Electronically Controlled 3000V Heavy Freight Locomotives Class 10E1

GEC
Transportation

GEC
TRACTION

Principal Data:

Axle arrangement	Co-Co
Gauge	1065mm
Supply system	3000V dc overhead
variation	2000 - 4000V
Length over couplers	18520mm
Width	2906mm
Pivot centres	10200mm
Bogie wheelbase	4060mm
Wheel diameter	1220mm
Total mass	126 tonnes
Continuous rating	3000 kW at rail
Starting tractive effort	450 kN
Continuous tractive effort	310 kN at 35 km/h
Maximum braking effort	195 kN (16 - 41 km/h)
Maximum speed	90 km/h
Continuous electric braking power	2187kW from 41 to 90 km/h
Minimum radius track curve	91m

Electronically controlled 3000V heavy freight locomotives

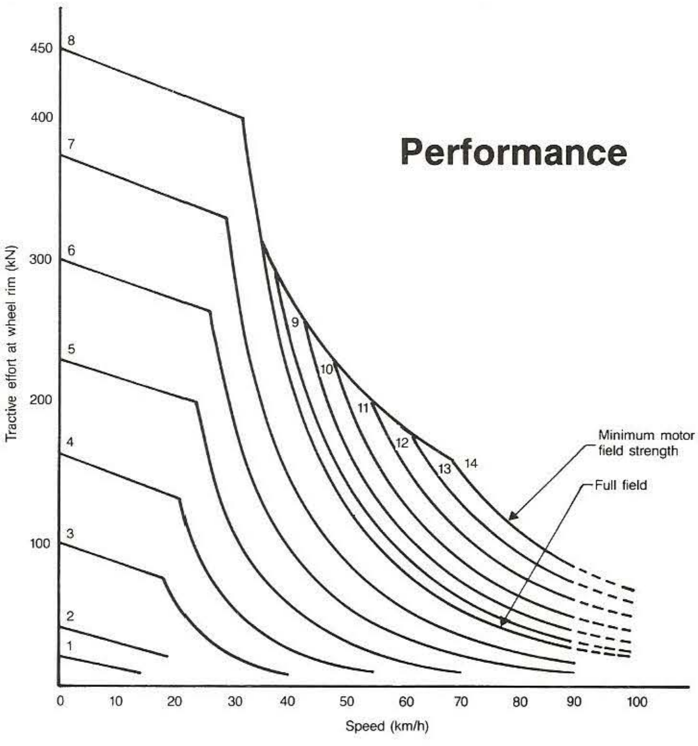
The Class 10E1 locomotive is a 126 tonne 6 axle locomotive designed for operation on any part of the South African Railways 3000V dc 1065 mm gauge system. The locomotives operate in multiple with the Class 10E locomotives supplied by other manufacturers, and are used to haul freight trains on the mineral lines. A typical loading is for four locomotives to haul a 10,000 tonne load on a line with a maximum gradient of 1%. Up to six locomotives can be operated in multiple.

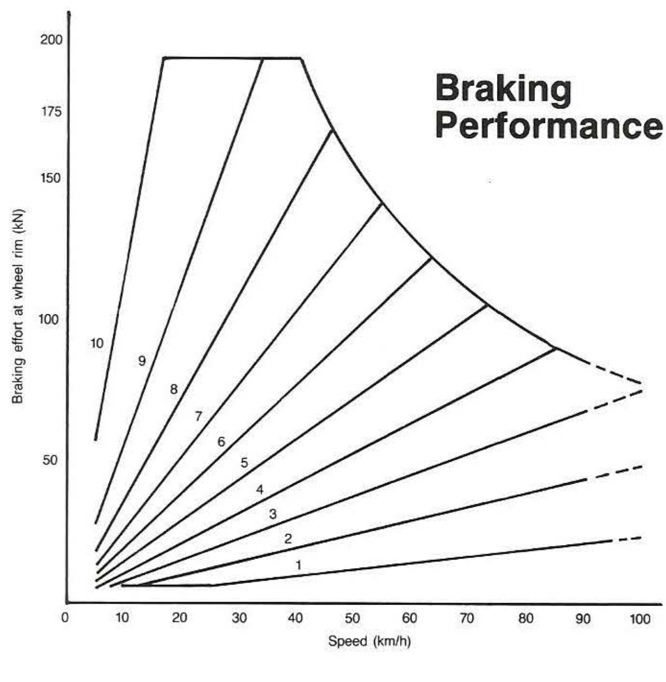
The locomotives work under arduous climatic and service conditions. Ambient temperature varies between −10 and 40°C and in coastal regions can have a high saline content with a relative humidity up to 86%. Snow, ice, severe dust and iron particle laden winds and frequent severe lightning storms also occur. The locomotives have to operate at altitudes up to 2000 m above sea level.

Performance

The performance in motoring and braking is shown in Figs. 1 and 2 respectively. The locomotive operates over a voltage range of 2 kV to 4 kV and has a starting tractive effort of 450 kN (equivalent to 37% adhesion) and a continuous tractive effort of 310 kN over the voltage range 2.4 to 3.75 kV. The microprocessor control system ensures matching of the performance characteristic over the entire speed range irrespective of wheel diameter.

The locomotive has a fully blended regenerative/rheostatic electric braking system; the maximum braking effort of 195 kN is available over the speed range 16 to 41 km/h; there is a continuously rated braking power of 2187 kW at rail. Dependent on the receptivity of the overhead line the braking energy is either returned to the supply or dissipated in forced cooled resistor banks, one for each bogie, which are continuously rated for the maximum braking power.





Mechanical Parts

The locomotive has 2 cabs with a full width body, with access available between coupled locomotives.

The body and underframe is an integral, all-welded steel fabrication made from low carbon structural sheets, plates, fabricated and rolled sections. The structure is designed to withstand a buffing load of 3000 kN applied at the locomotive couplers and is also of sufficient strength to allow the complete locomotive to be lifted from the ends. To verify the strength of the structure, strain gauge testing was performed on the first complete body shell.

The underframe consists of two longitudinal side members interconnected by intermediate cross members and at the end buffer beams and drag boxes. It supports the electrical equipment and also acts as an air duct for the ventilation air to some of the equipment. The side framing forms the side of the locomotive above the underframe. Openings in this structure provide access to the equipment inside the locomotive. The cab bulkheads divide the machinery compartment from the driver's cab. Removable roof sections over the machinery compartment facilitate assembly and maintenance. Rubber-cushioned draft gear is fitted at each end of the locomotive of the AAR Type "F" and to this is fitted an AAR Type "E" coupler. The coupler and yokes have a working strength of 2250 kN.

Bogie

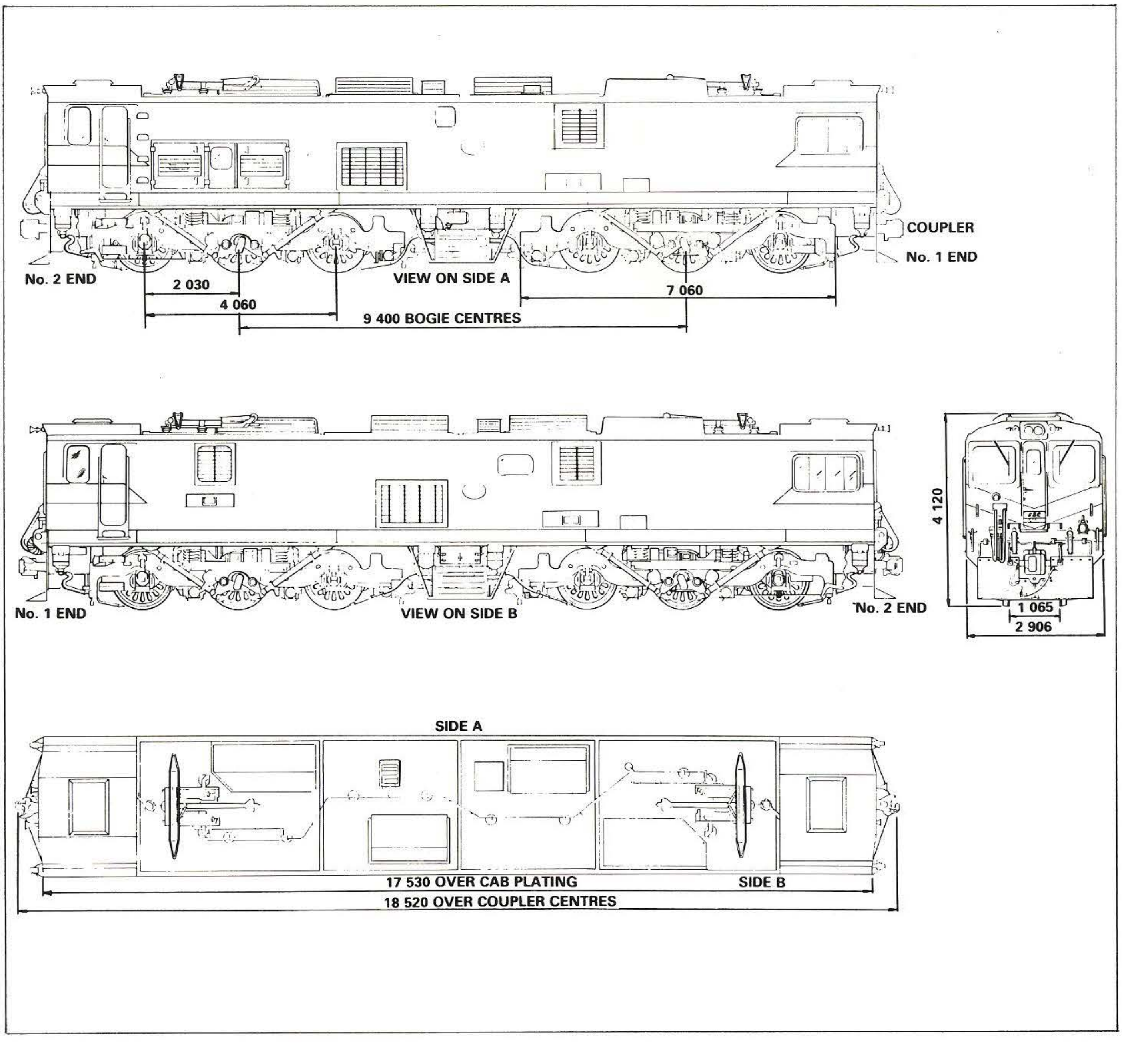
The 3 axle bogie is of a cast steel construction, and is a development of the bogie used successfully on a large number of previous South African Class 7E locomotives. Traction and braking forces are transmitted through inclined low level traction links which minimise weight transfer effects within the bogie. The traction motors are arranged in tandem which also helps to minimise the effects of weight transfer.

The bolster is connected to the body at the pivot which incorporates a wear sleeve of ultra high molecular density polyethylene and the side bearers are lined with PTFE to minimise maintenance.

Increased lateral tolerance at the centre axle is incorporated to assist curving and an inter-bogie linkage is fitted between the two bogies and comprises two A frames with a centrally connected spring device. This assists curving. The high level of the secondary springs on a wide base ensures good roll stability.

Spoked wheels are fitted and the gearwheel rim is bolted to an extension of the wheel hub, to make best use of the limited space available between the wheels on 1065 mm gauge.

Modular brake units are used with a single brake cylinder operating a composition brake block on each wheel. This eliminates the need for brake rigging between axles on the bogie. A lever operated hand brake is fitted in the No. 2 cab and operates on the bogie at that end of the locomotive.



Power Circuit

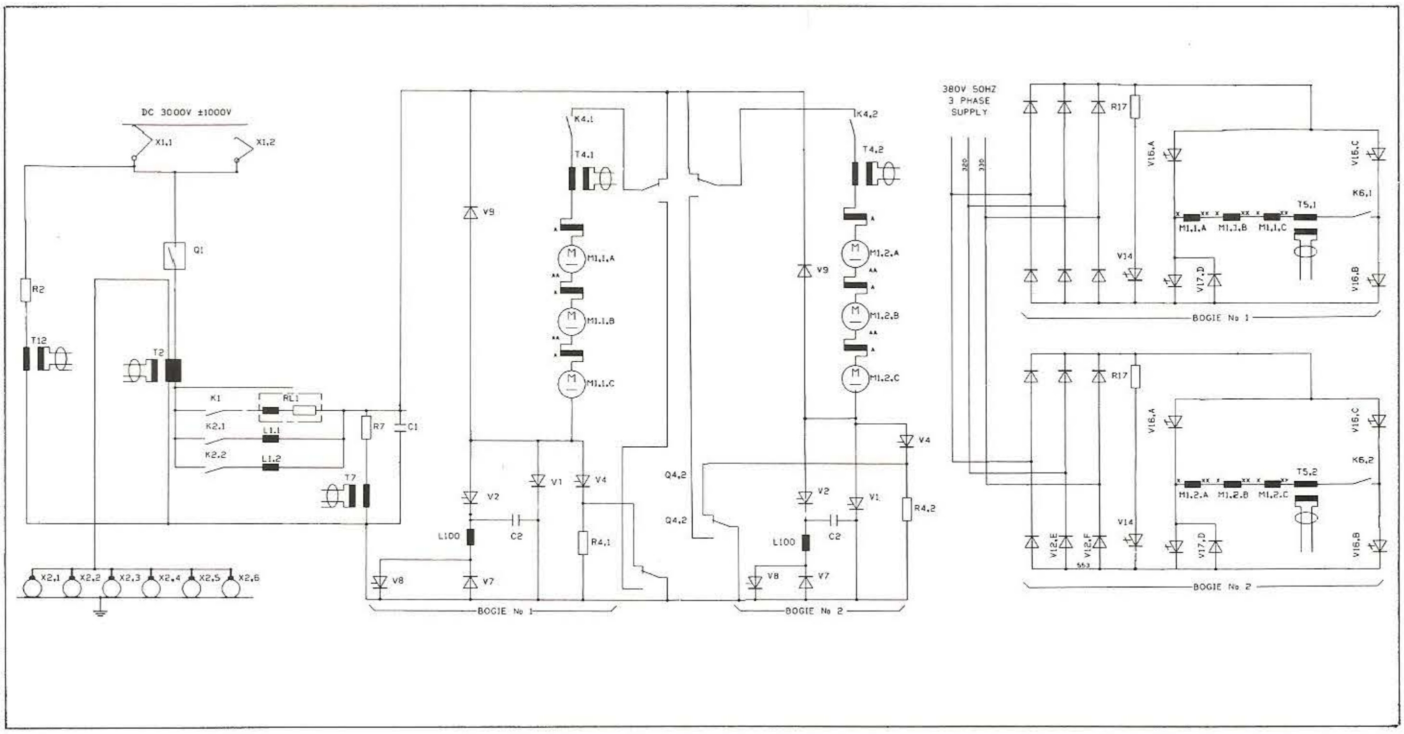
Armature Converters

Conversion of the 3000 V dc overhead supply into useful torque at the locomotive wheels is via thyristor choppers. The main converters uses the GEC standard "three thyristor" design. Power is provided separately to each of two bogie groups via 800A, 2000V — 4000V choppers connected on the negative side of the motors. Each chopper controls a series group of three separately excited dc traction motors.

Field Supply

The field supply is relatively low power, and is derived from a motor alternator set. To minimise waveform distortion and improve the power factor, the alternator output for each field group is full-wave rectified and then controlled by gate turn off thyristors (GTO's).

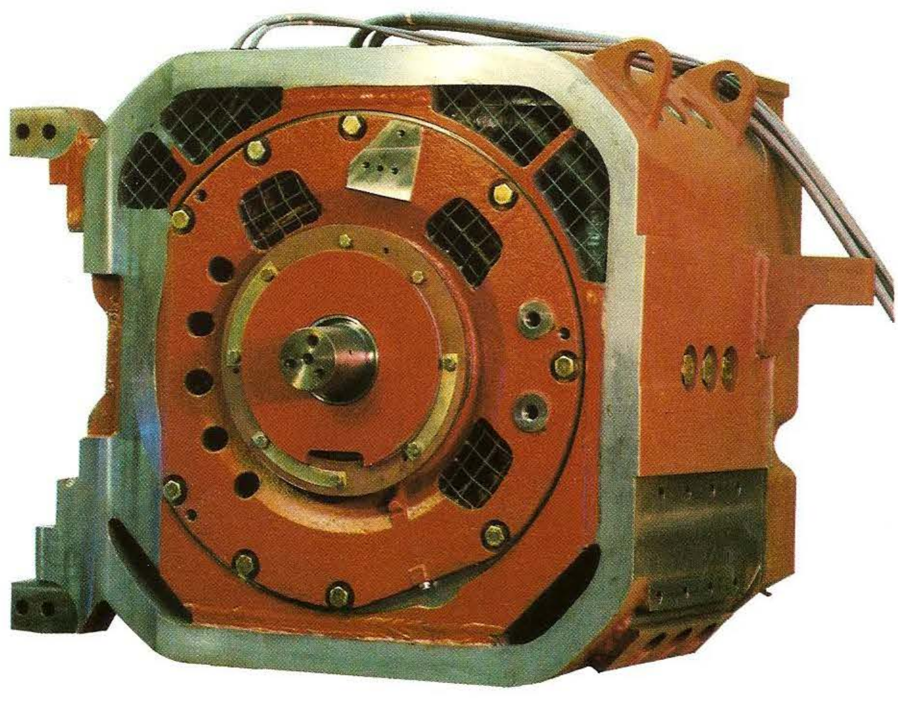
A separately excited traction motor has many advantages for locomotive control in its flexibility but can suffer from supply voltage transients. To overcome this potential problem the field drives were made "four quadrant", enabling the field current to be forced up and down in forward and reverse. The field drive is designed so that it can produce over three times the necessary voltage for full field current in either polarity. Thus the field responds very quickly without the need for any electro-mechanical switching.



Traction Motors

The type G425AZ motor is a 4-pole machine having a continuous rating of 900V, 645A, 546kW, 774rev/min. The armature is lap wound and both fields and armature are insulated to Class H standards. The motor is of the axle-hung nose-suspended type which drives through a single reduction gear train with a ratio of 17/87.

The fabricated motor frame is partially laminated.



Microprocessor System

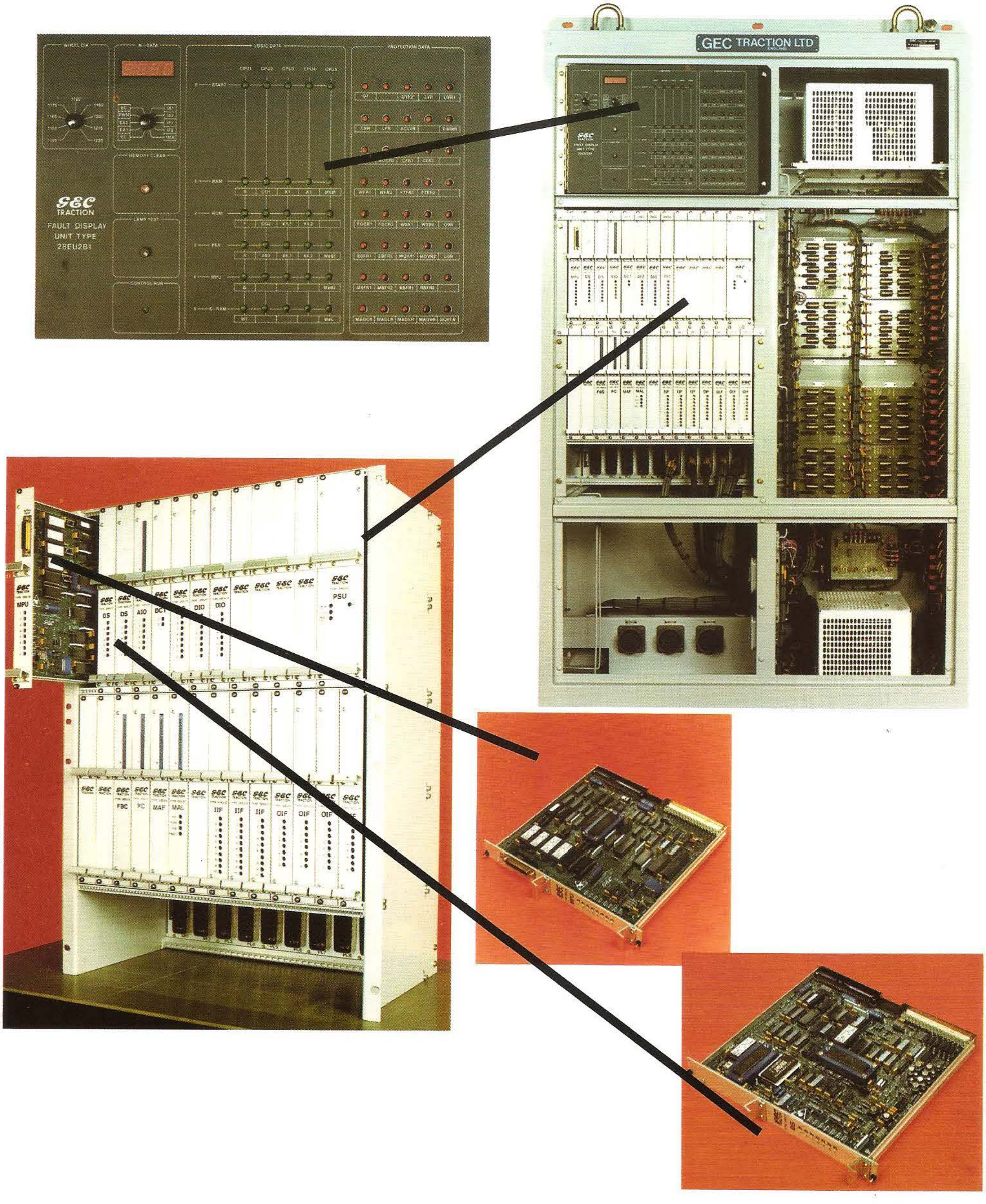
The microprocessor system used on this locomotive is based on the Intel 8086 processor, operating with four Intel 8031 micro-controllers. The 8086 microprocessor has overall control of the system, with 8031 micro-controllers operating in pairs to control the armature choppers, one pair to each motor group. Only the MA set is controlled independently of this system.

Previous designs of dc locomotives had large numbers of electro-mechanical relays. The design of this locomotive reduces the number of electro-mechanical relays to a practical minimum. This involved transferring much of the logic performed by these relays into the microprocessor system. Since such devices respond relatively slowly the additional load on the microprocessors is small.

Using a microprocessor allows much more complex and adaptive logic to be used. It is easy for the control system to change in response to conditions, which otherwise would be difficult to implement. This locomotive, using separately excited motors, makes full use of the microprocessor's adaptability.

Motoring

The required tractive effort characteristic is essentially a "series" characteristic. In order for the separately excited scheme to produce this, the control scheme emulates a series



machine. The advantage of this method is that step-less field weakening can be obtained. The motor voltage is controlled by the field; motor voltage demand is set depending on the required operating conditions (e.g. line voltage), while the field current limit is set depending on the wheelsize of the bogie group, and the power demand. The armature current is controlled independently to the field. The microprocessor is programmed with a set of look-up demand tables for each power level against speed. The system continuously calculates the required armature current, using these tables, and interpolating for intermediate values of power and speed.

At low speeds, the field current reaches its maximum value before the demanded motor voltage is achieved. In this region the vehicle accelerates with a constant field current. Combined with the armature current being constant, this will give the characteristic as a series motor operating on constant current. Once the speed has built up, the field current will be progressively weakened so as to maintain a constant motor voltage. This is analogous to field weakening a series machine. At this stage the armature current is controlled so as to maintain the required constant power characteristic. When operating in this mode, no wheelsize compensation is required, since it is inherently corrected by the constant voltage control.

Weight transfer compensation is incorporated into the control system. This is done by simply modifying the armature demand. The leading bogie has its armature demand reduced by 6.5% whilst the trailing bogie is increased by 6.5%.

Braking

The control scheme in electric brake is very similar to that used in motoring. The system has both regenerative, and rheostatic braking modes, with a regenerative/rheostatic mixed region. The rheostatic chopper is arranged within the motor group, not only to reduce the number of semiconductors but also to prevent the rheostatic chopper dissipating the energy from another locomotive.

The field current is set depending on notch demand, speed and wheelsize. A set of look-up tables are used. At high speeds the motor voltage limit is reached, and so the field is weakened to maintain the motor voltage limit. As discussed above it is essential that a transition from full regenerative brake to full rheostatic brake can be made very quickly with minimum disturbance to the system. To achieve this the armature current is also controlled in direct proportion to the motor voltage. Thus there is little change in armature current when such a transition takes place, say, due to pan bounce. The rheostatic choppers are independently controlled as a function of the filter capacitor voltage. A dV/dt term is used in addition to the proportional control term to improve the response time. Under decreasing voltage a lower dV/dt control is used. This prevents an oscillation being set up between the capacitor voltage and the rheostatic choppers.

Since a separately excited scheme is used there is no need for any special field excitation system while in electric brake. The system response under fault conditions is very good, without the need for any high speed circuit breakers in the motor groups. If the overhead line should become short circuit when in full regenerative brake, a rate of fall of line voltage detection system will quickly detect it before the filter capacitor voltage has changed noticeably. Under these conditions the HSCB is quickly opened, the fields forced off, and the armature choppers clamped.

Even though the motor voltage might exceed the line voltage and the blocking diode become forward biased, no damage will result as the field current is still rapidly decreasing under the control of the forcing circuit. On a series scheme these conditions would result in damage without a means to open the field circuit.

The field is powered from the output of the MA set, and it might be considered that such a system cannot sustain "loss of contact" when in electric brake. In fact it can sustain an indefinite loss of contact. The energy in the filter capacitor sustains the MA set. Once the capacitor voltage begins to fall the rheostatic choppers will phase back, allowing the capacitor voltage to rise again, whereupon full rheostatic operation will recommence.

On detecting a slip the armature current on the slipping motor group is quickly ramped down to minimum demand, and held there until the wheel has re-adhered. On re-adhering the demand is ramped back up to 82% of the armature current present at the start of the slip. The current is then ramped up slowly to the preset demand value. This creates an adaptive wheelslip correction system, which utilises the maximum adhesion available without any need for driver intervention.

Fault Logging

Since a microprocessor system inherently uses memory devices, it is a natural progression to incorporate a fault logging system. Such a system needs to be flexible, and simple to use.

A hand held Husky computer is used to communicate with the electronics frame on the vehicle. This computer, through a series of menus, allows the operator to perform several operations on the fault log. This includes setting the real time clock, retrieving the logged data, altering the logging parameters, and clearing the data. The operator can alter the:

(1) frequency at which data is recorded
(2) number of data records for each fault
(3) number of records before the fault occurred
(4) option to stop a particular fault type triggering a fault log record.

An additional feature is to prevent multiple logging of the same fault. Once a fault type has occurred, that type will not be logged further, until the expiry of a fixed time delay; this prevents the log memory becoming full of reset actions by the driver after the initial fault. Once the data has been transferred to the Husky it can be examined at leisure. The data can be examined there and then, or transferred to a personal computer and analysed later. Once transferred onto a PC, proprietary software packages can be used to present the data in graphical form.

Auxiliary Circuits

Power for the locomotive's auxiliaries and control system is supplied by a single motor alternator set, fed from the overhead line.

To obtain the benefits of relatively inexpensive and readily available induction motors, 380 V 3-phase 50 Hz was generated by the motor-alternator (MA) set. This provides power for both traction motor blowers, rheostat and body pressurisation blowers, the compressor and exhauster. The alternator output is also separately rectified to supply the field drives, the MA speed (frequency) control and the battery charging.

Two regulators are used, a self-contained voltage regulator that excites the alternator to provide 380 V and a frequency regulator that controls the speed of the 3000V dc driving motor.

The machine comprises a 4-pole double commutator drive motor with a controlled series-wound field system and a 4-pole 3-phase alternator with brushless exciter. All the rotating parts are mounted on a common shaft.

Motor armature and field system are insulated to Class H standards and the alternator stator and rotor have Class F insulation. The motor has a continuous rating of 2900V, 73A, 1500rev/min. and the alternator is rated at 380V, 287A, 190 kVA, 0.87 p.f. The alternator output is 3-phase and is controlled to 380V $\pm 2\%$, 50 Hz ± 1 Hz over a line voltage range of 2.4kV to 3.9kV.

The voltage output is regulated by control of the exciter field. The frequency is regulated by control of the speed of the set by weakening or strengthening the motor series field as appropriate. To strengthen the motor series field, part of the 3-phase output is rectified and is injected back into the field to weaken the field, and thus increase the motor speed, an inductive divert is connected in parallel with the field windings.

Starting and protective resistors are connected on the line side of the motor; the starting resistor is shorted out by a contactor after a pre-determined time during the start up sequence.

The output of the motor alternator set, as well as providing power for all the 3-phase ac machines and single phase ac loads also provides the dc power for the control system. This is achieved by means of a 3-phase transformer and full wave rectifier.

Braking System

The locomotive incorporates both an automatic air brake system for the train which results in proportional application taking place on all locomotives coupled in a multiple consist and an independent brake system to provide braking on the locomotives only. The locomotive brake control system is suitable for use with both air and vacuum braked trains. The brake equipment provides for both a two-pipe graduated-release train air brake system to UIC standards, as well as a direct release train air brake to AAR Standards.

When the locomotives are operated in the electric braking mode the locomotive air brakes are held off, thus reducing brake block wear. In the case of an emergency brake application, however, this is overridden and the air brakes on the locomotive are applied.

A 4 cylinder, motor driven, reciprocating compressor provides the necessary air for the brakes as well as for windscreen wipers, horns, sanders and electro-pneumatic control equipment. To produce the vacuum, when hauling vacuum braked stock, a motor driven rotary exhauster is fitted.

Electric Braking

The locomotive is designed to hold fully-laden trains descending the gradient from the South African Reef to the coast, a duty that lasts for several hours. For this braking duty the armature group is mechanically reconnected across the 3000V chopper and the field drive reverses. With the armatures excited by the fields, the power choppers using the "store and let fly" techniques transform up the armature voltage to match the overhead. Providing the overhead supply is receptive all the brake energy can be regenerated. However if the overhead supply approaches 4000V then the energy is diverted into the brake stack.

As the proportion of regenerated to rheostatic energy is calculated each chopper cycle, any overhead interruptions (pantograph bounce) do not affect the loco performance in any way. This is a very important consideration on long freight trains with high coupling forces.

Layout of Equipment

The principles adopted for the layout are functional grouping with ease of maintenance and minimum cabling and piping. A central corridor gives ease of access to the equipment.

The main power converter equipment cases are located at diagonally opposite corners of the compartment and are adjacent to the line filter and motor series inductor. These items are associated with control of the tractor motors at the adjacent end bogie. A motor-driven centrifugal fan draws air through bodyside louvres and discharges this through an intertial filter to provide cooling air for the inductor and chopper case as well as the three traction motors on the appropriate bogie. The arrangements are identical at opposite corners of the locomotive.

A separate centrifugal fan discharges filtered air into the body to pressurise the locomotive and generally cool the other items of equipment. This air exhausts from the locomotive through louvres next to the compressor and exhauster thus removing waste heat from these items.

The high-voltage cubicle houses the items of control equipment used to control the power circuits of the locomotive i.e. the electro-pneumatic contactors and power brake switches. It also houses the transducers used to measure voltage and current in the power circuits.

The low voltage cubicle holds the equipment to control the 110V dc and 380 V, 3-phase equipment. It also houses the miniature circuit breakers and is therefore located close to one of the cabs for easy access by the driver.

The capacitor cubicle houses the main filter capacitor which comprises 12 capacitors connected in parallel to provide the required capacitance for the input filter.

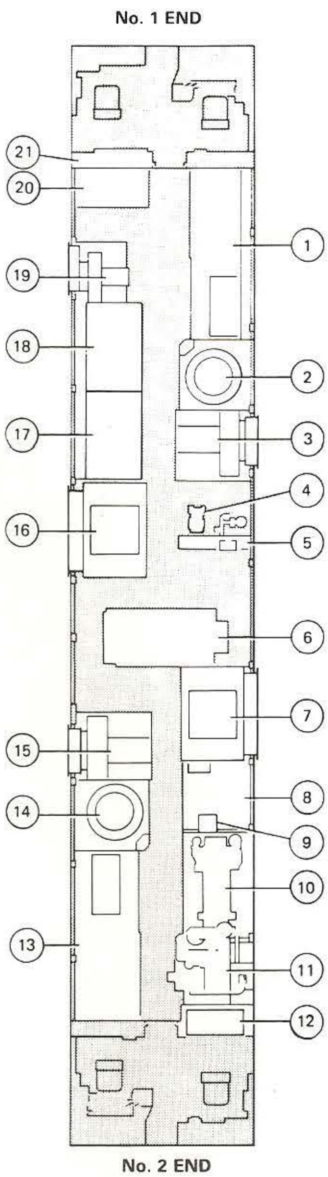
To isolate the locomotive from the overhead supply a high speed circuit breaker (HSCB) is provided. This is housed in its own cubicle which can only be entered after a special interlock key is obtained from the earthing switch after lowering of the pantograph and earthing of the power circuit. A similar lock is also fitted to the high voltage cubicle.

The breaker has a rupturing capacity of 35kA and operates either by a trip signal from the electronics giving a fast clearing time for a fault (4 ms) or by detection of an overcurrent by the breaker itself in this case clearing a fault in 40 ms. The breaker is continuously rated for 2600A.

The motor alternator, used to supply power to the control, auxiliary equipment and to excite the field of the separately excited traction motors, is located across the body of the locomotive close to the centre-line.

The cubicle housing the electronic equipment is located in the back wall of the No. 2 cub. This provides a clean environment for the equipment and allows ready access by maintenance staff to obtain data from the fault logging systems.

On the roof of the vehicle are located two single arm pantographs, only one of which is used at a given time; the second pantograph can therefore be used if damage occurs to the operating pantograph and thus enable the train to complete the journey. A non-linear resistor type surge arrestor is located next to each pantograph and protects the locomotive's electrical equipment against lightning strikes.



1. Bogie No. 1: Chopper cubicle
2. Bogie No. 1: Reactor frame
3. Bogie No. 1: Traction motor blower and inertia filter
4. Auxiliary compressor
5. Air equipment frame
6. Motor alternator set (MA resistors overhead)
7. Bogie No. 2: Brake resistor and fan
8. Main circuit breaker cubicle
9. Earthing switch
10. Main air compressor
11. Vacuum exhauster
12. Electronic cubicle
13. Bogie No. 2: Chopper cubicle
14. Bogie No. 2: Reactor frame
15. Bogie No. 2: Tractor motor blower and inertia filter
16. Bogie No. 1: Brake resistor and fan
17. High voltage cubicle
18. Capacitor cubicle
19. Pressurising fan and inertia filter
20. Low voltage cubicle
21. Radio cubicle

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