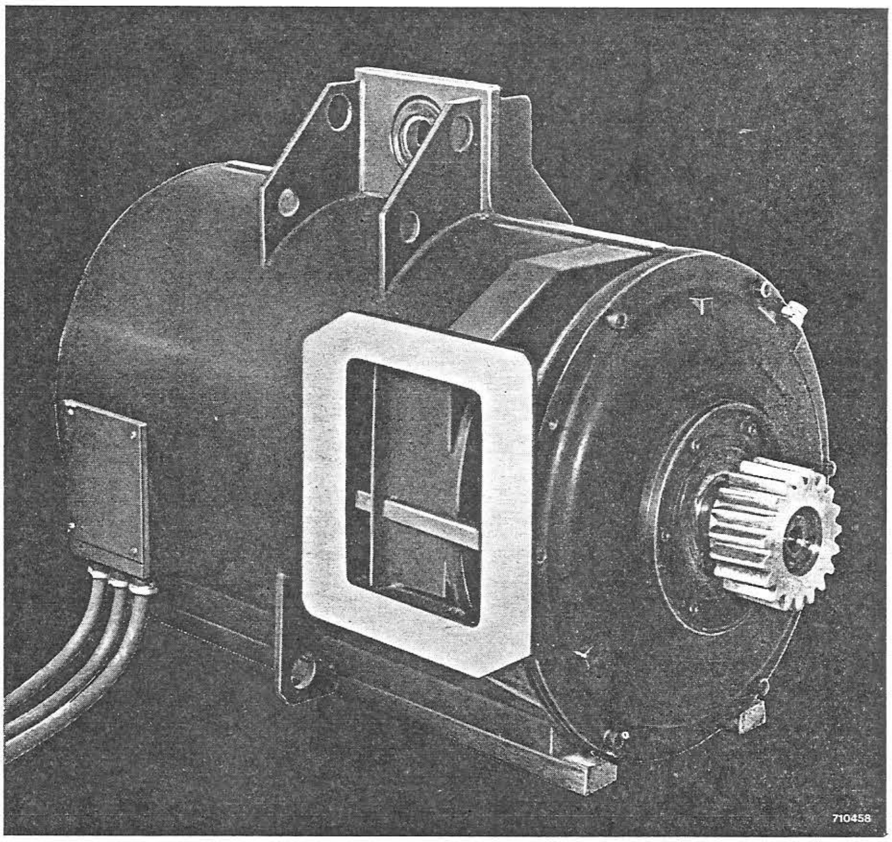
By using these two traction motor types it is quite easy to realize high-power locomotives.

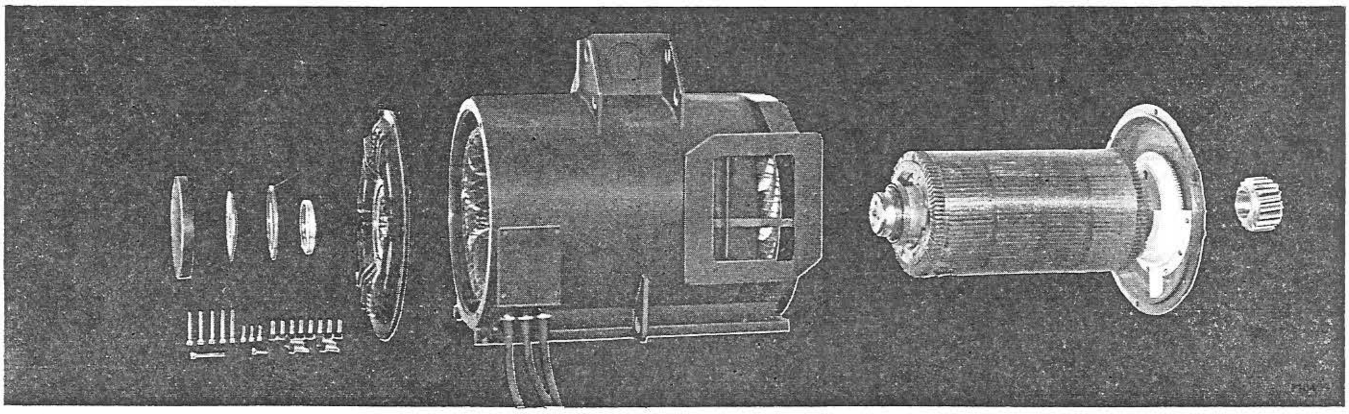
The stator of this "standard motor" is a welded construction of the self-supporting type where laminated stator core and support form one unit. In view of the high speeds and their use in railway systems, as compared to stationary motors, the copper bars of the short-circuited rotor have an additional wrapping or bandage. The motor is separately ventilated and provided with barrel-type roller bearings.

The flange for the cooling air inlet is designed in such a way that the bellows have a sliding fit without the use of bolts.

The driving pinion has a press fit on the motor shaft without fitting key. The mounting of the pinion is accomplished by hydraulic means.



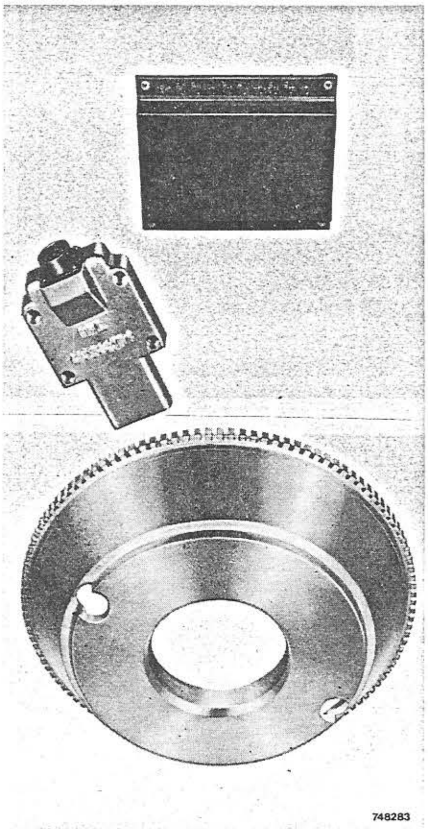
Motor type QD 335 N 4 for gauges of 1435 mm and up

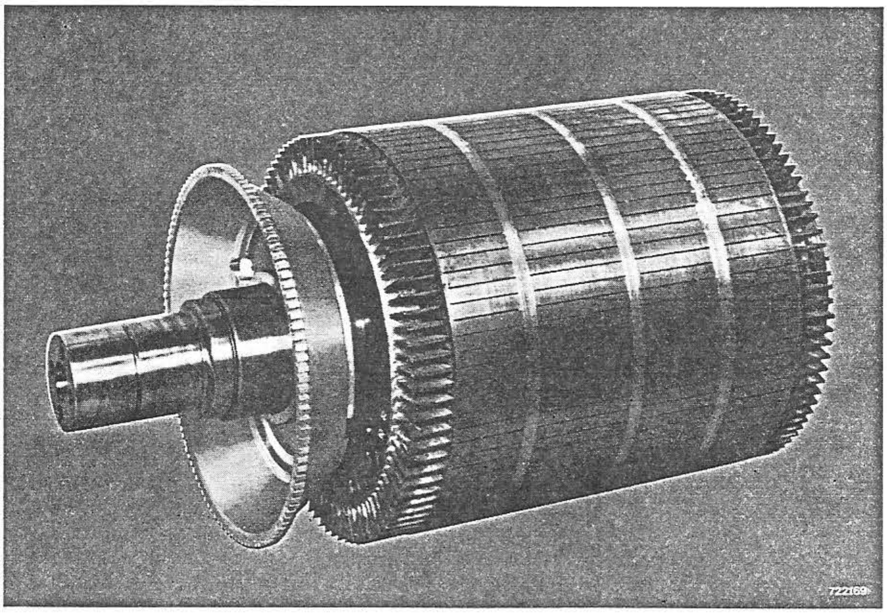


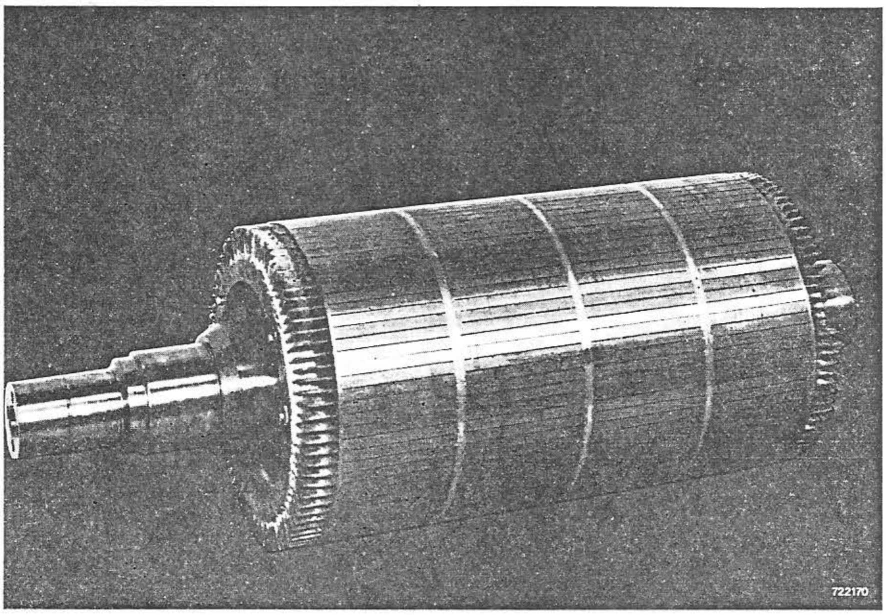
The illustrations show the simple design and the small number of parts required.

The following parts of the two motor types are uniform:
- dynamo sheets for stator and rotor
- bearing brackets
- bearings with accessories
- welded parts for motor suspension and air duct
- pinion
- small parts, etc.

The continuous frequency regulation requires a continual and undelayed measurement of the actual speed of the traction motor.
The measurement is accomplished by means of inductive feelers
- which are mounted in the bearing bracket of the traction motor
- which are contactlessly influenced by a toothed disc on the rotor shaft
- which supply an a. c. voltage that is proportional to the rotor speed. The output voltage is amplified for further use in a directly connected amplifier. This prevents the influence of interference voltages.
- which allow the detection of the sense of rotation by an appropriate geometrical arrangement.



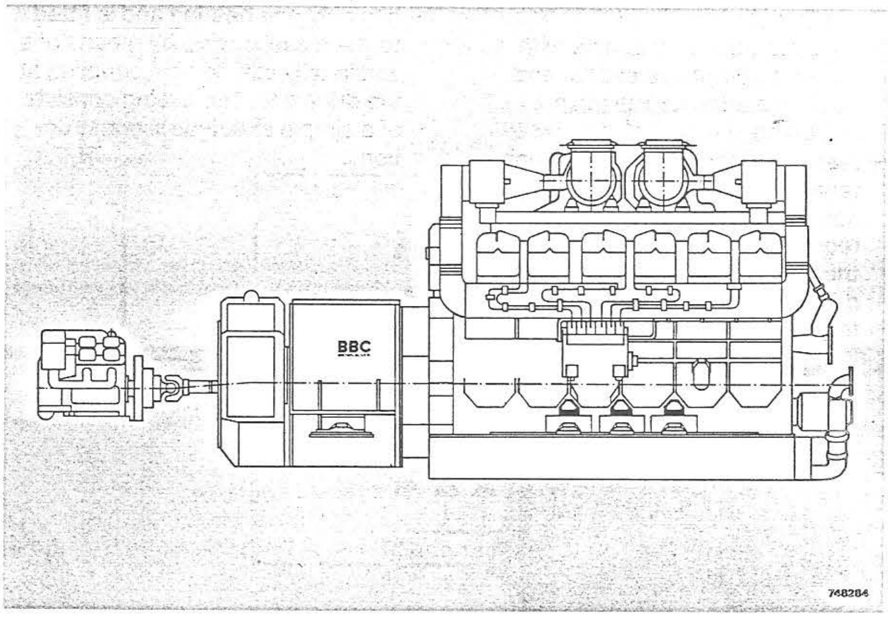




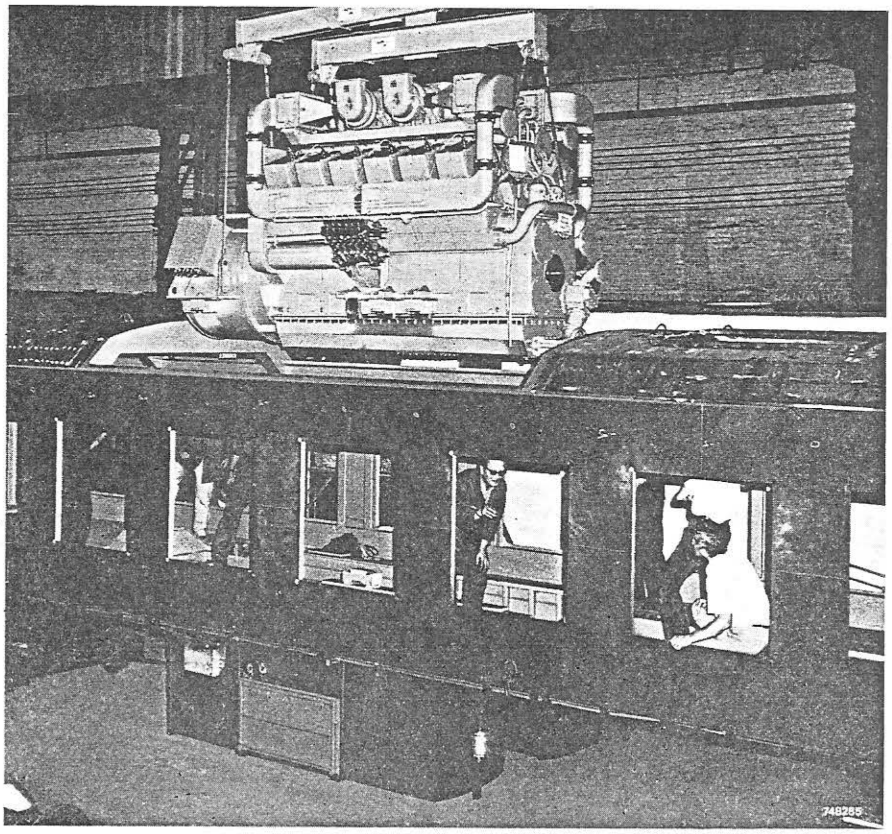
Diesel-engine-driven generating set

The Henschel Diesel engine and the BBC alternator are combined to form a well matched unit.

The diesel engine type 12 V 2423 Aa
- is provided with a cylindrical crank-case of cast iron GG-30
- has a site rating of 2500 HP (up to 3000 HP possible)
  speed 1500 rpm
  number of cylinders 12
  arrangement of cylinders V 60°
  bore x stroke 240 x 230 mm
- facilitates the unavoidable maintenance work since all parts requiring maintenance are easily accessible
- is started by means of compressed air which is directly admitted to the cylinders through a controlled distributor
- is provided with a Woodward regulator for speed and power regulation
- is supercharged by means of four BBC turbo-chargers RR 150 with charge-air cooling.

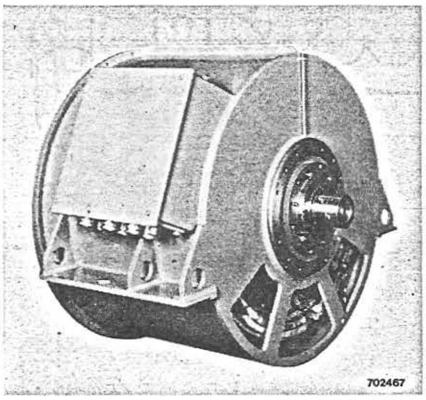


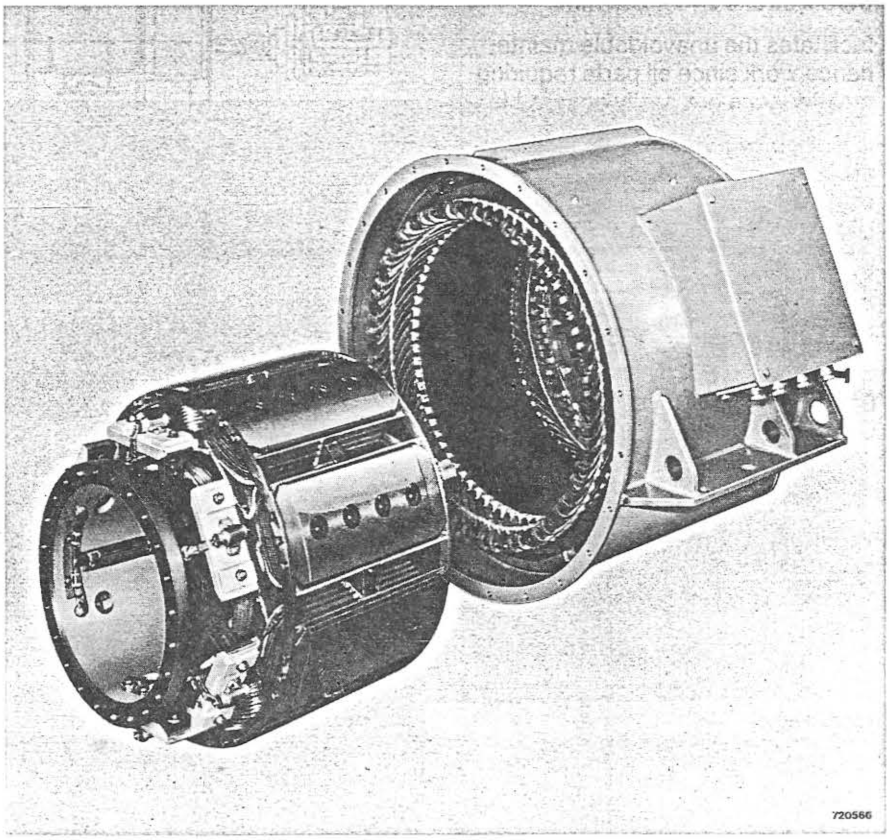
The alternator
- is bolted directly to a flange of the diesel engine casing at the drive end
- is coupled with the diesel engine by means of a torsionally stiff steel diaphragm
- can be assembled with the diesel engine outside the locomotive and moved into the locomotive as a complete preliminarily tested diesel engine/alternator unit.



Alternator

The alternator
- is a synchronous machine with built-in three-phase exciter and rotating diodes for the main excitation
- features a non-wearing and maintenance-free design
- has to be dimensioned for the required active power only since there will be no reactions from the drive (for instance, dimensioning for the starting current)
- has only one bearing and is fitted to the diesel engine by means of a torsionally stiff flexible coupling at the drive end. The casing consists of a simple sheet-steel construction
- has a free shaft end at the non-drive end. The blower used for self-ventilation and for the separate ventilation of the traction motors is mounted on this free shaft end from which the air compressor is driven through a flexible coupling.

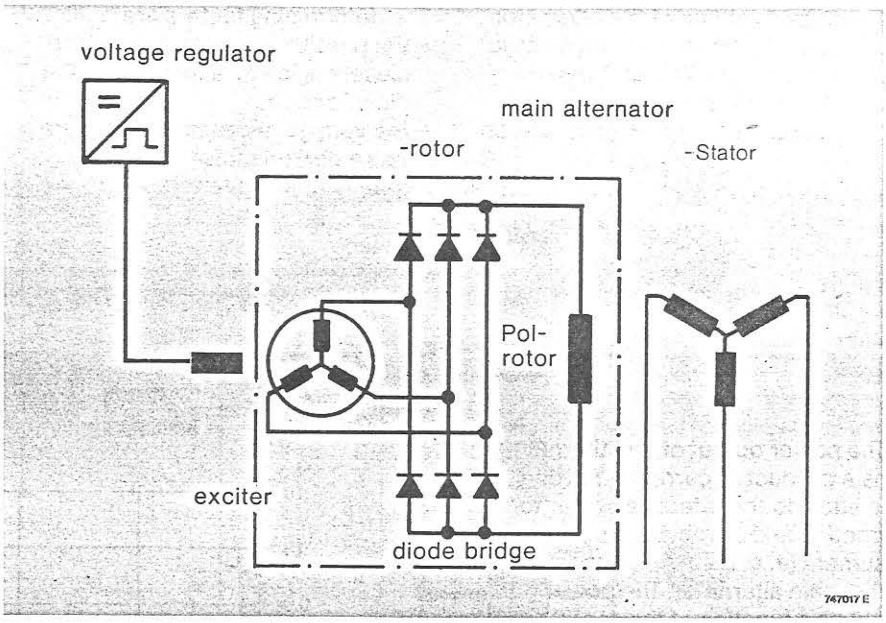




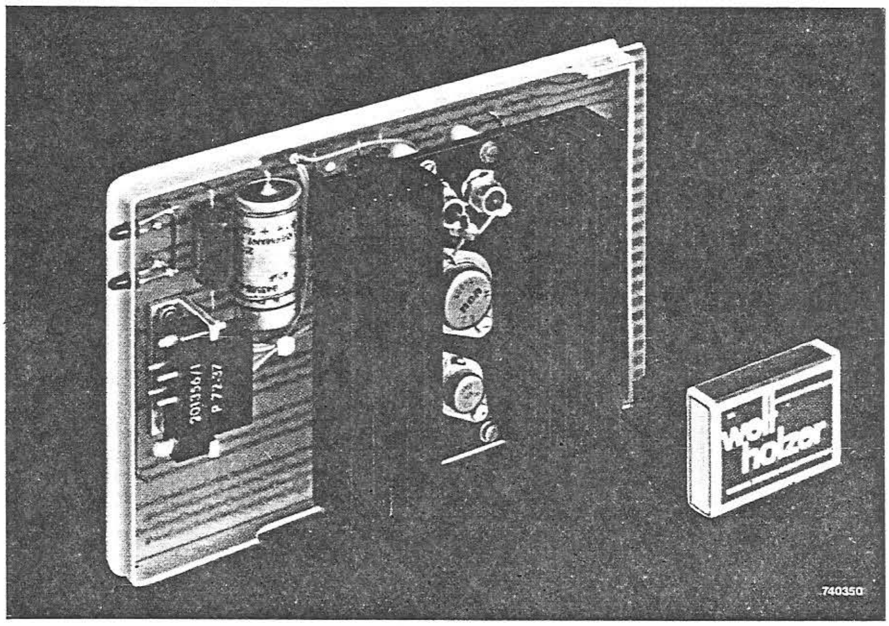
The alternator data for a 2500 HP locomotive are as follows:

continuous rating	1800 kVA
speed	600 to 1500 rpm
number of poles	8
frequency	40 to 100 Hz
voltage	1280 V
power factor	0.95
type of frame	B 2 DIN 42 950
bearing	grease lubricated roller bearing at non-driving end
forced ventilated	2.7 m^3/s
weight	2.4 tonnes

The voltage control of the alternator
- is accomplished by means of the three-phase auxiliary exciter whose output voltage is rectified and applied directly to the main exciter winding
- is non-wearing and maintenance-free since the diodes used to rectify the exciting current are mounted on the rotor and no slip-rings are necessary
- is supplied from the 110 V service network. The auxiliary exciter current is fed into the auxiliary exciter winding through a transistor regulator.



The regulator
- operates on the two-position principle with varying ON-OFF relation at constant pulse frequency and is an integral part of the electronic control and regulating device
- requires little space as shown by the comparison with a match box
- is also non-wearing and maintenance-free since it is a plug-in unit of the self-contained type that can be tested individually.

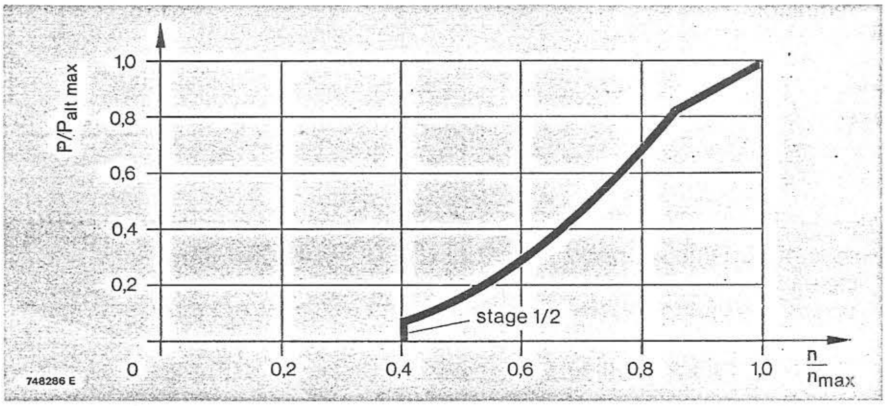


The rated data of auxiliary exciter and rotor are as follows:
- service network connection 110 V (90 to 130 V)
- auxiliary exciter current acc. to alternator speed 2 to 3.5 A
- exciter output 17 kW
- main exciter voltage 82 V
- main exciter current acc. to speed 75 to 140 A

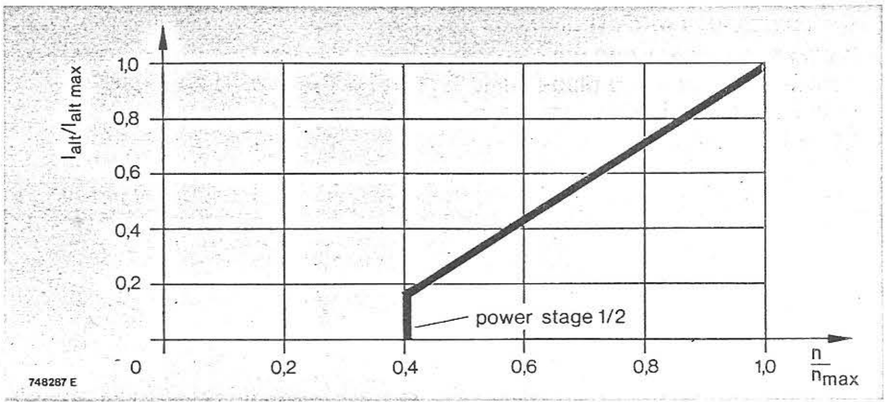
The output voltage of the alternator has been determined for an electric power transmission with three-phase asynchronous motors under consideration of overall optimization.

The determining factors are
- the possible power output of the diesel engine as a function of the diesel speed
- the voltage necessary for generating a certain motor current by means of the inverters.

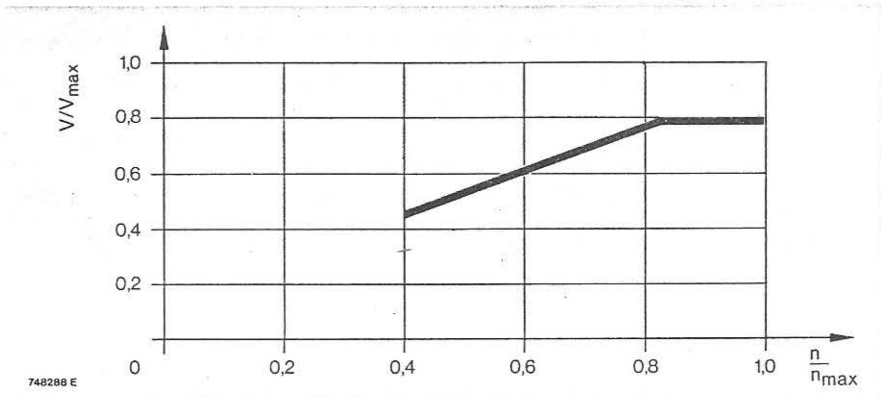
The power output of the alternator as a product of current and voltage is equal to the effective power for traction and all the auxiliary consumers (e. g. heating) connected to the main alternator. The power output as a function of the speed is shown at the right.



The alternator current is independent of the alternator voltage and determined solely by the load.



The voltage is preset as a function of the speed. The characteristic reaches its maximum value before the maximum speed is reached since in the partial-load range at full starting torque the full alternator voltage is required.



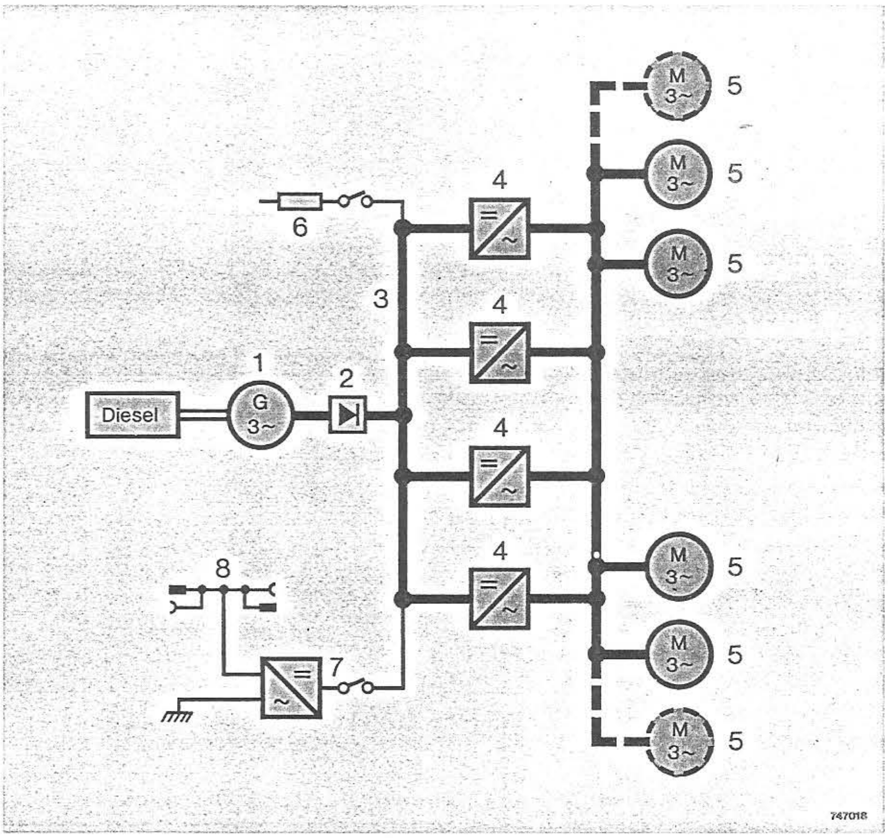
Main wiring diagram

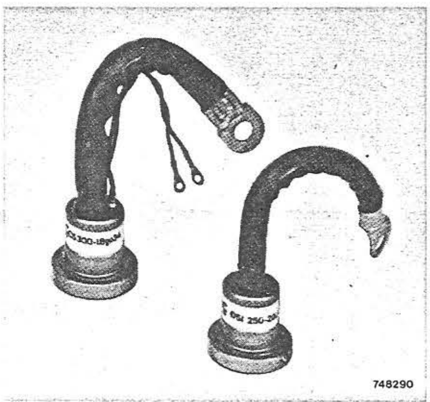
The main wiring diagram for power transmission with asynchronous motors comprises the following units:

1 alternator
2 rectifier
3 d. c. busbar
4 inverters for traction
5 traction motors
6 brake resistor
7 inverter for heating

The a. c. voltage of the alternator (1) is rectified (2) and fed into the d. c. voltage busbar (3) (d. c. voltage intermediate circuit). The inverters (4) for the traction motors (5) and the energy supply (7) for heating or cooling the train and the brake resistor (6) are connected to the d. c. voltage intermediate circuit and can be operated in parallel.

The inverter (4)
- converts the energy produced by the alternator into the voltage and frequency required for the traction motors
- is the control unit for producing the tractive and braking efforts of the locomotive
- separates the traction motor circuit from the alternator
- acts as "power transformer" so that no additional losses will result over the entire power range
- is subdivided into individual inverters which are connected in parallel on the input and output side for a better adaptation to the power range required.

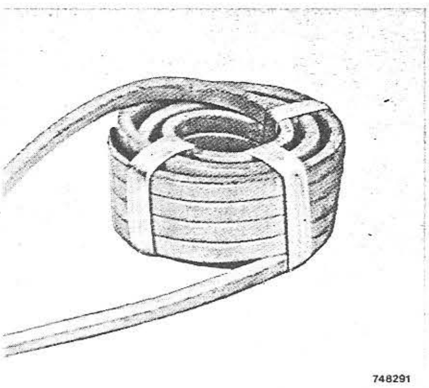


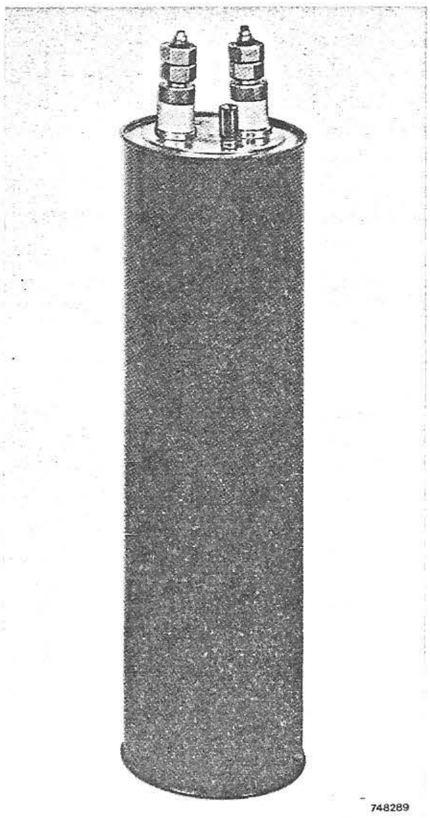


Except for the alternator and motor bearings, the entire electric power transmission does not incorporate any parts subject to wear.

The inverter consists only of the following parts:
- thyristors
- diodes
- capacitors
- reactors

They are also non-wearing.

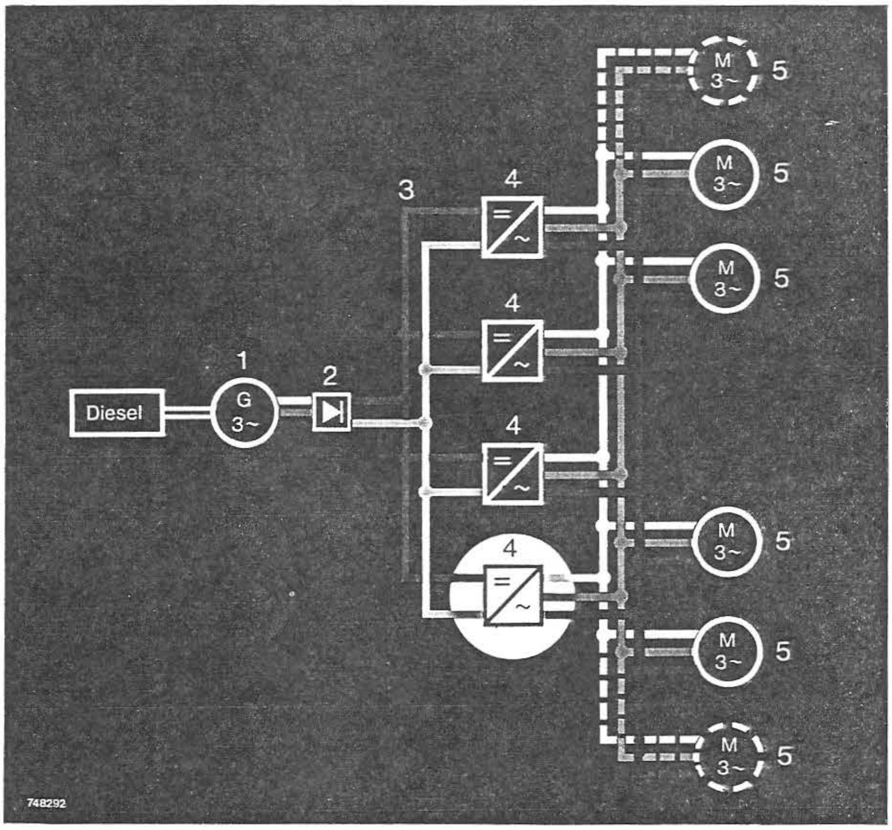


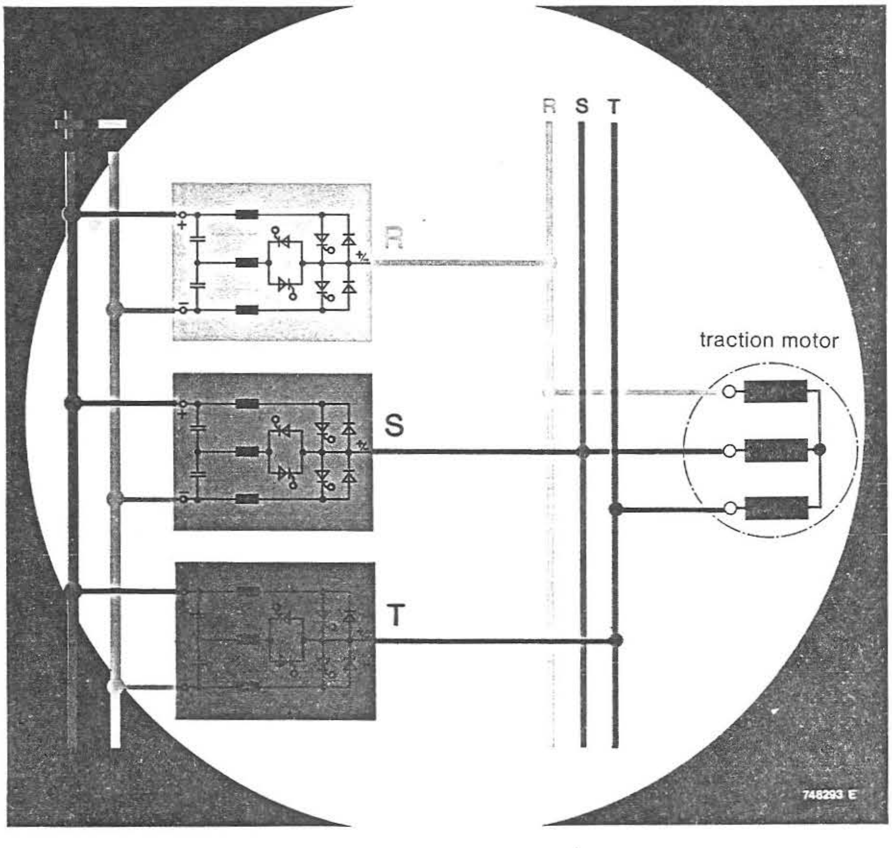


Inverter

In power class 2500 HP, four inverters are connected in parallel in order to obtain an optimum circuitry and design.

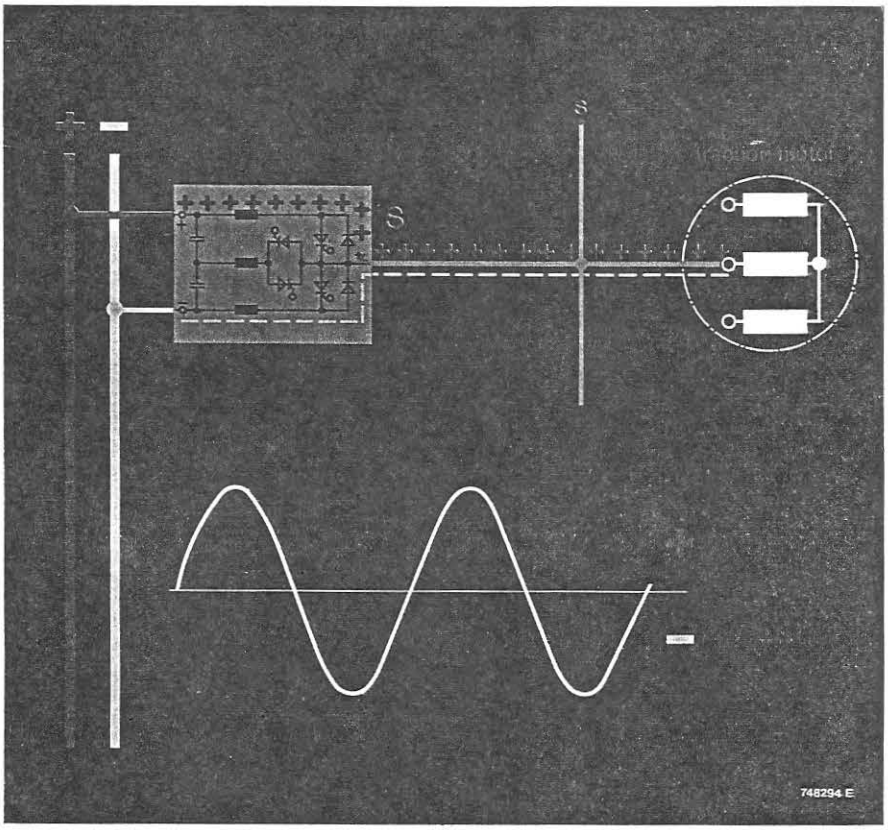
Each inverter
- is, on the input side, directly connected to the plus and minus pole of the d. c. voltage intermediate circuit
- is, on the output side, directly connected to the three-phase busbar for the traction motors
- consists of three identical components, the phases R, S, T.



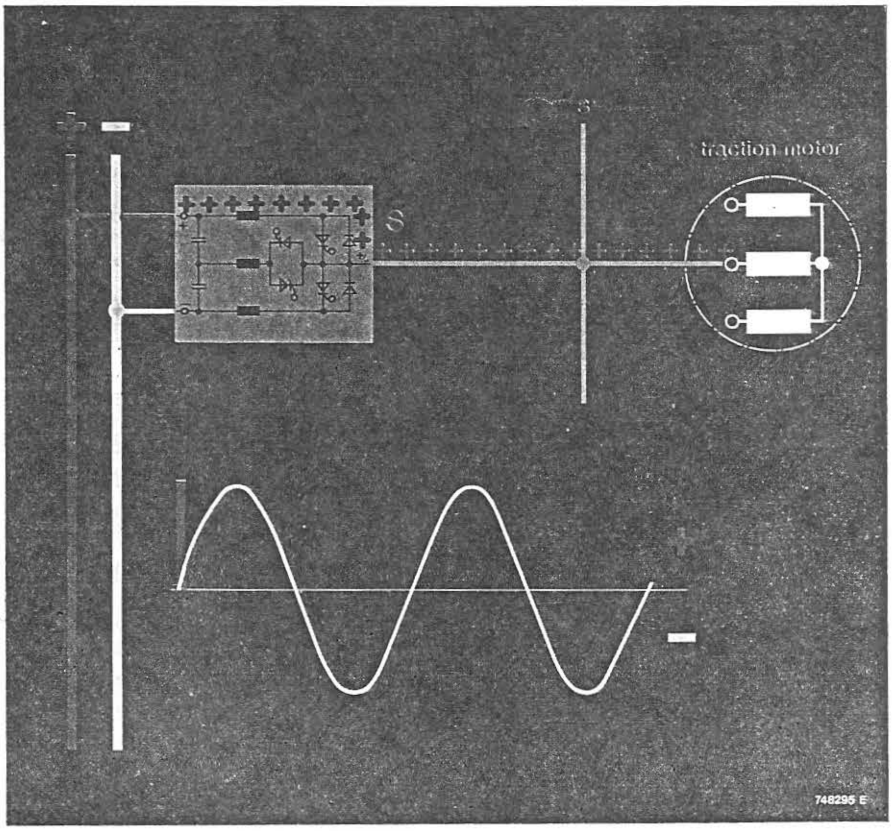


Switching rhythm in the inverter

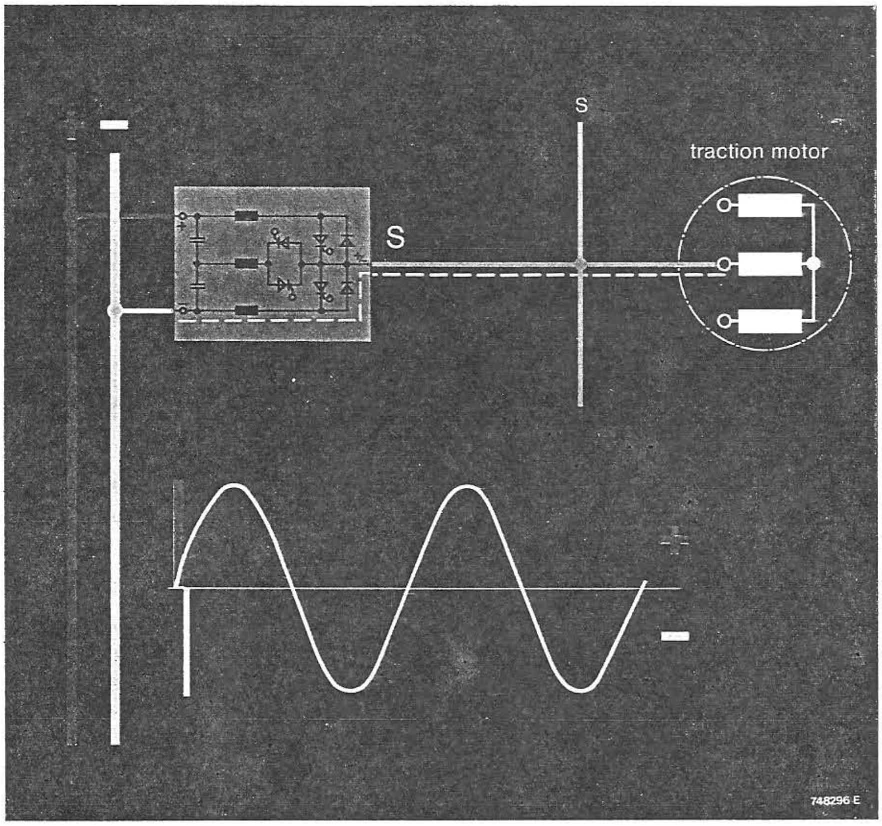
Each phase
- can connect to the traction motor not only the positive pole through the upper branch but also the negative pole through the lower branch
- can alter the switching rhythm in such a way that the mean value follows a sine curve.



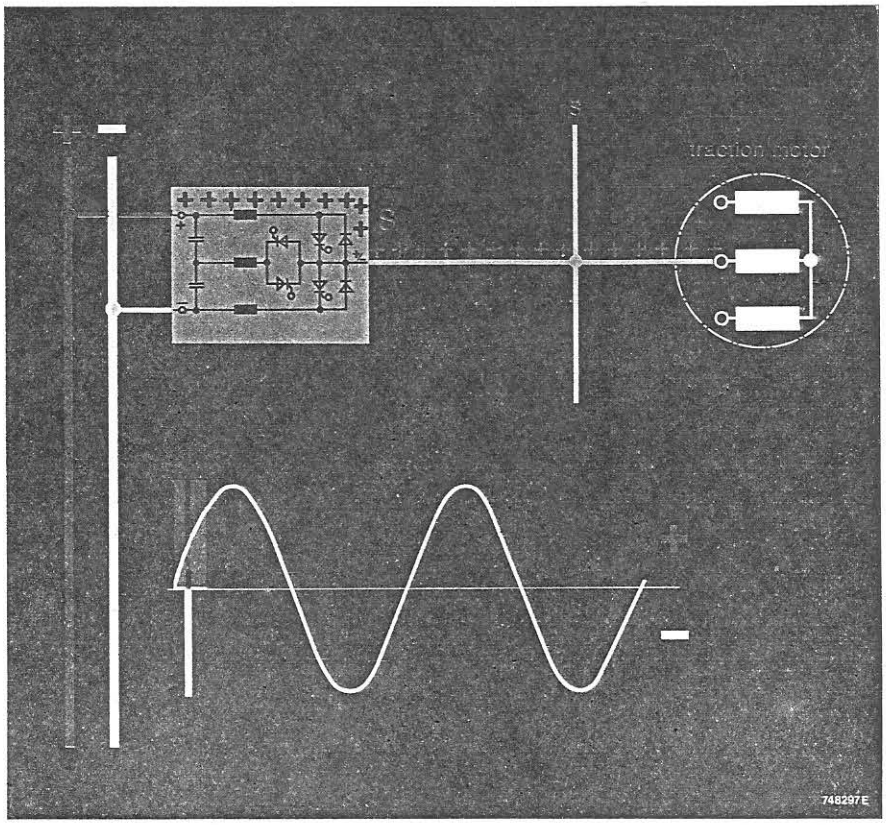
First a positive voltage block is applied to the traction motor through the branch for the positive polarity. The current in the motor winding increases. In order to avoid too great an increase, the thyristor branch is disconnected again after a certain time.



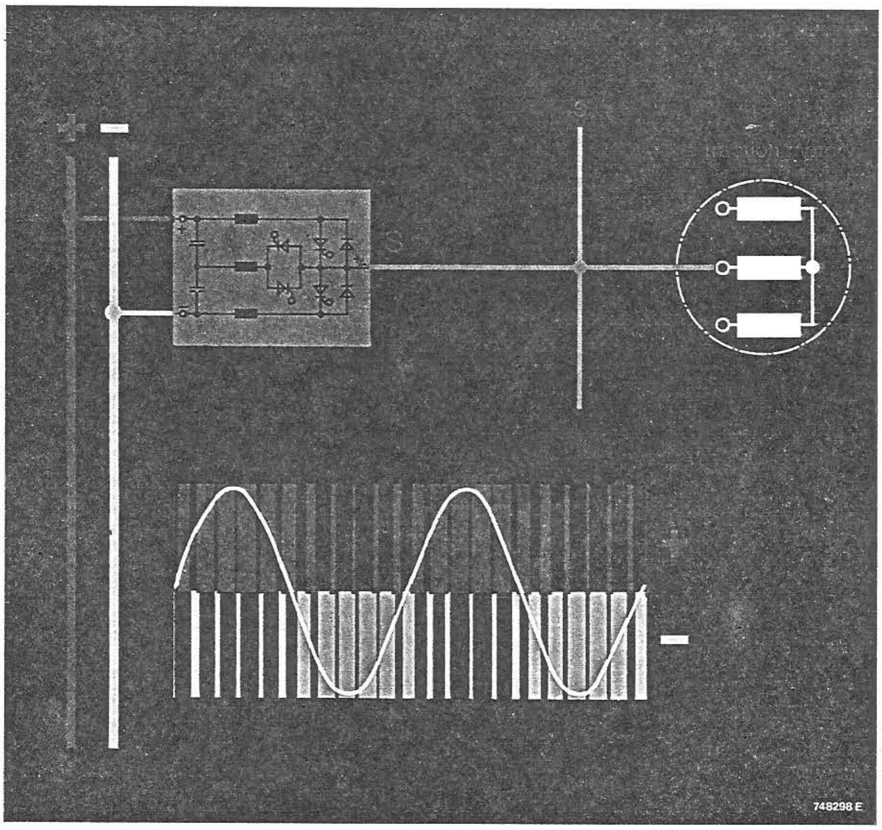
Following the first positive voltage block a negative voltage block is applied to the winding of the traction motor through the lower branch of the circuit. Now the current decreases slightly. In order to avoid too great a decrease, the voltage block is disconnected after a certain time.



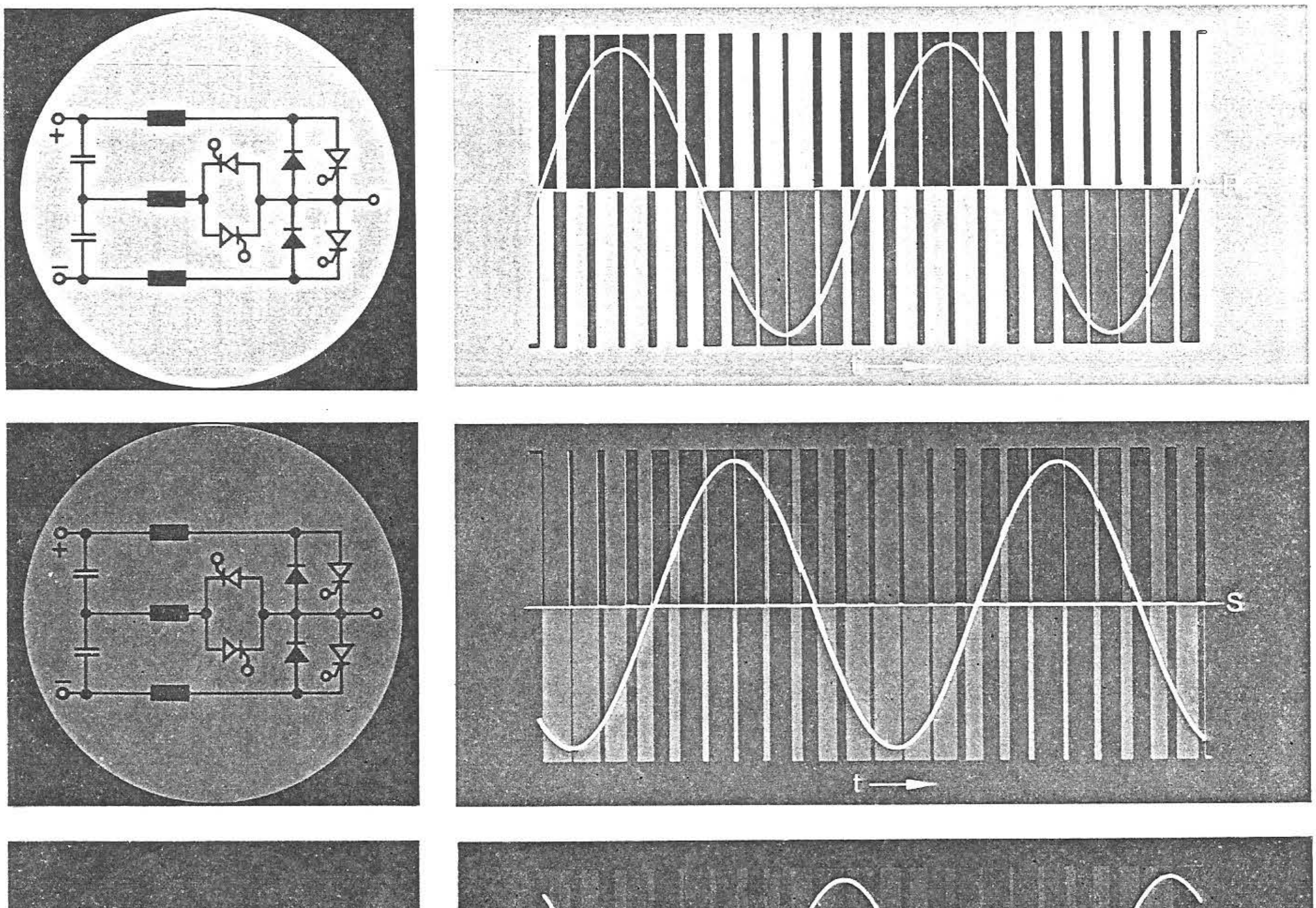
In order to obtain a further total current increase corresponding to the sine curve, a positive voltage block is applied again. For preventing the current from deviating from the sine curve upwards, it is necessary to disconnect again after a certain block length.



With an appropriate predetermination of the switching rhythm, the desired sine curve can be obtained just by switching on and off and by changing the polarity. By variation of the positive and negative block widths, the amplitude of the desired sine curve can be changed. If, for instance, the positive and negative blocks are completely identical, the mean value of the amplitude will be zero. By varying the rhythm, the a. c. voltage can be changed between the minimum and the maximum value shown in the drawing. Should the switching rhythm become different in speed, this would mean a change of frequency. The simple power electronic switch is thus capable of changing the voltage and the frequency.



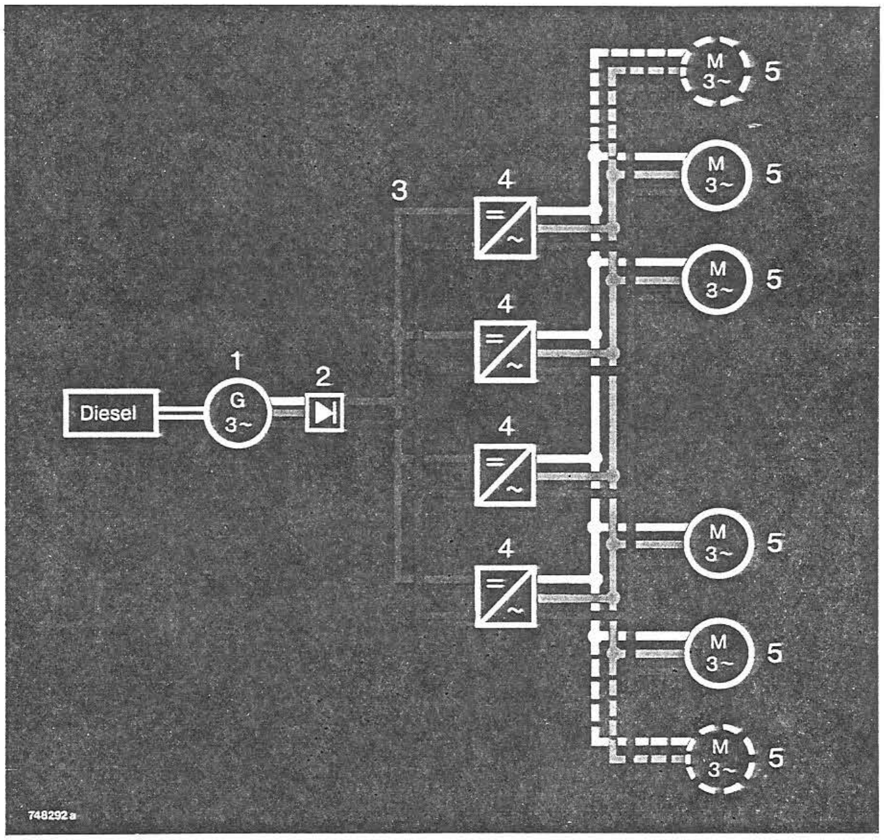
A complete three-phase system requires the use of three phases as described, shifted by 120°. The inverter system applying the principles described is called the "sub-harmonic method".



Design of inverters

The modular principle of the electric power transmission with asynchronous traction motors is applied also for the design of the inverter. Four identical inverters are connected in parallel.
The entire circuitry of a three-phase inverter is combined in a standardized basic unit with the following rated values:

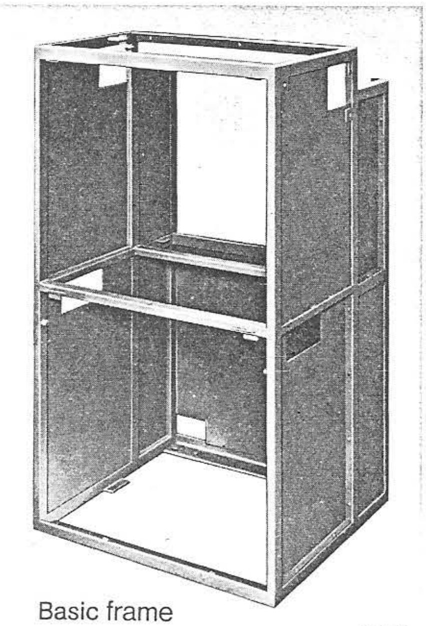
rating	750 kVA
input voltage	1500 V d.c.
output voltage three-phase	1250 V_{rms}
output current	375 A_{rms}
weight	582 kg

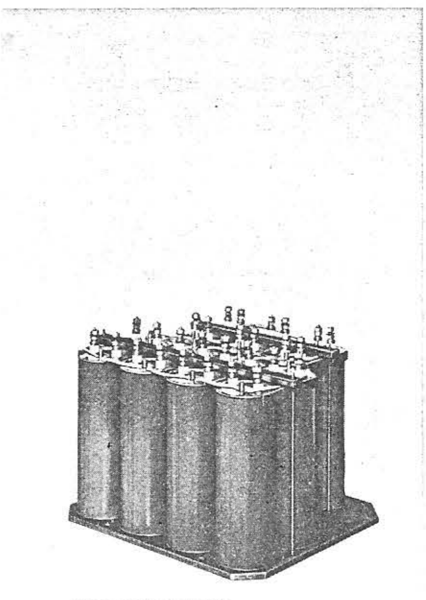


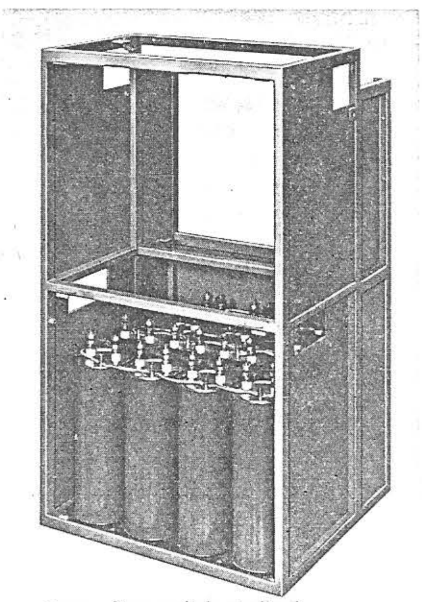
The modules are:
- frame
- capacitor unit
- plastic box for semi-conductor elements
- reactor unit
- plug-in modules for semi-conductor elements.

The module "capacitor unit" comprises:
- the commutating capacitors of an inverter
- the intermediate circuit or storage capacitors corresponding to the unit capacity of 750 kVA.

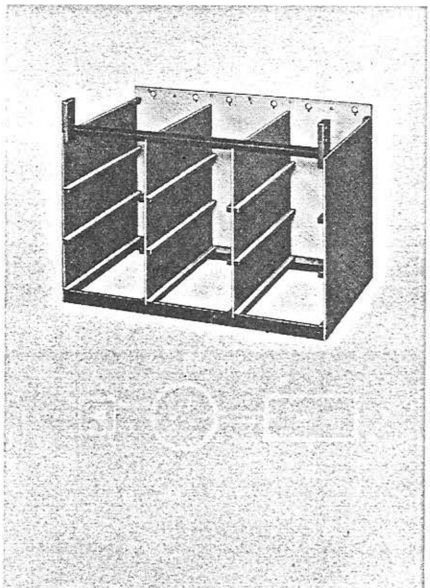
The module is fitted in the lower part of the frame.


Basic frame 721779 E


Capacitor unit 721780 E

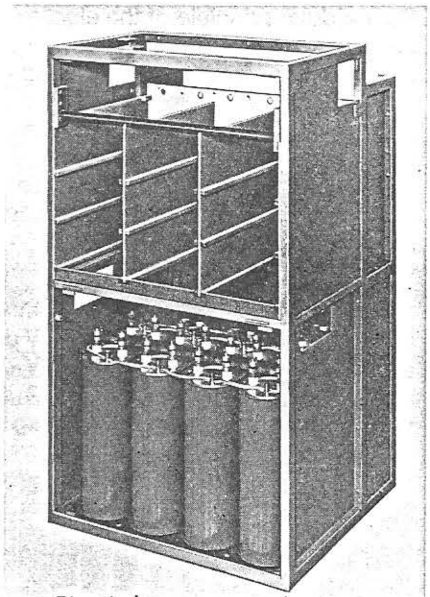

Capacitor unit installed 721782 E

The module "plastic box"
- is used for accommodating the semi-conductor elements
- is mounted in the upper part of the frame on the operating side
- ensures easy installation of the semi-conductor elements and easy access
- ensures excellent insulation.



Plastic box

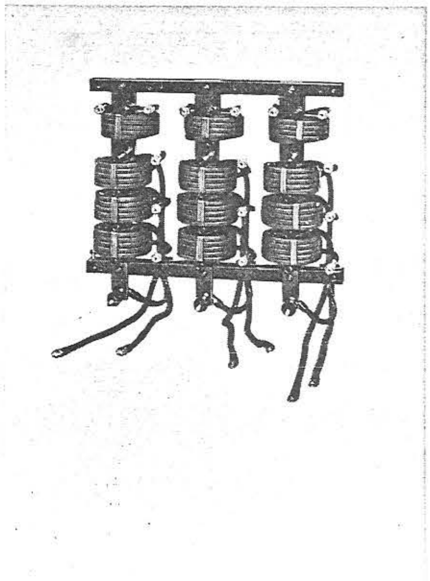
721781 E



Plastic box mounted

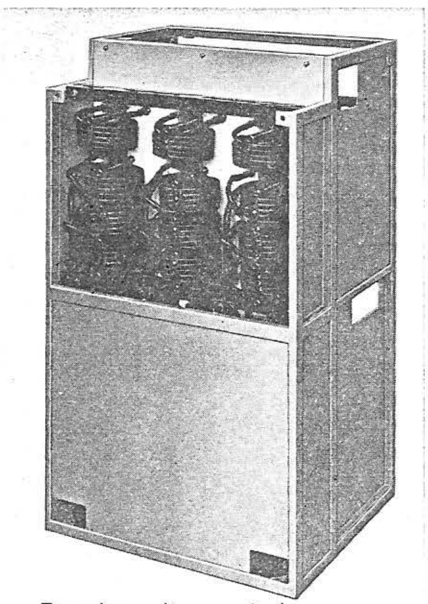
721783 E

The module "reactor unit"
- combines appropriately the three commutating reactors for each inverter phase, which are arranged one above the other
- includes for parallel connection of several inverters a protective and/or compensating reactor for each phase, which is arranged between the three-phase connection and the three-phase busbar.
- is placed immediately behind the plastic box for the semi-conductor elements.



Reactor unit

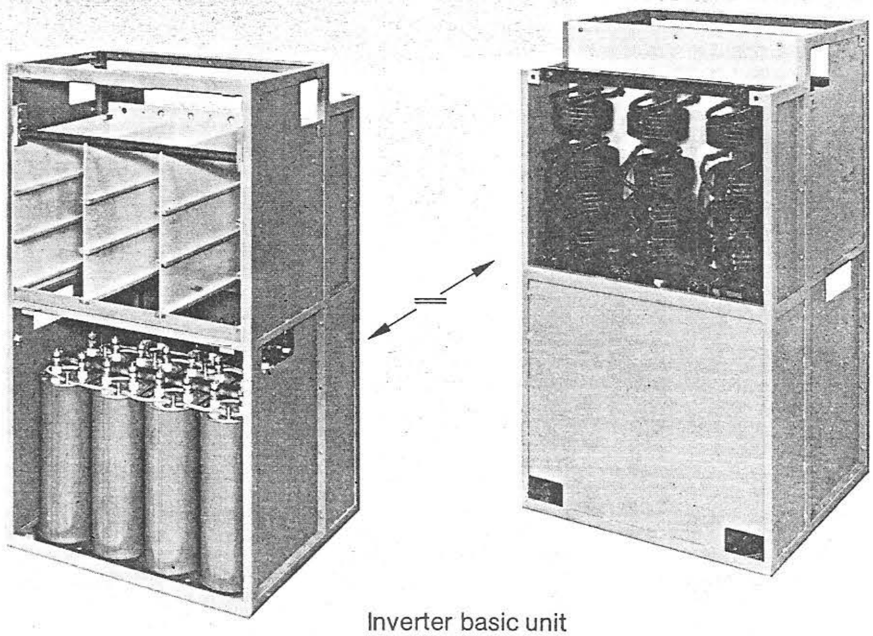
721792 E



Reactor unit mounted

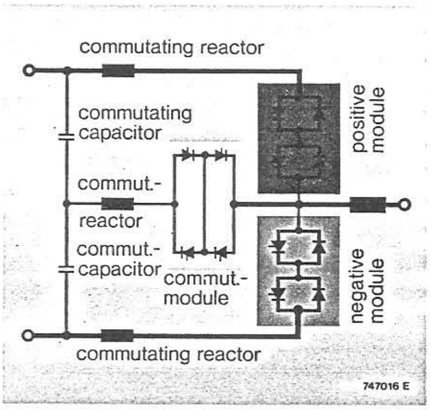
721784 E

The design of standardized inverters
- ensures simple power grouping
- allows good space utilization in the locomotive since the inverters are arranged back to back and several units can be placed side-by-side
- allows easy accessibility for tests in the locomotive
- ensures a minimum of expenditure for the connection of d. c. and a. c. busbars since only short links are required
- allows very short distances for the energy flux to the three-phase traction motor busbar.



Inverter basic unit

724546 E

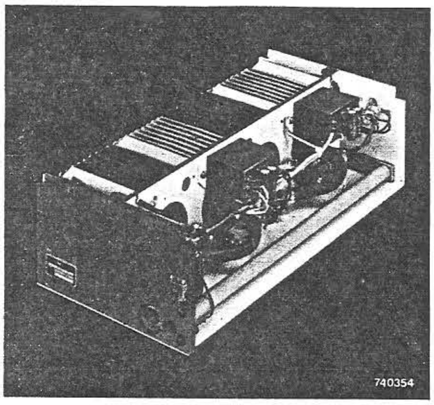


The thyristors, diodes etc. for the inverter circuit are grouped together in plug-in modules which are easy to handle.

These plug-in modules

- are classified for each phase in
  positive module
  commutating module
  negative module

  and placed in the plastic box one below the other
- are connected to the three-phase bus by means of a common link accessible from the front
- are provided with test sockets for locating defective components or faults which are displayed on the central diagnostic system.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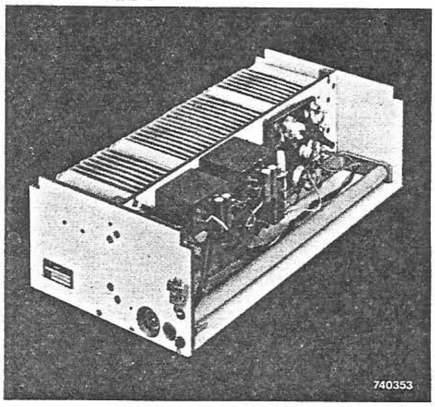
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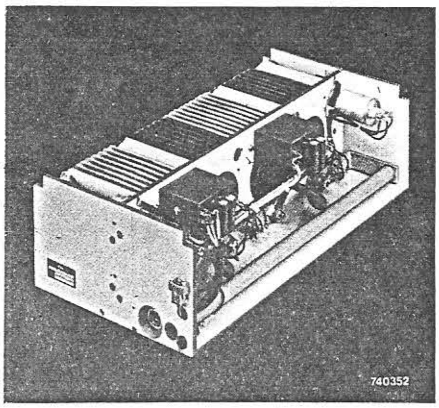
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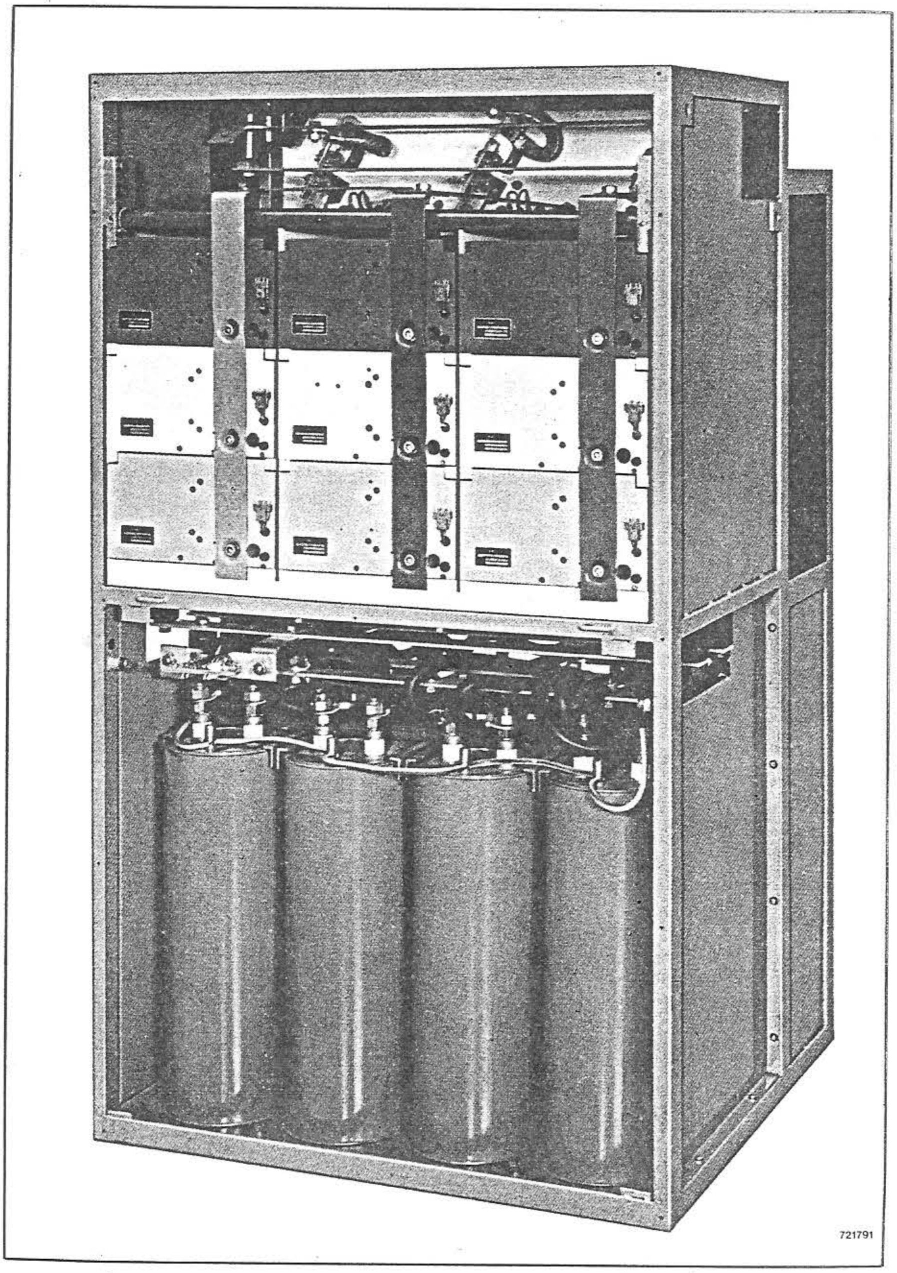
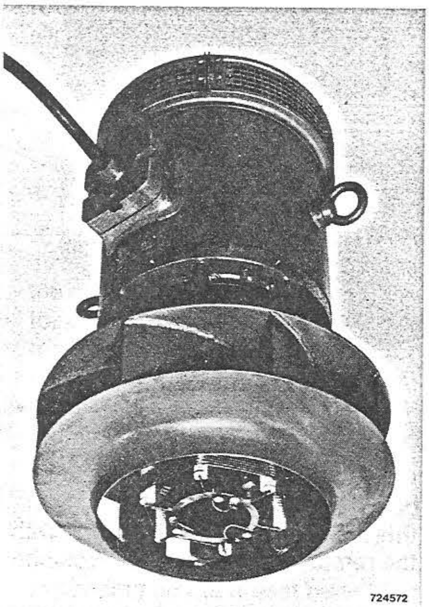

721791

Inverter and brake resistor ventilation

The inverters and brake resistors are cooled by forced ventilation.

The air cooling of the inverters
- results in low weight for the standardized unit
- offers the advantage of better accessibility to the individual functional groups
- facilitates testing
- ensures that only the heat-generating parts are exposed to the air current so that pollution can be kept to a minimum
- is combined with the ventilation system for the brake resistor

so that the expenditure for ventilation can be kept to a minimum. The cooling air is sucked in by a blower through two inverters and escapes into the open air (outlet in roof) through the brake resistors.



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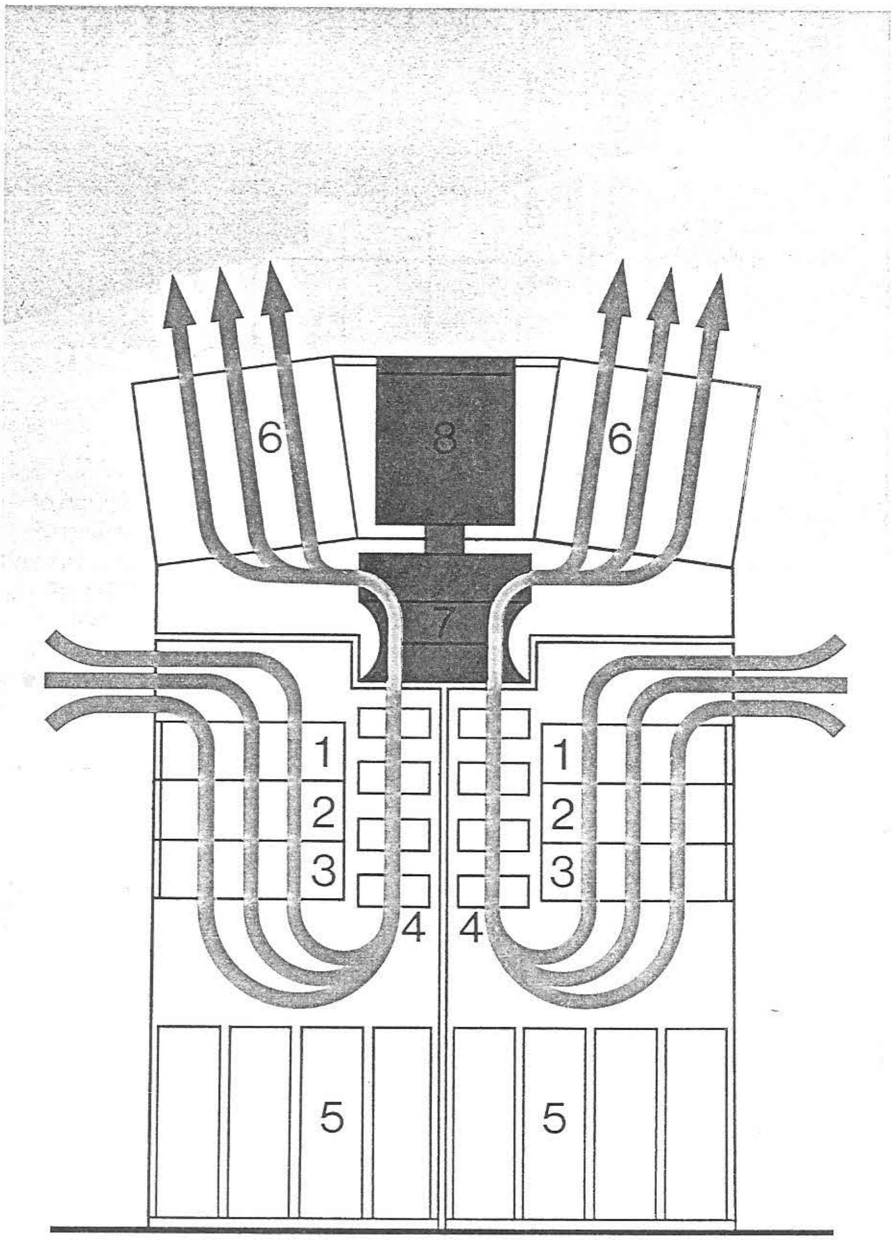
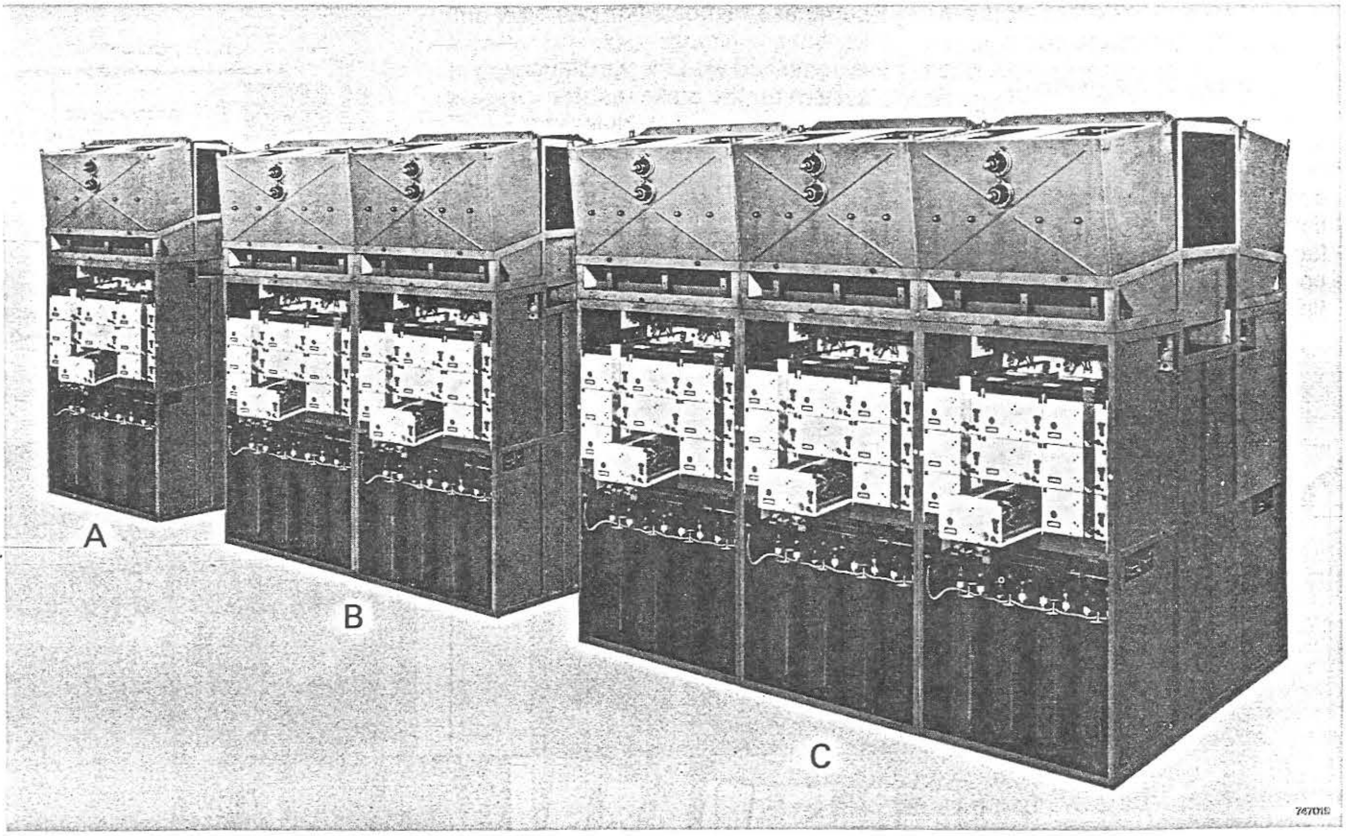


747015

The blower motor is fed directly from the main alternator.

The motor
- is designed as asynchronous motor with large rotor resistor and without sliprings
- has its rotor resistors mounted directly on the rotor in such a way that they are cooled by the cooling air system
- has a "soft" characteristic due to the rotor resistors so that the speed range is smaller than the frequency ratio of no-load to full-load speed of the alternator.

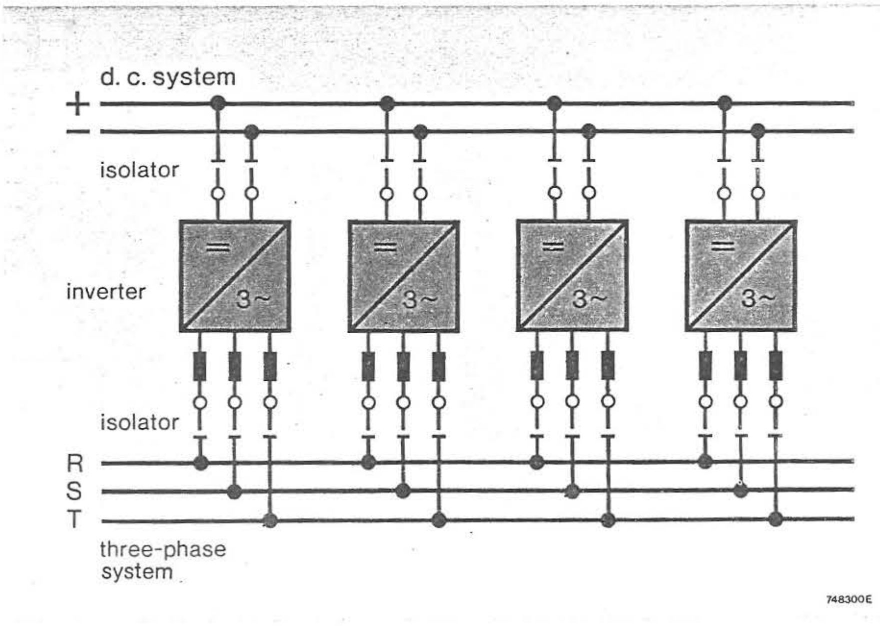


The power grouping of the standardized inverters is characterized by
- parallel connection of the inverters
- compact and space-saving design
- good accessibility
- simple circuitry. The busbar connections are accomplished by simple links.
  Furthermore, each inverter can be disconnected selectively from the busbar by means of manual isolators at any time.
- grouping of the resistors for the electric brake similar to the grouping of the inverters
- simple design concept with regard to ventilation.

The illustrated groupings apply approximately to the following power classes:

2 inverters 1500 HP
4 inverters 3000 HP
6 inverters 4500 HP

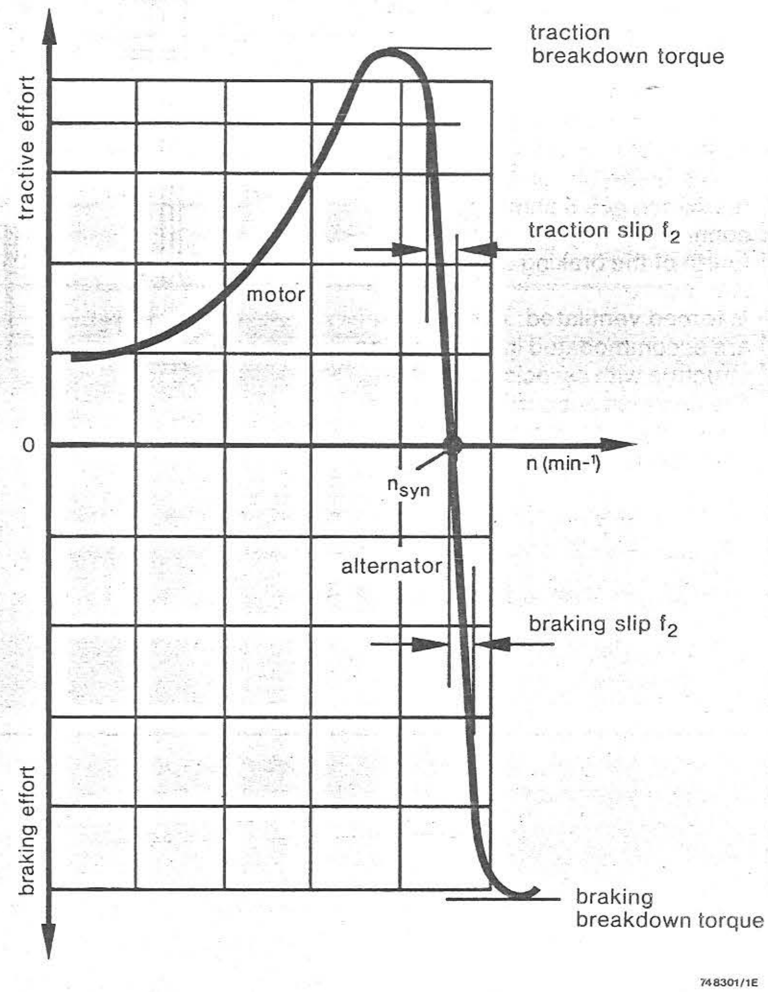
The diagram shows the position of the isolators in a unit consisting of 4 inverters. The total rating of the unit is thus appropriate for a 3000-HP locomotive. In the case of fault, each inverter can be disconnected both on the d. c. side and on the three-phase side. The operation with the remaining part of the unit can be continued.



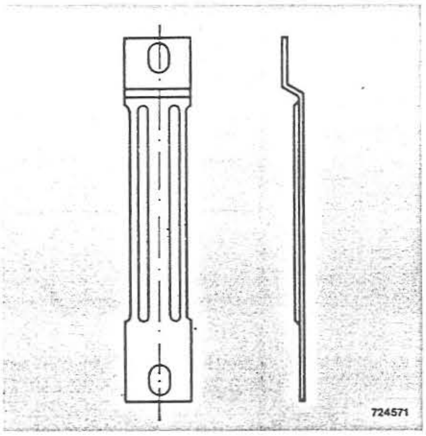
Electric brake

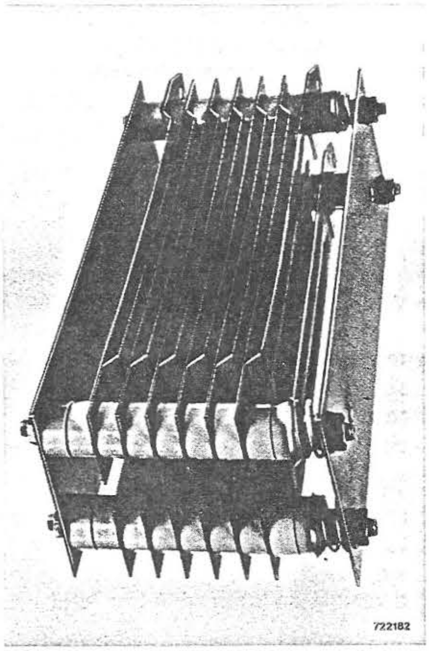
The electric brake of a power transmission system using an asynchronous motor is very simple with regard to circuitry and operation for the following reasons:

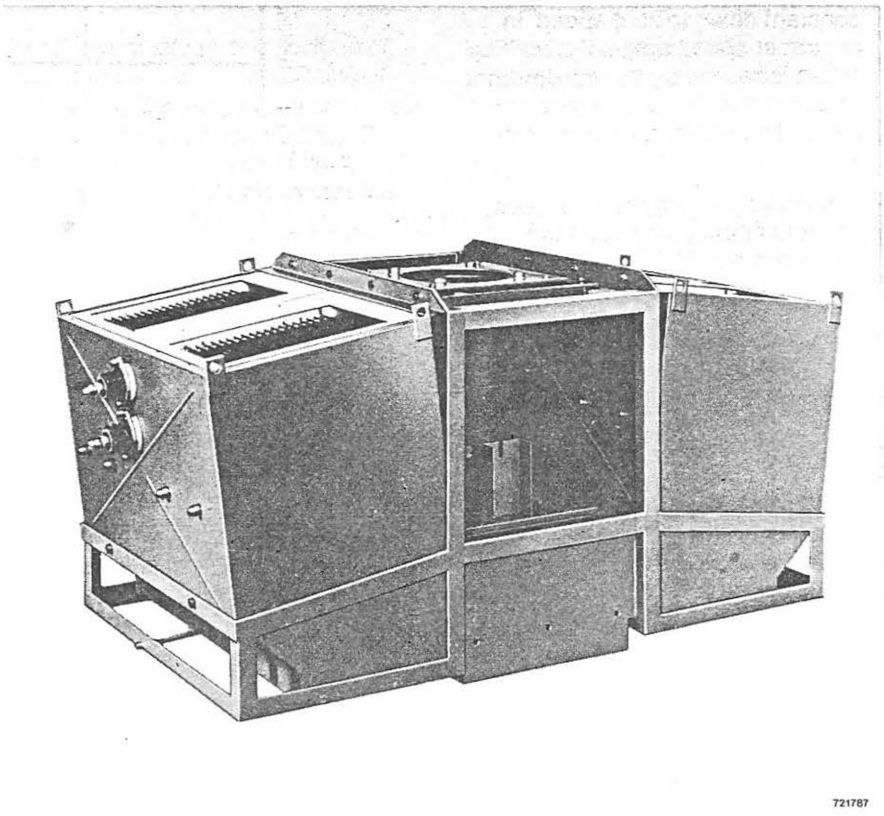
- The asynchronous motor operates as a generator as soon as the mains frequency is lower than the rotor frequency.
- When changing to braking operation it is only necessary to adjust the inverter output frequency in such a way that it is lower than the rotor frequency by the value of the slip frequency f_2.
- The power circuit during braking requires only an isolating contactor for inserting the brake resistor with constant resistance value in the d. c. voltage intermediate circuit.
- The braking effort is regulated through the inverter by means of the same regulating device as for traction. Only the preset reference value is slightly adapted for regulation to constant braking effort.
- The braking effort can be kept constant down to zero speed. In the upper speed range, the braking effort is limited by the maximum power of the traction motors, depending on the preset reference value.
- The braking energy can be used for train heating provided the heating is switched on.



The brake resistor of the DE 2500
- consists of standardized resistor strips which are interconnected to form identical resistor units
- is subdivided into eight resistor units of 2.8 ohms each
- consists of four brake resistor boxes where two units with a total resistance of 5.6 ohms are interconnected. They can absorb a fourth of the braking energy of the locomotive.
- is forced ventilated. Two boxes are accommodated in a supporting structure with associated blower. The common supporting structure is mounted above two inverters placed back to back.





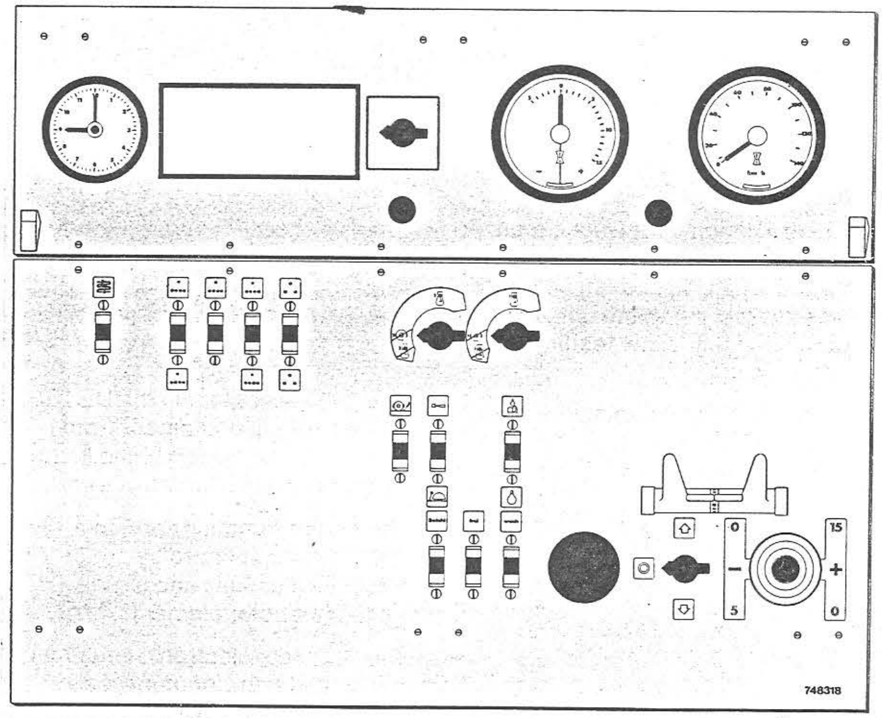


- is a non-wearing and maintenance-free component
- has the following rated values:

braking power	1730	kW contin.
resistance	2 x 2.8	ohms parallel
voltage	1500	$V_{max.}$
cooling air	6.2	m^3/s

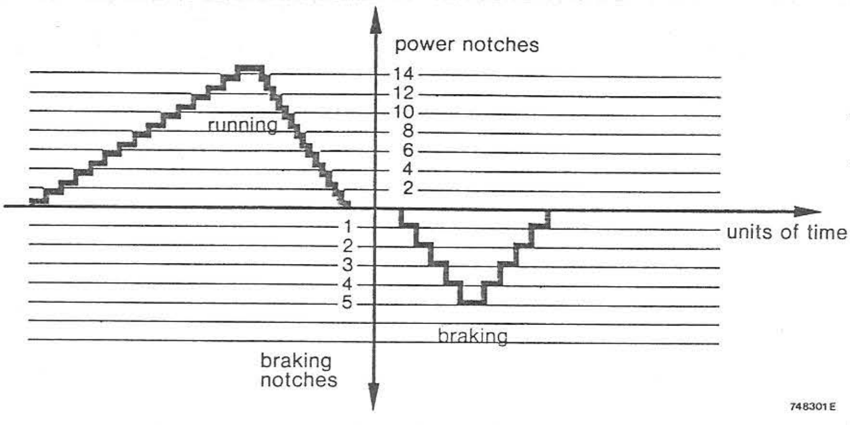
Traction control
Braking control

The driver
- gives only the following commands to the control and regulating device:
  - running direction
  - traction
  - braking
  - power ON
  - power step
- need not control any electrical values
- can give full attention to the track ahead.



The traction/braking control
- is virtually an up/down control with 15 power and 5 braking notches
- has as central unit a 15-bit binary counter which signals the individual power or braking steps in binary code. With constant pulse rate, the notch number is increased in the UP position and decreased in the DOWN position. The notch just on hand is registered when the lever is kept in normal position.
- allows connection of power only when the main air pipe is filled up and is otherwise independent of the compressed-air brake
- automatically switches on the electric brake with braking notch 1 upon operation of the compressed-air brake.

The signals issued by the binary counter in binary code
- are present simultaneously in all locomotives if multiple control is used
- are used for speed adjustment through the code converter and the Woodward regulator
- provide simultaneously the reference value for the electronic control and regulating device
- are indicated to the driver as analogue value and are the only information for the selected power.

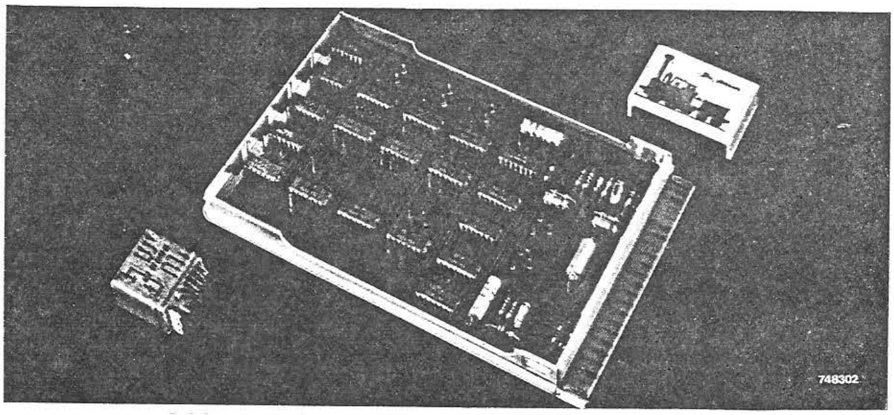


Electronic

The electronic equipment is built up according to the standards of the Brown Boveri electronic system:

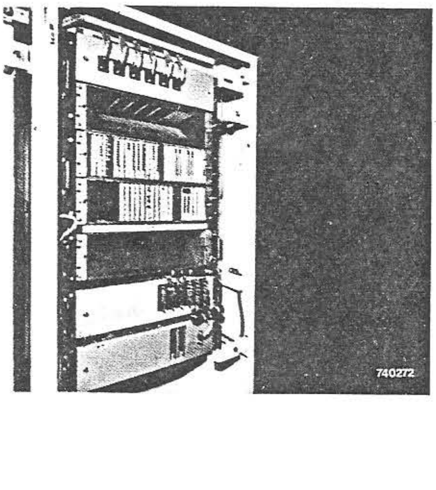
- pluggable functional groups of related circuitry elements, known as prints.
- plug-in modules as internationally standardized 19 in. racks for accommodating the prints.

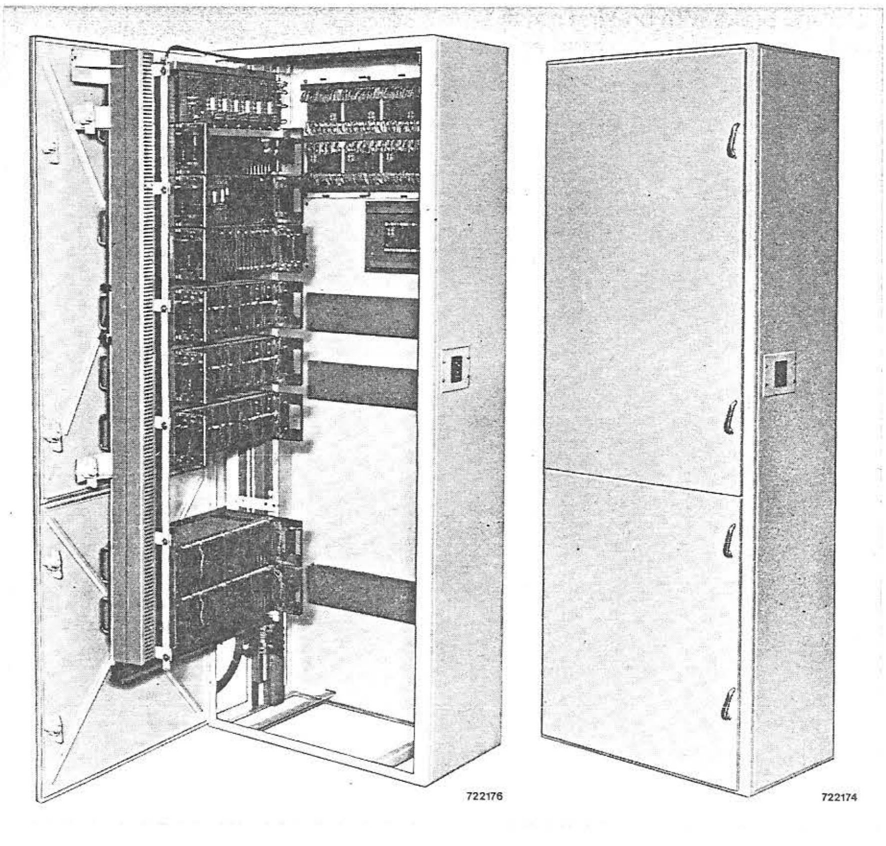
  By combination of definite circuitry elements, such as control unit, protective device and reference value source, complete units are obtained which allow testing and exchange.
- hinged frame with cabinet for accommodating the 19 in. racks.



Electronic equipment in the DE 2500:

- The electronic equipment from input to output is combined in a hinged frame in the driver's cab.
- The control functions are, to a great extent, realized by means of integrated circuits and silicon semi-conductor elements.
- The complete electronic equipment is installed in the locomotive as a previously tested unit.
- A complete separation of the power wiring from the electronic equipment wiring, using crimped connections, ensures a high reliability in service and prevents disturbances.
- Built-in test sockets and indicating lamps allow easy testing of all important functional groups.





Tractive effort and speed of the DE 2500 depend on the diesel engine output just available.

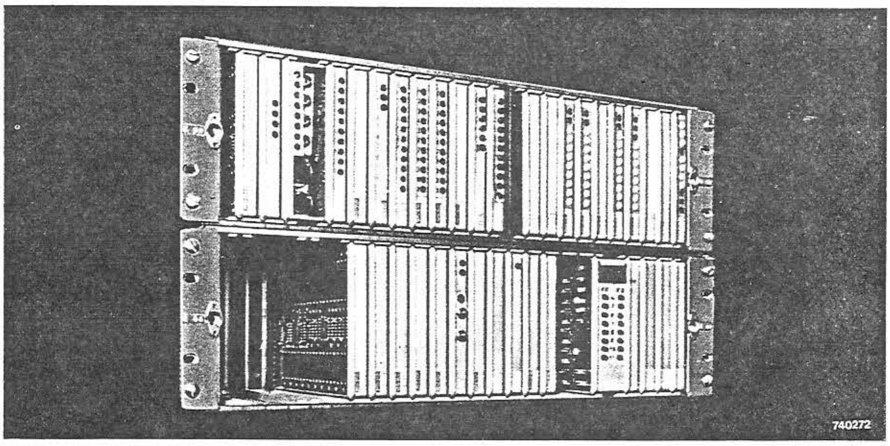
- The output is preset by adjustment of the individual speed steps of the diesel engine. The output coordinated to the speed is obtained by fuel injection adjustment in the Woodward regulator.
- The power steps are simultaneously preset as reference value for the electronic control. Running speed (motor frequency) and torque (slip) are regulated automatically. Only the available diesel engine output is used for traction or heating. The running speed depends on the respective track or load conditions.

The electronic equipment is subdivided in:

- Three-phase reference-value source.
  This part determines the three-phase control rhythm of the inverter thyristors and is used for frequency and voltage regulation of the traction motors.
- Control unit for direct control of the inverter thyristors.
- Power regulation of the traction motors during traction and braking. Torque (tractive effort, braking effort) and speed are determined solely through regulation of the slip frequency.
- Logic for setting the diesel engine speed and switching on the power, presetting the reference value for traction and braking, electric train heating, limiting control depending on the actual fuel injection, etc.
- Input and output units, transducers for processing and passing on all the necessary data from and to the locomotive control.
- Protective and supervisory equipment for the inverter.
- Power supply units for feeding the individual supply busbars.

Checking and fault indication

Every operator should be able to check with normal measuring instruments and simple check lists the entire system to the smallest detail. To this end, the most important electronic prints are provided with test sockets.



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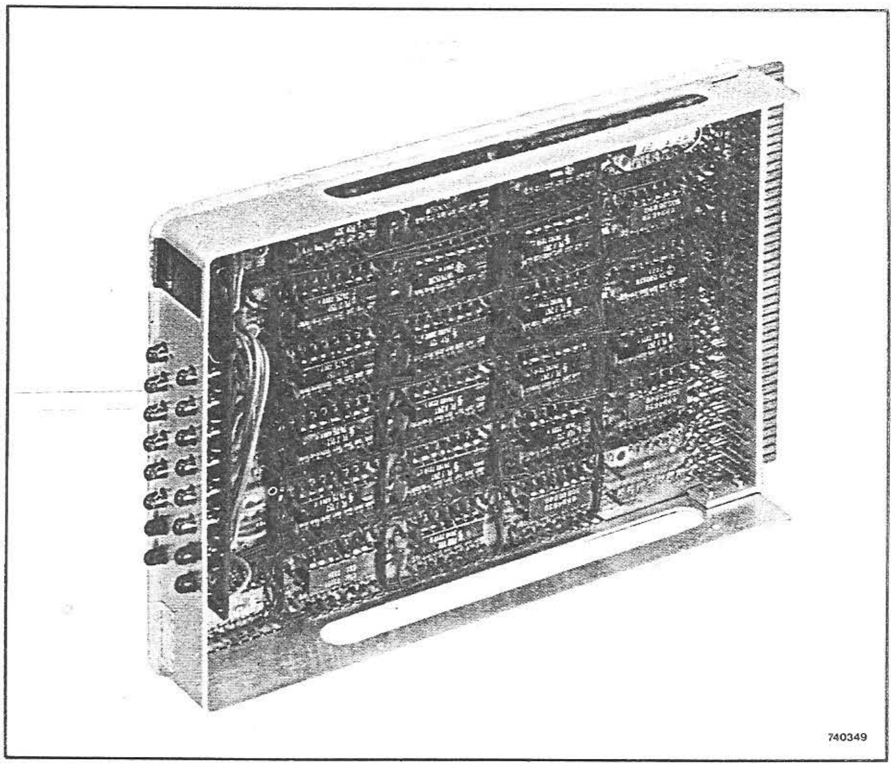
All important functional values, measurands, and output signals are displayed by luminous diodes. Normal operational functions are indicated by green lamps and disturbances by red ones.



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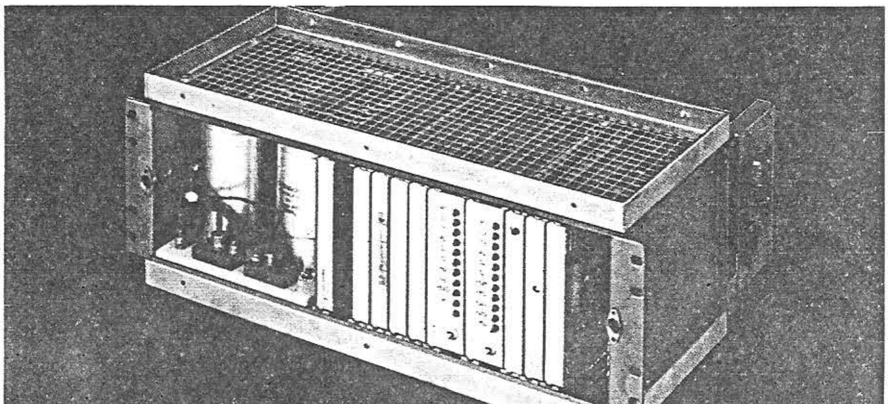
The device for monitoring the inverter unit is installed in a special tier. It controls the individual phases and stores the signal in the case of fault. The signal is stored for approx. 5 min. even if the power supply is disconnected.



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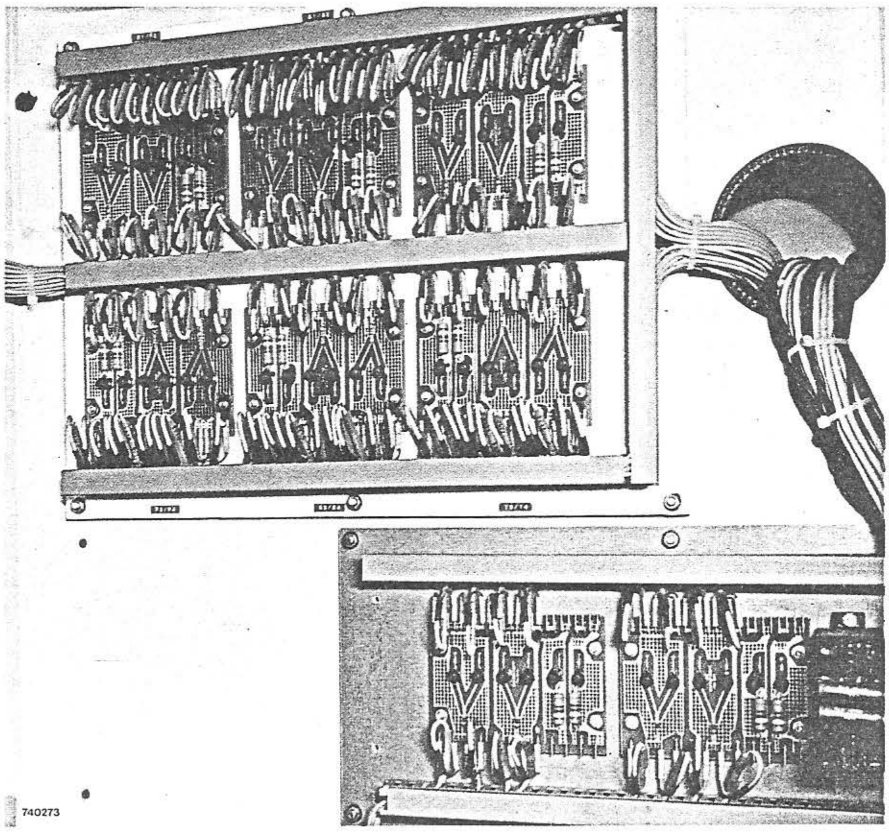
Also the inverter plug-in modules are provided with test sockets which allow the connection of usual instruments for blocking and conduction measurements. Thus defective power thyristors or diodes can be detected.

740281/2

The control signals for the inverter thyristors are routed through signal distribution plates. Luminous diodes indicate the signal flow for the inverter control without the use of an oscillograph or other high-quality measuring devices. The plates are fitted to the rear of the control cabinet.



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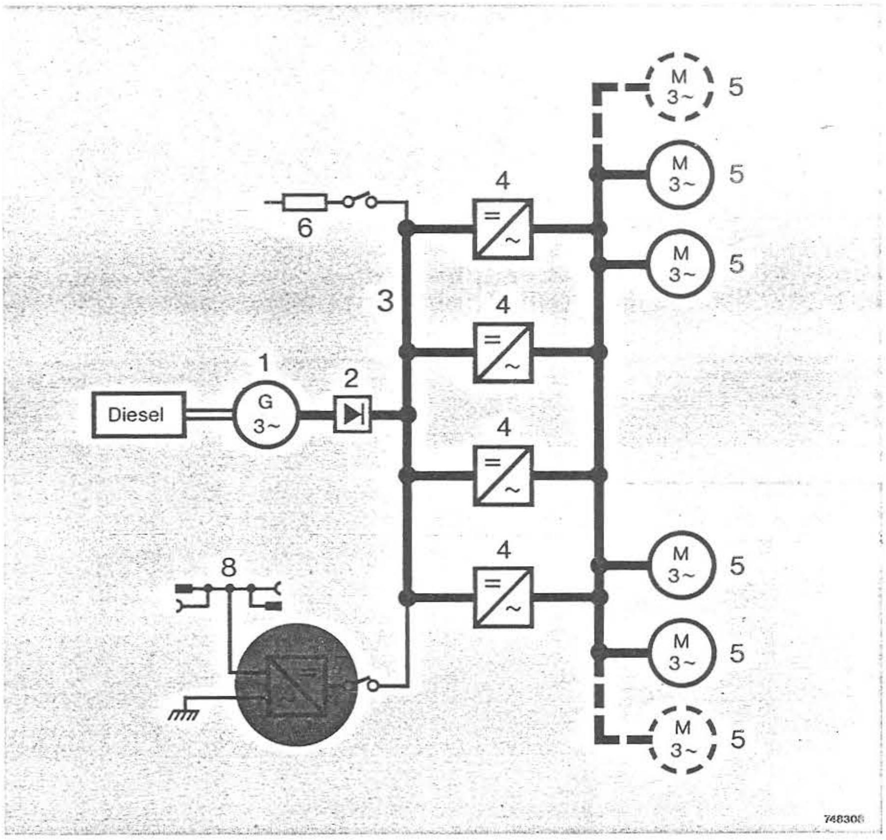
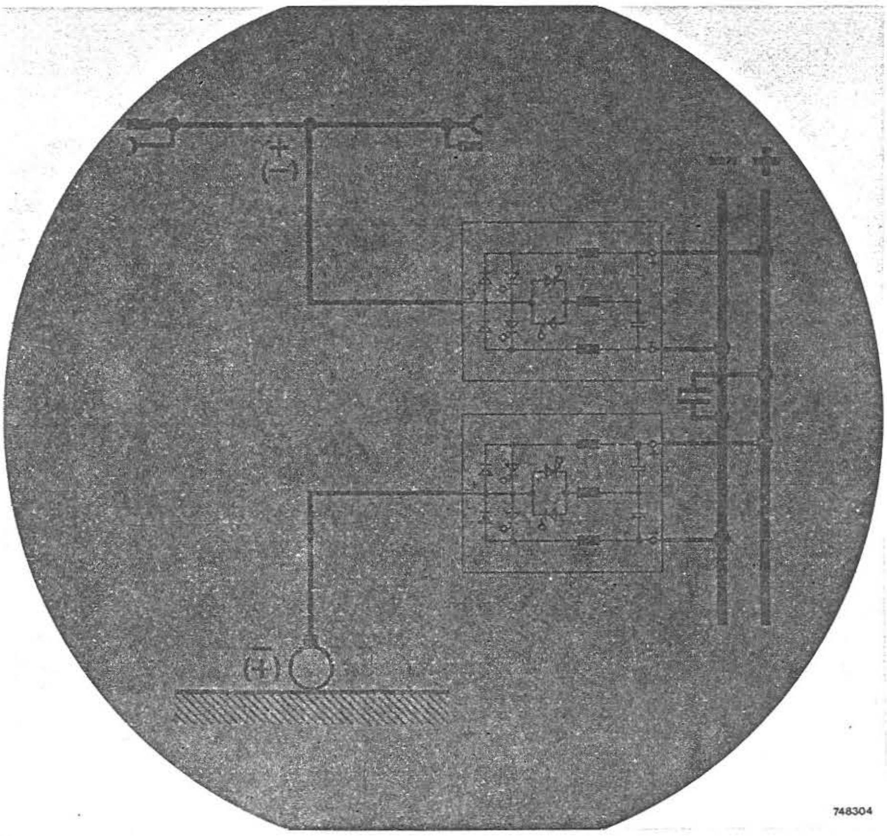
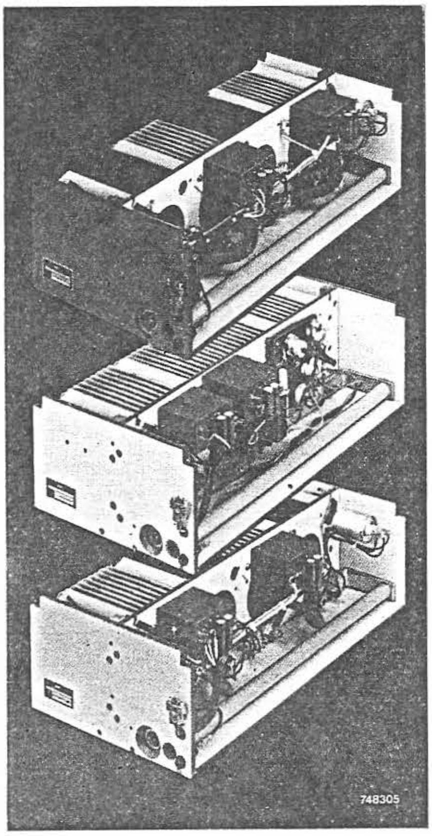
Heating

Feeding the train busbar from the d. c. intermediate circuit

- makes it possible to generate, without changing the main circuitry elements, the a. c. voltage desired (e. g. 1000 V, 16 2/3 Hz or 1500 V, 50 Hz) by applying the same method as used for the traction inverter (two-phase instead of three-phase) and using the same modules. The components are largely the same as for traction.
- allows direct connection to the d. c. intermediate circuit
- makes it possible to use the energy produced during braking without special measures
- makes it possible at any time to use for traction the energy not required by the train busbar
- makes it possible to build a goods train locomotive without heating system without influence on traction.

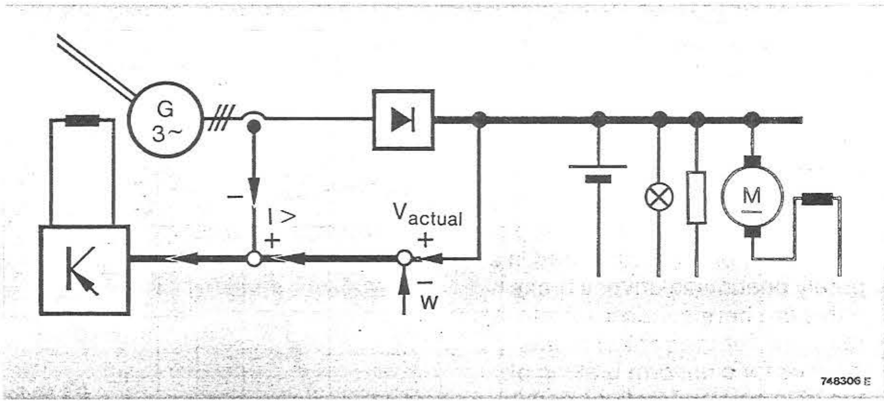






Auxiliaries

The control equipment suitable for multiple traction and push-pull operation, auxiliaries for the diesel engine, lighting, time depending dead man's control and automatic signal control are fed from a 110 V service network.

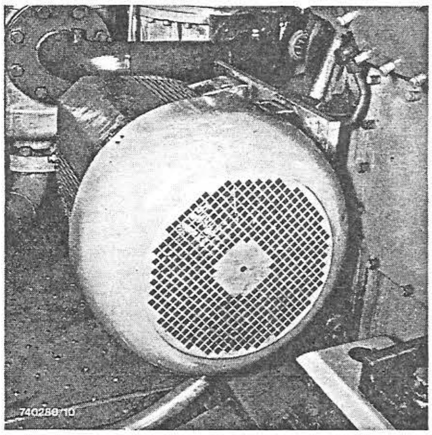


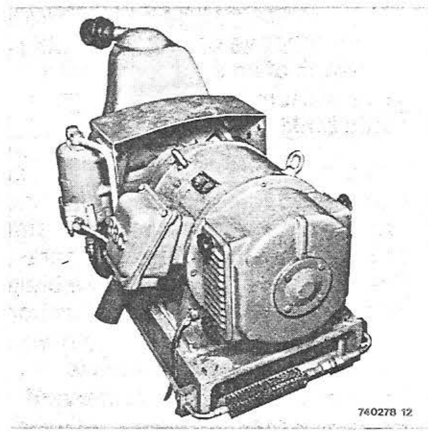
The 110 V service network supply uses a three-phase claw-type alternator directly powered by the diesel engine. The output voltage is regulated according to the voltage/current characteristic and rectified in an uncontrolled rectifier.

Heating elements and circulating pumps fed from an external 220 V, 50 Hz supply system keep the cooling circuit and the diesel engine warm.

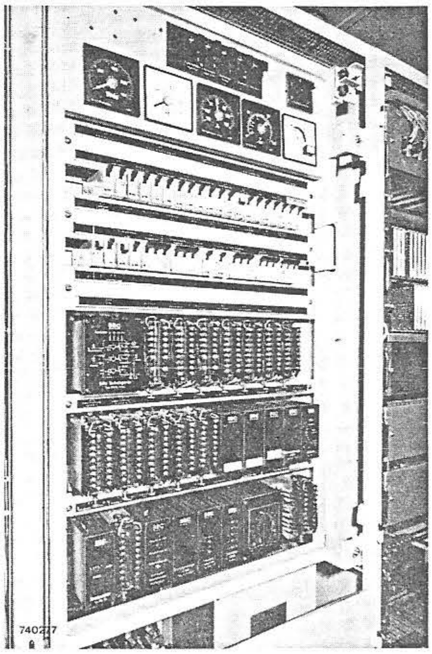
Diesel engine fire is acoustically indicated to the driver by means of heat sensors and signalling bells.

Faults with the diesel engine and power transmission system, such as excessive speed, lack of cooling water or excessive cooling water temperature, lack of fuel, frequency converter trouble and over-temperature of the traction motor are signalled at the driver's desk by means of signalling lamps.





The auxiliary air compressor used for starting the diesel engine is driven by a d. c. motor.

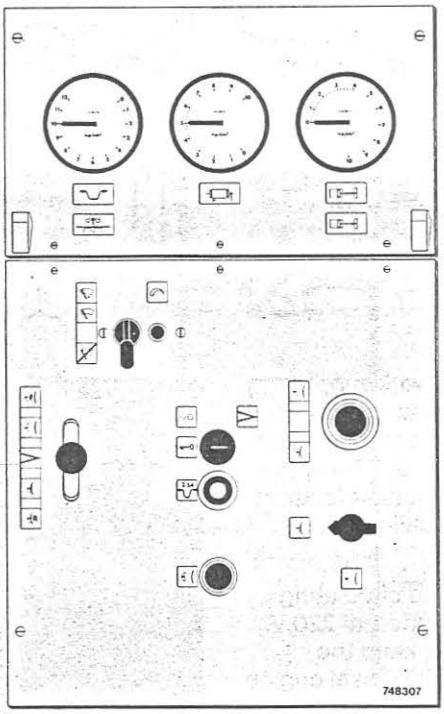


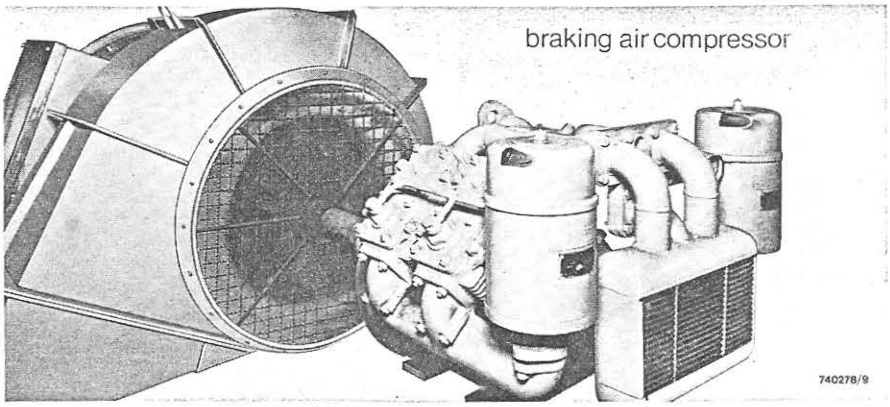
The devices for the individual auxiliaries, such as battery main switch, rectifier and regulator of the alternator, auxiliary relays, dead man's control and monitoring devices in the well-known VH8 program, miniature automatic circuit breakers for the individual control circuits and indicating instruments for diesel engine speed, battery and intermediate-circuit voltage are accommodated centrally in a cabinet in cab 2.

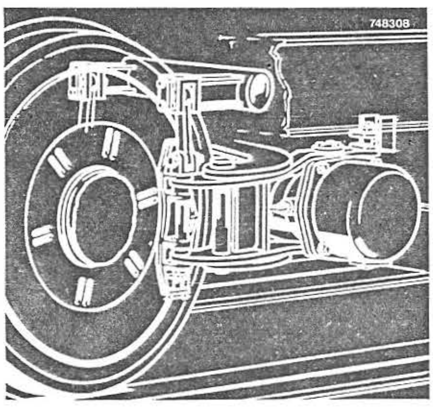
Electro-pneumatic brake

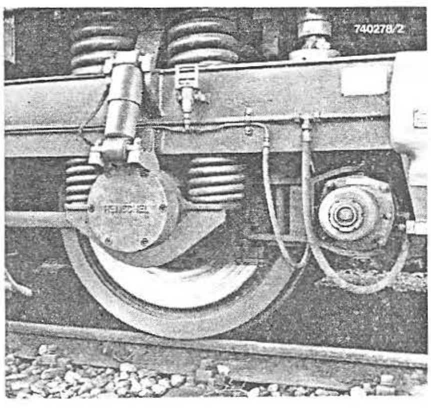
The DE 2500 uses an electro-pneumatically operated automatic compressed-air brake (disc brake), type KE - GPR, with additional brake.

- The automatic braking device is controlled by means of an electric driver's brake switch and a central relay unit. The functional units which are normally combined in a purely pneumatic driver's brake valve are here subdivided into (a) relay unit for the control of the devices for a uniform braking of the train and locomotives and (b) brake switch in the driver's desk.
- The locomotive can also be braked by means of an additional brake valve without the use of the automatic braking device.
- The automatic braking device of the locomotive is such that the electric brake with a constant braking effort of 3.2 Mp becomes always operative. This reduces wear of the brake discs. In the case of full application of the service or emergency brake, the brake cylinder pressure is reduced appropriately to prevent excessive braking.
- The compressed air is produced by a Knorr air compressor, type VV 450/150-1, which is directly coupled to the diesel engine by means of a flexible coupling. Regulation is effected by control of the intake valves, dependent on the pressure.
- The manual brake is designed as spring-operated brake, i.e., the braking force is produced by spring force. For traction, the brake action must be made ineffective by means of compressed air applied to the brake piston.





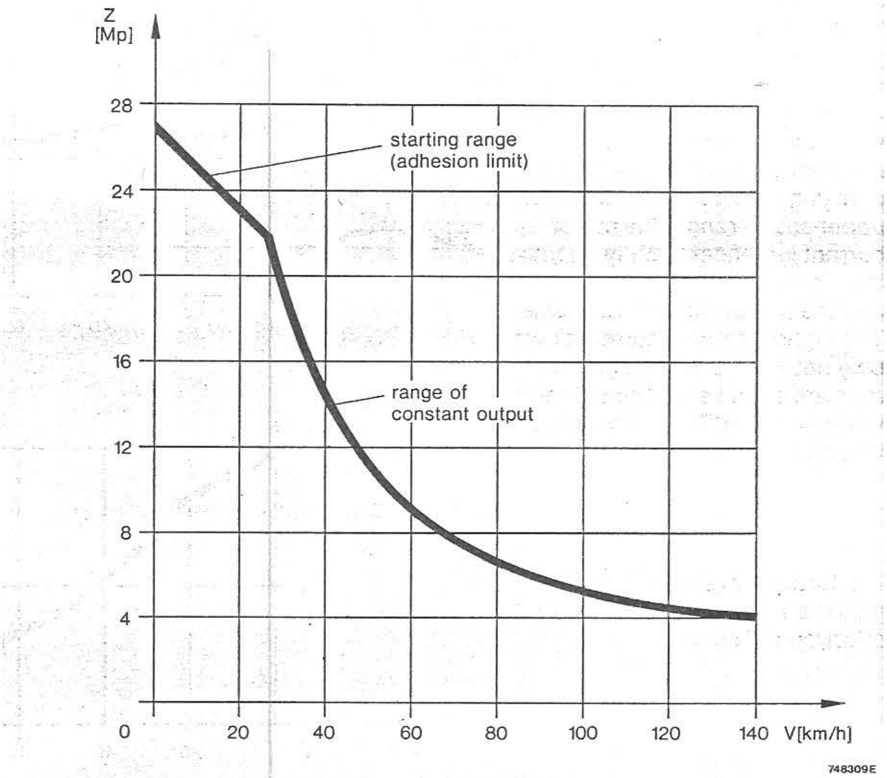




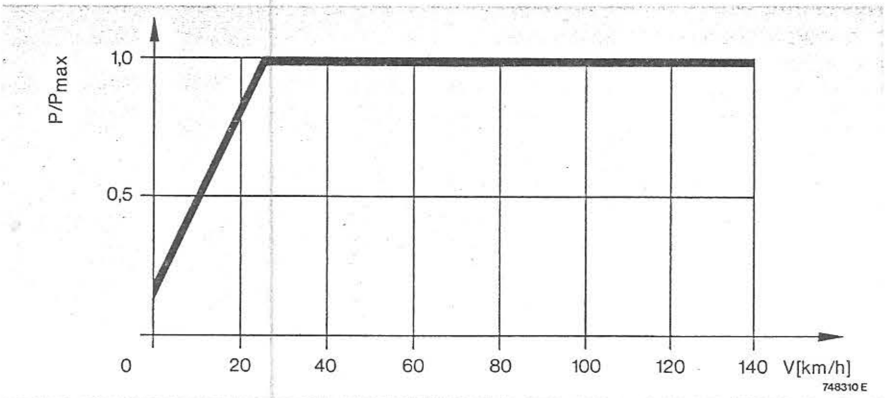
Operating characteristics

With regard to the power required for the three-phase power transmission the following distinction must be made:

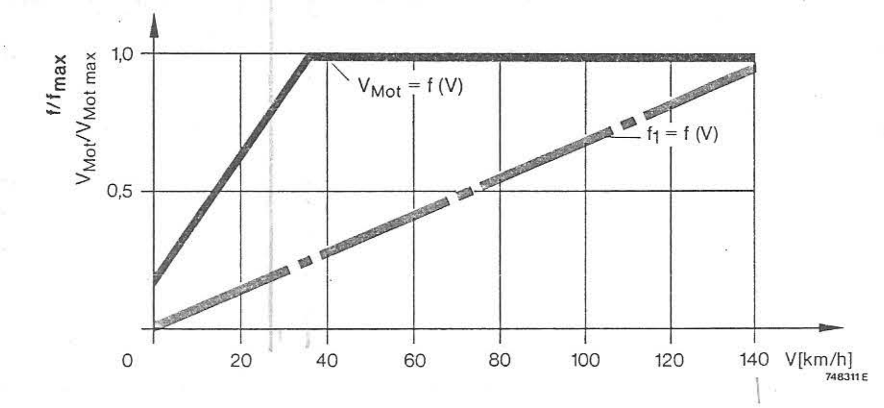
- Starting range
  The tractive effort follows the adhesion value; the power increases until the maximum diesel engine power is reached.
- Constant power range
  Up to maximum speed, the torque at wheel rim decreases according to the hyperbolic function.



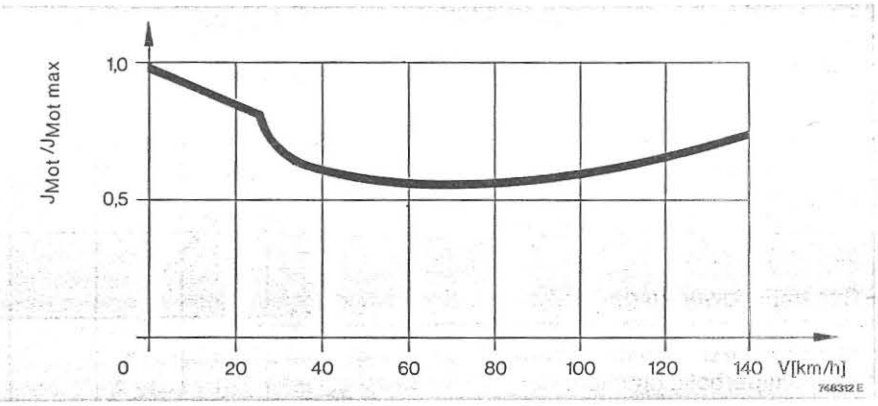
In order to realize the tractive effort/ speed curve, the power input increases first linearly. When the rated power is reached, the power input remains constant for remaining speed range.



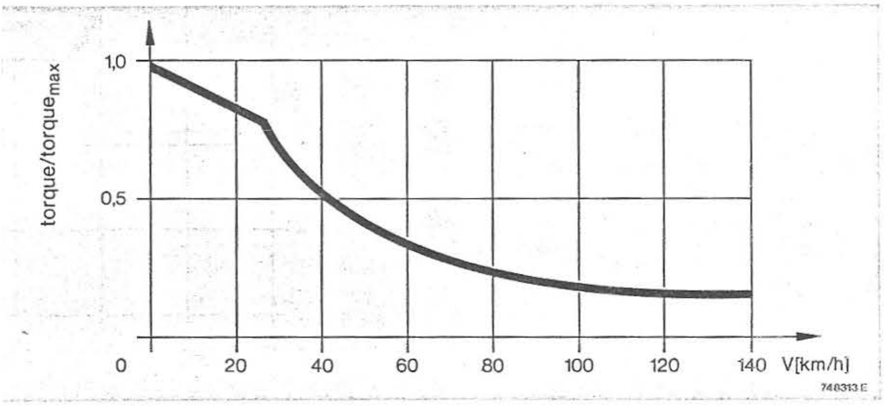
The torque which is approximately constant on starting requires a constant excitation flux for the asynchronous traction motor. In this range, the traction motor voltage has therefore to be regulated proportionally to the motor frequency and/or running speed. Because of the overall optimization of traction motor and inverter the motor voltage remains however constant within a wide range.



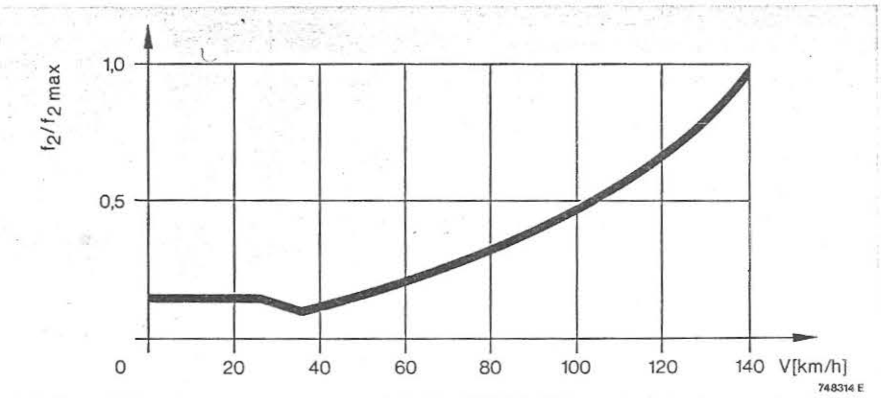
The approximately linear increase and then constant characteristic of the traction motor power can be perceived from the values for traction motor current and voltage. The decrease of the motor current when the power hyperbola is reached is caused by the still increasing voltage in this range. In the upper speed range, the motor current increases slightly because the slip frequency f_2 becomes higher and the power factor thus worse. This higher reactive current flows only between d. c. voltage intermediate circuit and asynchronous traction motor. The alternator is not loaded with this current.



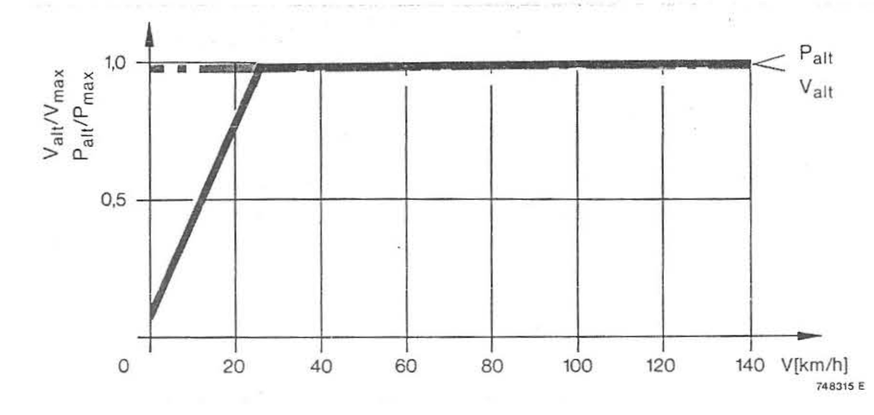
The torque developed by the traction motor is a replica of the tractive effort/speed curve.



This characteristic within the range of constant traction motor voltage and still increasing frequencies is possible only by a higher slip frequency f_2.



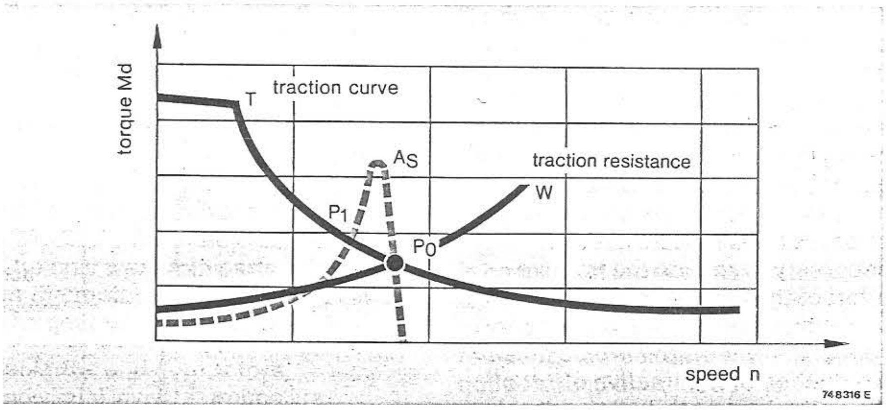
The alternator has to supply only the output corresponding to the tractive effort/speed diagramm. The alternator output is determined solely by the alternator current.



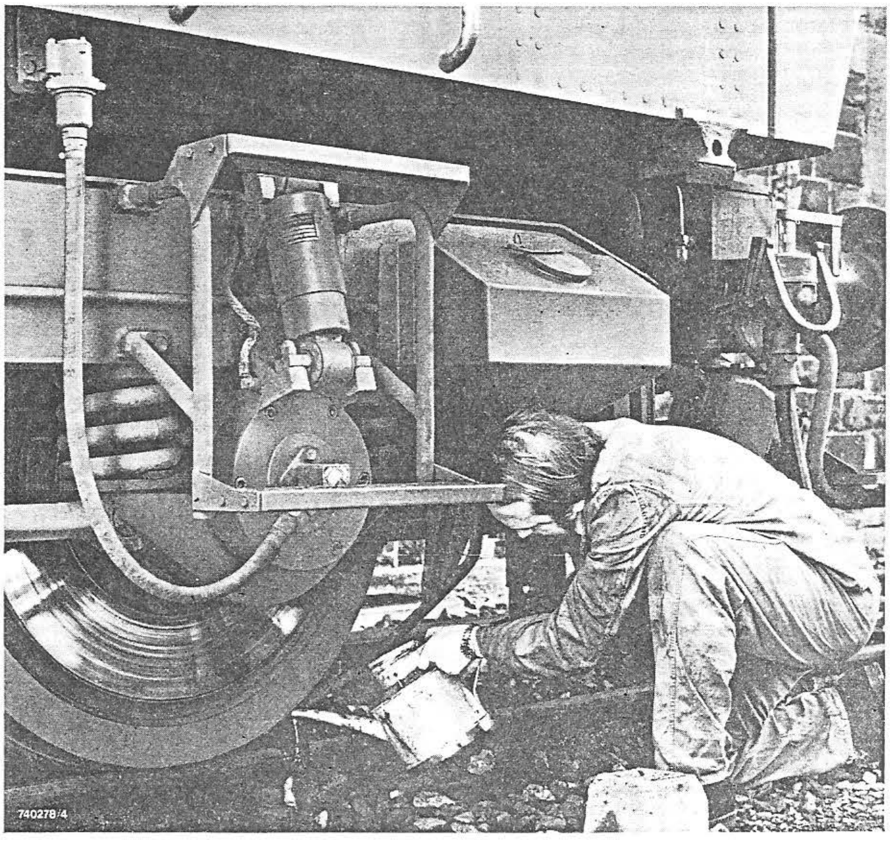
Why no slipping?

Slipping of individual driving axles of a locomotive using asynchronous traction motors is, on principle, not possible for the following reasons:

- All motors are connected in parallel and are thus electrically coupled.
- Due to the automatic regulation of the inverter output frequency, dependent on the momentary speed of the traction motor, the point where the torque-speed diagram intersects the load curve will always be stable.
- The operating point is the same for all traction motors since the torque is regulated through the slip frequency f_2.



- In the case of a sudden reduction of the adhesion value of individual axles (e. g. arbitrary oiling of a wheel in the case of heavy starting) the maximum possible speed of this axle is determined by the fed-in frequency of 0.4 Hz for starting.

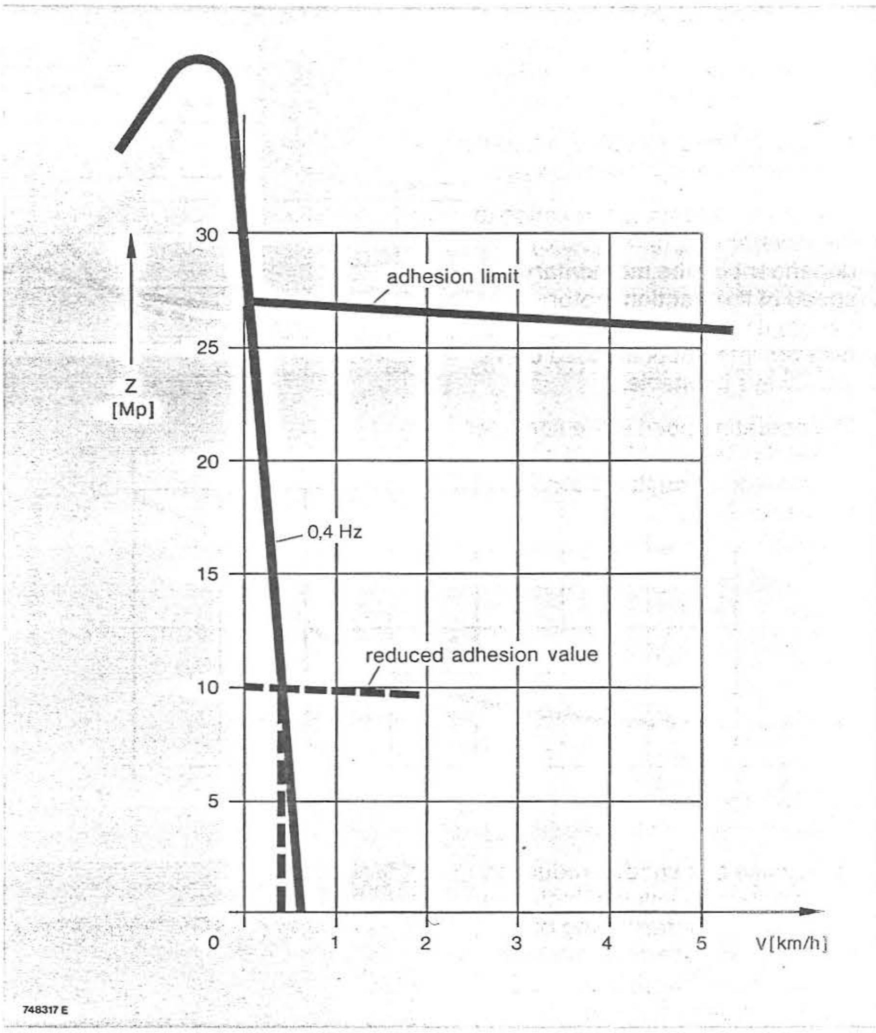


If, for instance, the adhesion value drops to approx. 12 %, the axle can develop a speed of not more than approx. 0.4 km/h with this poor adhesion value since the speed is determined by the preset frequency of 0.4 Hz. The other axles, however, develop the full tractive effort. For this reason, it is not necessary to reduce the tractive effort of the other axles with a good adhesion value accordingly. In conventional systems this would mean a reduction of the tractive effort of the entire locomotive to an adhesion value of approx. 12 % only because a single axle slips on an oiled track section.

For instance, in the case of a six-axle locomotive using the three-phase asynchronous motor drive system five axles will develop the full tractive effort corresponding to an adhesion value of 33 % and only the axle on an oiled track section will participate in the development of the total tractive effort with a reduced adhesion value corresponding to approx. 12 %. This behaviour has been shown for starting. The same applies, of course, also to all the other speed ranges from zero to maximum speed.

However, if all axles lose their adhesion value at the same time, a very quick-acting electronic wheel slip control device takes over. This device is part of the electronic control and regulating device and has the following features:

- Extremely fast detection of speed variations of the driving axles. For this purpose, the inductive feelers are used to measure the traction motor speed.
- Very quick and undelayed reduction of the torque as soon as a wheel slip signal is detected.
- Slowing down of the slipping wheel since a steep torque-speed diagram quickly results in an intersection with the curve showing the reduced adhesion value.
- Negligible mechanical stress on the driving gear since there are no additional acceleration and deceleration forces.



The electronic wheel slip control can be realized with a minimum of additional expenditure. It consists only of a plug-in module since all the other data are already stored in the electronic control and regulating device. The fact that all processes take place in the electric system, i. e. in the power electronic equipment, ensures an unequaled fast intervention.
However, due to the natural characteristic of the asynchronous motor this additional electronic wheel slip control device for all axles comes into effect very rarely since slipping begins in most cases on one axle only. Such a slip is automatically stopped due to the natural characteristic of the asynchronous motor as described above.

Non-wearing technique

Largely non-wearing and maintenance-free techniques since most important components of the three-phase power transmission system do not incorporate any parts subject to wear, e. g.

Alternator
The alternator has no commutator, sliprings or brushgear. There is only one bearing and thus only one part subject to wear.

Rectifier unit
The rectifier unit is made up of non-wearing power diodes. They are designed to withstand safely the short-circuit current of the alternator.

Inverter unit
The inverter unit is made up of elements of power electronics, such as diodes, thyristors, capacitors and reactors. All components are non-wearing and have a long life.

Traction motors
The asynchronous traction motors are the simplest electrical machines. They have no commutators, slip-rings, brushgear or uninsulated parts. The stator winding is fully insulated. The rotor uses simple copper bars which are hard-soldered onto a short-circuiting ring. The only wearable parts incorporated in the motor are two bearings and the gear drive for the axle.

Isolators and contactors
Individual inverter groups are disconnected by simple isolating switches. These switches are not operated during normal operation but are only opened at no load when a fault occurs. Thus they are not subject to operational wear. Other switching devices used for galvanic isolation are also operated at no load.

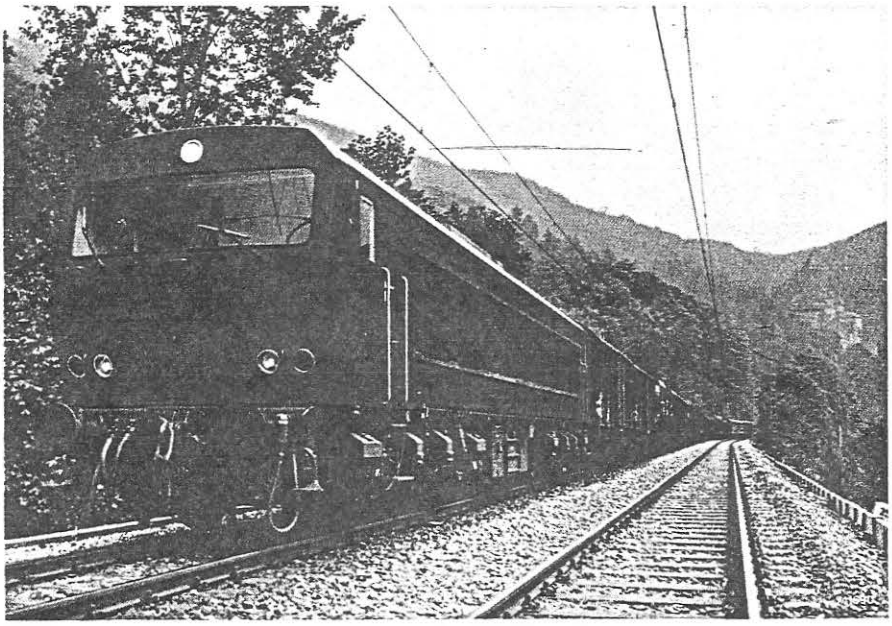
Protection of the inverter system
The protective equipment for the three-phase power transmission also operates without contacts; it is made up of electronic components.

Electronic control system
The electronic control system, too, does not use any switching devices. It is thus maintenance-free.

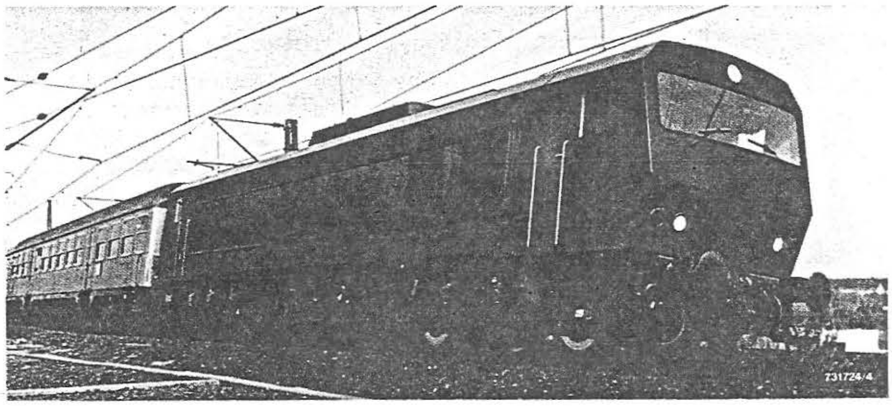
Bogie
The bogie and the elements for the transmission of tractive and braking efforts are largely made up of non-wearing components. They have no laminated springs, no frictional areas, no axle-box guides and no bogie pivots.

In conclusion it can be said that the entire three-phase power transmission is free from maintenance-requiring components to an extent not achieved up to now. The only components that are subject to wear are the unavoidable bearings and gear wheels.

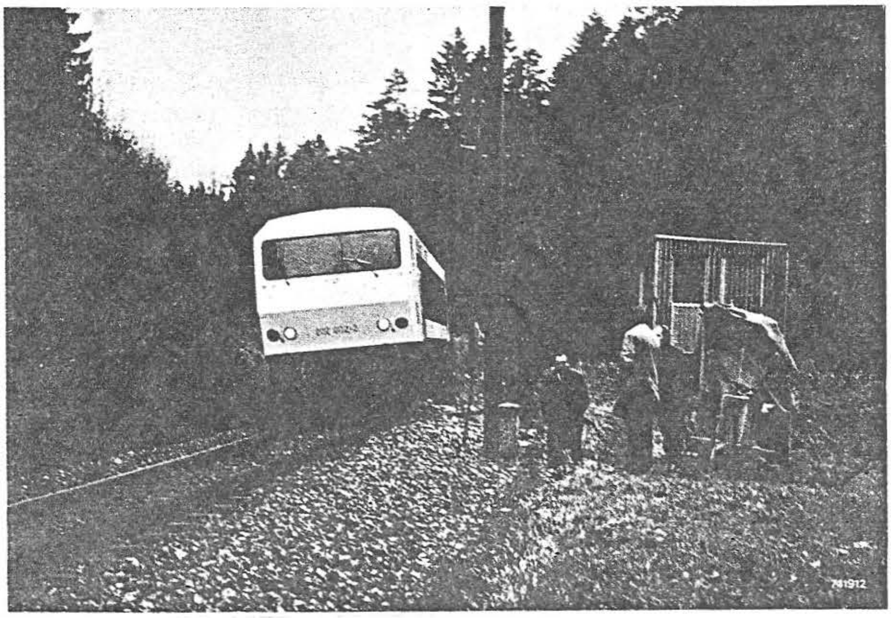
Examples of testing, trials, and operation



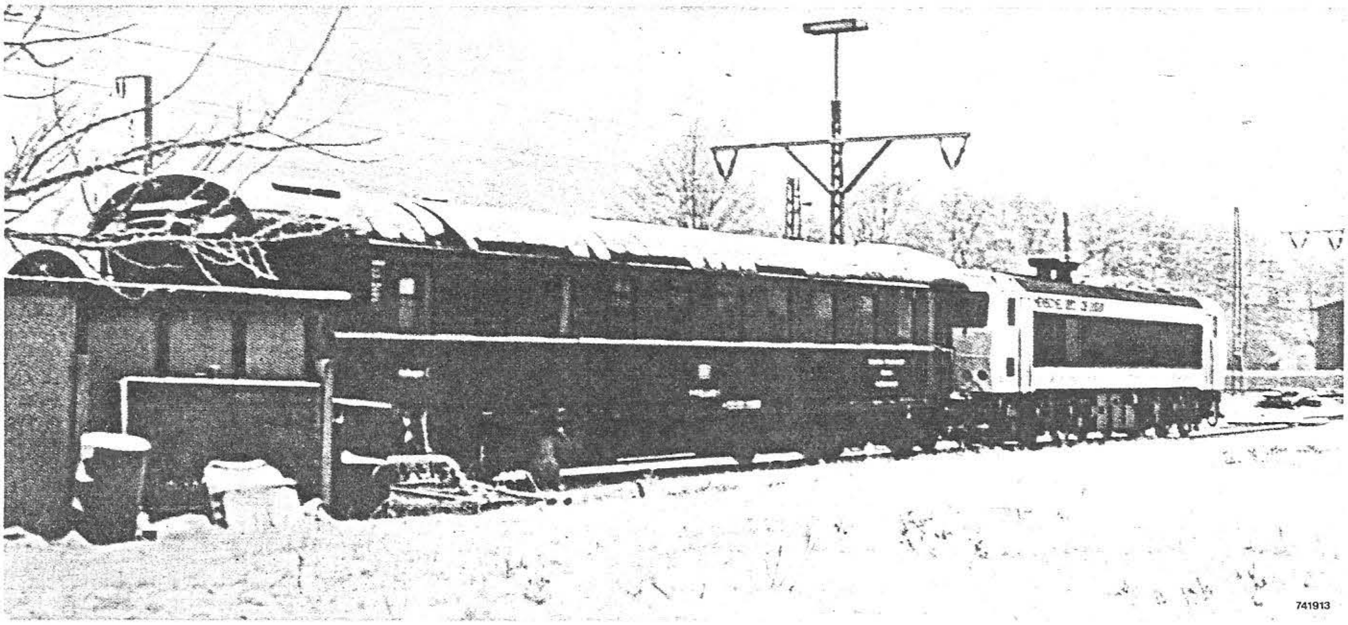
DE 2500 with a goods train on the German Federal Railway



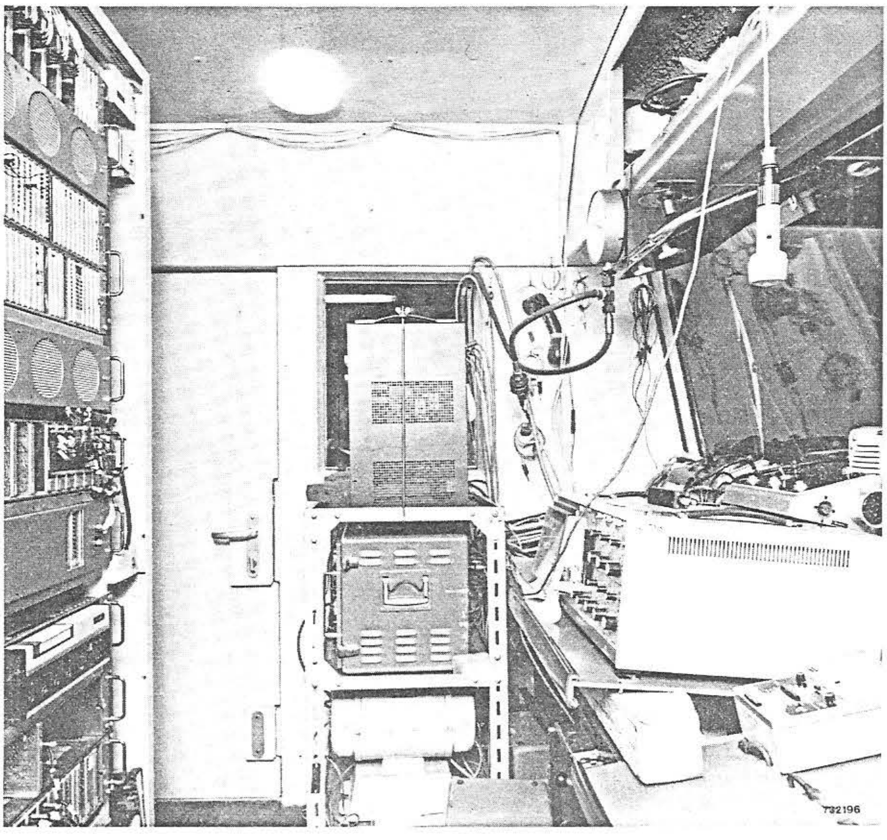
DE 2500 in passenger service on lines of the German Federal Railway with maximum speed of 140 km/h



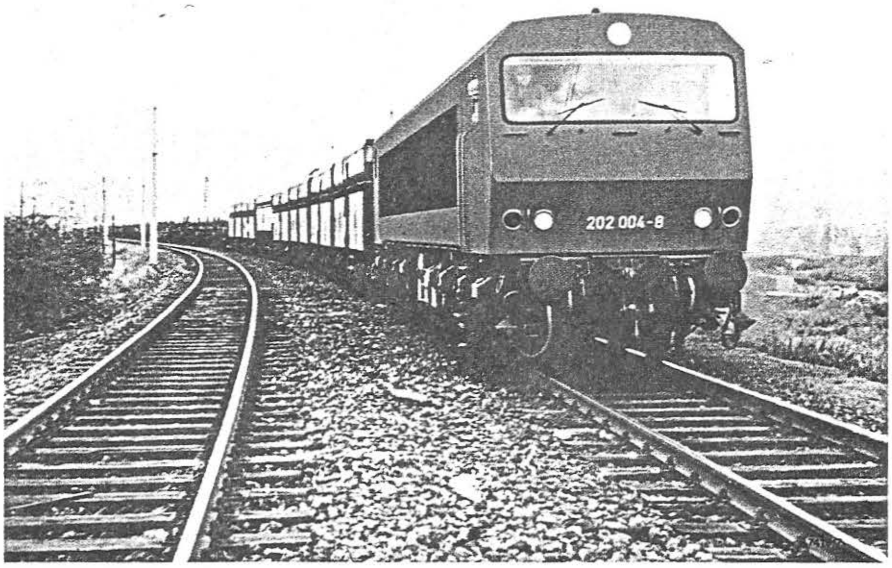
DE 2500 on trial runs by the Swiss Federal Railway in a 300 m test curve near Ossingen



DE 2500 during heating tests carried out by the electrotechnical laboratory of the German Federal Railway

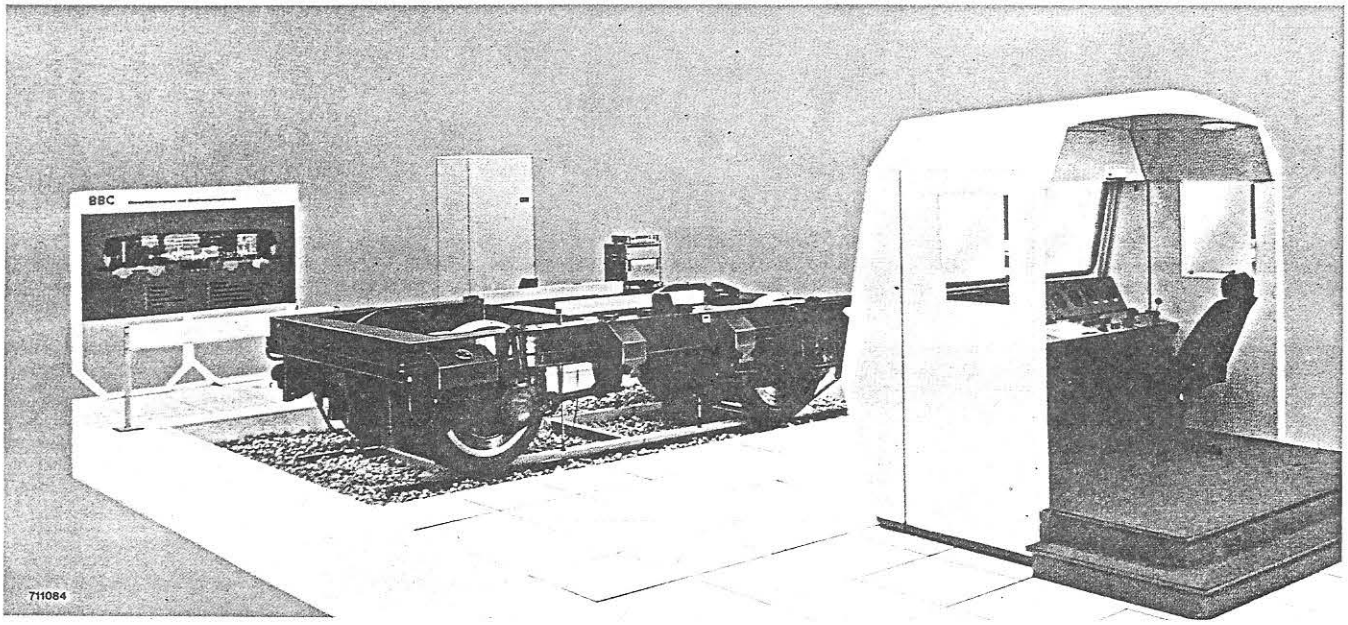


Driver's cab of the DE 2500 during tests of the mechanical and electrical braking system by the Minden testing laboratory of the German Federal Railway.
The driver's cab is equipped with all sorts of measuring devices of the testing laboratory.

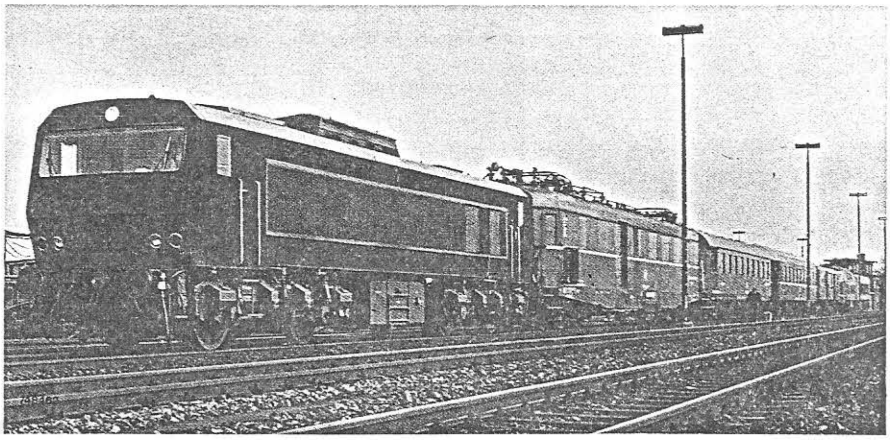


DE 2500 in goods train and shunting service under severe conditions; total weight 3500 t.
The locomotive was used in a speed range of only 0 to 25 km/h during this run though it is rated for a maximum speed of 140 km/h.

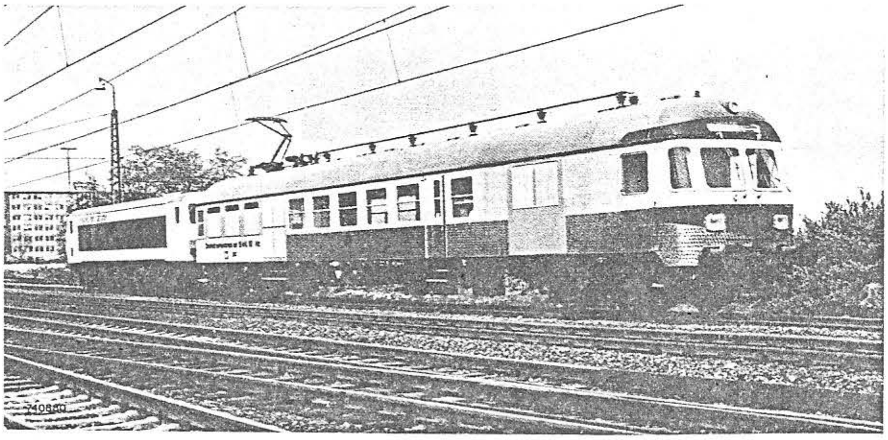
DE 2500 at the Hanover Fair



Driver's cab, bogie and inverter system during the testing stage of the components



DE 2500 during power, efficiency, and thermic measurements by the testing laboratories for electrical engineering and combustion of the German Federal Railway



DE 2500 as test unit fed with 15 kV, 16 2/3 Hz from the overhead line instead of the customary energy supply from the Diesel-generator unit

BROWN BOVERI

BROWN, BOVERI & CIE
AKTIENGESELLSCHAFT
MANNHEIM
Federal Republic of Germany
Traffic Division
Telephone (06 21) 38 11, Telex 04-62411 122
P. O.-Box 351, D-6800 Mannheim 1

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