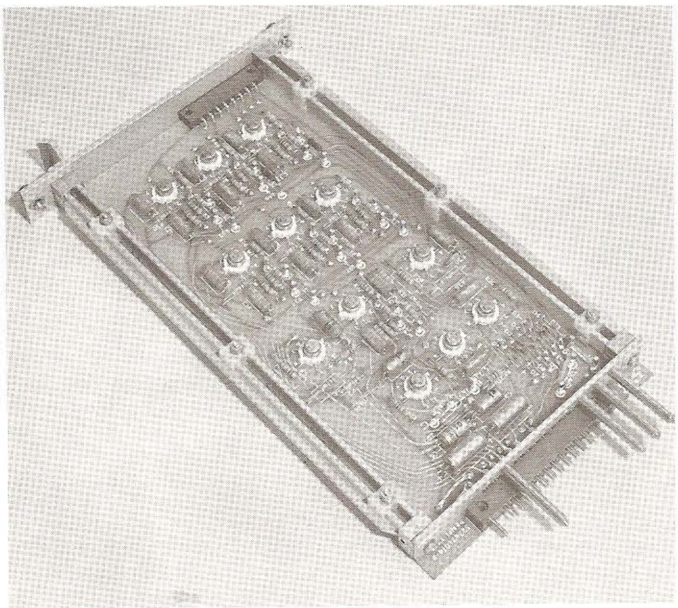
Fig 8. Thyristor module showing double heat sink arrangement

Components are specially selected, then operated at below their rated capacity, both as regards voltage and current. An increasing proportion of devices are becoming available to standards specified in the new BS 9000 series, "electronic components of assessed quality," and it is expected that their use will improve reliability even further.

Practical experience has shown that variable potentiometers can give trouble and so are no longer used except where essential, eg, compensating for wheel wear on speedometer equipments. Modern electronic devices do not drift with age and, provided the module is accurately calibrated during manufacture, there is no need for further calibration during the remainder of its life.



Close up of turret pins on which calibrating resistances are mounted when on test.



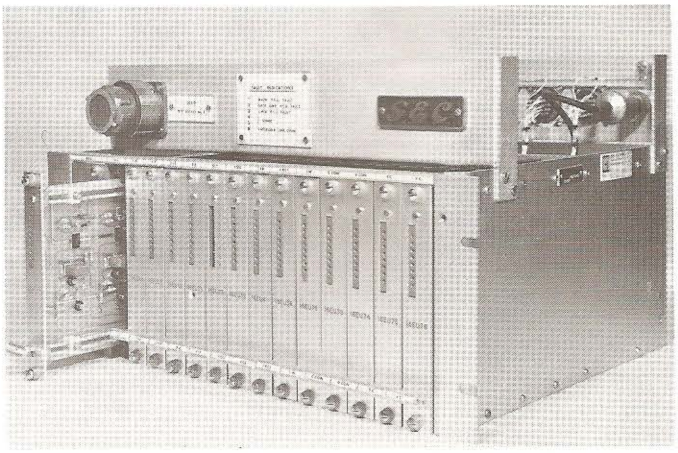


Fig 9. Electronic module showing (large) polarising pins to prevent the module being plugged into the wrong position

Fig 10. A typical standard mounting rack with a set of modules plugged-in. More complex control systems are housed in racks of similar width, but two or more modules in height

Traction motors

The G413AZ dc traction motor is an adaptation of the GEC/AEI 283 AY motor, some 3000 of which are in service in the Class 6E1 3000 V dc locomotives of South African Railways.

The major modifications are that the main field is separately excited instead of being of series type, and to cater for the ripple component at 120 Hz in the supply, the pole and stator laminations are reduced in thickness and insulated from one another. The motor is of robust design and incorporates many features to ensure long life with minimum maintenance. It is axle-hung on a roller-bearing 'U' type suspension tube, supported at the nose end by a resilient link which connects between the motor frame and the bogies. It is a non-compensated four-pole machine having a continuous rating of 1470 V, 380 A, 660 rev/min, 530 kW.

Transformer

The transformer is built by GEC Power Transformers Ltd. and complies with IEC Specification No 310. It is a core-type with two limbs, each with two secondaries adjacent to the core and the primary and tertiary windings wound concentrically around them. The primary coils, and the excitation and auxiliary windings, are all disc-type, with the latter two located at either end of the primary. The light-weight aluminium tank housing the transformer is bolted rigidly to the locomotive frame with the conservator placed above roof level mounted as an integral part of the tank assembly. Oil circulation of the totally-immersed windings is by pump through a forced-cooled radiator.

In addition to the standard safety equipment a pressure relief device is fitted to the transformer tank which, in the event of build-up of internal gas pressure, releases oil direct from the transformer to discharge on to the track. On release of this pressure, the device resets having permitted the discharge of the minimum quantity of oil. Should the transformer oil become too warm a thermostat shuts off power for traction but maintains the auxiliaries, thus continuing to cool the oil with the radiator fan.

The locomotives are fitted with roof-mounted GEC vacuum circuit-breakers similar to those which have had extensive service on BR. The breaker is rated at 600 A, has a rupturing capacity of 250 MVA and a short-circuit withstand capability of 12 000 A for 2 seconds. Compared with conventional air-blast breakers this type offer lower first cost and maintenance and higher reliability. They are also quieter in operation and require less space.

Pantographs

Two GEC crossed-arm pantographs are fitted, so minimising the roof area required. Current collection is by copper-impregnated carbon rubbing strips and auxiliary springing ensures that the pan head itself follows quickly any irregularities in the contact wire. Only one pantograph is used at a time.

Deadman and vigilance

The locomotives are fitted with a combined vigilance and deadman system designed to ensure that the driver remains alert whenever the locomotive is moving above a threshold of 2 km/h. It is only inoperative if the speed is below the threshold and the master controller handle is in the 'off' position.

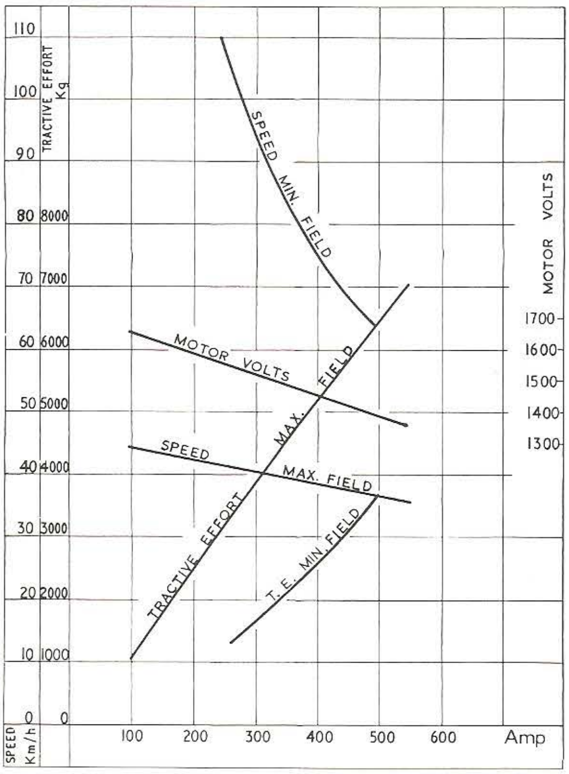
The deadman feature is operated by a foot switch at each driver's position and a desktop push-button switch at each assistant driver's position, either of which must be depressed to maintain a feed to the deadman valve. As soon as the valve is de-energised a seven second air timing cycle starts and, if not interrupted, causes an emergency brake application. The brake application can be interrupted and normal running restored by the driver pressing the switch and putting the brake handle to the 'service' position and back into 'release' again.

The deadman device is augmented by a vigilance system which requires a positive action from the driver (or assistant) at least every minute. The positive action for resetting is to release the pedal (or push-button) momentarily and this starts the one minute timing cycle again. If the timing cycle is not reset a buzzer sounds. If not reset within a seven second safety cycle, the air timing cycle starts which leads to an emergency brake application. Between the end of the safety cycle and the brake application becoming effective, it is still possible to reset, but only by operating the pedal/pushbutton twice.

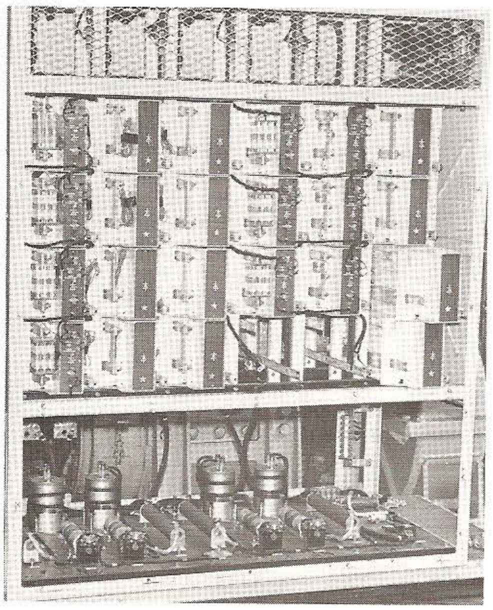
Wheelslip protection

Each traction motor gearcase has a magnetic probe which detects the passage of gearwheel teeth and is a direct indication of wheel rotational

Fig 11. Characteristics of the G413 traction motor. The continuously variable control available means that the entire band-width can be used between the curves shown as maximum and minimum fields, as compared with series connected motors where distinct intermediate curves are used. ▶



Thyristor cubicle with two modules withdrawn prior to assembly in the locomotive ▼



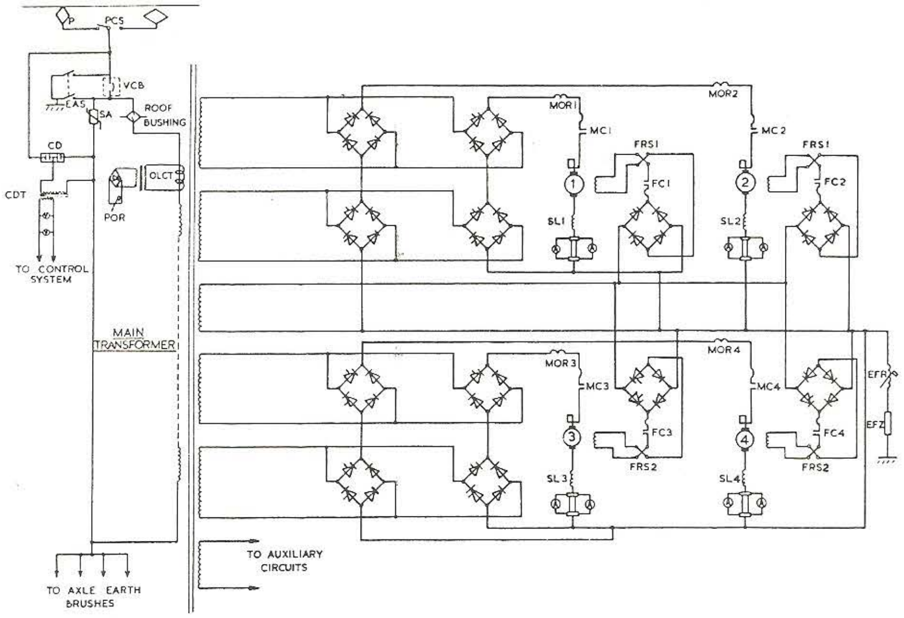


Fig 12. Circuit diagram of Taiwan Locomotive's traction power circuit. Key: A Ammeters; CD Capacitor divider; CDT Capacitor divider transformer; EAS Earthing switch; EFR Earth fault relay; EFZ Earth fault limiting resistance; FC1–4 Field contactors; FRS1–2 Reversers; MOR 1–4 Motor overload relays; MC1–4 Motor contactors; OLCT Primary overload current transformer; PCS Pantograph changeover switch; P Pantograph; POR Primary overload relay; SA Surge arrester; SL1–4 Motor series reactor; UVRR Undervoltage relay; VCB Vacuum circuit breaker; V Voltmeter

speed. The signals received are amplified and used for operating the locomotive speedometers and for the anti-slip and the deadman/vigilance equipments.

Though the separately-excited traction motors give much better performance for the adhesion conditions prevailing than conventional series motors, the wheels will slip if the driver demands too much tractive effort. The anti-slip protection senses the following three conditions:

(1) different speeds between axles;
(2) excessive acceleration, ie, higher than is possible with a light locomotive under the best adhesion conditions;
(3) overspeed

If any one axle slips with all four motors in operation, the only action taken is to inhibit the load sharing on that motor, ie, the motor field is held fixed and the axle is allowed to regain adhesive working on its own. If both axles on one bogie slip together or if any axle slips in the motor 'cut-out' condition, the tractive effort is removed by retarding the firing angle of the thyristor. When slip has ceased tractive effort is re-applied, but at a controlled rate, until it regains the 'demanded' value.

Condition (3) can be more serious and may be a case of the locomotive overspeeding rather than overspeed due to wheelslip. Traction power is therefore cut out and a fault indication given. In order to restore power, the driver must reset after the speed has fallen to a reasonable value. A desk warning lamp lights up when an axle slips.

Auxiliaries

There are three electrical circuits on the locomotive, each of which is allied to particular functions. The usual 110 v dc supply is regulated for battery charging, control circuits, lighting, etc. There are many functions, however, where a regulated supply is unnecessary and unregulated supplies can save money.

The transformer tertiary provides a 240 V single-phase output at nominal contact wire voltage but, of course, the actual voltage varies with that of the supply itself. This is quite acceptable for items such as heaters, pumps, radiator fans and cab fans. In the case of the compressors and traction motor blowers the power and starting torque are too high for satisfactory operation by single-phase motors, therefore, the 240 V ac has been rectified, to a nominal 220 V for these machines.

The two air compressors are type 3VC75 supplied by Westinghouse Brake & Signal Co Ltd and each is driven by an integral 220 V dc series motor. They are three-cylinder vertical in-line two-stage machines with a swept volume of 2.0 m^3/min capacity and a free air delivery of 1.5 m^3/min against a pressure of 9.8 bar (10 kg/cm^2) at a speed of 1570 rev/min. There is also an auxiliary compressor driven by an integral 110 V motor supplied from the battery. It is governor-controlled and used for charging the air supply to the vacuum circuit-breaker and for raising the pantograph if there is insufficient air in the reservoirs when the locomotive is being prepared for service.

Traction motor blowers

Two 508-mm diameter centrifugal fans, each driven by a 220 V dc series motor supply 170 m^3/min of ventilating air to the two traction motors on the adjacent bogie. This air cools also the double smoothing reactor for the same two motors. Rectifier and transformer cooling is by two 483-mm diameter axial fans driven by 240 V single-phase induction motors, mounted above the transformer radiator.

A 72-cell Alcad nickel-cadmium alkaline battery of 135 Ah capacity supplies lighting and control loads and floats at 110 V across the battery charger. When fully charged it will supply essential lighting and control loads for 8 hours in the event of failure of the battery charger.

A Hasler combined speed and distance indicator and recorder is fitted in one cab, a right-angle gear unit on the adjacent axlebox driving the indicator through a sheathed flexible cable.

Taiwan Railway 2100 kW thyristor-controlled electric locomotives

Wheel arrangement	Bo-Bo
Track gauge	1067 mm
Maximum service speed	110 km/h
Locomotive service weight	72 tonne
Axle load	18 tonne
Line voltage	25 kV 60 Hz
Voltage range (normal)	19-27.5 kV
Minimum voltage (short time)	17.5 kV
Length over buffer beams	14 050 mm
Height over cab	3720 mm
Width over body panels	2820 mm
Bogie wheelbase	3430 mm
Bogie centres	7250 mm
Wheel diameter (new)	1219 mm
Wheel diameter (minimum permitted)	1141 mm
Minimum radius curve (on running lines)	300 m
Minimum radius curve (yards, workshops, etc.)	100 m
Gear ratio	18/67
Number operating in multiple	up to 3
Locomotive brakes	Air
Train brakes	Air

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