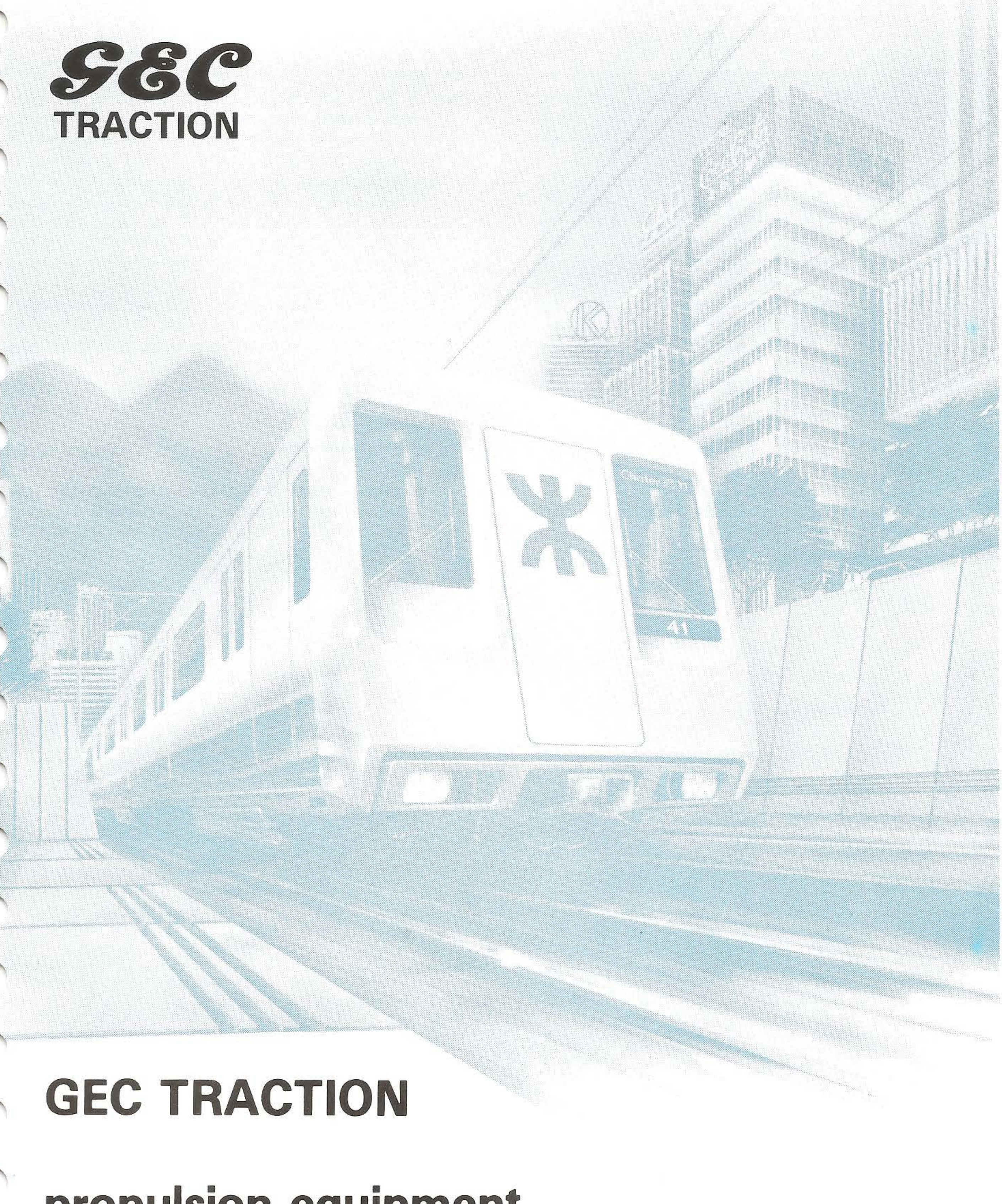
GEC
TRACTION



GEC TRACTION

propulsion equipment for Hong Kong Metro

HONG KONG METRO

For the Hong Kong Mass Transit Railway scheme, 1976 saw many of the major contracts placed for the construction of the Modified Initial System after a period of considerable activity. The road traffic congestion position in the Colony had led the Hong Kong Government to publish a study report in 1967 and two years later it commissioned consulting engineers to pursue the matter further. The 1967 report had put forward the proposition of building an underground metro railway system to meet the Colony's needs. The appointment of consulting engineers, therefore with professional competence on such a project where civil engineering was a major part, was obviously a first step. The firm appointed to the Corporation in 1969 was Freeman Fox & Partners (Far East) of Hong Kong, and they in turn retained the following as special advisers:

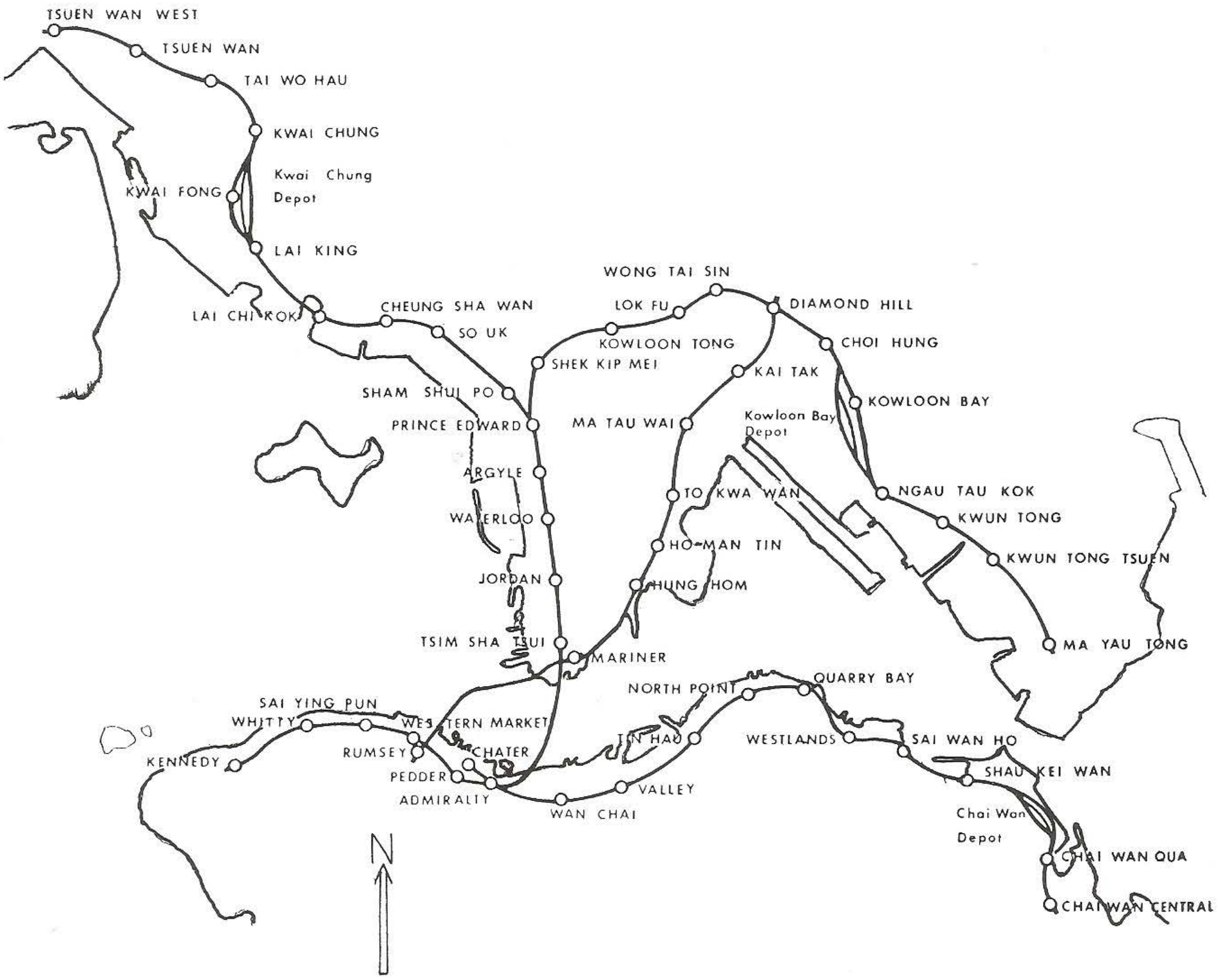
Kennedy and Donkin . . . . Electrical and Mechanical Plant and Equipment
Freeman Fox & Partners . . . . . . General Civil Engineering
Charles Haswell & Partners. . . . . Bored Tunnelling
Design Research Unit . . . . . . Architecture and Industrial Design
Per Hall Associates Ltd . . . . Immersed Tube Tunnel
London Transport. . . . . Operations
Freeman Fox & Associates. . . Traffic and Fare Structures

Freeman Fox & Partners (Far East) were retained as advisers for planning and design, and their first task was to do further studies to establish the changes in the design year (1986) traffic arising from the 1966 bi-census. A further Studies Report was drawn up and submitted to the Hong Kong Government in 1970. In this, the firm recommended the building of the Initial System which would subsequently be extended to the Full System (Fig. 1),that being the preferred system. The Full System embraces a route -km of 52.6 and comprises four lines:

Kong Kow Line - Chater Station to Ma Yau Tong Station
Tsuen Wan Line - Prince Edward Station to Tsuen Wan West Station
Island Line - Kennedy Station to Chai Wen Central Station
East Kowloon Line - Rumsey Station to Diamond Hill Station

In 1972, the Government decided to go ahead with the Initial System and invitations were sent to interested parties in July of that year for proposals to be submitted. The outcome was that in 1973 the Government decided

Fig 1. Full proposal for the Hong Kong Metro



Derived from an article originally printed in Railway Engineer November/December 1976
Cover illustration shows an artists impression of the train in service [Metro Cammell Ltd.]

to negotiate with four major consortia for the work to be placed on a single fixed-price contract and in 1974 a letter of intent was sent to a Japanese consortium. The latter, however, subsequently withdrew its offer on the terms agreed and the Government decided to abandon the single-contract concept.

Modified Initial System

The Initial System was later superseded by the Modified Initial System known as MIS (Fig 2) comprising the line from Chater to Kwun Tong on the Kong Kow Line. The Modified Initial System will be about 15.6 km of which 12.8 km will be below ground and the remainder overhead. It will serve 12 underground stations and three overhead and incorporates a maintenance depot on the Kowloon Bay reclamation east of Kai Tak Airport. The depot will stable the stock and provide inspection and service facilities as well as carry out overhauls. The administration offices will also be located there and the programme provides for its construction and completion ahead of the rest of the line so that it will be in a position to receive the rolling stock when it becomes due for delivery in mid 1978. From the depot, incoming and outgoing lines run north in twin bored tunnels in rock to Choi Hung Station where they join the running lines. To the south, the latter are in bored tunnel to Kwun Tong Road and serve the overhead stations at Kowloon Bay, Ngau Tau Kok and Kwun Tong.

The line running north and west from Choi Hung Station curves round Kowloon partly in twin bored

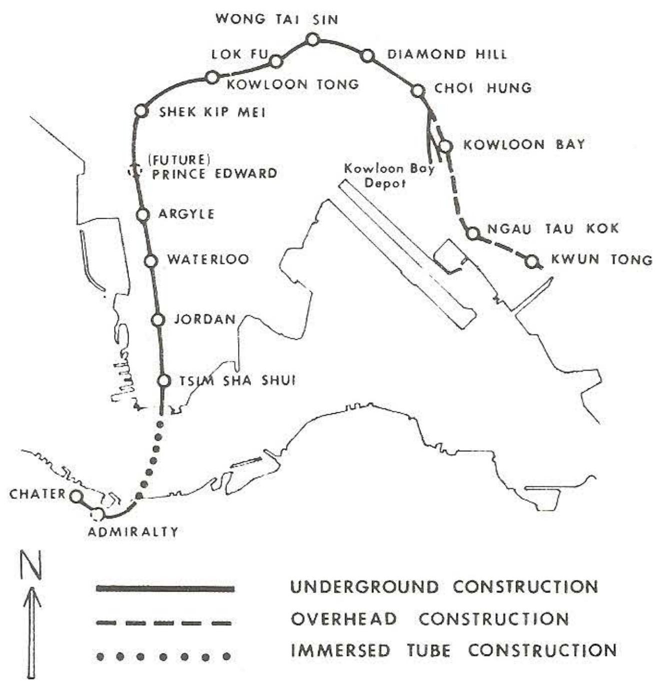
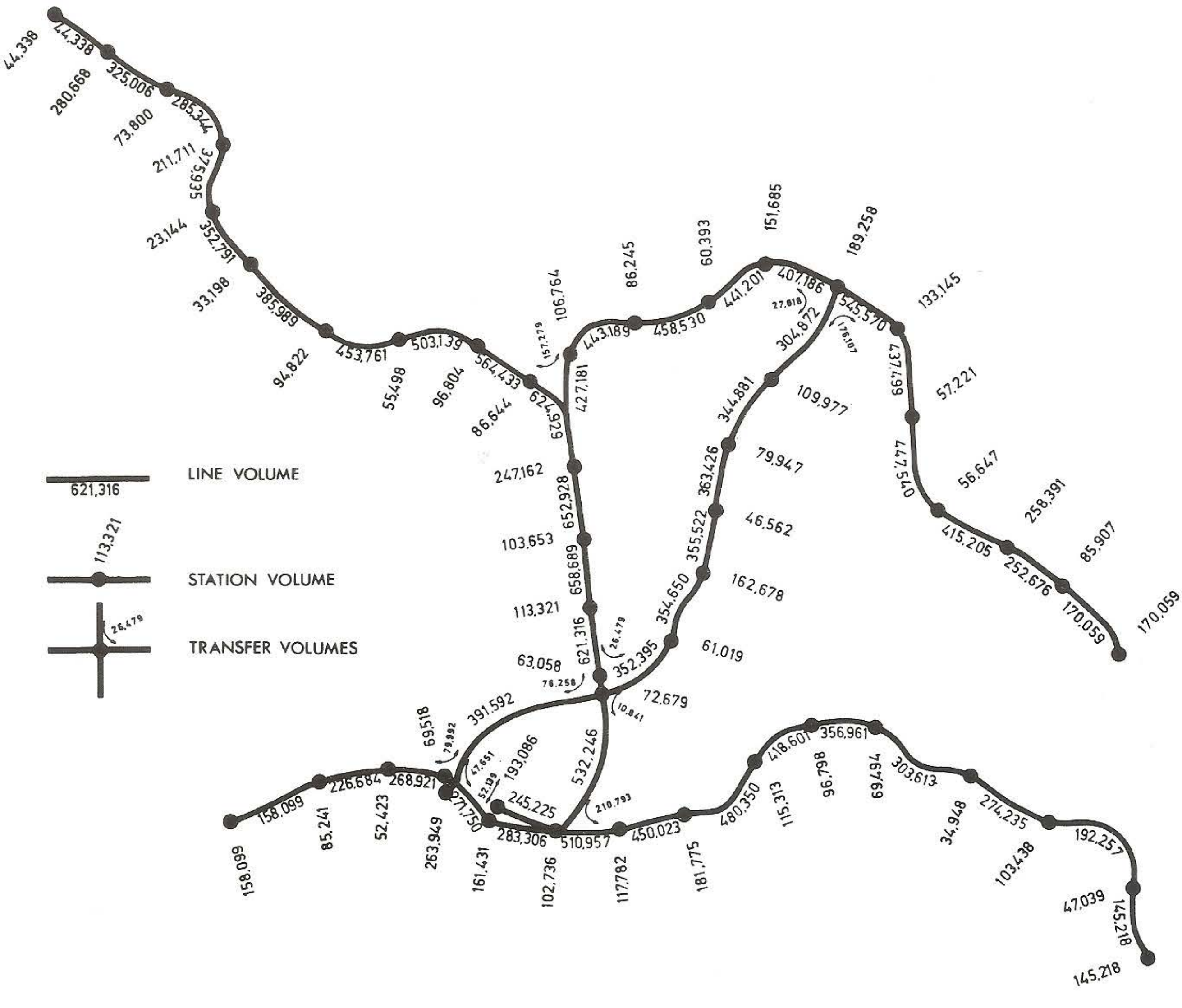


Fig 2. Hong Kong Metro Modified Initial System, now under construction

Fig 3. Line and passenger throughput for sections and stations, 1970 further study



tunnels, and partly in cut-and-cover tunnelling serving Wong Tai Sin, Lok Fu, and Shek Kip Mei Stations which will be underground. It will also serve the undeveloped area of Diamond Hill and the open residential area of Kowloon Tong. The Lok Fu Station will be the only station built by bored tunnel methods, the others on this length being located beneath public highways.

From Shek Kip Mei the line runs south beneath Nathan Road, at its north end a heavily populated commercial area and at the south a tourist hotel and shopping district. Continuing south west, the stations on this line will be cut-and-cover and number four: Argyle, Waterloo, Jordan and Tsim Sha Tsui. All these are located beneath Nathan Road and the line serving them will be in bored tunnels. Provision for the Tsuen Wan Line is being made at a lower level at Waterloo and Argyle Stations and another station, Prince Edward, is planned between Shek Kip Mei and Argyle.

The line will pass beneath Victoria Harbour by immersed tube to Hong Kong Island, and by twin bored tunnels to Admiralty Station (an undeveloped area) to terminate at Chater. The latter is to have two track levels, the lower to provide for stabling of stock. Stations will be basically twin level locations, the upper providing the concourse, booking offices etc., and the lower level, a single island platform.

Over recent years extensive site investigations including trial tunnels have been carried out. The variable ground conditions and high water table indicate that most of the underground stations will be built using diaphragm wall or similar techniques and compressed air working will be required for most of the bored-tunnel work. The underground stations are to be air conditioned. Power supply will be by the China Light & Power, and Hong Kong Electric companies at 33 kV, with system distribution at 11 kV and traction current by overhead at 1500 V dc.

Electrical & Mechanical Contracts

Operation is planned for a 90 s headway and a two-minute interval service with automatic train operation (ATO) and eight-car trains when the full system is commissioned. Initially four-car sets are programmed which will be increased to six and eventually eight cars when full demand is reached. Operation will be a 19 h day with three peak periods, and the 2- or 3-minute interval service will be operative for 75% of the day's timetable. The network being built will be dealing with up 60,000 passengers hourly in each direction. The majority of stations are located on 'humps' and the most severe grade on the system is limited to 3%.

July 1976 saw the awarding of rolling stock and associated contracts. These included 140 metro cars types 'A' and 'C' to Metro-Cammell Ltd., with an option for a further 70 (35 type 'B' and 35 type 'C') with electric traction equipment supplied by GEC Traction Ltd. GEC Rectifiers Limited is providing the 33 and 11 kV equipment for the substations, and Westinghouse Brake & Signal Co has the contract for the signalling and control. The ATC (automatic train control) consists of three independent systems, supervision and control from Kowloon Bay under normal operation, and local control from stations under emergency conditions. The digital ATO information transmitted to the train at strategic points defines coasting and stopping points and includes appropriate allowances for gradients. The train will stop in the station within a margin of $\pm$ 0.5 m.

Westinghouse are also supplying Westcode analogue controlled electro-pneumatic brake equipment for the cars. This system includes control of the brake through a pulsewidth modulated train wire and is arranged in the energise-to-release fail-safe mode. It is integrated with the electrical dynamic brake and with the ATO equipment. The contract includes also bogie tread-brake units, one brake unit for each wheel.

With respect to operation, a mosaic diagram and control desk installation is being supplied to provide control and indications of normal signalling functions, as well as controlling the train coasting programmes. The indications will include train description using two

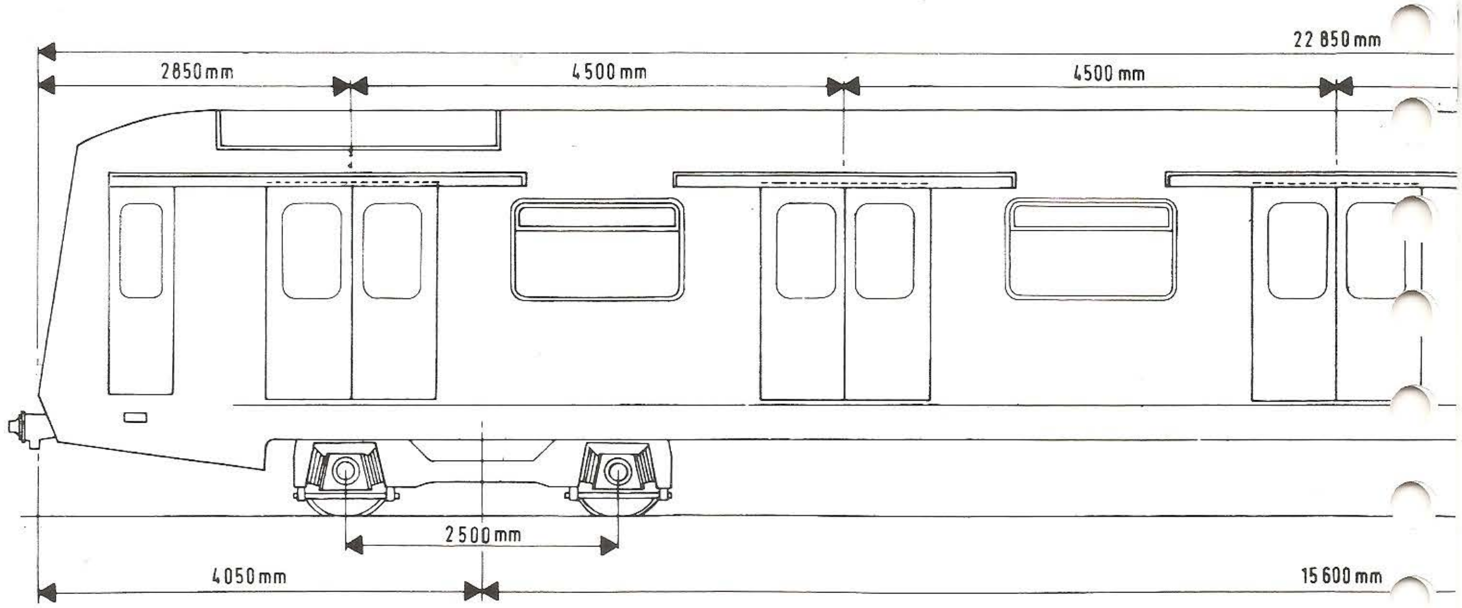


Fig.4 General diagram of 'A' car. The five outside suspended power-operated doors give generous access to the single open saloon, laid-out with profiled bench-type seating backing along the side walls

computer-based train describer equipment with automatic train reporting and selected train recording functions.

Automatic Train Protection (ATP) is by a coded-carrier signal to the exit end of each track circuit, consisting of one of two carrier frequencies modulated by one of four codes. The coded carrier feeds information to the trains concerning the maximum speed for that track circuit plus an indication of target speed. The particular code/carrier combination for each track circuit will be determined by the state of occupancy of tracks ahead, together with the interlocking requirements. The coded carrier will be transmitted via conventional jointed 50 Hz track circuits using impedance bonds.

Rolling stock

The rolling stock being designed and supplied by Metro-Cammell in the UK are believed to be the largest capacity Metro cars in the world. The initial contract is for 70 pairs of cars, type 'A', which are being fitted with half the control equipment and have a driving cab, and type 'C' which have the remainder of the control equipment and carry the pantographs but have no cab. Further pairs of vehicles (on which an option exists) will include type 'C', as now, and type 'B', which are as type 'A' in terms of general equipment but without the driving cab.

The first trains will be four-car formations - AC-CA, which will be progressively lengthened as demand increases to AC-BC-CA and then AC-BC-BC-CA.

The passenger accomodation in all three types is identical and thus the cab type 'A' is longer, at 22.85 m, than the types 'B' and 'C' which are 22 m. Maximum passenger accomodation is obtained by a number of features including a very generous car body width of 3 m and only a single row of longitudinally-arranged seats each side of the saloon. Swift loading and unloading will be by having five 1.4 m door openings each side per car, with movement within the train itself facilitated by wide vestibule-connections between cars. It is envisaged that a fully loaded eight-car train could accommodate 3300 passengers.

To make the maximum use of the railway itself, high train performance is required and to achieve this all axles are motored. Initial acceleration is 1.3 m/s² (4.68 km/h/s) and normal retardation is 1.35 m/s² of which 1 m/s² is obtained from rheostatic braking. In emergency 1.4 m/s² can be obtained. Maximum service speed is 80 km/h.

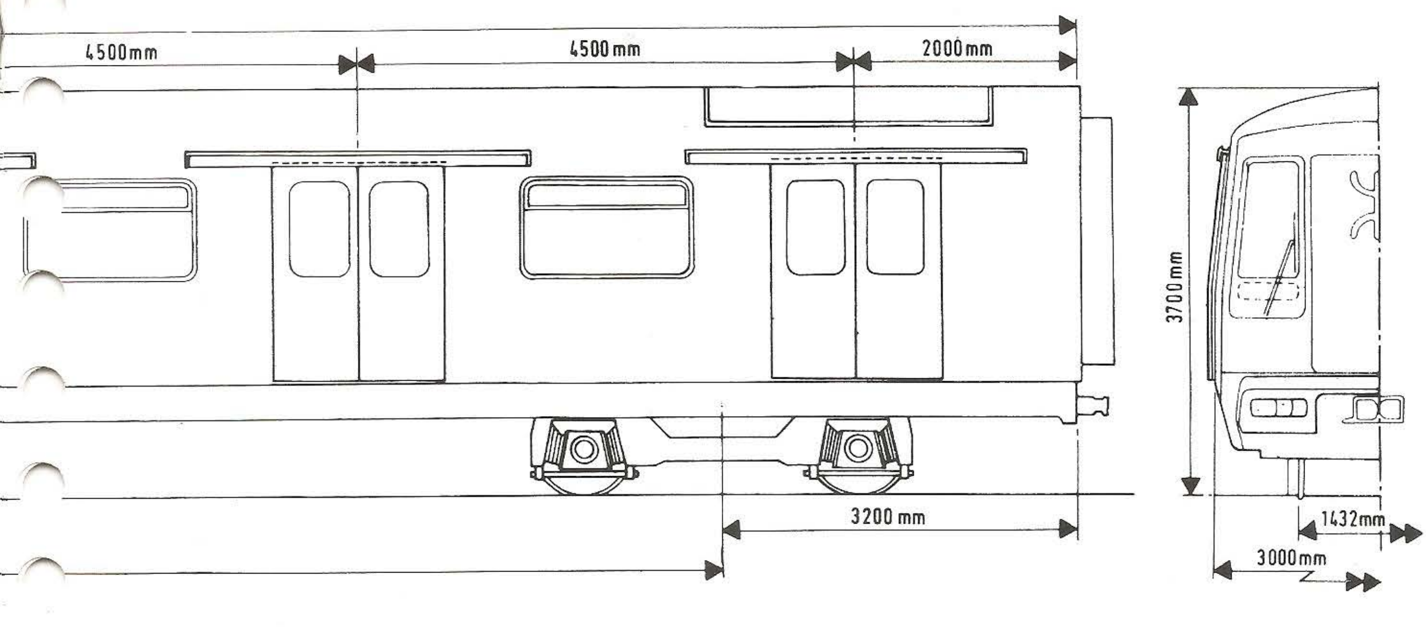
The trains are formed of semi-permanently coupled pairs with 'A' cars at each end. The 'C' cars are semi-permanently coupled to either the 'A' or 'B' cars by Metcalfe-BSI couplers, while the outer ends carry Metcalfe-BSI automatic centre couplers. The couplers incorporate the AL6 resilient universal joints and accomodate traction and buffing forces up to 834 kN (tension) and 981 kN (compression). The intermediate train line connection between 'A' and 'C' cars will be by jumper connections manually engaged and there are extra jumpers for the 1500 V dc traction current for the 'A' and 'B' cars and to the motor alternator sets and compressors.

The bolsterless bogies are H-frame fabrications with chevron primary suspension elements. Vertical, lateral and rotational oscillations are accommodated by large diameter single-convolution airbags and are hydraulically damped. The airbags are fixed at the underframe and rotationally free at the bogie mountings to avoid torsional distortion and excessive bogie rotational resistance. The airsprings maintain floor height irrespective of the large payload variations, facilitate load weighing and are located as high and as far apart as possible to inhibit body roll. One of the two tread brake sets at each axle incorporates a spring applied air-released stabling brake.

Control scheme and equipment

All eight traction motors on a pair of cars (either AC or later BC) are controlled by a single equipment. Fig 7 shows equipment schematically and also indicates the physical disposition of particular items on two cars. Power is collected by a double headed pantograph mounted on the 'C' car and is taken to the line breaker circuit. This consists of three line breakers in series which under normal operation all open simultaneously. Under fault conditions, however, LC3 opens first inserting a fault limiting resistance into the circuit and thereby reducing the current to be interrupted by LC1 and LC2.

Thereafter the circuit splits into two paths each of which contains four traction motors in series. At starting the series camshaft (on the 'C' coach) is used to control all eight motors in series, power being carried between



vehicles by power jumpers, rated for full line voltage and accelerating current. After transition the parallel camshaft takes over and cuts out resistance from each motor leg in turn.

Braking uses the crossed field braking scheme whereby armature current from motors 1-4 flow in the field of motors 5-8 and vice-versa, the combined current flowing through the series resistance. Field injection is used to ensure a rapid build-up of braking effort regardless of the speed at the entry into braking.

Traction motors

The GEC type G313 traction motors are series wound self ventilated machines derived from those presently being supplied for British Rails' dual-mode 25 kV/750 V dc multiple units working the Great Northern inner suburban services. They are connected in permanent-series strings of four which in turn are connected in series or parallel across the supply.

The electro-magnetic features of the motor, construction, insulation systems and components are designed for high reliability. The motor incorporates class 'H' Kapton insulated armature coils, glass banding on the armature, commutator V-rings moulded from epoxy

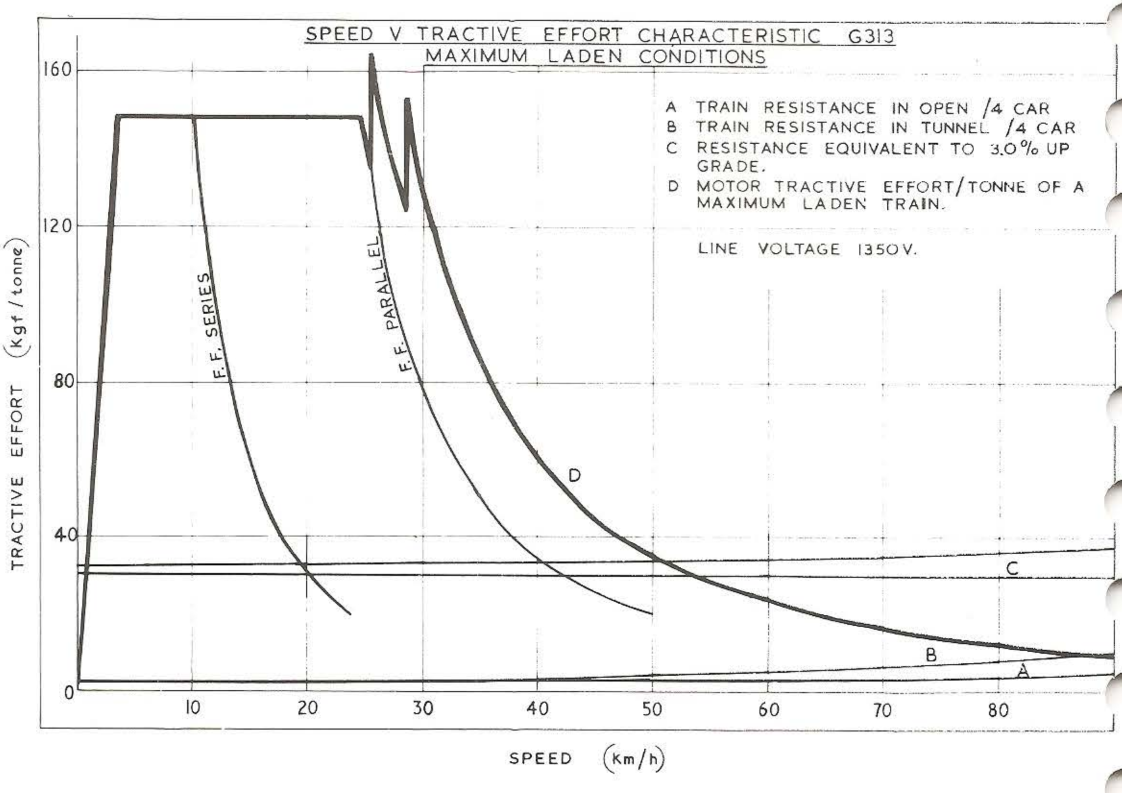


Fig 5. Tractive effort/speed characteristics of the all-motored Metro cars

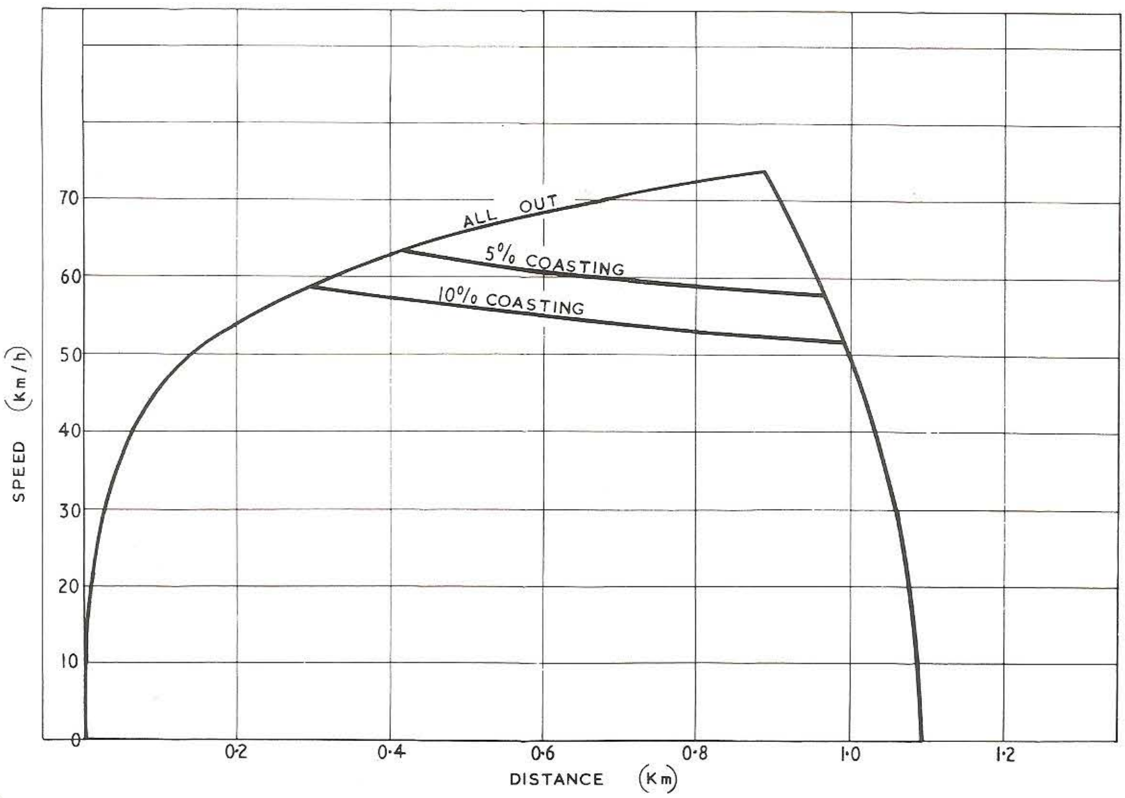


Fig 6. Running performance characteristics

glass, armature conductors TIG welded to the commutator, class 'F' epoxy insulated field coils, PTFE sleeves on the brush gear insulators and PTFE on the extension of the commutator front V-ring. The magnet frame is a steel fabrication to which is bolted a commutator chamber. High-ratio, single reduction helical gears are fitted. A cast light alloy U-type suspension unit carries the motor on the axle and incorporates insulation to protect the bearings of the tube from damage in the event of an electrical fault on the motor.

The motor has a high torque, relatively low speed characteristic in full field to save energy and reduce power demand at the high initial acceleration used on these rapid transit trains while the balancing speed is obtained by field weakening using an inductive divert. A high level of electric rheostatic braking is provided. The rating suits train operation on the short interstation spacing of rapid transit systems and the temperature rise of the windings at the continuous rating is well below the permitted limits. The motor has a large overload capacity which will result in a long life.

The risk of flashover is minimised by very low levels of voltage per commutator segment in motoring and only moderate values at the high voltage, speed and power developed during rheostatic braking. Stability in weak field operation is provided by a relatively high ratio of field to armature turns. The use of an inductive divert gives good transient response to supply interruptions due to gaps in the overhead conductor system.

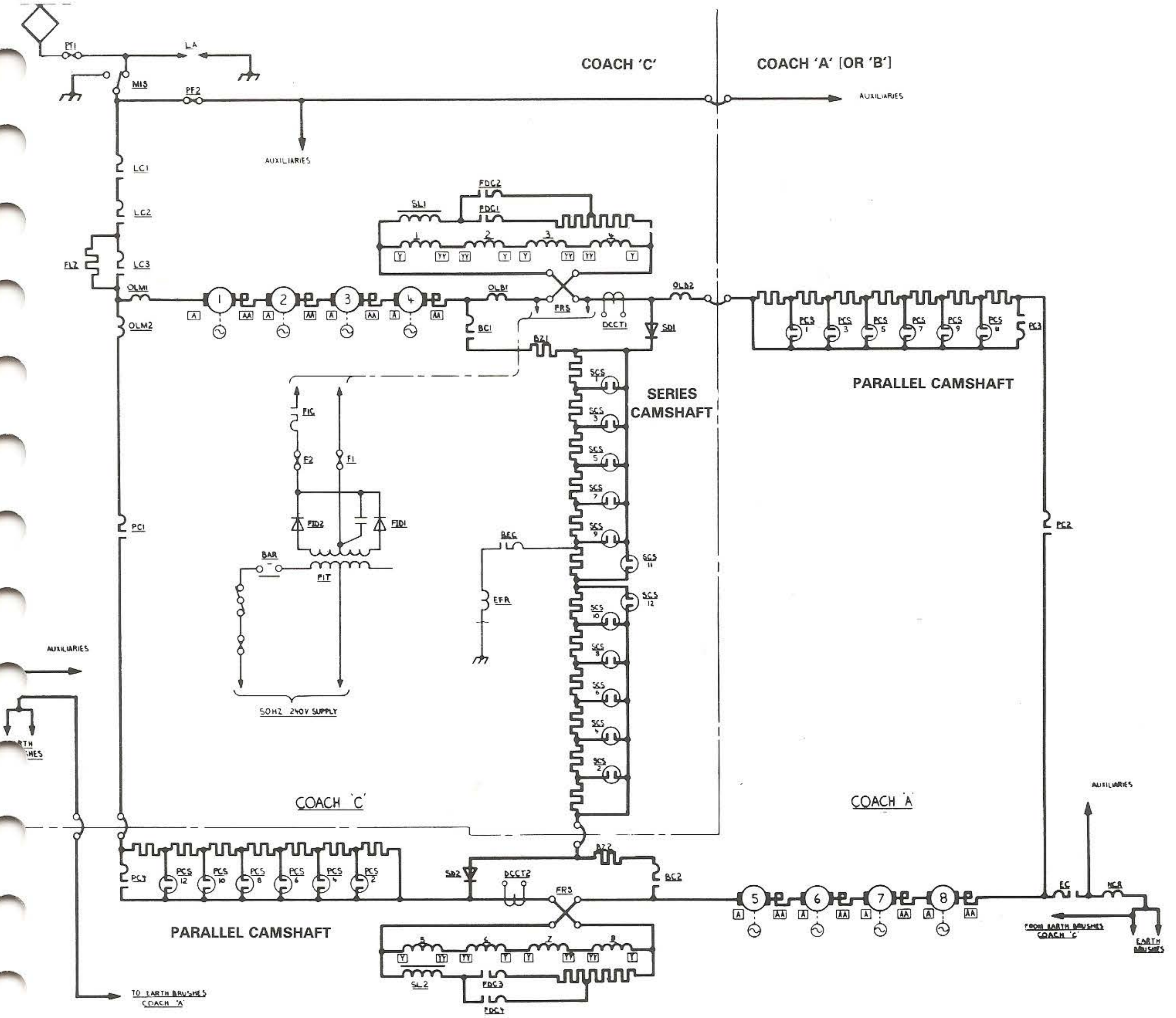


Fig 7. Schematic circuit diagram for twin-car sets: BAR – brake actuating relay; BC1–2 – brake contactors; BEC – brake earthing contactor; DCCT1–2 – dc current transformers; EC – earthing contactor; EFR – earth fault relay; FDC1-4 – field divert contactors; FIC – field injection contactor; FID1-2 – field injection diodes; FIT – field injection transformer; FLZ – fault limit resistor; FRS – forward reverse switch; LA – lighting arrestor; LC1–3 – linebreaker contactors; MIS – main isolator; NCR – non-current relay; OLB1–2 – overload braking relay; OLM1–2 – overload motoring relay; PC1–4 – parallel contactors; PCS – parallel camshaft switch; PF1 – pantograph fuse; PF2 – main auxiliary fuse; SCS – series camshaft switch; SD1–2 – series diodes; SL1–2 – inductive shunt.

Layout of Equipment

The main traction control gear on each car is mounted in a 'pannier' type case which is the full width of the car. Resistances for both starting and braking are located in the centre of the case and force-cooled by air driven by fans mounted at the end. Other apparatus is located at either side and protected by resin-impregnated glass fibre covers designed to keep out moisture, dust etc. while giving good access for inspection and maintenance. The camshaft controllers are of the air/oil type which has been extensively used in the UK and overseas for both 1500 V and 750 V applications.

The equipment is divided between the 'A' and 'C' cars which have basically similar underfloor layouts. Each carries a motor-alternator set, but the Metcalfe C6 air compressor for the brake, suspension, doors, and controls is allocated to one vehicle and the Alcad nickel cadmium 110 V batteries to the other. The MA sets and compressor are 1500 V dc driven.

	NOTCH Nº	SCS STEP	PCS STEP	LC1-3, EC	PC1-2	PC3-4	BC1-2	SERIES CAMSHAFT												PARALLEL CAMSHAFT												FDC 1&3	FDC 2&4
								1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12		
OFF	0	1	1																														
SHUNT	1	1	1	●																													
MOTORING – SERIES	2	2	1	●				●																									
	3	3	1	●				●	●																								
	4	4	1	●				●	●	●																							
	5	5	1	●				●	●	●	●																						
	6	6	1	●				●	●	●	●	●																					
	7	7	1	●				●	●	●	●	●	●																				
	8	8	1	●				●	●	●	●	●	●	●																			
	9	9	1	●				●	●	●	●	●	●	●	●																		
	10	10	1	●				●	●	●	●	●	●	●	●	●																	
	11	11	1	●				●	●	●	●	●	●	●	●	●	●																
	12	12	1	●				●	●	●	●	●	●	●	●	●	●	●															
	13	13	1	●				●	●	●	●	●	●	●	●	●	●	●	●														
	14	14	1	●				●	●	●	●	●	●	●	●	●	●	●	●														
MOTORING – PARALLEL	15	14	1	●	●			●	●	●	●	●	●	●	●	●	●	●	●														
	16	14	2	●	●			●	●	●	●	●	●	●	●	●	●	●	●	●													
	17	14	3	●	●			●	●	●	●	●	●	●	●	●	●	●	●	●	●												
	18	14	4	●	●			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●											
	19	14	5	●	●			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●										
	20	14	6	●	●			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●									
	21	14	7	●	●			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●								
	22	14	8	●	●			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●							
	23	14	9	●	●			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●						
	24	14	10	●	●			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●					
	25	14	11	●	●			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●				
	26	14	12	●	●			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			
	27	14	13	●	●			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		
	28	14	14	●	●	●		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		
MOTORING – WEAK FIELD	29	1	2	●	●	●														●												●	
	30	1	1	●	●	●																										●	●
COAST	0	1	1																														
BRAKING	1	1	1		●		●																										
	2	2	1		●		●	●																									
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	13	13	1		●		●	●	●	●	●	●	●	●	●	●	●	●	●														
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	15	14	3		●		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●												
	16	14	4		●		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●											
	17	14	5		●		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●										
	18	14	6		●		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●									
	19	14	7		●		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●								
	20	14	8		●		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●							
	21	14	9		●		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●						
	22	14	10		●		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●					
	23	14	11		●		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●				
	24	14	12		●		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			
	25	14	13		●		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		
	26	14	14		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		

The three-phase alternator output is fed through a field forcing unit to the auxiliary transformer and also a three-phase circuit breaker, this latter providing supplies for those services supplied at phase-voltage and frequency. The transformer provides a voltage suitable for rectifying to 110 V dc for the control system supplies and for charging the batteries. The air governors on the train are electrically connected in parallel so that all air compressors operate together on the highest cut-in governor. The Stone Platt air conditioning compressors, condenser and evaporator fans are driven by 440 V three-phase 60 Hz motors, but the evaporator's fans have stand-by 110 V dc motors to maintain car ventilation off the battery in the event of failure of the 1500 V supply.

Static notching equipment is used, comprising a current monitoring unit and a relay. The monitoring unit converts the 110 V battery supply into a square wave ac supply which is then used to excite the power current transductor. The transductor output is rectified to give a dc voltage proportional to the power current and this signal is fed to the relay which operates whenever the current signal is lower than the preset reference. Load weighing of course varies the reference level.

Because of the high performance required of the trains there is a risk of wheelspin or wheelslide particularly on open sections of the track. To detect and compensate for this comprehensive protection is fitted. A speed measuring probe is mounted on each gearbox and the output of each is fed to its own amplifier which converts the signal to four outputs:

(1) a dc voltage proportional to the input frequency;
(2) a digital signal indicating rate of change of speed;
(3) a square-wave signal at the input frequency;
(4) a digital output if the speed is greater than 3km/h.

Wheelspin/slide of one or more axles is detected by comparing the highest dc output with the lowest while simultaneous slip on all four axles is detected by the rate of change circuit. Actual speed is given by the amplitude of the square wave whilst the fourth function can be used as a safety signal on the door circuit to prevent them being opened unless the train is stationary.

If wheelspin is detected in motoring, LC3 is opened to give an immediate reduction in applied voltage (and thus current) and notching of the camshaft is stopped until spin ceases. In braking, the camshaft's progression is halted.

Automatic train control operation

The control outputs from the automatic driving control (ADC) equipment are connected to an interface unit. The outputs from this are connected to the motoring and braking train-line control wires which would be energised from the master controller when under manual operation. The interface unit ensures that the train responds fully to all commands given by the ADC equipment and the response times and rates of acceleration and deceleration are those as would apply for manual control.

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