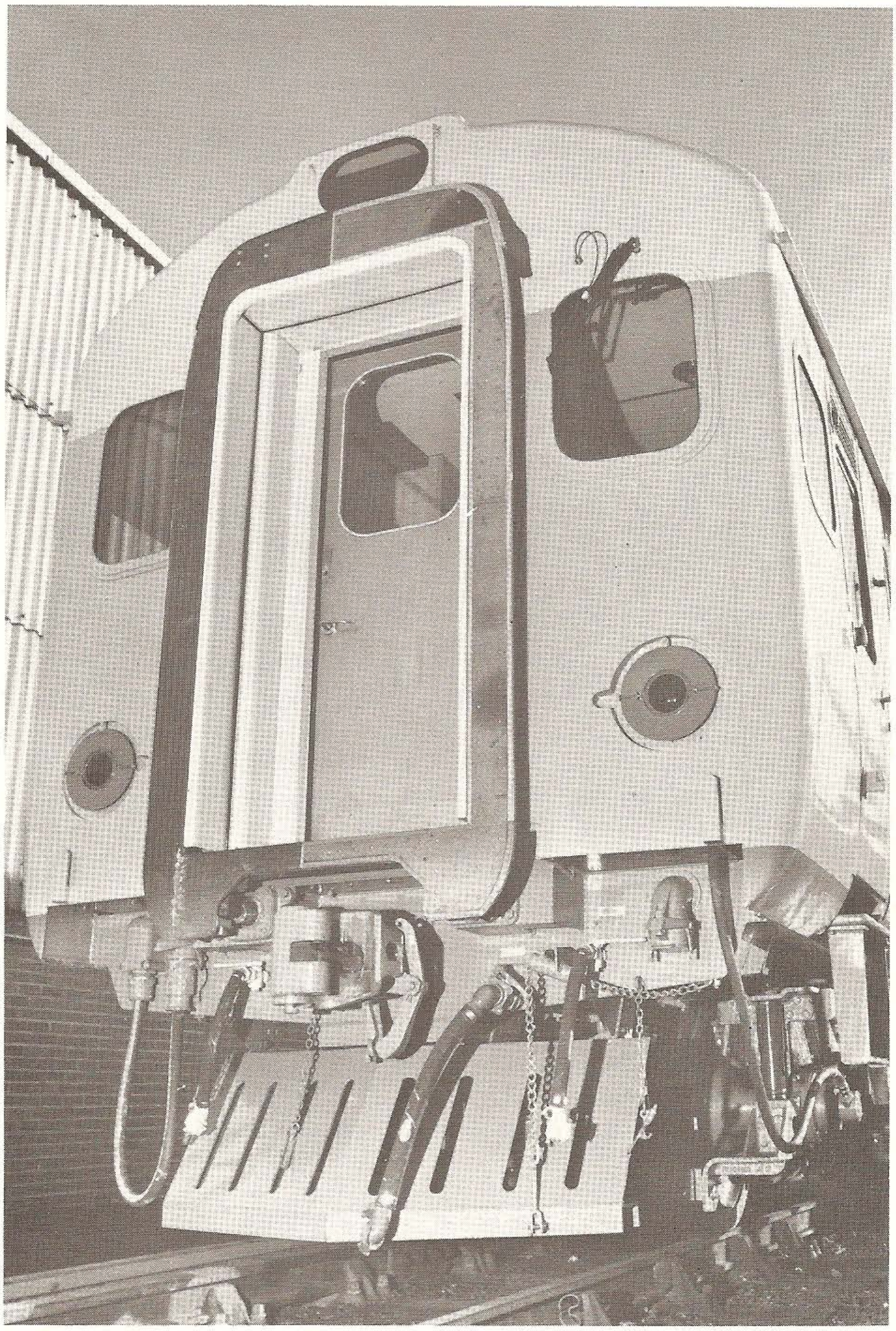
Luxury express electric trainsets for Taiwan from GEC Traction

As part of the plan for the electrification of their 1067 mm gauge railway system at 25 kV 60 Hz single phase, the Taiwan Railway Administration recently placed orders with GEC Traction Limited for twenty 2100 kW locomotives and 13 five-car luxury express multiple-unit passenger train sets. The locomotives have been delivered and the train units are due for delivery later this year and into 1978.

These latter high-speed air-conditioned trains are intended for running between the North and South of the island, covering the 400 km non-stop between Taipei and Kauhsiung in 4 hours. Optional advanced reservation facilities are to apply to all seating but the power units are designed with sufficient margin to do the specified service with 50% passenger overload in peak periods. The normal service will be provided by trains comprising three five-car sets operating in multiple giving a total of 15 coaches.

Each train unit comprises a driving power car, a motor car, two plain trailers and a driving trailer. The power car and driving trailer each have seats for 44 passengers, the motor car and each non-driving trailer having 52 seats. The power car carries the pantograph, main transformer, traction rectifiers and one motor-alternator set. The motor car has two motored bogies each with two traction motors, most of the conventional control equipment (including the 110-V battery charger and battery) and the main air compressor. The driving trailer carries a further motor-alternator set. Every car has its own 24-V emergency-lighting battery and charger.



Speed control

One of the special features of the trains is the simplicity of the driving controls, only one handle (a speed controller) being used except when coming to a complete stop. This feature is particularly useful where there are a number of different speed restrictions close together, a situation which applies on the route in question. Fig 4 shows speed restrictions for a 20 km section of the Mountain Line.

The speed controller has an 'off' and an 'inch' or 'shunt' position, followed by speed graduations up to the maximum service speed of 120 km/h. To start the train the driver selects 'forward' or 'reverse' and moves the handle from 'off' to the speed he requires. The train accelerates at a controlled rate up to the speed demanded, (provided track gradients do not dictate a lower balancing speed), and the speed is then held within a small margin. On a downgrade sufficient rheostatic braking is applied to hold the speed.

The rheostatic brake is also used as an

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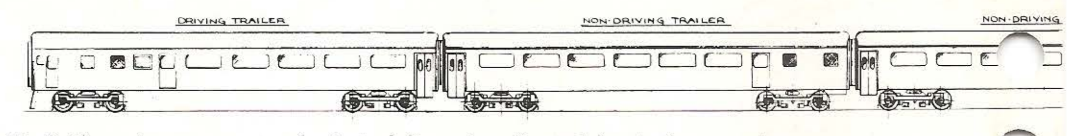
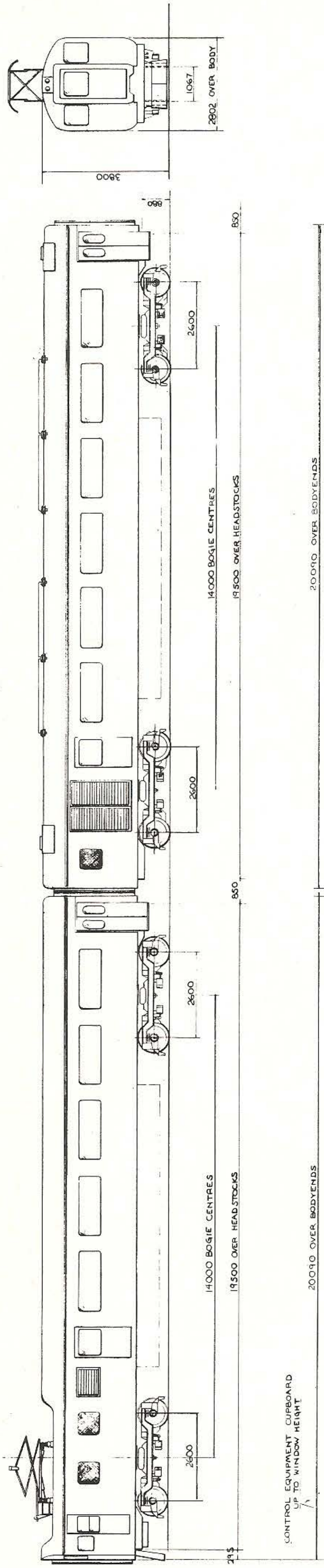




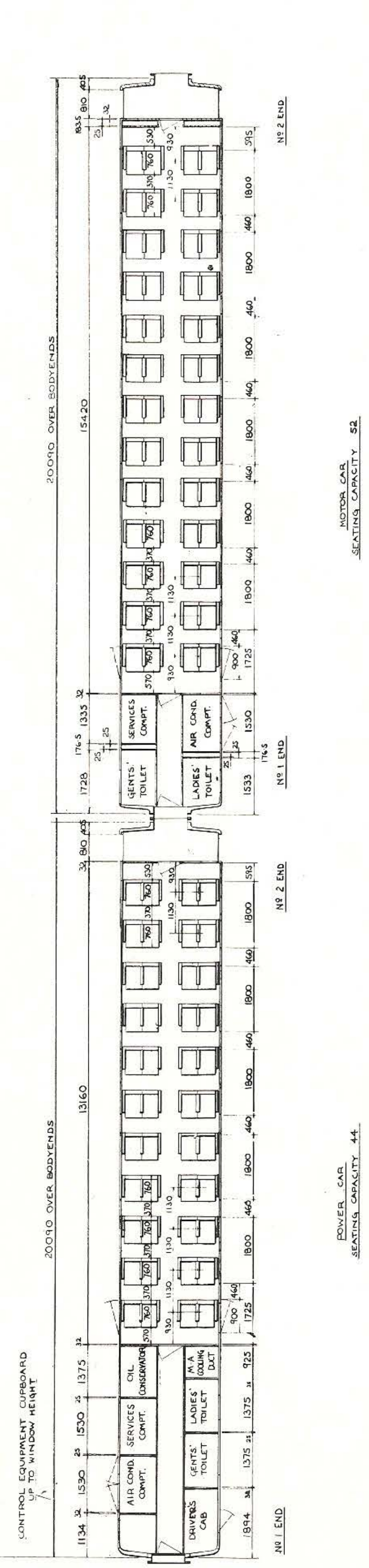


Fig 2. General arrangement and principal dimensions (in mm) for the five-car train set

integral part of the speed control system when the driver calls for a reduction in speed. The greater the reduction demanded, the greater the braking force applied, bringing in air brakes on the un-motored cars as required in addition to full rheostatic braking. As the train speed approaches that demanded, the air braking is progressively reduced, followed by reduction of rheostatic braking as necessary. By moving the handle to 'inch' position, a very low speed suitable for shunting duties is obtained, while in 'off' position, all speed control is removed and the train coasts (or remains stationary).

For normal braking to a stop, or in emergency, there is a self-lapping Westinghouse Brake & Signal 'Westcode' electro-pneumatic brake controller with 'automatic' air brake back-up. Any movement of the brake controller handle from 'release' cuts off all power and rheostatic braking and applies the block brakes on all wheels, the brake pressure being proportional to the degree of handle movement. In the event of failure of the electrical supply to the brake controller, an 'automatic' air-brake application is made, of the same degree as the electro-pneumatic application.

Regardless of the speed required by the position of the controller handle, there are limits to the amount of accelerating or braking tractive effort permitted (determined by considerations of comfort) and the rate of change of tractive force (the jerk rate) is also limited for the same reason.

There is an 'emergency' mode of operation in which the minimum of electronic equipment is utilised. In this situation, movement of the speed control handle directly controls traction motor current, and functions such as field weakening or rheostatic brake are not permitted.

Thyristor control

The series traction motors are thyristor controlled in parallel pairs, each pair being fed by two asymmetric half-controlled bridges connected in series on the dc side. The motors are connected in parallel groups because there is less tendency to 'run away' under wheelslip conditions. Thyristor control is used because

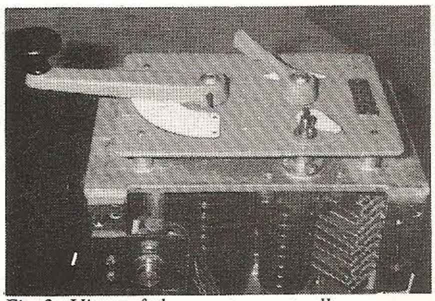
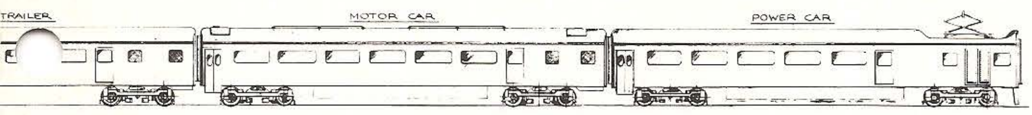


Fig 3. View of the master controller



it is notchless and infinitely variable.

In accelerating from standstill, first one bridge of each pair has the firing angle of its thyristors gradually advanced to increase its output voltage from zero to maximum. During this period the thyristors of the second bridge are not fired so they do not contribute to the dc voltage but their diode arms act as a through path for the traction motor current. When the first bridge is fully advanced the second bridge firing angle is gradually increased until it also is fully advanced. The traction motors are then on full voltage. Two bridges are used as, by advancing one bridge at a time to full conduction, only half the accelerating power is handled by each bridge, with the advantage that the reactive kVA and harmonics due to retarded firing angle are reduced.

The trains have to contend with grades of up to 2.5%, having curves amounting to an equivalent grade of a further 0.2% in places, and the climate can be very humid, with consequent poor adhesion conditions. In order to make the most of the comparatively high adhesion available at low speeds the accelerating current and therefore tractive effort is high at standstill and reduces gradually with speed until the full voltage full-field characteristic of the motors is reached, the smooth voltage control being greatly facilitated by the use of thyristors. From then on, the tractive effort falls away with increasing speed, on a normal dc series-motor characteristic, to the point at which weak field is taken.

The field is weakened in one step by field tap and simultaneously the voltage is reduced to avoid any change in tractive effort and thus give a jerk-free transition. Voltage is then gradually increased to maintain the tractive effort with increasing speed until full voltage is reached in weak field. The train then accelerates along the weak field characteristic.

In view of the long steep down grades and the frequent speed restrictions due to curves, rheostatic braking is used to save wheel tread and brake block wear (and therefore maintenance). In rheostatic braking each traction motor armature is connected across a fixed resistance while the fields are connected all four in series and separately excited from one of the half-controlled bridges normally used during motoring. The braking resistors are mounted on the roof, giving good natural ventilation.

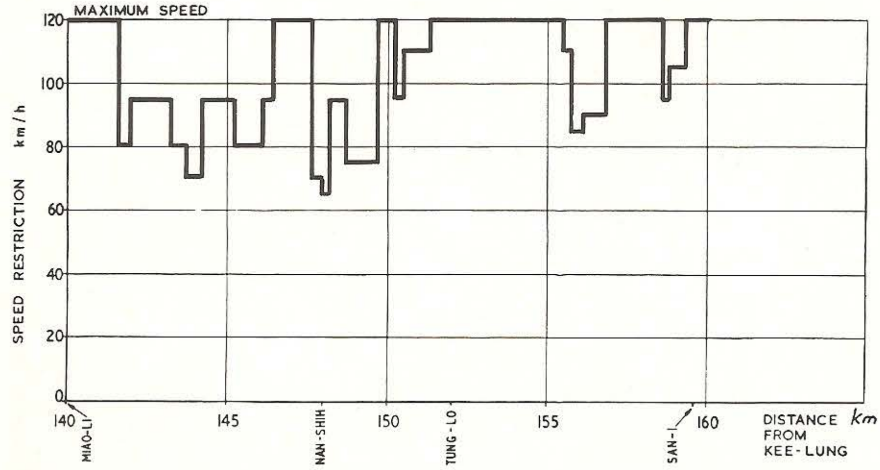


Fig 4. Details of speed restriction for only a part of the Mountain Line. With so many changes in speed restriction (and on changing gradients), the direct selection of speed is invaluable in easing the work-load on the driver

The vehicles

The coaches are built by British Rail Engineering Ltd. (BREL), (the bodies at York and the bogies at Derby) and are based on the British Railways Mark II coaches extensively used on 160 km/h Inter-City trains on that system. The body width has been increased to conform with Taiwan requirements and there have been other detail changes such as the larger double-glazed windows and the layout of the interior accommodation, conforming with usual TRA practice.

Each car has separate ladies' and gentlemen's toilet accommodation with wash basins and electric hot-air hand-dryers. A services compartment with a hot cupboard, a refrigerator and a hot water urn on every car enables an attendant to serve hot and cold drinks and hot snacks. The driving trailer has an additional compartment for the conductor which includes a handset and socket for the public address system tape recorder.

Folding access doors are situated on both sides of the car, with steps recessed into the car floor, enabling passengers to enter or leave the cars from low-level station platforms. There is a through passage between all cars with well-sealed bellows as used on many modern BR coaches. Powerful springs keep the bellows flanges in firm contact in all conditions.

The saloon air conditioning is supplied by Stone-Platt Crawley Ltd who have considerable experience in this field, especially in tropical countries under conditions similar to Taiwan, and the units actually used are very similar to those already operating on coaches in Cuba. The air conditioning is designed to maintain a temperature of 25°C at a relative humidity of 55% in the car when the outside ambient varies from 0°C to 40°C with relative humidity occasionally as high as 100%. Under cold conditions a bank of heaters is brought into action to hold the internal temperature at 20°C.

The air-conditioning units are mounted above floor level and air entry is through body-side louvres. Air entering the bottom half of the units is used by the condenser and then exhausted. Air which enters the top of the units is conditioned and discharged into the main ceiling duct system of each vehicle and then into the saloons and toilets via the air metering boxes which are situated within the reflectors of the fluorescent light fittings. Used air is exhausted through louvres and vents at a number of points on the vehicles although some air is recirculated.

The body-side pillars and panelling form an integral unit with the solebar, underframe, roof framing and roof panels. The floors are of corrugated-steel sheeting covered with plywood and insulation. Corten steel is used extensively, to give strength and corrosion resistance.

The bogies (both on the motor and on the trailer cars) are a development of the BR BX1 type modified for the narrower gauge and with air suspension and an automatic-levelling system. The primary suspension consists of a radius arm with a rubber chevron spring mounted directly on top of the axlebox. The radius arm and axlebox are an integral casting connected to the bogie frame at the pivot point by means of a rubber-bonded bush. This type of primary suspension provides both sufficient wheelset yaw stiffness for lateral stability and the necessary vertical flexibility with minimum noise transmission.

The secondary suspension consists of two air springs per bogie. Lateral oscillations are controlled by hydraulic dampers while air damping devices incorporated in the design of the air suspension restrict oscillation in the vertical plane. The bogie has a floating centre pivot with rubber-bushed traction links. The frame is constructed of welded box sections formed into a short 'H' configuration without headstocks. This design gives low inertia and weight while ensuring a fatigue-free life.

The use of a double-block pusher brake, with a brake cylinder for each wheel, gives a very short overall length to

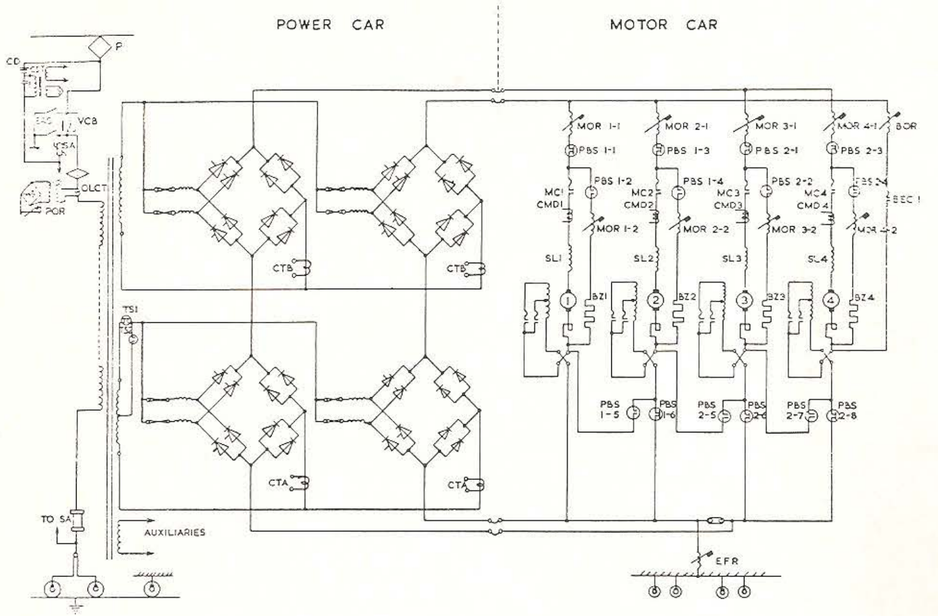


Fig 5. Simplified power schematic for the power car and the motor car

BEC	*Braking excitation contactor*		
BOR	*Braking overload relay*		
BZ	*Braking resistor*	*OLCT*	*Primary over current transformer*
CD	*Capacitor divider*	*P*	*Pantograph*
CDT	*Capacitor divider transformer*	*PBS*	*Power-brake switch*
CMD	*Current monitoring device*	*POR*	*Primary overload relay*
CT	*Current transformer*		
		SA	*Surge arrestor*
EAS	*Earthing switch*	*SL*	*Motor series reactor*
EFR	*Earth-fault relay*		
		TS	*Tap switch*
MC	*Motor contactor*		
MOR	*Motor overload relay*	*VCB*	*Vacuum circuit-breaker*

the bogie. Automatic slack-adjusters are incorporated. On the driving power car and driving trailer Westinghouse air-operated stabling brakes are fitted on each bogie. These brakes can be released directly by hand, using a special lever.

Electric propulsion equipment

There are two converter/rectifier cubicles each containing two series-connected armature bridges. The semi-conductor devices are of the capsule type and are mounted two-in-parallel on one heatsink. Cooling is single sided, using box clamps. Two such heatsinks are mounted on a glass-fibre panel and there are four panels per converter cubicle. Both thyristor and diode assemblies carry snubber circuits for transient voltage suppression but thyristor firing transformers are mounted separately as are chokes and fuses for the thyristors. The thyristor and diode panels are mounted so that cooling air flows over the heatsink fins projecting into the air ducts at the back of the cubicle.

The electronic control system uses closed-loop techniques to give accurate control of speed (and also motor currents). Signals from the master controller, and those feeding train lines for multiple-unit operation, use pulse width modulation (PWM) techniques to protect the signal from interference. All input signals from the 110 V dc supply are isolated from the electronics using optical couplings whilst outputs from the electronics are isolated by reed relays. Control-logic checks both internal electronic signals and external inputs from power and control equipment and only if the correct signals (for a particular operating mode) are present is power allowed to be applied.

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 11 while Fig 12 shows a number of modules in a three-tier mounting rack.

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 vibration and shock. All electronic equipment is tested for vibration and shock resistance as laid down in IEC Specification No 77.

Traction motors

The G414 AZ traction motor is a variant of the widely used AEI 253 motor which has been supplied for service on main-line diesel locomotives in many parts of the world, as well as on 25-kV ac multiple unit trains in Calcutta. The continuous rating is 300 kW. It is a four-pole lap-wound series machine, and field weakening to meet the performance requirements is obtained by a tapped field.

Series motors are used, in contrast to the separately-excited motors on the GEC Traction locomotives, because the extra cost of the control equipment for separate excitation is not justified with a fixed train make-up. The accelerating tractive effort is tailored, however, to match the comparatively low adhesion curve.

The motor is nose-suspended using a rubber sandwich-spring unit, precompressed and inserted across jaws in the bogie frame and motor. This arrangement ensures that the rubber is fully compressed regardless of the direction of motor torque. Motor suspension on the axle is by a roller-bearing U unit of tube design, spigotted and bolted to the motor frame. Roller-bearings require less maintenance than conventional sleeve bearings.

The drive to the axle is by straight spur gears incorporating a resilient gearwheel. The gearwheel has a two-part centre consisting of a hub, integral with the road wheel hub, and a detachable side plate. The rim is mounted on the centre by resilient bushes, each consisting of two concentric steel tubes between which is sandwiched a rubber cylinder. In addition to damping torsional vibration the resilient gear reduces gear noise.

Because of the restriction on space due to the 1067 mm track gauge, the traction motors are force-ventilated by centrifugal fans mounted in the roof of the motor car. Two fans are mounted in a common chamber at each end of the car. Air is drawn through roof louvres and discharged at the underframe through flat ducts in the body partitions, as on the diesel-electric cars supplied to Argentina and Northern Ireland.

Transformer

The primary of the 2120 kVA main transformer is fed from the 25 kV overhead line via a crossed-arm pantograph and a vacuum circuit-breaker, as fitted on the 20 locomotives already supplied to Taiwan. The transformer has two 635 V secondary windings, each of which supply two of the half-controlled rectifier bridges which feed the traction motors. There is, in addition, a 1580 V tertiary winding for the auxiliary supply to the motor-alternator sets. The transformer is a core-type design with two limbs, each having four primary-to-secondary groups of windings in sandwich formation. The coils are wound as discs with flat rectangular conductors insulated with paper.

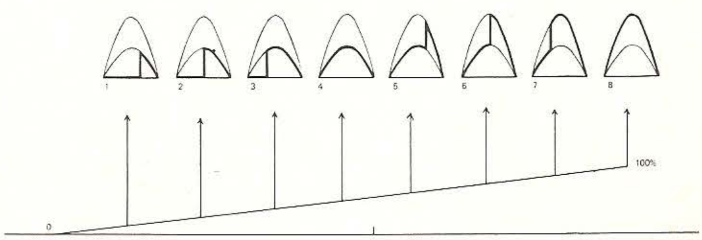


Fig 6. Voltage progression as firing angles are advanced on a two-bridge network

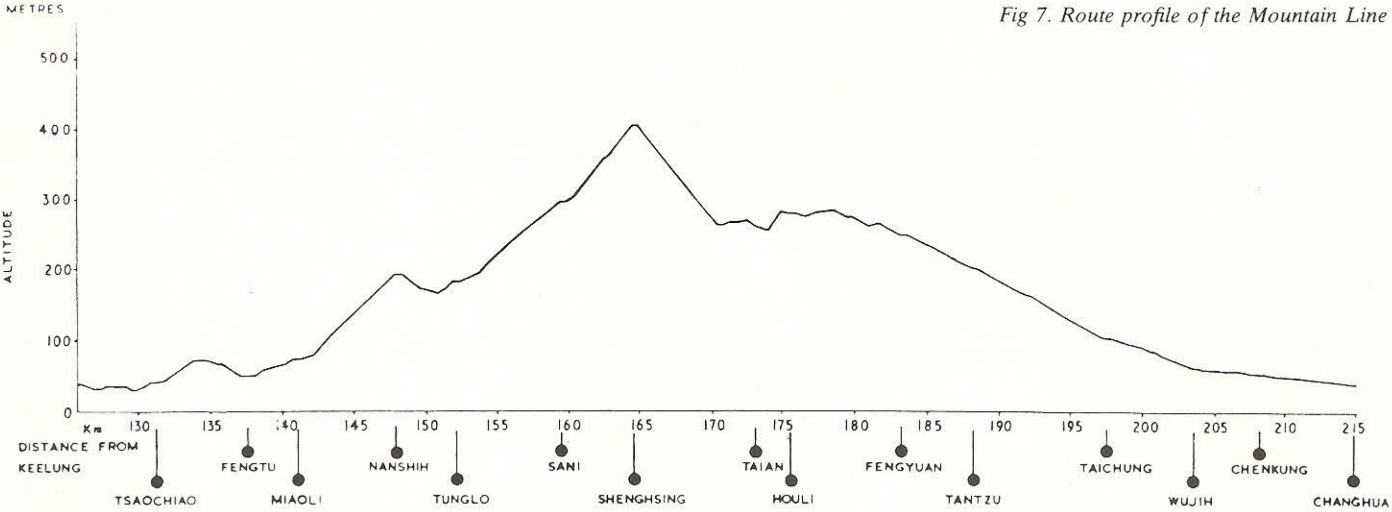


Fig 7. Route profile of the Mountain Line

The core is of grain-oriented steel laminations, each insulated with heat-resisting material.

It is underframe-mounted and is the largest transformer of this type supplied to date. Forced oil circulation is by an immersed pump to an overhung plate-type radiator. The latter is designed for natural ventilation when the train is in motion but because of the heavy tertiary load when stationary due to the train air conditioning, an axial fan is mounted at one end of the radiator. The direction of rotation of the fan is governed by the reverser such that it assists the natural ventilation due to train movement.

A conservator tank in a compartment above the transformer allows expansion of the oil and a GEC-manufactured Buchholz relay in the pipe to it protects against gas accumulation. If, for any reason, there is a sudden generation of gas, a Qualitrol spring-loaded pressure relief device discharges on to the tracks and also opens the vacuum circuit-breaker. The device acts very rapidly to protect the tank and radiator from distortion due to internal pressure and the vacuum circuit-breaker prevents further damage.

Automatic power control

In order not to draw an arc when passing over section insulators in the overhead line it is necessary to open the vacuum circuit-breaker before the pantograph reaches the gap and close it after the gap. As opening the breaker not only cuts off power for traction but also cuts off the auxiliary supply, it is very desirable to open it for as short a time as possible. This is achieved by an Automatic Power Control (APC) system.

Permanent magnets are placed on each side of the track a short distance before and after the section insulator. A sensing probe on each power car picks up the signal from the first magnet which causes the vacuum circuit-breaker to open. As the probe passes the second magnet the breaker is closed. Power is thus lost on each five-car unit in the train for the minimum length of time. This is especially useful on steep up-grades (or if a train is stopped with a pantograph on an insulated section of the overhead catenary system) as only one unit loses power at a time and the other units continue operating. This would not be possible if the driver had to open all the breakers simultaneously as would be the case in the absence of APC.

Vigilance

In the interests of safety the train units have GEC Traction's Vigilance equipment in each cab. This is more foolproof than the conventional 'deadman' equipment which can often be made inoperative by putting the reverser in 'off' and in other ways. The GEC Traction Vigilance incorporates a normal 'deadmans' pedal but it has to be released at regular intervals (which can be pre-set at any value between 1 and 2 minutes and which is being initially set at 60 seconds) and it cannot be rendered inoperative except when the train is being hauled 'dead'. If the driver does not release and depress the pedal within 60 seconds a warning sounds for 7 seconds, followed by an automatic brake application. The driver can prevent the automatic brake application after the warning signal by depres-

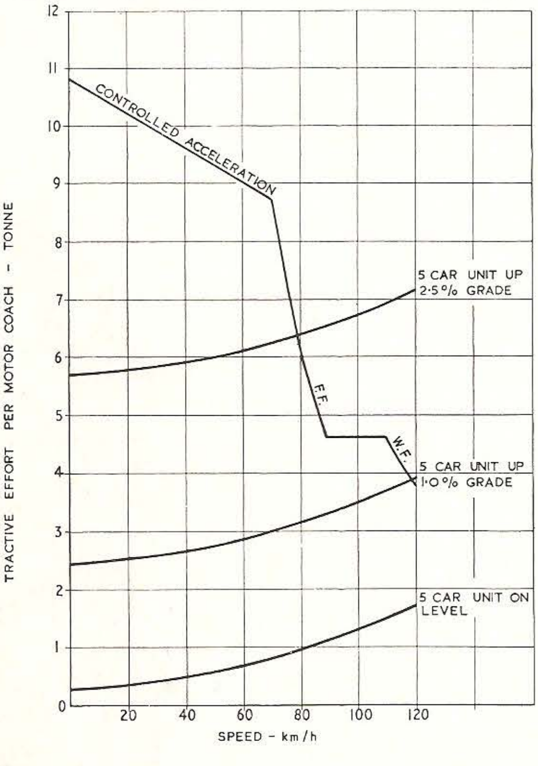


Fig 8. Performance characteristic for the train showing actual performance for a normally-loaded train on various gradients

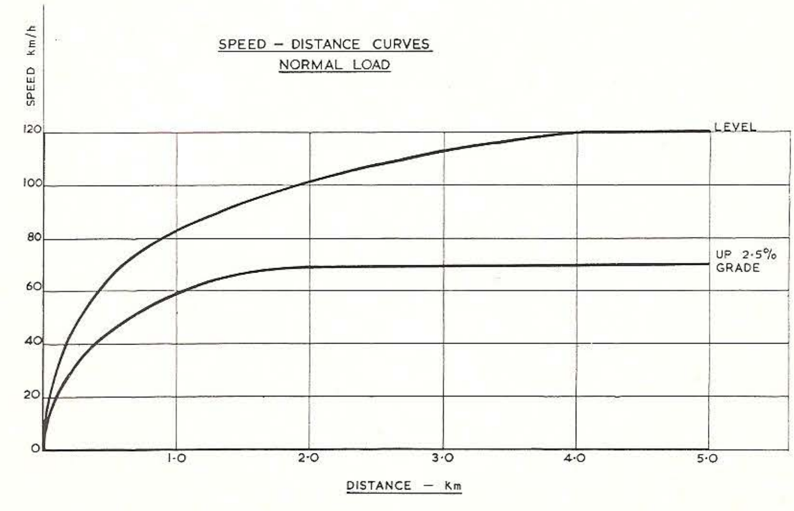


Fig 9. Acceleration for a normally-loaded train on the level and up the steepest gradient

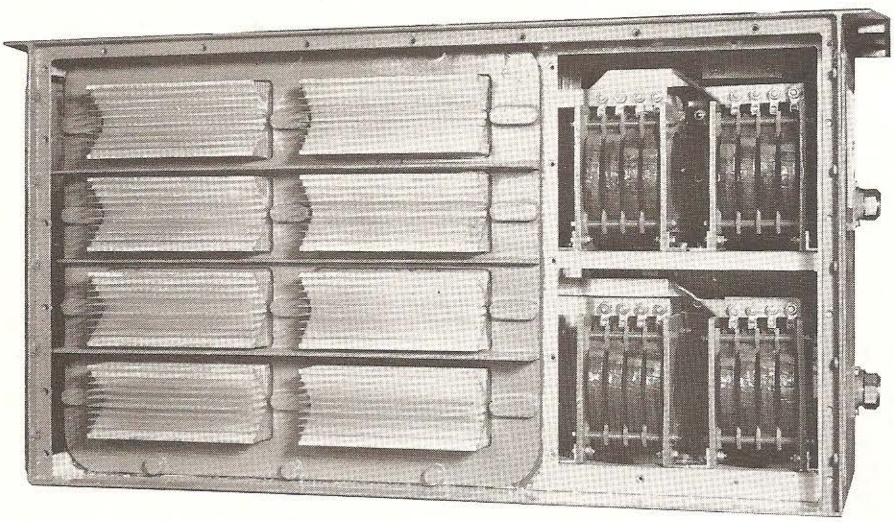


Fig 10. One of the thyristor assemblies showing the heatsink

sing the pedal twice.

To enable the driver to leave the cab when the train is stationary a speed-sensitive relay cuts out the vigilance equipment below 5 km/h. Failure of the vigilance causes a shutdown of traction power which can only be regained by the driver 'resetting'. As a further safeguard against the driver over-running signals at danger, L M Ericsson ATW/ATS equipment is fitted as part of the new signalling system being installed by the Taiwan Administration. This sounds a warning, followed by an automatic brake application, if the train speed has not been reduced to a certain value well in advance of a signal at danger. A magnetic 'beacon' on the track transmits a 'danger' signal to a receiver mounted under the car. The equipment then measures the speed after a certain time and applies the brakes if the limit is exceeded.

Speed indication is given to the driver by a GEC Type JB axle-driven tachogenerator with an indicator in the driving trailer cab. In the power car cab there is a Hasler tachograph driven by a flexible cable from an axlebox-mounted gearbox. In addition to speed indication the Hasler instrument shows the time of day and records time and speed against distance (time only when stationary) on a roll chart.

The train braking installation fitted is the Westinghouse Brake & Signal Co's Westcode electro-pneumatic brake, an 'energise-to-apply' system using only three train-line wires to give seven stages of brake pressure. Signals from contacts in the brake controller are converted into suitable train-line signals by a code conversion unit in the operative driving car. A brake unit in each car, acting in response to the train-line signals, admits the required air pressure to the brake cylinders by a multi-diaphragm valve. Electro-pneumatic braking is also called for by the electronic speed-control system when sufficient reduction of speed is required. The three-wire system used enables signals to be fed from the electronic traction control equipment to the code conversion unit in the power car to operate the brake units.

Speed and wheel-slip sensing

The speed control system takes its signals from magnetic probes in the four traction motor gearcases. Each probe sends a pulse back to a central processing unit as a gear tooth passes. A counting-and-timing circuit then computes the speed, which is compared with that demanded by the driver.

The same pulses are used also on the motor car to compare wheel speeds and acceleration or retardation to sense whether any wheel-slip is occurring. If so, the voltage to the motors on that bogie is immediately reduced until slip ceases, and is then increased slowly so as not to induce a further slip.

If slide occurs during rheostatic braking, excitation is similarly reduced but in this case on all motors as all the fields are in series. When slide ceases excitation is reapplied gradually. In electro-pneumatic braking, a brake cyclinder cut-out magnet valve operates to release air from the brake cylinders on the affected bogie under wheel-slide conditions. On cessation, the magnet valve is de-energised to allow the demanded brake-cylinder pressure to be re-applied.

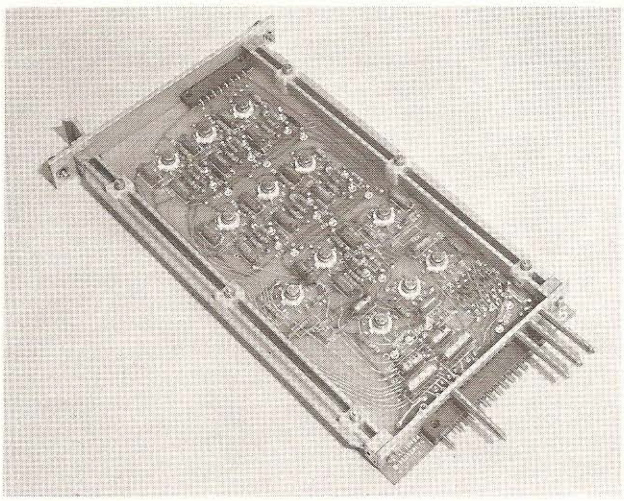


Fig 11. A typical electronic module showing the (large) polarising pins which are used to prevent the module being inserted into the wrong position

Simulator

In the early stages of contract, a simulator was built to investigate fully the speed control and other aspects of the advanced equipment used in these trains. It incorporated a speed controller, similar in operation to that proposed, and a series of instruments indicating train speed, difference between actual and demanded speed, armature current, tractive effort and braking effort (both rheostatic and electro-pneumatic). The motor characteristics as well as train weight, rotary inertia and tractive resistance formulae were all included.

In addition any values of grade and adhesion anticipated in service could be inserted. Thus the performance of the equipment could be studied on various grades and under widely varying conditions of adhesion. The simulator was invaluable in proving the integrity of the control system and was also much appreciated by visiting engineers from the operator. When the first complete equipment was built it was tested at the GEC Preston Works with the aid of the simulator.

Auxiliaries

Because of the desirability of using standard three-phase induction motors the auxiliary power is 440 V, 60 Hz, three-phase and neutral. The use of a neutral enables 250 V fluorescent lighting to be used as well as 250 V hand-dryers, refrigerators, hot cupboards and small extractor fans.

The three-phase is supplied by two GEC Type G783 AZ 100 kVA motor-alternator sets, one at each end of the train unit. The set on the power car supplies all the traction auxiliaries, such as the transformer oil pump, the main compressor and the machine ventilating fans, as well as saloon lighting and air conditioning on the power car and motor car. The saloon lighting and the air conditioning on the driving trailer and the two plain trailers are supplied by the motor-alternator set on the driving trailer. In emergency, either set can supply the traction auxiliaries, all the train lighting, and air conditioning on the two end cars but only ventilating fans on the remaining three cars.

The motor-alternator sets take their power from a single-phase 1500 V ac bus line fed from the transformer tertiary. A half-controlled rectifier bridge produces a controlled dc for each motor-alternator motor. A frequency regulator connected to the alternator output varies the dc voltage from the bridge in order to keep the speed, and therefore the frequency, steady. This is a more satisfactory method than directly controlling the speed of the set by varying the motor excitation.

The alternator is a brushless machine having an exciter mounted on the shaft. A voltage regulator controls the alternator output by varying the exciter excitation. To cope with sudden short-period heavy loads such as the starting current of the various motors, there is an excitation feed from the secondary of a current transformer in the alternator output. This boosts the field on heavy loads and prevents the voltage falling to a 'stall' point, where it would be insufficient to provide the field current necessary for recovery.

The main compressed-air supply for the five-car unit is provided at 9.84 kg/cm² (140 lb/in²) by a Westinghouse Type 3HC55 compressor. The machine is direct driven at 1150 rev/min by a GEC 11 kW 440 V three-phase squirrel-cage induction motor. The motor is mounted on the compressor flange by a cage, in the centre of which is the flexible coupling through which the drive is taken. The complete motor-compressor set is suspended from the coach underframe by three resilient mountings to reduce the vibration transmitted to the body of the car.

A Bristol type BPO2 auxiliary compressor is provided in the power car to raise the pantograph and close the vacuum circuit-breaker in the event of there being insufficient air pressure in the main reservoirs. The compressor is driven by a 0.75 kW dc motor fed from the 110 V battery and controlled by its own compressor governor. The auxiliary compressor starts when the battery contactor is closed and cuts out when the pressure in the pantograph reservoir reaches 5.3 kg/cm² (75 lb/in²). As the main compressor maintains the pressure in the pantograph reservoir at 5.3 kg/cm² and the auxiliary compressor will not cut in unless the pressure drops to 4.3 kg/cm², it only operates for a short period when the driver takes over a train which has been standing for some time.

The traction rectifiers are in two identical cases either side of the power car underframe and are force-ventilated. Two centrifugal fans are mounted in a compartment above the driving-end bogie. They draw their air through louvres and oil-wetted filters in the side wall. The air is discharged through the floor into ducts on the underframe and thence into the rectifier cases. Most of the air from the rectifier cases is discharged horizontally towards the centre of the coach but a proportion is ducted into the self-ventilated motor-alternator set.

The control equipment operates from a 72-cell 65 Ah Alcad nickel-cadmium battery located on the motor car. A thyristor-controlled charger fed from the 440 V three-phase supply maintains a constant 110 V at the battery terminals. In addition every car has a 20-cell

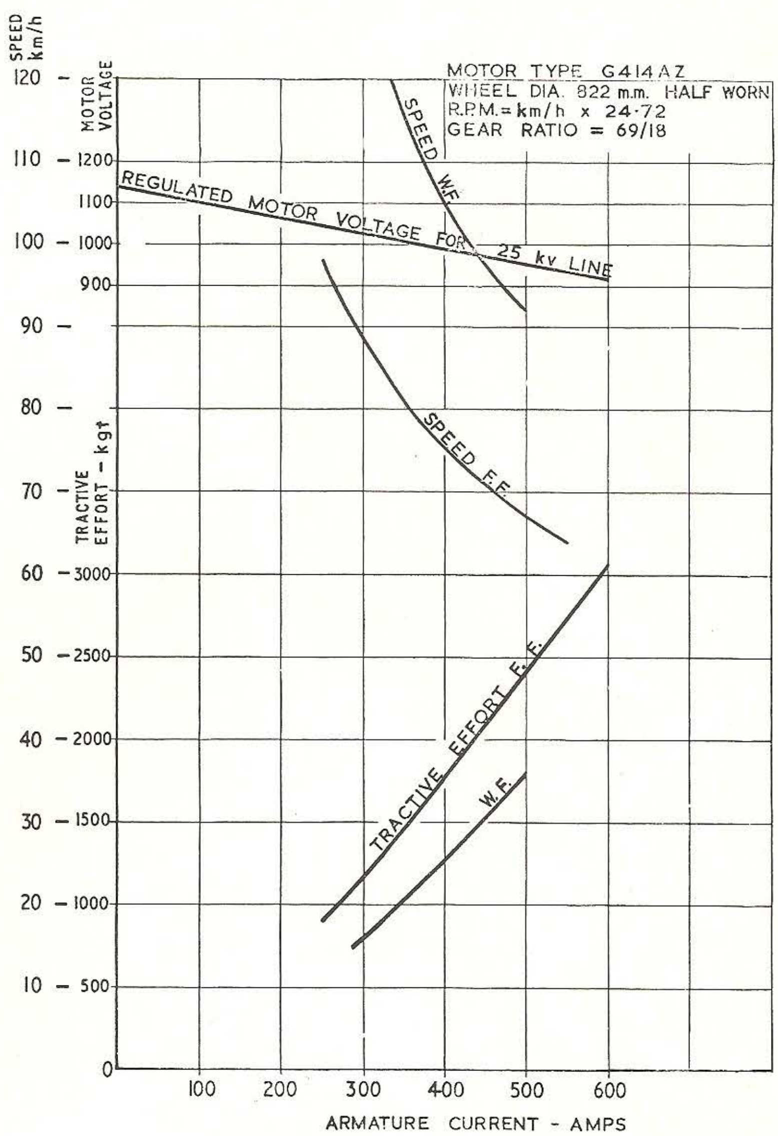


Fig 12. Characteristic of the G414 traction motor at the nominal line voltage and shown for the half-worn tyre condition

115 Ah battery for emergency lighting. It is fed at 29 V by a single-phase thyristor-controlled charger connected between two phases of the 440 V supply.

The car interior lighting is fluorescent, half of the fittings being fed at 250 V 60 Hz between line and neutral of the 440 V three-phase supply and half at 24-29 V dc from each car's own battery, to maintain continuity over section gaps in the overhead line. The battery-fed lights have individual inverters, or for the smaller powers, are connected two to an inverter. In the event of a power failure the majority of the battery lights are switched off automatically after 10 minutes, with only a few emergency lights remaining, in order to conserve the battery.

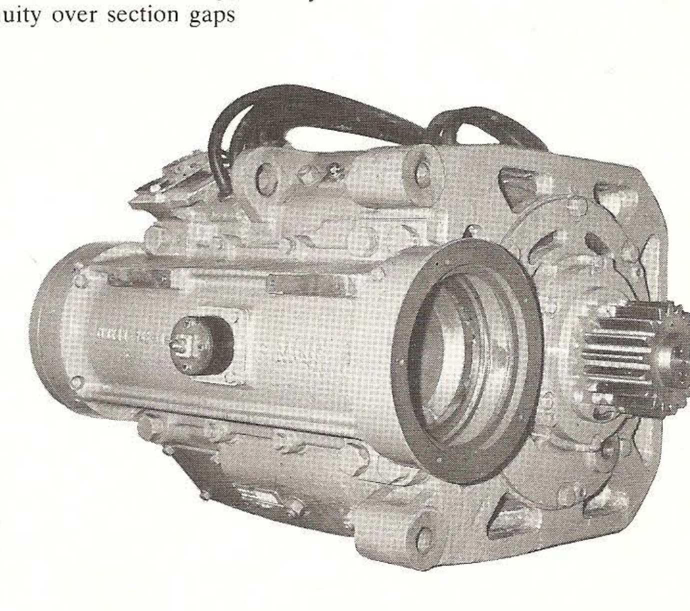
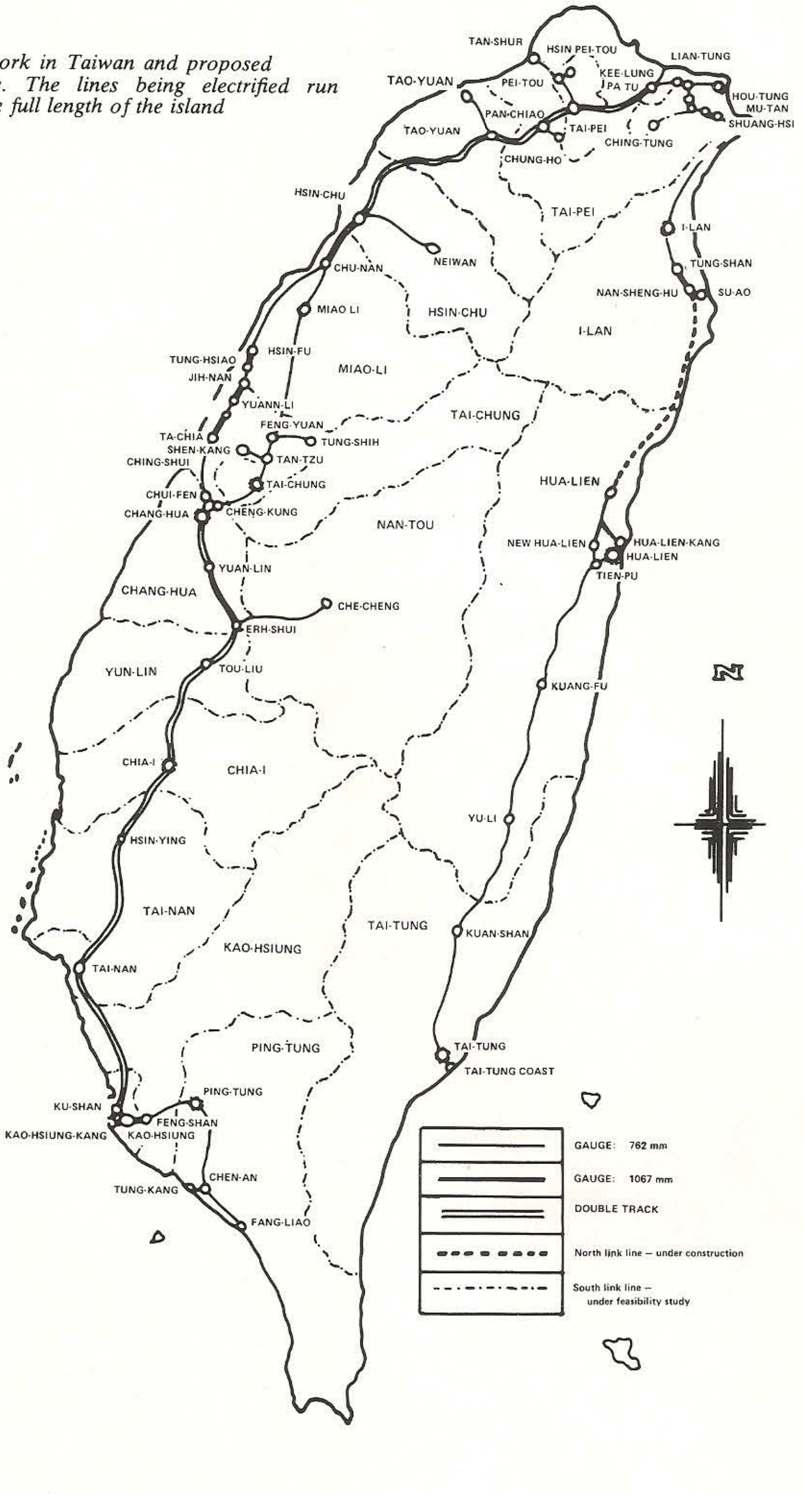


Fig 13. The G414 traction motor viewed with the 'U' tube suspension unit in the foreground

Rail network in Taiwan and proposed extensions. The lines being electrified run almost the full length of the island



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