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Cover:
Train compositions of the Vereinigte Bern–Worb (VBW) and Solothurn–Zollikofen–Bern (SZB) railways near Worblaufen

Traction and Rolling Stock Equipment

Page

Type Bo'Bo' + 2'2' Electric Motorcoach Compositions No. 41 to 52 of Class Be 4/8 for Suburban Services on the Solothurn–Zollikofen–Bern (SZB) and Vereinigte Bern–Worb (VBW) Railways

U. Baechler

With the object of improving traffic facilities in the Bern area, the Vereinigte Bern–Worb and Solothurn–Zollikofen–Bern railways, which provide suburban services to the east of the city, ordered 12 type Bo'Bo' + 2'2' electric motorcoach compositions of class Be 4/8. The conventional switchgear (electro-pneumatic contactors) is controlled through an electronic system. This permits constant acceleration or deceleration during starting and braking and also speed preselection during downhill running. Warm air heating combined with forced supplementary ventilation is used for the first time in suburban passenger vehicles, increasing passenger comfort. The electrical equipment for these vehicles is described in detail.

Introduction

Reorganizing the suburban traffic to the east of the city of Bern included combining the approach line of the SZB and the Worblental line of the VBW. Since the Ittigen–Kornhausplatz section of the VBW discontinued operation in May 1974, the Worblental vehicles now approach Bern through Worblaufen. In contrast to the original line arrangement where the permanent way was laid in the road surface and the tram tracks were also used, the new, communal section between Worblaufen and Bern is a twin-track permanent way laid entirely on its own bed and, for part of the way, runs underground (Fig. 1).
The higher contact-wire voltage of the SZB and the advanced age of the VBW rolling stock made it necessary to replace all vehicles for the Worblental line. At the same time the SZB required further rolling stock and consequently the two railway undertakings ordered a total of 12 class Be 4/8 motorcoach compositions from the Swiss Industrial Company, Neuhausen (mechanical equipment) and Brown Boveri (electrical equipment) in 1971 and 1972 (Fig. 2).

Design Concept

The smallest self-contained unit was stipulated by the railway undertaking as an 8-axle double motorcoach. It must be possible to operate up to three of these units in multiple traction (Fig. 3). Careful investigations showed that with proper weight distribution, the tractive effort can be provided by four driving axles. This is possible because the train length is matched to passenger capacity not in the usual manner by adding trailers or driving trailers, but solely by adding identical double motorcoach units. Consequently the ratio of tractive effort/train tonnage is maintained, even at peak periods. Optimum weight distribution was achieved by dividing the unit into a motorcoach and driving trailer section. The steel-bodied motorcoach section contains all the electrical power equipment and auxiliaries. The driving trailer has a light alloy body.

Technical Data

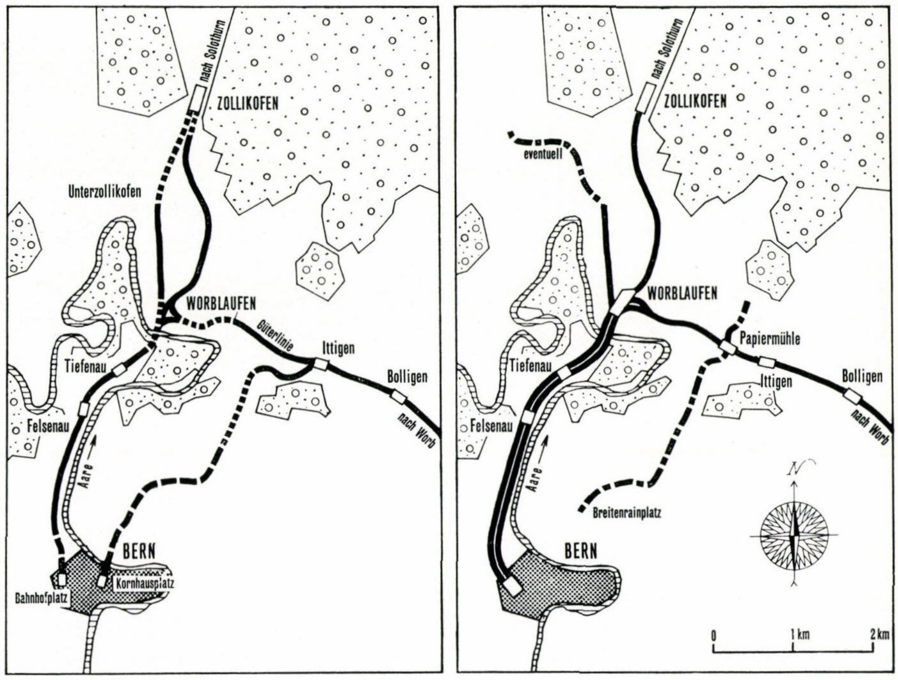
Supply	d.c.
Rated contact-wire voltage	1200 V
Maximum contact-wire voltage	1350 V
Minimum contact-wire voltage	750 V (Worb station)
Gauge	1000 mm
Axle sequence	Bo'Bo' + 2'2'
Adhesion weight	32·7 t
Service weight	48·7 t
Weight of mechanical equipment	40·4 t
Weight of electrical equipment	8·3 t
Capacity	20 t
Seating capacity	128+8
Total passenger carrying capacity (without corridor)	220
Driving wheel diameter (new)	770 mm
Transmission ratio	1:6·166
One-hour rating at wheel at 39 km/h	314 kW
One-hour tractive effort at wheel	29 kN
Maximum speed	75 km/h
Tractive effort on starting	68 kN
Tractive effort at wheel at maximum speed	12 kN
Switchgear	Electro-pneumatic contactors
Control system	Electronic acceleration and deceleration control, speed control for downhill running

Traction Equipment

Mounted on the roof of the motorcoach are the current collector type ESg 12-2500 (design similar to that of Swiss Federal Railways), type HMD 2 surge diverter

Fig. 1 – Diagrams of the original and new railway systems

The original track system for the Bern suburban railway is shown on the left with the new layout on the right. Important features of reorganization include the double track between Bern and Worblaufen incorporating the VBW on this line, the underground station in Bern and the new transport facilities in Worblaufen.



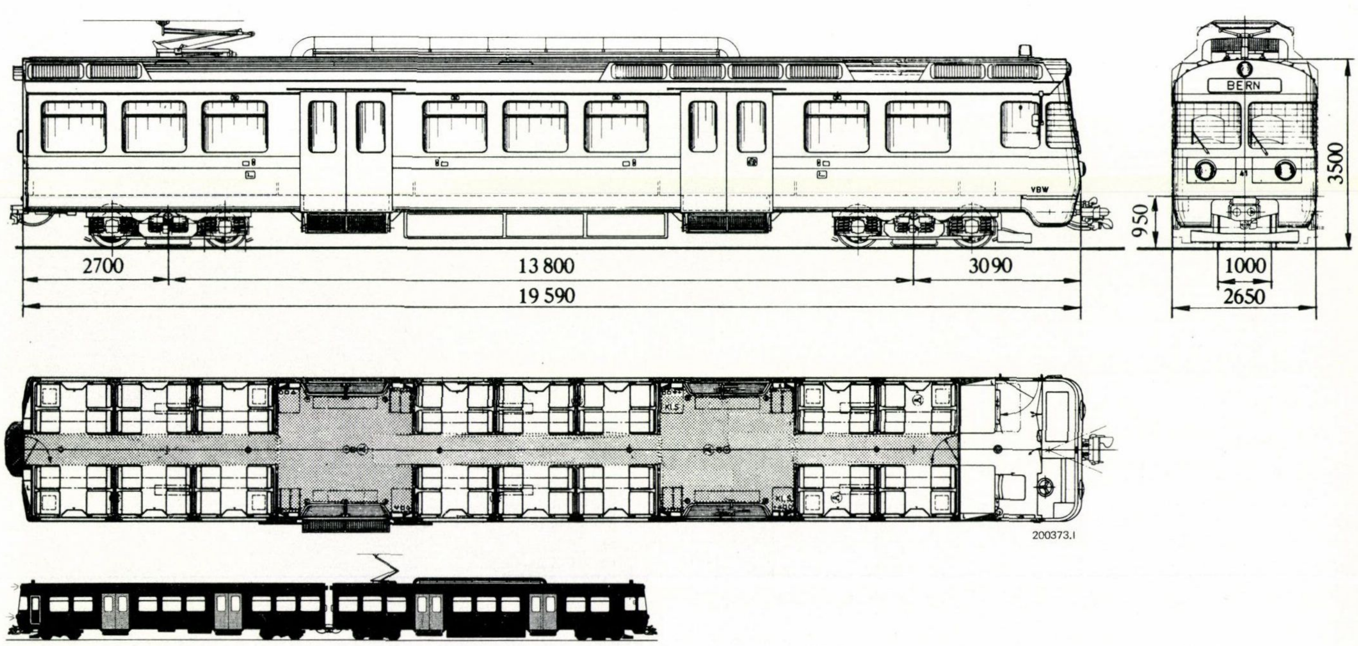


Fig. 2 – Be 4/8 traction composition

and the self-ventilated starting and braking resistors. Also on the roof are the air inlets for the traction motors and for the heating and ventilation equipment.

The motoring and braking circuits use type PH 12.04 electro-pneumatic contactors throughout. Starting is conventional by means of series and series/parallel connection of the traction motors followed by regrouping by means of the bridge connection shown in Fig. 4. Braking is by means of a crossover short-circuit connection (Fig. 5). There are altogether 16 series motoring steps, 14 parallel motoring steps, 3×2 field-weakening steps and 14 braking steps available. The complete

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Fig. 3 – Two units in multiple traction

switchgear, together with the inductive shunt is beneath the floor of the vehicle.

Each motorcoach has four self-ventilated series motors of type 4 ELG 1830 A with a total one-hour output of 327 kW. The vehicle characteristics are shown in Fig. 6a and 6b. Each pair of motors is mounted longitudinally in a bogie and drives one axle each through a cardan shaft and worm gearing (Fig. 7). The motor insulation is to class F (stator) and H (rotor) in accordance with modern practice. The correctness of the

Fig. 4 – Basic circuit diagram for motoring

1 = Current collector
2 = Surge diverter
3 = Main contactor
5 = Grouping, reversing and stepping contactors
8 = Traction motor
12 = Starting and braking resistor
16 = Shunt for measuring motor current

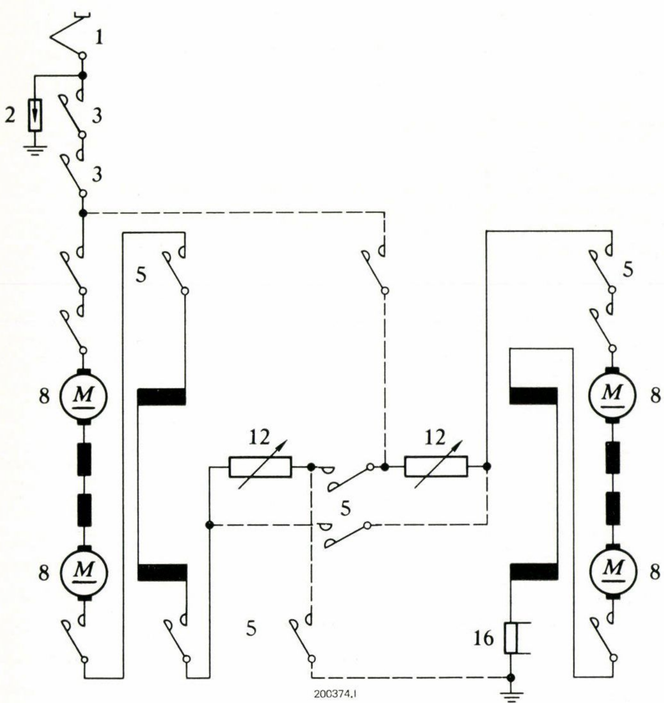
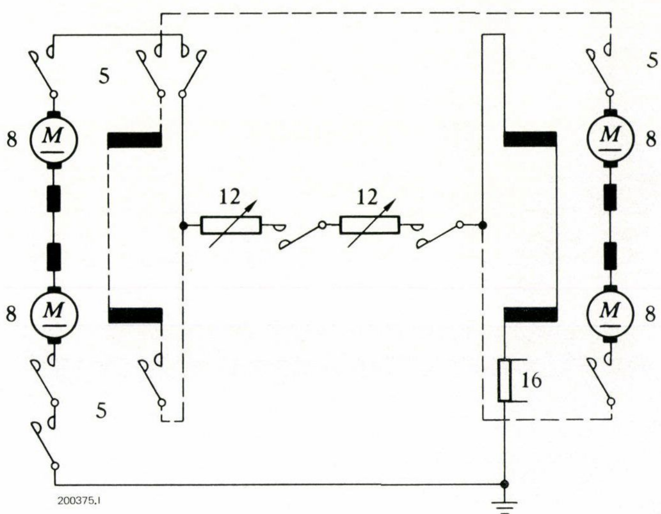


Fig. 5 – Basic circuit diagram for braking

5 = Grouping, reversing and stepping contactor
8 = Traction motor
12 = Starting and braking resistor
16 = Shunt for measuring motor current



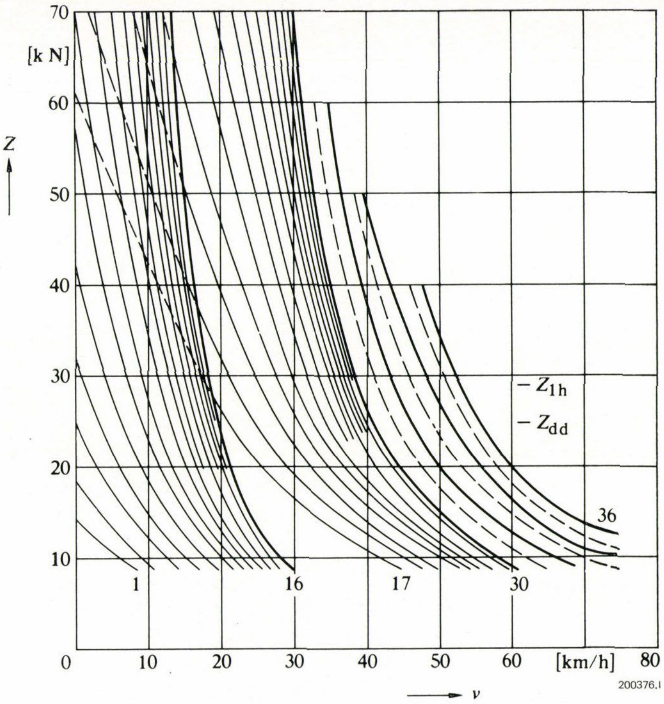
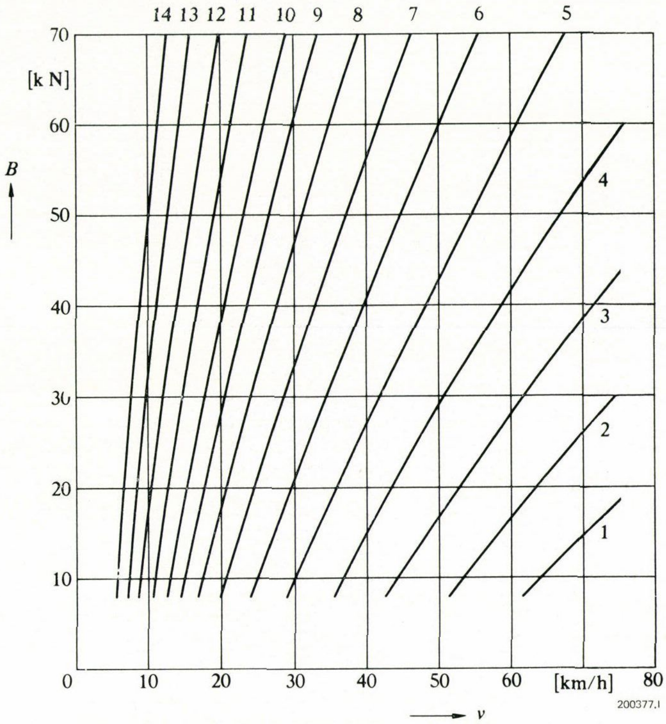


Fig. 6a – Vehicle characteristic for motoring

1 to 36 = Motoring steps
Z = Tractive effort at wheel
Z_{dd} = Continuous tractive effort at wheel
Z_{1h} = One-hour tractive effort at wheel
v = speed

Fig. 6b – Vehicle characteristic for braking

1 to 14 = Braking steps
B = Braking effort at wheel
v = Speed



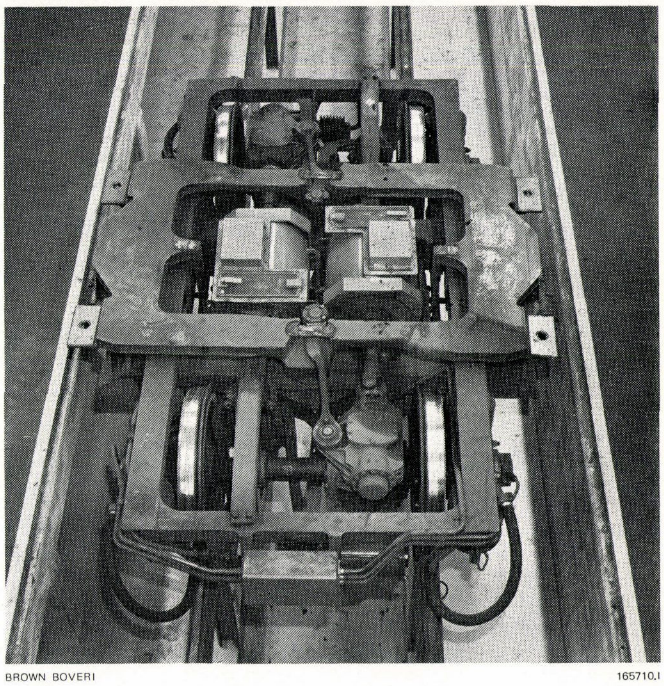


Fig. 7 – Bogie with built-in traction motors

power rating of the motors gained from computer-simulated traction conditions has been confirmed by protracted running under heavy load.

Auxiliaries

The auxiliaries (Fig. 8) are supplied from a rotating d.c./a.c. motor/generator set. The advantages associated with this traction vehicle configuration thus become evident:

- The heating and ventilation system for both vehicles requires a large number of fan motors which are usually located where maintenance is difficult. The three-phase supply permits squirrel-cage motors to be used, which are also superior to commutator motors as far as space requirement is concerned.
- The normal 220 V, 50 Hz lighting equipment available on the market can be used.
- The battery charging and defrosting equipment is easily arranged.

The control range of the motor/generator set permits operation on both 1200 and 800 V networks without changeover. The pneumatic equipment is supplied with compressed air from a type 2A70 compressor set. To facilitate starting at 750 V at low temperatures (some of the rolling stock is parked outdoors) the series-connected resistor is switched over by a voltage relay.

Heating and Ventilation

In spite of the short average journey time per passenger the railway undertaking made every effort to considerably improve heating and ventilation relative to that of previous rolling stock. The equipment is designed for fully automatic operation and must cope with the heat losses resulting from frequent stops, wide doors and lack of dividing walls.

The high-capacity supplementary ventilation system ensures a comfortable atmosphere even in the summer with a full complement of passengers.

The heating and ventilation system for each motorcoach composition is divided into four largely self-contained units. Each unit comprises a 16·5 kW air heater with fan and a separate fan unit for supplementary heating. This equipment is located above the doors [4]. The warm air is fed to ducts arranged at the side of the vehicle floor where it enters the passenger compartment. If no heat is required the same system can be used to provide fresh air. If the air temperature within the compartment, which can be controlled to a limited extent by the passengers, exceeds a certain value the supplementary air system operates automatically. This provides up to 4000 m^3 of fresh air per hour through the perforated false ceiling.

Electronics

In accordance with the comprehensive traction programme, the high ratio of tractive effort to adhesion and the facilities for multiple traction of one to three e.m.u's, the vehicles were equipped with control electronics (Fig. 9).

All possible combinations which can be achieved with a contactor control system were made use of. These are, in particular:

- Constant acceleration or deceleration control by means of variable current limiting depending on grouping
- Speed control for downhill running
- Anti-slip and skid control
- Matched series/parallel transition where different parallel stages are used for changing over depending on speed or motor current. This keeps acceleration virtually constant even during regrouping. There is no need for a diode in the bridge limb.
- Direct changeover to parallel grouping if the master controller is switched from zero to a parallel stage at above a given speed. This reduces the number of switching operations of the contactors and the tractive effort is reached more quickly.
- Variable switching rate depending on motor current
- Built-in zero-current monitoring, i.e. immediate switch-down to the first motoring step if the contact wire voltage fails
- Direct switching to the braking steps regardless of speed to achieve rapid but jerk-free rheostatic braking
- Complete integration of seven-stage electro-pneumatic spring-operated brake; it operates as
  - retarding and holding brake when the rheostatic brake no longer functions at low speed,
  - alternative service brake if the rheostatic brake is not functioning (e.g. motor fault) and as
  - supplementary brake, particularly in the driving trailer, if a high braking force is required.

The driver's brake switch for the electro-pneumatic brake is not operated under normal conditions but its functions override the commands of the electronic control system.

In the event of a fault in the electronic control system the stepping contactors can be controlled direct from the master controller according to a reduced programme.

Space is provided in both electronic racks (Fig. 10) for a check module for testing the functioning of the electronic gear. These check modules permit certain operating conditions (current, speed) to be simulated,

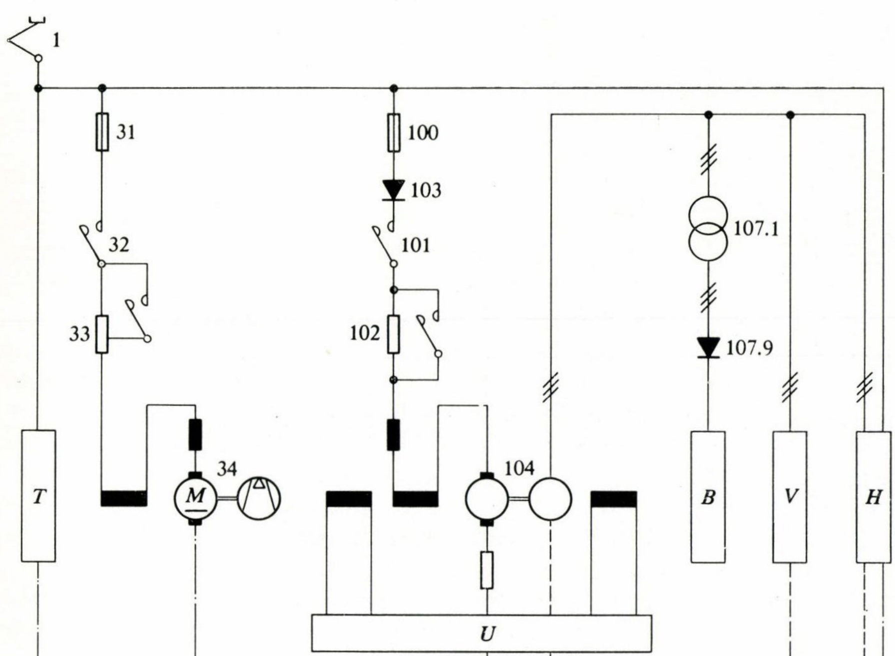
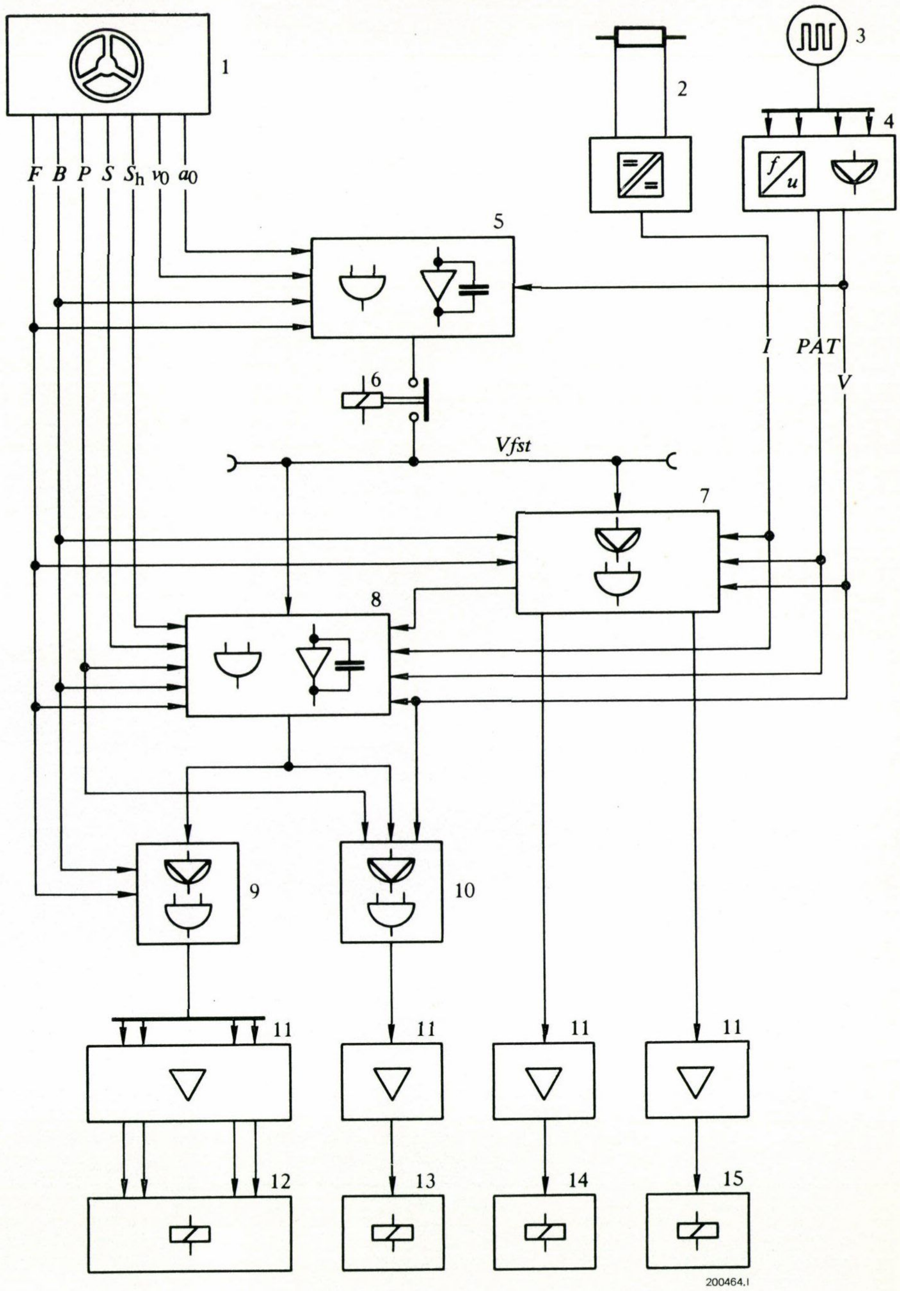


Fig. 8 – Auxiliaries

1	= Current collector
31	= Fuse for compressor motor
32	= Contactor for compressor motor
33	= Series resistor for compressor motor
34	= Compressor set
100	= Fuse for convertor motor
101	= Contactor for convertor motor
102	= Series resistor for convertor motor
103	= Inverse current diode
104	= Motor/generator set
107.1	= Transformer for battery charging
107.9	= Rectifier for battery charging
B	= Battery charger, 36 V loads
H	= Heating current circuit
T	= Traction current circuit
U	= Convertor control
V	= 220/380 V loads

Fig. 9 – Electronic control system (block circuit diagram)

1 = Master controller (set point input)
2 = Current measurement
3 = Speed transmitter
4 = Speed measurement and anti-skid and slip control
5 = Speed and acceleration regulator
6 = 'Guiding vehicle' relay
7 = Ep braking control
8 = Step regulator
9 = Step logic
10 = Grouping logic
11 = Short-circuit-proof output amplifier
12 = Step and shunt contactors
13 = Transition contactor
14 = Electro-pneumatic brake valve, motor-coach
15 = Electro-pneumatic brake valve, driving trailer
a_0 = Desired acceleration/deceleration
v = Actual speed
v_0 = Desired speed
B = Braking
F = Motoring
I = Motor current
P = Parallel grouping
PAT = Slip/skid signals
S = Series grouping
S_h = Field-weakening
V_{fst} = Multiple traction line



important internal signals to be measured and various switching conditions to be displayed. Faulty PCB's can rapidly be located with the aid of a check list.

Supplementary Equipment

The following supplementary equipment was installed to improve safety, economy and operational flexibility:

- Dead-man's handle
- Automatic train control
- Automatic doors with photo-electric cell control, pressure sensors under the doorsteps and also in the edges of the doors to prevent injury to passengers
- Two-way radio link with the control centre
- Public address system with indoor and outdoor loud-speakers
- Wheel flange lubricating equipment
- Automatic couplers as used on underground railways with additional couplers for the electrical control leads and the compressed air lines (Fig. 11)

Facilities for remote controlled coupling and decoupling of electric motorcoaches were provided here for the first time. Without any assistance the motorman can decouple the third unit from the second or the second from the first by depressing the appropriate push-button on his control desk. The number of units coupled is displayed by a special instrument (Fig. 13). In the case of the decoupled units the traction equipment and the electro-pneumatic, spring-operated brakes remain locked and all auxiliary and ancillary equipment remains in the final condition before decoupling.

For instance, if the current collector is in the raised position the heating and ventilation equipment, compressor and motor/generator set continue operation supervised by the monitoring equipment.

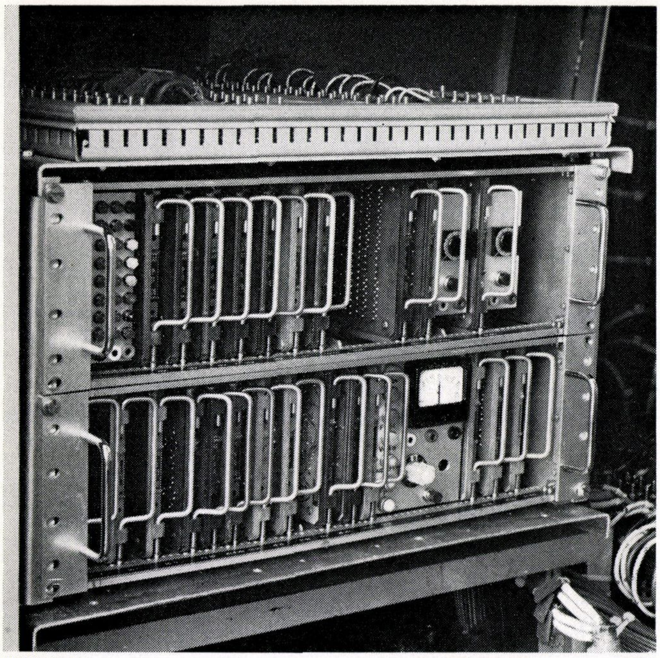


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Fig. 10 – Electronics racks

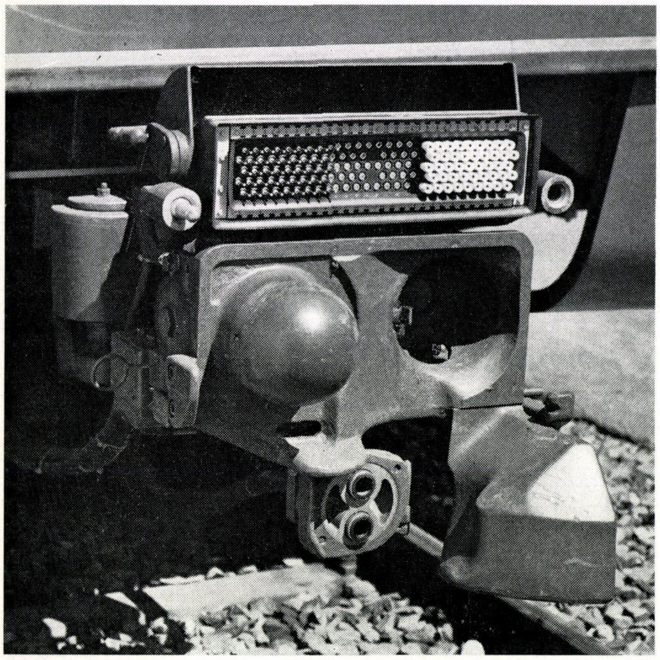

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Fig. 11 – Auto-coupler with control current line

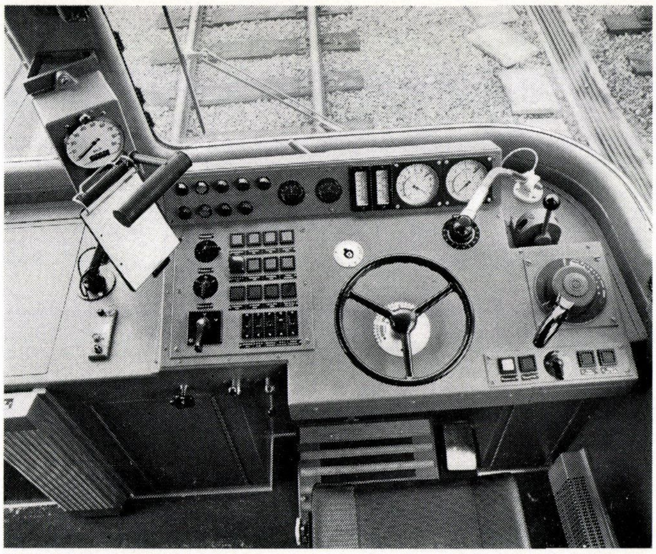

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Fig. 12 – Control desk

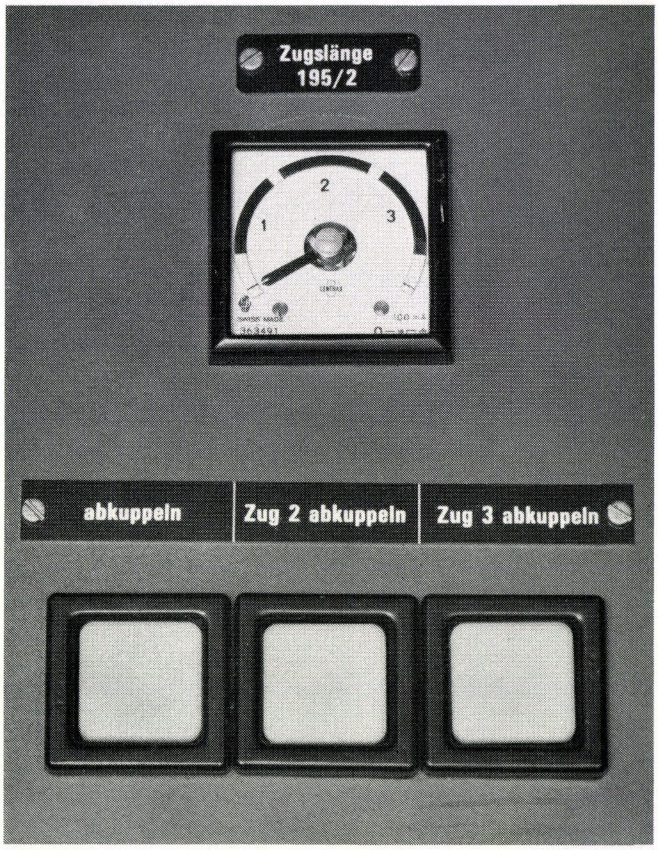

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Fig. 13 – Instrument indicating the state of the train-set

If the doors were unlocked when the unit was decoupled, passengers can continue to enter because the appropriate safety equipment remains active.

Performance

The new vehicles and the revised, more attractive time-table led to a significant increase in passenger traffic even in the first few months of operation. Both vehicle concept and electrical equipment have proved themselves.

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Standard Trolleybuses with Chopper Power Control

R. Kaller, K. Vollenwyder and S. Manzoni

The electrical equipment of a standard trolleybus, of which 113 have been ordered to date for the cities of Zurich, Bern, Basel, Lausanne, Geneva and Neuchâtel, is described. The traction equipment and auxiliaries are treated in detail.

Introduction

The trolleybus is attracting increasing attention in the general move against the harm and annoyance caused by noise and air pollution, since it does not suffer from these drawbacks. In Switzerland, unlike other countries, interest in this form of transport has never lapsed entirely.

In 1970, the trolleybus committee of the Association of Swiss transport operators (VST) approached industry with the suggestion of developing a standard trolleybus. Some of the 500 and more trolleybuses in service at that time were due for replacement, and certain fleets were to be enlarged.

These new vehicles were required to have the following features:

- simple equipment
- largely standardized components
- reduced maintenance
- economical power comsumption
- easy to operate
- better-than-average passenger comfort
- auxiliary power supply independent of the contact wire

Through collaboration between public transport operators and the industry it was possible to devise a vehicle with electrical equipment capable of meeting these requirements (Fig. 1).

Simple Equipment

Previous systems with two motors for articulated vehicles were abandoned, and instead only one axle is driven. The motor has a rating which allows it to be used either in articulated trolleybuses with gross vehicle weight of 26 to 27 t, or in two-axle trolleybuses which can also pull a trailer. Such a formation weighs 30 t when laden.

Standardized Components

With standardized components the operators are able, if necessary, to exchange the most important mechanical and electrical components among themselves.

Fig. 1 – Standard (articulated) trolleybus 1974

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Reduced Maintenance

Through choosing an electronic chopper, there are very few items of equipment which, under normal circumstances, switch under load. Wear on the switching gear is thus reduced to a minimum. The power electronics in the chopper are subject to no wear at all. The experience of the St. Gallen public transport service, which has operated trolleybuses fitted with choppers for several years shows that this goal has been achieved.
Infinitely variable control of both tractive and braking effort eliminates abrupt torque loads on the drive equipment.

Economical Power Consumption

Compared with a trolleybus in which starting is controlled by switched resistors, a chopper with electronic control gives a power saving of about 15 to 20%, depending on traffic conditions. By eliminating current spikes on starting, the rectifier supply equipment can have lower ratings and existing substations can be better utilized.

Ease of Operation

Urban traffic conditions make ease of operation essential. The fully electronic control system of the vehicle meets this requirement both when motoring and when braking. The driver applies the necessary tractive or braking effort by means of the accelerator or brake pedal. The maximum acceleration, or deceleration and its rate of change are controlled.

The electric brake and air brake are linked to each other so that each pedal position corresponds to a constant braking force.
It is thus possible to dispense with the second, separate pedal often used in the past for the air brake.

Passenger Comfort

Stepless regulation of tractive and braking forces results in a very comfortable ride.

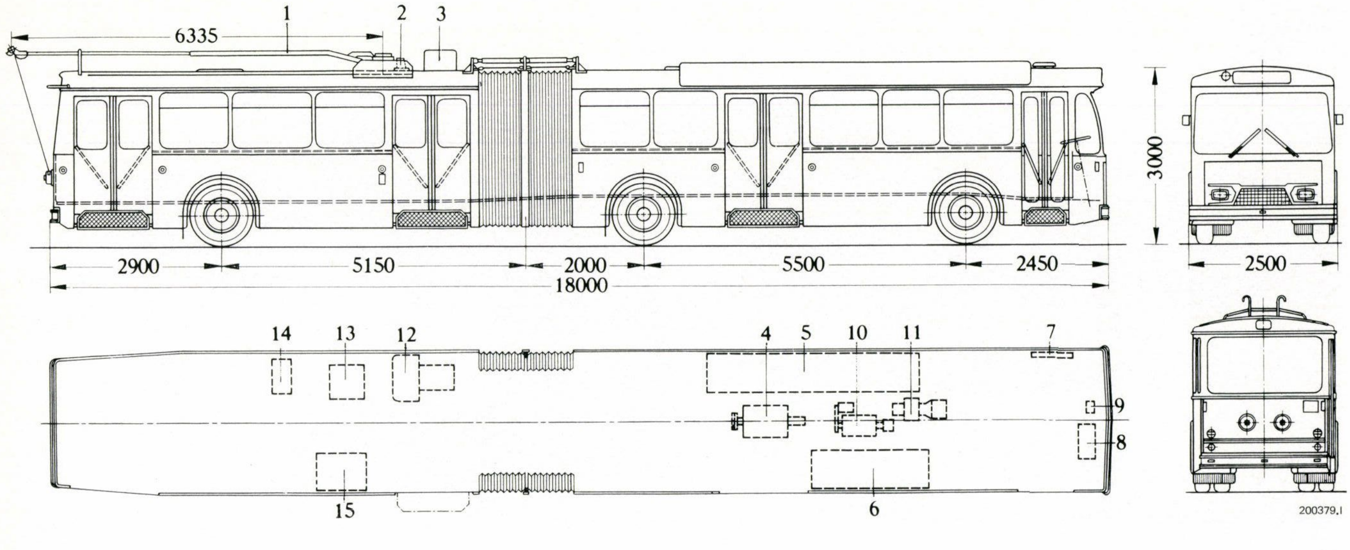
Auxiliary Power Supplies

A thermoelectric unit with no strict limits on duty period permits operation at up to 25 km/h along the level with a full load in the event of traffic diversions or faults on the contact wire. Where only short distances are to be covered at low speed this unit is not needed, and the traction motor can be fed from the bus battery.
The decision of Swiss public transport operators to buy modern trolleybuses has also aroused great interest in other countries. Apart from Sécheron in Geneva and Brown Boveri in Baden, the following firms are engaged in the building of these trolleybuses:

- Aktiengesellschaft Franz Brozincevic & Co. (FBW), Wetzikon, for chassis and drive components
- Swiss coachbuilding firms under the general direction of the companies: Ramseyer & Jenzer, Bern, and Carrosserie Hess, Bellach, for the bodies and interior fittings.

Fig. 2 – General arrangement of articulated trolleybus

1 = Trolleys
2 = Lightning arrester
3 = Protection unit
4 = Traction motor
5 = Chopper
6 = 600 V switchgear unit
7 = 24 V switchgear unit
8 = Control electronics
9 = Angle transmitter
10 = Motor/compressor/generator set
11 = Fan for chopper
12 = Thermoelectric emergency power unit
13 = Control gear for emergency power unit
14 = Petrol tank for emergency power unit
15 = Storage battery



Mechanical Features

The chassis is based on two welded load-bearing frames joined together by a ball joint. The body is fixed to the frame cross-members. All the drive components, auxiliaries and the electronic control gear are mounted in the frame of the front coach.
The articulated vehicle is carried on three axle assemblies with air suspension. The middle axle is driven through an epicyclic bevel gear. Some of these vehicles have a steered axle on the semi-trailer, in which case the trailer follows more or less in the track of the driving coach. This arrangement is used on the buses for Zurich and Bern; the articulated buses for Basel, Geneva and Neuchâtel have a semi-trailer with a rigid axle.

Table I: Main data

Mechanical		
Wheel diameter [mm]		1020
Tyre size		11·00 × 20
Transmission ratio		10·3 : 1
	Artic. trolleybus	*2-axle trolleybus*
Weight of mech. part [t]	11·8	8·4
Weight of elec. gear [t]	3·7	3·4
Total weight empty [t]	15·5	11·8
Passengers, seated	44+1	29+1
Passengers, standing	115	60
Total	159+1	89+1
Electrical		
Rated voltage		600 V
Maximum voltage		720 V
Minimum voltage		400 V[1]
No. of motors		1

[1] Maximum motor current is limited below a contact-wire voltage of 400 V.

Electrical Equipment Layout

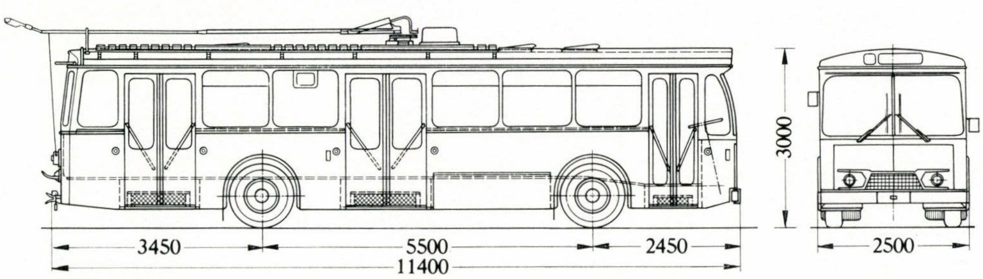
The main dimensions and the arrangement of the electrical equipment in the articulated trolleybuses can be seen in Fig. 2. The two-axle bus is shown in Fig. 3. The equipment is divided by function into separate units that are assembled, wired and tested outside the vehicle. The traction motor and the most important items are located between the first and second axle. The electrical equipment layout is thus identical for both types of vehicle. The space between the main frame members is covered over at the bottom, forming a longitudinal channel in which the auxiliary services equipment and the traction motor are fitted. These two items are exposed to the flow of air passing through this channel.
The chopper unit, comprising filter, power pack and braking resistor, is on the left side of the vehicle. Between the doors on the right-hand size is the unit with the 600 V switchgear. This arrangement provides low-induction links between the chopper unit and the switchgear of the traction circuits, which helps cut down radio interference. The 24 V relay panel and the control electronics are easily accessible in the driver's console. In the articulated buses, the battery and the thermoelectric emergency power unit are mounted in the semi-trailer. All the equipment is easily accessible through panels in the floor and sides.
All racks holding 600 V equipment are insulated from the vehicle body, i.e. the equipment is doubly insulated. The insulating resistance between the 600 V equipment and the racks, and between racks and body, can be checked at the depot.

Motoring and Braking Circuits

Motoring

The basic arrangement of the motoring circuit is shown in Fig. 4. Immediately after the trolleys is the protection unit, comprising two main contactors and their associated maximum-current relays. The contactors are remotely controlled from the driver's seat and permit two-pole disconnection of the electrical gear. Main contactors located directly after the trolleys provides protection in the event of an overload. If there is power failure, the contactors open after a preselected time.
At the articulation junction box the main feeders are divided into a branch feeding the traction motor and a branch to the auxiliary services. An input rectifier bridge allows operation irrespective of the contact-wire polarity, without any need for switching. The input filter reduces feedback effects on the power system, and at the same time protects the chopper against overvoltages.
The input voltage is measured by an instrument transformer which acts via the control electronics to block the

Fig. 3 – General arrangement of two-axle trolleybus



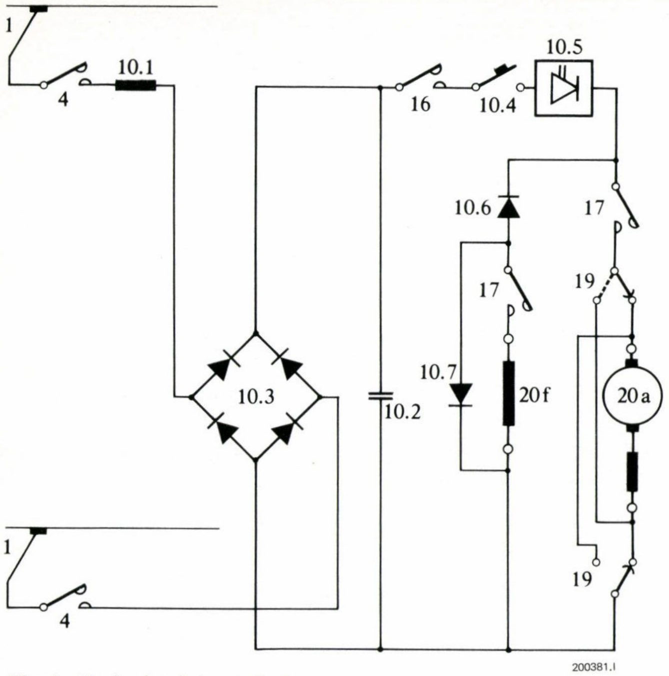


Fig. 4 – Basic circuit 'motoring'

1 = Trolley
4 = Main contactor
10 = Chopper, comprising
- 10.1 Input choke
- 10.2 Input capacitor
- 10.3 Input rectifier bridge
- 10.4 Protection switch
- 10.5 Chopper
- 10.6 Armature freewheel diode
- 10.7 Field freewheel diode

16 = Line contactor
17 = Isolating contactor
19 = Reversing switch
20 = Traction motor
- a = Motor armature
- f = Motor field

chopper if the contact-wire voltage drops below a specified minimum value. This prevents the input filter from discharging.
The voltage arrives at the chopper via an off-load line contactor. The chopper is so arranged that field weakening begins automatically beyond a certain firing angle [1]. It works at a fixed frequency of 400 Hz. A drum switch operated electropneumatically performs the necessary regrouping for reversing and the changeover from motoring to braking. To isolate the circuits the armature and the exciter circuit each include an isolating contactor which under normal circumstances switches at no load.

Braking

When braking (Fig. 5), the chopper is disconnected from the input filter by the line contactor and the drum switch. The traction motor operates as a generator, feeding power to a braking resistor. The chopper and the excitation winding of the motor are connected in parallel with part of the resistor.
In this configuration the motor functions in the same way as with a conventional series-excited rheostatic brake, except that owing to the chopper the braking resistance is infinitely variable.

The circuit arrangement with automatic field weakening is retained, whether motoring or braking. Braking commences with a small firing angle, i.e. little excitation, which means that in the upper speed range the braking effort is in practical terms controlled solely by variation of the excitation current. As the speed falls, the firing angle increases until the braking resistor is to all intents and purposes short-circuited. With this circuit it is possible to traverse the whole range of the B/v diagram continuously, without additional switching operations. The vehicle characteristics when motoring and braking are shown in Fig. 6a and 6b.

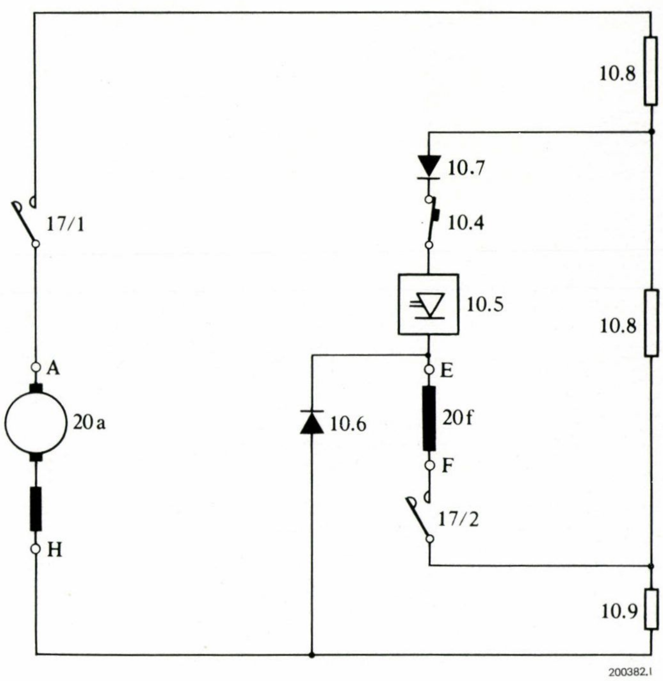
Emergency Operation

To be able to travel independently of a contact wire, the trolleybuses are equipped with emergency equipment for feeding the traction motor from the bus battery or from a thermoelectric power unit.
In the first case the vehicle battery is switched from the normal configuration of three batteries in parallel to a series connection (Fig. 7). In this mode, too, the traction motor is controlled by the chopper. In this way the limited battery capacity can be utilized with the best possible efficiency. This kind of operation is chiefly used only for short distances at low speed.

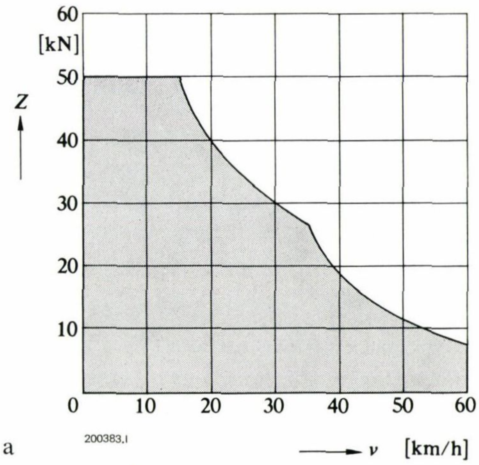
Fig. 5 – Basic circuit 'braking'

10 = Chopper, comprising
- 10.4 Protection switch
- 10.5 Chopper
- 10.6 Freewheel diode
- 10.7 Blocking diode
- 10.8 Braking resistor
- 10.9 Stabilizing resistor

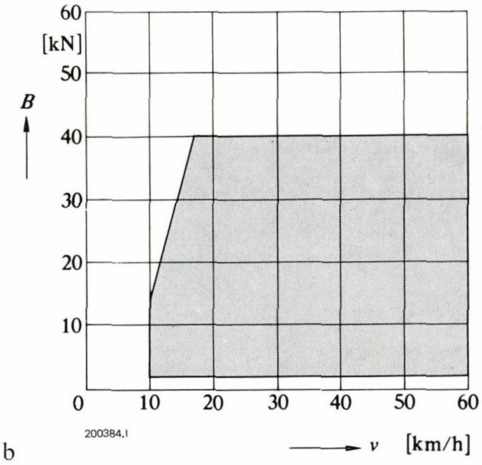
17 = Isolating contactor
20 = Traction motor
- a = Motor armature
- f = Motor field



Those buses which need increased performance and a large degree of autonomy are fitted with a thermoelectric power unit. A three-phase generator, with no brushes or sliprings, is driven by a petrol engine and feeds the traction motor, which in this case is connected as a series motor, through a rectifier bridge (Fig. 8). Power output is regulated by varying the speed of the petrol engine, the setting of the accelerator pedal being transmitted electrically to the engine throttle. The unit is started by turning the mode selector switch from 'contact wire' to 'auxiliary power'. The necessary alterations to the motoring circuit take place at the same time.
The motor/compressor/alternator set starts automatically, but not until the power generated by the thermoelectric plant is no longer needed in full to move the bus. The unit is started via a voltage relay. If required, it can also be started non-automatically by raising the speed of the petrol engine with the bus braked.



a



b

Fig. 6 – Vehicle characteristics

a: Motoring
b: Braking

v = Vehicle speed [km/h]
B = Braking effort [kN]
Z = Tractive effort [kN]

Components of Main Circuit

Roof-Mounted Equipment

The equipment on the roof consists of the trolley and the protection unit. An HMD1 lightning arrester situated immediately next to the trolley base limits overvoltages originating from the supply network. The roof-mounted gear is accessible from above and also from inside the bus.

D.C. Chopper

The chopper unit is mounted on the left-hand side of the vehicle (Fig. 9) and contains the input filter, r.f. suppressors, input diode bridge, the chopper itself and the braking resistor. The unit is separately ventilated. The components of the power electronics are mounted in plug-in racks in the usual Brown Boveri manner (Fig. 10) [2]. They can quickly be replaced if necessary.

600 V Equipment Unit

The other switchgear for the 600 V circuits is contained in one unit (Fig. 11). Because of the restricted space, the equipment is arranged in two planes. The electropneumatic mode drum switch, with the positions 'forward' – 'brake' – 'reverse', is fitted on the rear plane. In front of this switch, the line contactor, the isolating contactors for the armature and exciter circuits, and the two contactors for emergency operation are mounted on a hinged frame. The contactors, of type PH 380, are operated electropneumatically and are the same as those used in large numbers on vehicles with 600 V electrical equipment. This compartment also contains the d.c. instrument transformers for measuring the armature current and field currents. The transformers isolate the 600 V circuits from the electronic circuits. They are screened on all sides to suppress radio interference.
A further compartment of this unit contains the fuses for the motor/compressor/alternator set, the type HS electromagnetic contactors for the auxiliaries unit, the heating system and the contactors for emergency operation of the petrol-engine generator set.
The whole unit can easily be drawn out after releasing the power connections and removing the multi-pin plug for the control circuits.

Traction Motor

The traction motor is a four-pole, uncompensated, self-ventilated series-wound machine. The windings of the stator are insulated to class F, and those of the rotor to class H.

Table II: Data of motor type 4 ELG 2553, at terminal voltage 600 V

		Continuous rating	1-hour rating	Max.
Shaft output	[kW]	147	166	–
Current	[A]	265	300	550
Motor speed	[rev/min]	1425	1375	3200
Road speed	[km/h]	18·8	18·1	60
Torque at shaft	[kN m]	1·00	1·17	2·60

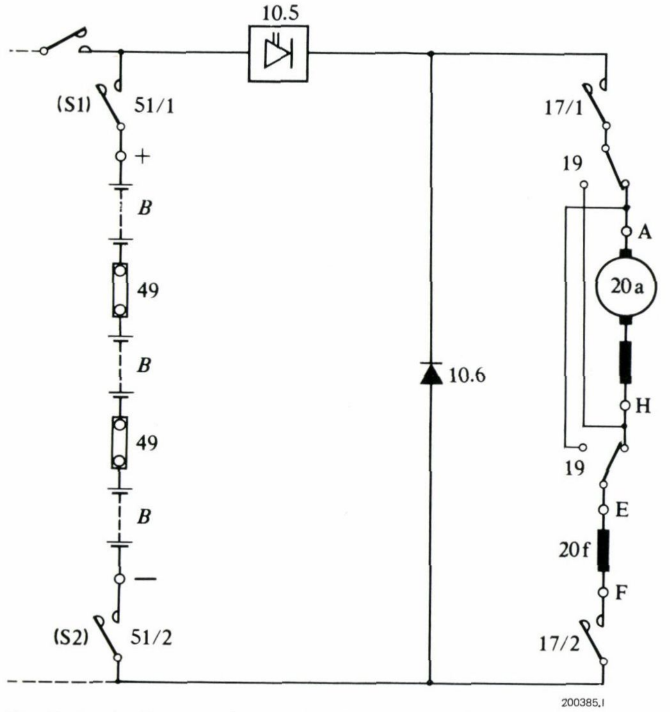


Fig. 7 – Basic diagram of emergency battery operation

10 = Chopper, comprising

10.5 Chopper
10.6 Freewheel diode

17 = Isolating contactor
19 = Reversing switch
20 = Traction motor

a = Motor armature
f = Motor field

49 = Battery switch
51 = Contactor for battery motoring
B = Storage battery (each 24 V)

Auxiliary Services

The equipment for the auxiliary service comprises:

– A motor/compressor/generator set (Fig. 12), consisting of a compound motor of 7·5 kW at 1900 rev/min, a self-stabilizing compressor with a swept volume of 424 cm^3 and a service pressure of 16 $\pm$ 2 bar, and a three-phase generator of 28 V/85 A. One end of the motor shaft drives the compressor direct through a flexible coupling. The three-phase generator is driven from the other end via vee-belts. The compressor supplies air to the air suspension, the door-operating mechanism, the electropneumatic contactors and the motoring/braking switch. The generator charges the battery through a rectifier, and supplies power to the lighting, the control circuits, the fan motor of the chopper and the fan motors of the heaters and windscreen defroster.
– Warm-air heaters with unit ratings of 2 $\times$ 1·5 kW. There are either 5 or 6 heaters, depending on customer requirements.
– A 6 kW, two-stage defroster for the front windows.

Electronic Control

In order to make full use of the possibilities presented by the chopper-regulated drive, the trolleybuses are equipped with electronic control. The vehicle is operated by means of an accelerator and a brake pedal. The control electronics are divided functionally into a motoring/braking regulator and the control gear for the chopper.

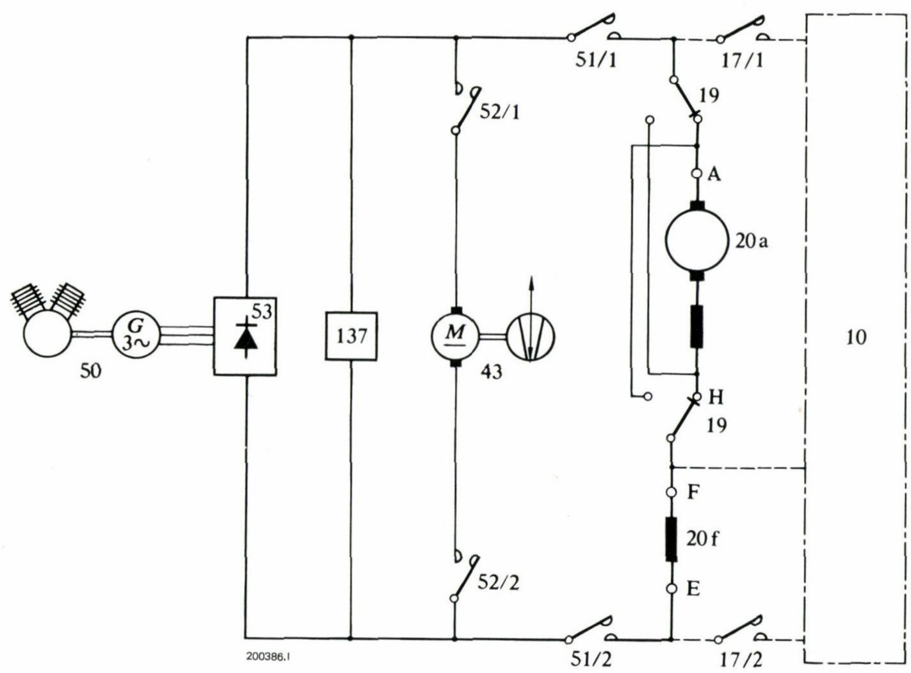


Fig. 8 – Basic diagram of emergency operation with thermoelectric power supply

10 = Chopper (not operating)
17 = Isolating contactor
19 = Reversing switch
20 = Traction motor

a = Motor armature
f = Motor field

43 = Compressor set
50 = Thermoelectric unit
51 = Contactor for traction motor
52 = Contactor for compressor motor
53 = Rectifier
137 = Voltage measurement

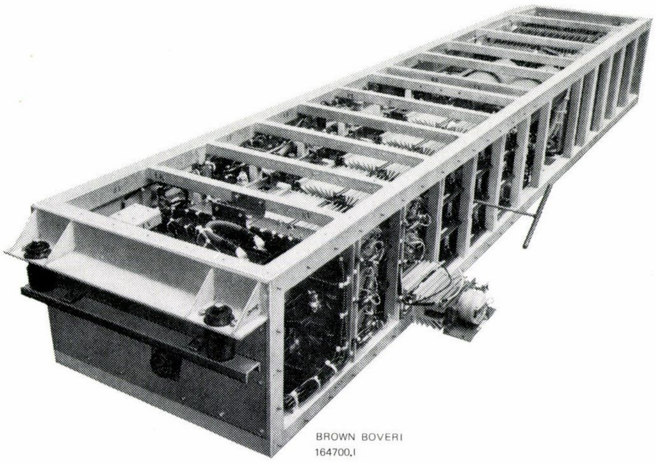


Fig. 9 – Chopper unit, screening removed

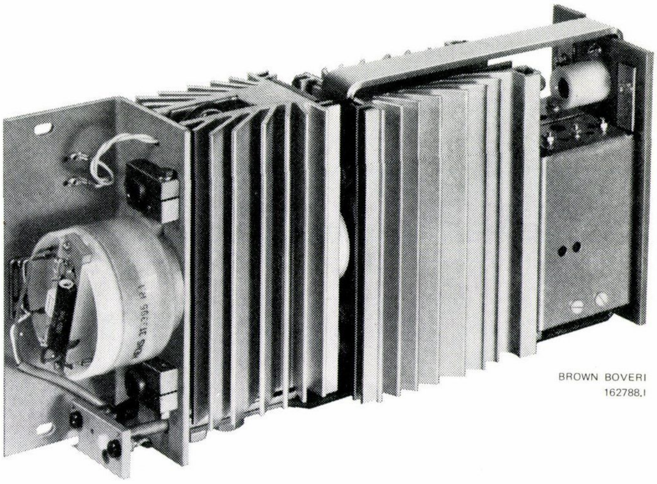


Fig. 10 – Plug-in rack with power electronics

The functions of the motoring/braking regulator are as follows:

When motoring, with the accelerator pedal depressed:

– to generate a current set point for the traction motor current, corresponding to the pedal position.
– to limit acceleration to the preset maximum value, and limit the rate of acceleration.

When braking, with the brake pedal suppressed:

– to regulate the sum of pneumatic and electric braking effort to the desired value selected by the driver.
– to generate a current set point corresponding to the value set by the driver and to the electric braking effort being applied.
– to operate the electropneumatic differential values in the braking circuits of the front and middle axles, i.e. to reduce the braking force applied pneumatically to these axles in accordance with the electrical braking force acting at a given time.

The control unit for the chopper performs the following tasks:

– to compare the set point generated by the motoring regulator with the actual armature current.
– to generate the firing and turn-off pulses for the chopper, and to shift their respective positions in accordance with the actual value and set point.
– to supervise
  – turn-off capability,

Fig. 11 – 600 V switchgear unit, screening removed
Left, the isolating contactors on a hinged frame, right, the control gear for the auxiliary services.

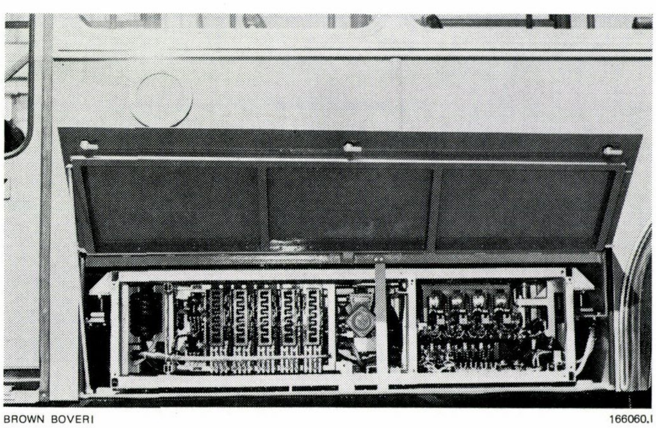


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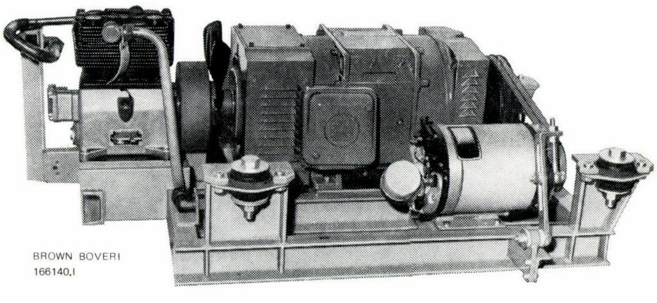
Fig. 12 – Motor/compressor/generator set, 600 V motor with a direct-coupled self-stabilizing compressor and an a.c. generator with vee-belt drive



- maximum value of armature current and field current,
- voltage of turn-off capacitor,
- minimum contact-wire voltage.

– to limit the current set point as a function of the contact-wire voltage if this drops below a certain limit value.

The control electronics are composed of separate circuit boards, and are contained in a single rack. Two multi-pin plugs provide the connection to the remaining control gear and to the chopper. A special test board allows the control electronics to be checked out under any operating conditions.
The way the electronic control system functions can be explained with the aid of the basic circuit shown in Fig. 13.

Motoring

The driver selects the desired traction motor current with the accelerator 1 and angle transmitter 4. The integrator 5 limits the rate of rise of this signal when the preset maximum acceleration is attained. It also limits the signal when the prescribed maximum road speed is reached.

The signal then passes to the minimum value transmitter 7, which also receives a signal from the monitoring unit 11. The smaller value is taken as the set point for the motor current and compared with the actual armature current. From the difference between the two, the integrator 8 generates a control voltage which modulates the chopper 10 via pulse stage 9.

Braking

In the braking mode the air brake and electric brake are actuated in parallel by the pedal. Master valve 3 causes a pressure corresponding to the pedal position to be applied to the brake cylinders of all the axles. At the same time, the angle transmitter provides an equivalent signal for the set point of the electric braking effort by generating the desired current for the control unit via integrator 5. From the armature current and excitation current the unit 14 calculates the electrical braking effort available at the time. This signal actuates the differential valves of the front and middle axles. These valves reduce the pressure in the brake cylinders in accordance with the elec-

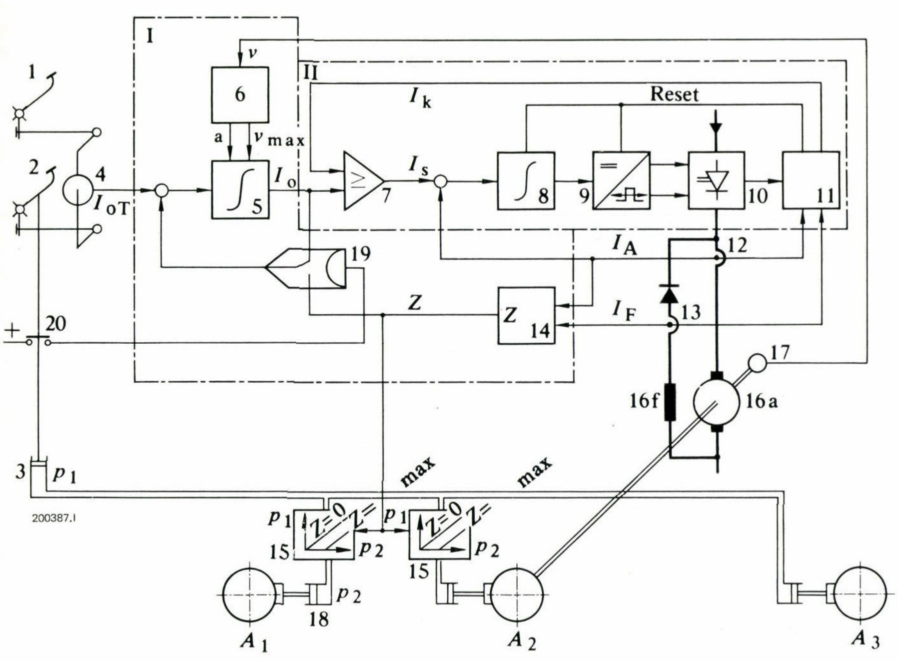


Fig. 13 – Basic diagram of electronic control system

I = Motoring/braking regulator
II = Chopper control unit
A 1 = Front axle
A 2 = Middle axle
A 3 = Rear axle
I_{0T} = Output signal of angle transmitter
I_0 = Current set point of motoring regulator
I_k = Correction current from monitoring unit
I_s = Armature current set point
I_A = Armature current
I_F = Field current
p 1 = Braking pressure
p 2 = Corrected braking pressure
Z = Braking effort, electric
v = Road speed
v_{max} = Max. road speed
a = Acceleration

1 = Accelerator pedal
2 = Brake pedal
3 = Master valve, air brake
4 = Angle transmitter (variable capacitor)
5 = Integrator
6 = Acceleration measurement
7 = Minimum-value transmitter
8 = Integrator
9 = Pulse generator
10 = Chopper
11 = Monitoring unit
12 = Armature current measurement
13 = Field current measurement
14 = Braking effort computer
15 = Differential valve
16a = Armature of traction motor
16f = Field of traction motor
17 = Tachogenerator
18 = Brake cylinder
19 = Mode switch
20 = Contact on brake pedal

trical braking force so that the total braking effort applied to the vehicle remains constant. If the electric brake is inoperative, at low speeds for example, the output signal of the braking effort computer is smaller. The differential values raise the pressure in the brake cylinders accordingly. The total braking effort applied thus always corresponds to the value selected with the pedal, and so is independent of the road speed.

Orders Received

By the autumn of 1974 the urban public transport authorities of Zurich, Bern, Basel, Lausanne, Neuchâtel and Geneva had ordered a total of 113 of these standard trolleybuses. Delivery of the buses has been under way since the summer of 1974.

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Type B'B'B'B' Class Be 8/8 Double-Articulated Trams No. 1 to 16 of the City of Bern Transport Authority

R. Venetz

With the object of increasing transport capacity the City of Bern Transport Authority purchased 16 double-articulated trams with four single-motor bogies. The conventional switchgear equipment (electro-pneumatic contactors) is controlled through traction electronics. This permits constant acceleration or deceleration during starting and braking and also constant speed downhill running. The electrical equipment was designed to facilitate operation with trailers. As a result, the carrying capacity can be adapted to peak period demands. The electrical equipment for these vehicles is described in detail.

Introduction

It is generally agreed that there is a need for improving local passenger traffic by using fast, up-to-date and comfortable vehicles running at frequent intervals. These conditions are fulfilled by the 16 double-articulated trams of series Be 8/8 (Fig. 1) supplied to the City of Bern Transport Authority between January and August of 1973. Hitherto the Bern tram service was based on two basic intervals; 6 minute and 10 minute services. These basic services were operated by standard tramcars. Capacity was increased in two phases for peak periods, i.e. the first phase involved drawing trailers and the second phase meant increasing service frequencies with additional units. The drawbacks included employing additional staff for coupling and uncoupling the trailers and the extra units were of older, slower rolling stock.
The 16 new double-articulated trams enable uniform rolling stock to be operated and thus adapt the service frequency to the various operating conditions. Basic services remain as 6 and 10 minute intervals, but for semi-peak periods there are services every 5 minutes and during peak periods the interval between trams is four minutes.

Fig. 1 – Articulated tramcar

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The new vehicles enabled the Bern tram service to reduce their staff by 17 [1].
In designing the double-articulated tramcars (Fig. 2), whose mechanical equipment was supplied by the Swiss Car & Elevator Manufacturing Corporation Ltd., Zurich/Schlieren, the following demands had to be complied with in addition to the traction performance requirements:

- shorter running times
- improved passenger comfort
- large capacity
- minimum maintenance, easy to carry out
- use of tried and tested components
- facilities for drawing trailers

All these requirements were complied with because it was not necessary to take heed of existing rolling stock.

Technical Data

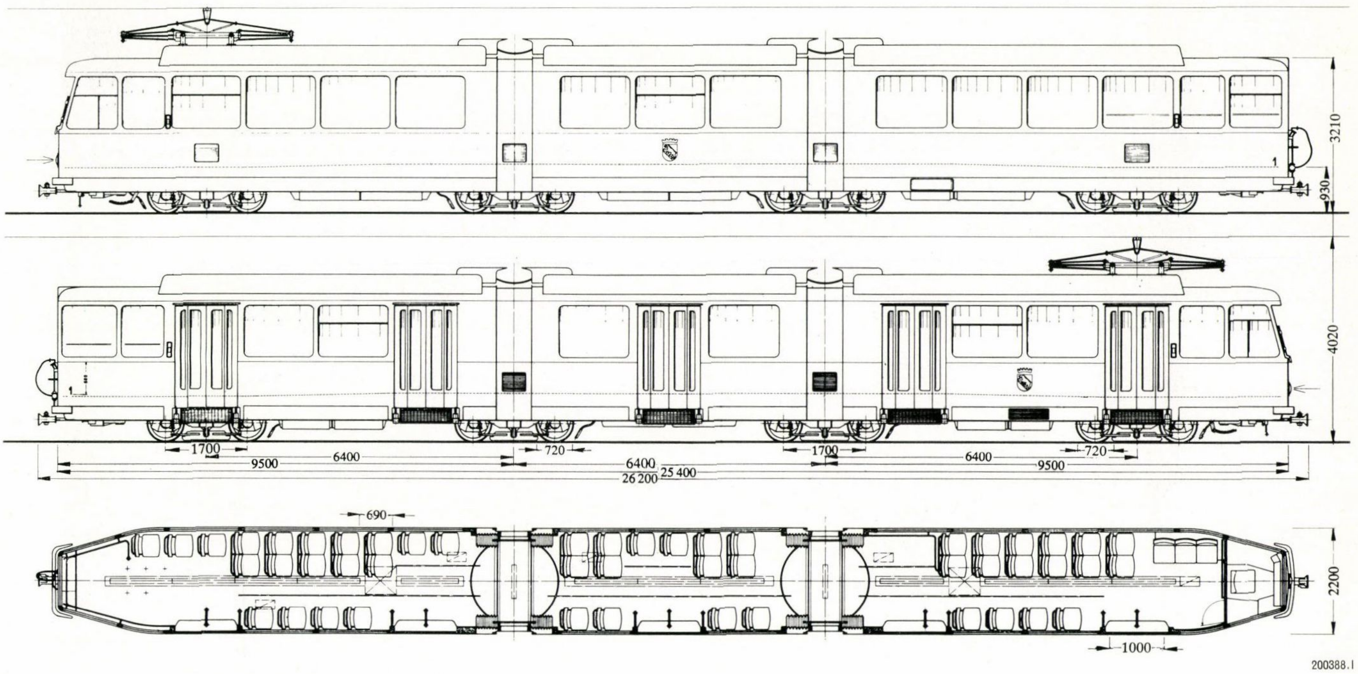
Gauge	1000 mm
Axle arrangement	B′B′B′B′
Weight of mechanical equipment	25 t
Weight of electrical equipment	9 t
Total tare weight	34 t

Passenger accomodation:	Seated	52
	Standing	168
	Total	220
Driving wheel diameter (new)		720 mm
Maximum incline		1 in 15·4
Transmission ratio		1:6·44
Number of traction motors		4
Supply		600 V d.c.
One-hour rating at motor shaft (4×89 kW)		356 kW
One-hour tractive effort at wheel (at 29 km/h)		43 kN
Maximum speed		60 km/h
Tractive effort at wheel at maximum permissible current		82 kN
Switchgear	Electro-pneumatic contactors	
Control	Electronic acceleration and deceleration control independent of vehicle weight and incline (positive or negative); speed control for downhill running at pre-determined speeds	

Traction Motors

The specification for the electrical equipment stipulates the following traction conditions:

Fig. 2 – Type Be 8/8 articulated tramcar



- The composition must be able to start and accelerate at 0·76 m/s² to 24 km/h on a 1 in 20 incline with the traction vehicle half full and a fully occupied trailer. This corresponds to a friction of $\mu = 0{\cdot}14$. The resultant motor current for this type of starting is 470 A.
- Unrestricted rheostatic braking must be possible from the maximum speed of 60 km/h.

Data of type 4 ELG 2030 traction motors with 600 V d.c. supply:

		Continuous	1-hour	Max.
Shaft output	[kW]	80	89	–
Current	[A]	295	330	550
Voltage	[V]	600/2	600/2	–
Motor speed	[rev/min]	1512	1450	3000
Vehicle speed	[km/h]	30	29	60
Torque at shaft	[N m]	510	600	1150

The insulation corresponds to class F. It is a glass/mica composition impregnated with epoxy resin under vacuum. The stator coils are cast in the same mould with the pole core and gain great mechanical strength and excellent thermal conductivity from the voidless impregnation [2]. The motor is self-ventilated. The cooling air enters through louvres half-way up the side wall of the vehicle and is ducted to the motor. This arrangement results in minimum pollution and, accordingly, minimum maintenance.
The arrangement of the driving bogie is shown in Fig. 3. The motor is fully suspended from the wheelsets and drives both axles (one from each shaft end) through bevel gearing and cardan shafts. The traction and braking characteristics of the four motors are shown in Fig. 4a and 4b.

Switchgear of the Traction Current Circuits

The electrical equipment is afforded protection against overcurrent by two relays built into the main breaker. A surge diverter connected in the immediate vicinity of the current collector conducts dangerously high overvoltage waves to earth.
The switchgear (Fig. 5) is based on type PH 380 electropneumatic contactors [3]. They are used generally for stepping control, motoring and braking circuits, reversing and motor isolation. The combination circuit of the stepping contactors (economy circuit), where the individual resistors are connected in series or parallel, considerably reduces the number of switchgear units required. Twenty-nine steps can be achieved with only ten contactors (16 series and 13 series/parallel steps) and also 14 braking steps. After reaching the maximum field stage 29 the speed can be further increased with two shunt steps. They reduce the excitation current from 100% to 68 and 50% respectively. The main motoring circuit is shown in Fig. 6.
In braking duty the two motor groups operate in parallel as generators and feed a common, separately ventilated starting and braking resistor (Fig. 7).
Maximum safety is attained with three independent braking systems: motor brake (rheostatic brake), electro-

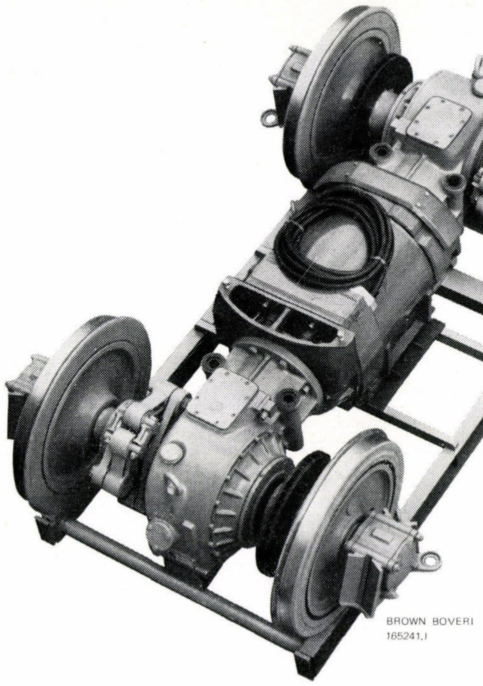
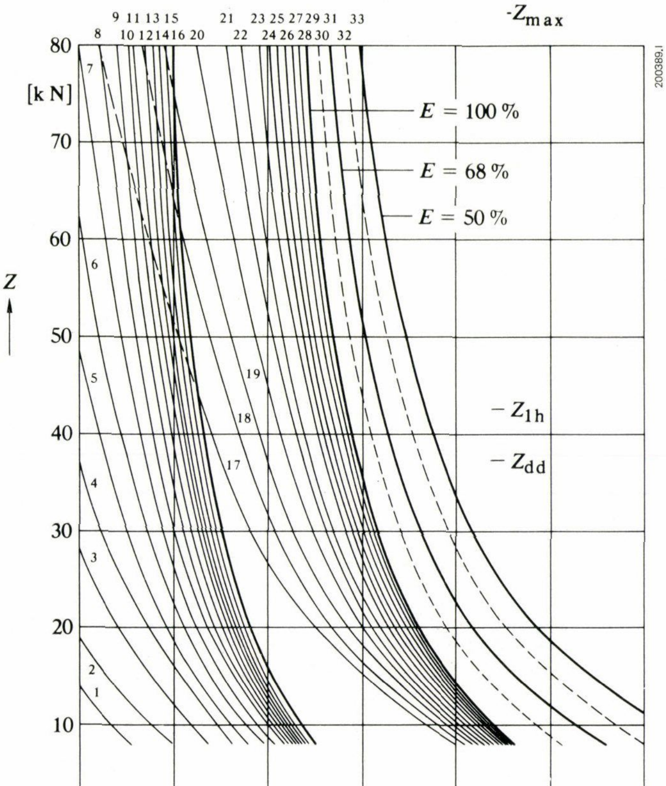


Fig. 3 – Driving bogie

Fig. 4a – Characteristic curves for motoring

v	=	Speed
E	=	Excitation
Z	=	Tractive effort at wheelrim (total)
Z_{dd}	=	Continuous tractive effort
Z_{1h}	=	One-hour tractive effort
Z_{max}	=	Maximum tractive effort
1 to 33	=	Motoring steps
16	=	Final series step
29	=	Final parallel step at maximum field
30 to 33	=	Shunt steps



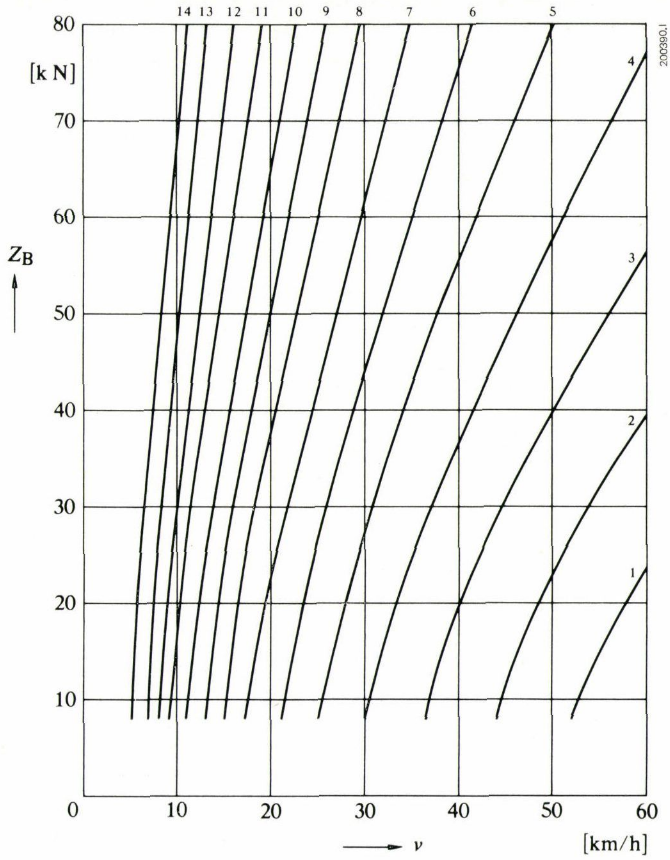


Fig. 4b – Characteristic curves for braking

v = Speed
Z_B = Braking effort at wheelrim (total)
1 to 14 = Braking steps

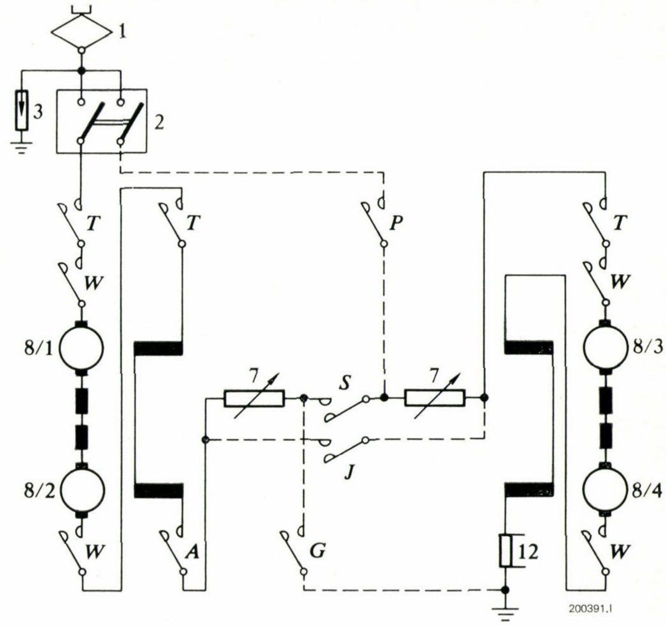


Fig. 6 – Main current circuit for motoring

1 = Current collector
2 = Main breaker
3 = Surge diverter
7 = Starting resistor
8/1 to 8/4 = Traction motors No. 1 to 4
12 = Shunt
A = Isolating contactor
G, P = Parallel contactor
J = Transition contactor
S = Series contactor
T = Traction contactor
W = Reversing contactor

pneumatically controlled, spring-operated brake, and magnetic rail brake.

Under normal conditions the rheostatic brake and the electro-pneumatically-controlled spring-operated brake are combined such that when the braking effort of the rheostatic brake reduces at low speeds, the spring-operated brake supplies the necessary braking effort.

Auxiliaries

Motor/Generator Set and Battery Charger

A d.c./three-phase motor/generator set with an output of 4·15 kVA provides the 380 V, 50 Hz three-phase supply. The frequency is kept constant regardless of contact wire voltage and load. This network supplies the fan motors for the 6 warm-air heaters (4 kW each at 600 V), the fan motors for cooling the starting and braking resistors and the fluorescent lighting within the

Fig. 7 – Main current circuit for braking

7 = Braking resistor
8/1 to 8/4 = Traction motors
12 = Shunt
A = Isolating contactor
B = Braking contactor
S = Series contactor
W = Reversing contactor

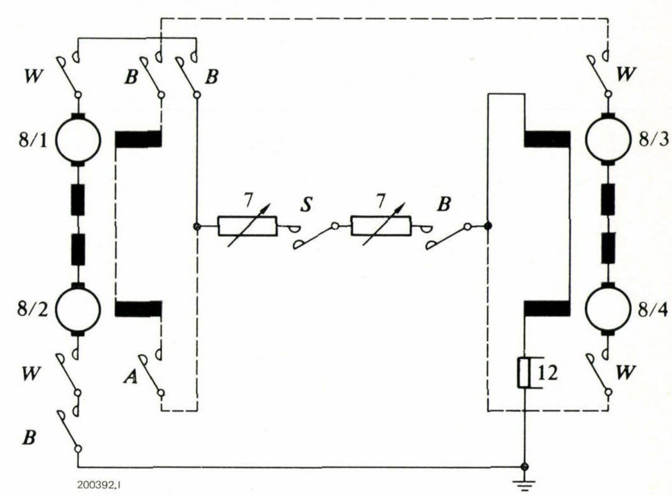
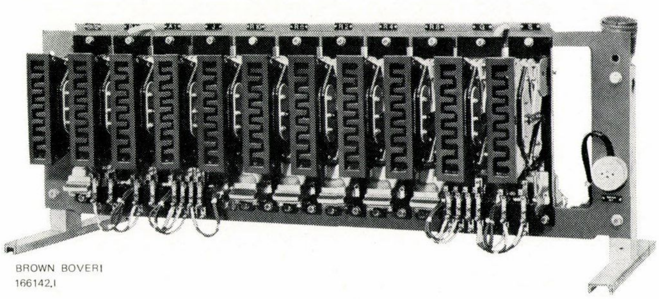


Fig. 5 – Switchgear unit with type PH 380 electro-pneumatic contactors



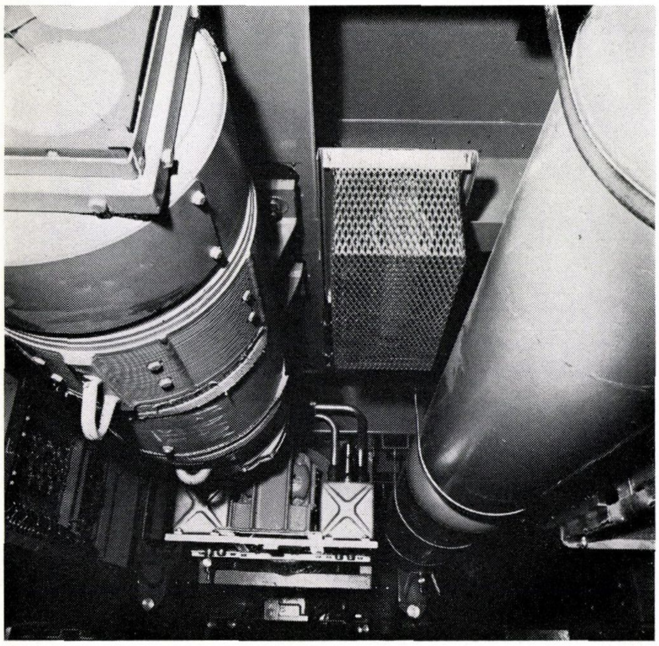


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Fig. 8 – Auxiliary machines mounted beneath the floor of the vehicle

Background: Motor/compressor set
Left: Motor/generator set
Right: Main air receiver

cars. If the contact wire voltage fails, a combination of relays ensures automatic changeover from the 220/380 V fluorescent lighting to the 36 V emergency lighting. The battery is charged through a transformer and rectifier from the network as shown in Fig. 9. All auxiliary machinery is mounted beneath the floors of the cars (Fig. 8).

Motor/Compressor Set

The compressed air is supplied by a piston-type compressor unit of type 2A70 [4]. The throughput, related to the inlet conditions of the air, is 500 dm^3/min at 1000 rev/min with a permissible duty period of 70%. Through appropriate pressure reduction valves the compressed air system supplies the electro-pneumatically controlled compressed air brakes, the electro-pneumatically controlled switchgear, door operating mechanism, sander and windscreen wipers.

Control

The commanded values for acceleration or deceleration, and also for controlled speeds on downhill runs, are fed to the control electronics from the master controller.

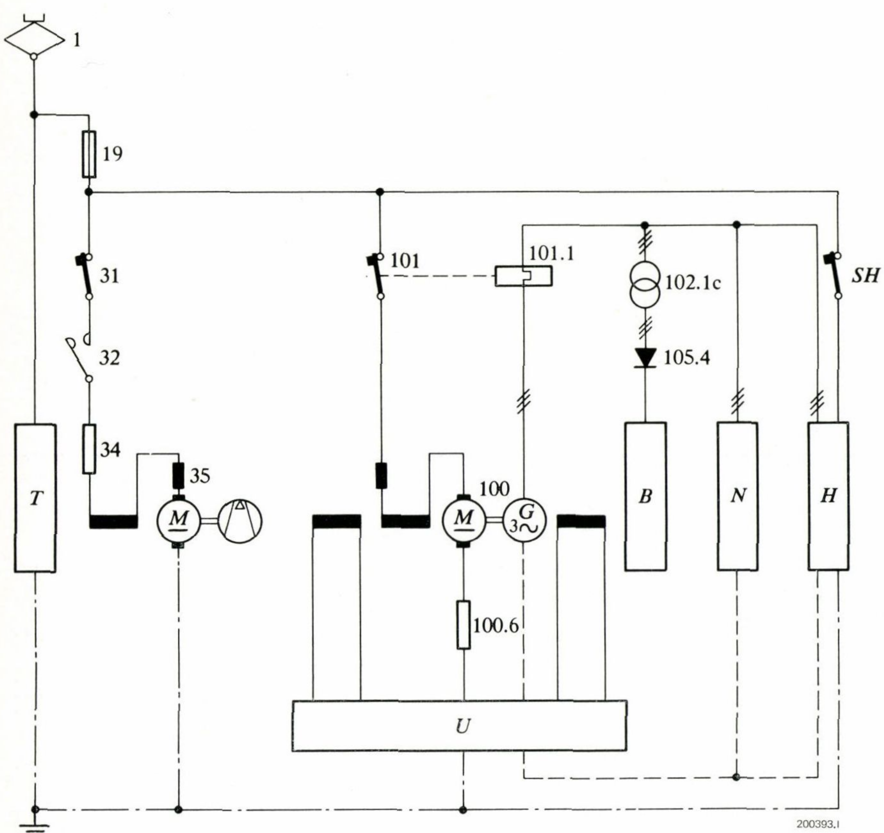

Fig. 9 – Current circuits for auxiliaries

1 = Current collector
19 = Fuse for auxiliaries
31 = Protection switch for compressor motor
32 = Contactor for compressor motor
34 = Series resistor for compressor motor
35 = Compressor unit
100 = Motor/generator set
100.6 = Series resistor for motor/generator set
101 = Protection switch for motor/generator set
101.1 = Thermal trip for motor/generator set
102.1c = Transformer for battery charging
105.4 = Rectifier for battery charging
B = Battery charging, 36 V consumers
H = Heating circuit
N = 380/220 V consumers (auxiliaries)
SH = Protection switch for heating
T = Traction current circuits
U = Control for motor/generator set

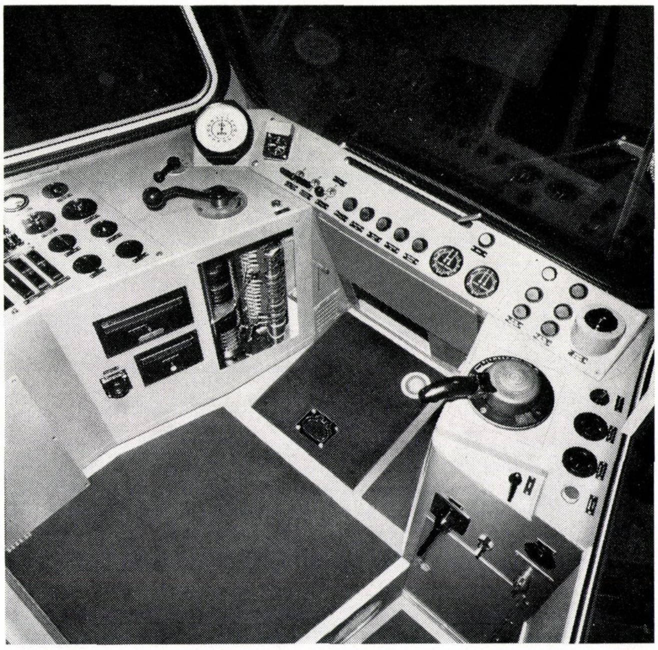

Fig. 10 – Driver's desk with clearly laid-out instruments and controls

The functions correspond largely to those of the vehicles described in [5]. The clearly laid-out control desk is shown in Fig. 10.

Performance

The articulated tramcars have been in operation for over a year. Experience has shown that the set objectives in respect of traffic and traction have been fully complied with.

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D.C. Traction on the Rhaetian Railway

C. Florin and K. Vollenwyder

High-power electric motorcoaches were built for operation under extremely difficult traction and climatic conditions on the d.c. lines between St. Moritz and Tirano (Bernina Pass) and between Chur and Arosa. The conventional electrical equipment for these vehicles is described.

Introduction

In addition to its basic network of a.c. lines, the Rhaetian Railway (RhB) also operates two metre-gauge d.c. lines:

- the Bernina line (BB) and
- the Chur–Arosa line (ChA).

The system network is shown in Fig. 1.
The two d.c. rail systems are typical mountain railways. They operate all year round under extreme climatic conditions.
The necessity for replacing existing rolling stock and coping with increased passenger and goods traffic gave impetus for acquiring high-power traction vehicles.
The first series of six motorcoaches was delivered to the Bernina line in 1964. A further order for three more units of similar design was received in 1970. At the same time another two were ordered for the Chur–Arosa line.

Main Data of the Lines

The main data for the two line sections are shown diagrammatically in Fig. 2 and numerically in Table I.

Main Data of Motorcoaches

The units for the two d.c. lines have the same mechanical design (Fig. 3). Their performance figures are compiled in Table II.

Table I: Details of the Bernina line (BB) and the Chur–Arosa line (ChA)

		BB	*ChA*
Length	[km]	60·7	25·7
Maximum altitude	[m]	2256·5	1742
Maximum gradient		1 in 14	1 in 16·5
Minimum track radius	[m]	40	60
Number of tunnels		11	18
Total length of tunnels	[m]	2190	2714

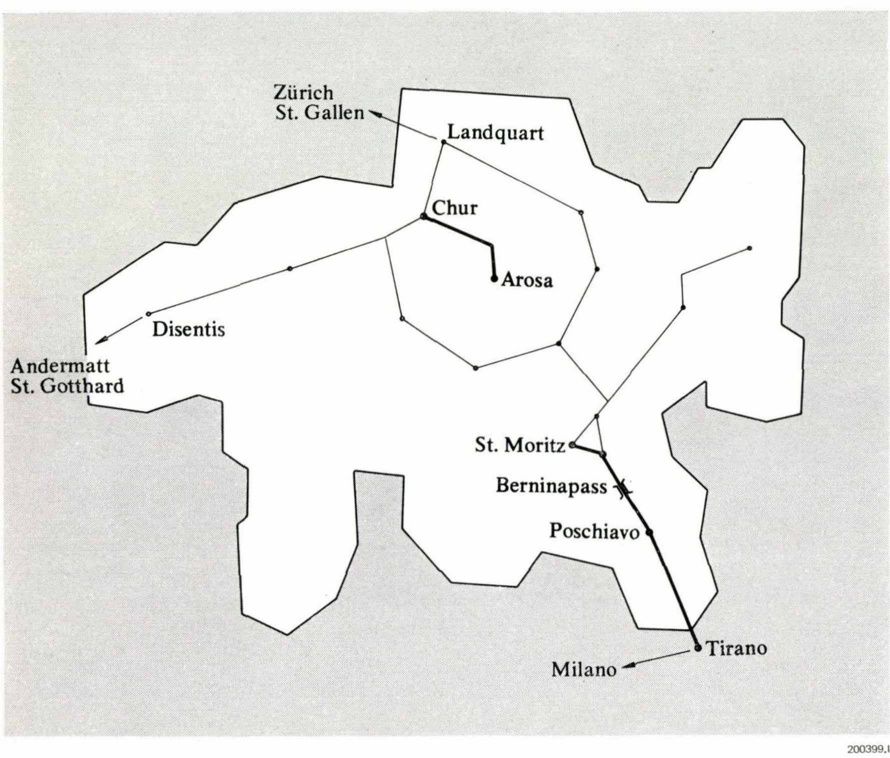

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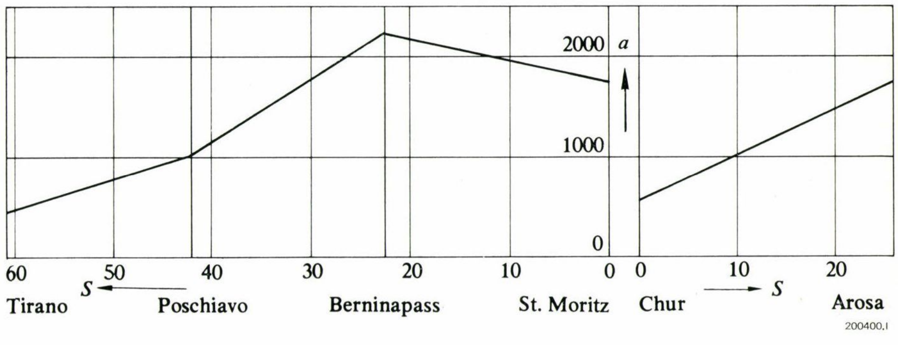
Fig. 1 – Configuration of the Rhaetian Railway network (11 kV, $16^{2}/_{3}$ Hz) and the d.c. section

Fig. 2 – Gradients

Left: Bernina line
Right: Chur–Arosa line

S = Distance [km]
a = Altitude [m]



The ABe 4/4 Bo'Bo' Motorcoaches of the Bernina Line No. 41 to 49

Operating Requirements

The specification for these motorcoaches stipulates the following traction modes on the lines with gradients of up to 1 in 14:

a. Uphill traction with a 60 t trailing load at
   - 25 km/h on 45 m track radii and
   - 30 km/h on 70 m radii

   each on the most economic tapping, i.e. with starting resistors short-circuited.
b. Uphill traction with 15 t trailing load at 30 km/h on 45 m radii on the most economic tapping.
c. Downhill running with 40 t trailing load at between 15 and 30 km/h. A train must be held at constant speed within the range mentioned by the electric brake alone.

Additional requirements:

- When pushing a rotary snowplough (Fig. 4) it must be possible to run at 10 km/h at the one-hour rated current (slow running).
- The vehicles are fitted with a regenerative brake.
- In addition to the regenerative brake a rheostatic brake is provided which is independent of the contact wire; if the supply voltage fails the auxiliaries are fed with the braking energy.
- Two motorcoaches must be able to operate as a double-headed unit (Fig. 5).

Fig. 3 – Bo'Bo' class ABe 4/4 d.c. motorcoach for the Bernina and Chur–Arosa lines

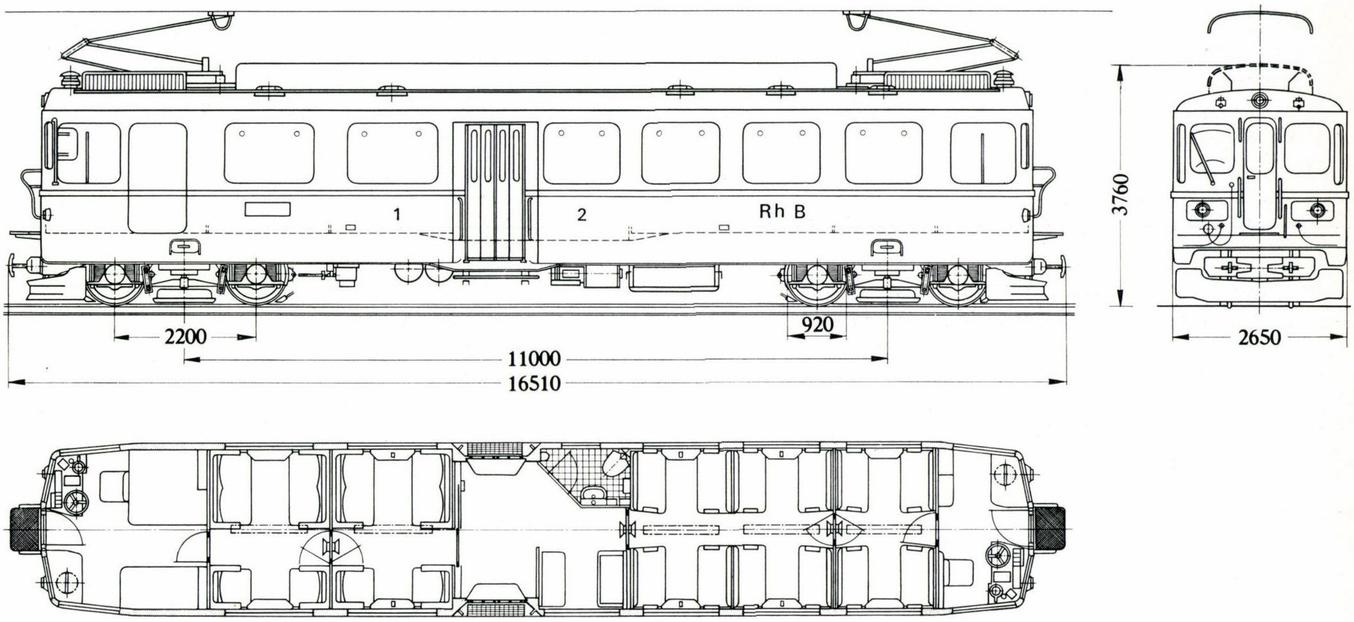


Table II: Details of the d.c. motorcoaches

		BB	*ChA*	
Axle sequence		Bo'Bo'	Bo'Bo'	
Permissible axle pressure	[t]	12	12	
Tare weight	[t]	44	44	
Load-carrying capacity	[t]	3	3	
Supply voltage	[V]	1000±20%	2400±25%	
Rated motor voltage	[V]	1000/2	2400/2	1500
Motor current				
– continuous rating	[A]	300	82	
– one-hour rating	[A]	375	110	
– maximum	[A]	600[1]	220[1]	
Shaft output				
– continuous	[kW]	560	360	450
– one-hour	[kW]	680	480	600
Tractive effort at wheels				
– continuous	[kN]	80	39	
– one-hour	[kN]	106	59	
– maximum	[kN]	192[1]	113[1]	
Speed				
– at continuous current	[km/h]	24·5	32	40
– at one-hour current	[km/h]	22·7	28	36
– maximum permitted	[km/h]	65[1]	70[1,2]	
Regenerative braking				
– max. braking force at wheel	[kN]	68	87	
– at speeds of	[km/h]	22–25	25–30	
Rheostatic braking:				
– max. braking force at wheel	[kN]	165	167	
– at speeds of	[km/h]	12–27	4–40	

[1] Values are not obtained simultaneously.
[2] The maximum speeds authorized on the Chur–Arosa line are 35 km/h uphill and 30 km/h downhill.

Electrical Equipment

Item 'a' of the specification was the criterion on which the design of the traction equipment was based. The operating conditions impose the following limits on transmitting the tractive forces:

- It is not permissible to start on 1:14 gradients with all traction motors connected in series because of the decided tendency to slip;
- Regrouping the traction motors from series to parallel connection by the bridge method is to be avoided because of the unavoidable drop in tractive effort;
- Alternate cutting out of resistors per group of motors results in excessive jumps in tractive effort and is therefore not suitable.

As a result of these restrictions the circuit decided on has the following features:

- The four traction motors are divided into two fixed groups, each having two motors connected in series.
- Grouping the traction motors with the same connection as follows for the required mode of operation:
  - Normal traction: 2 groups in parallel (Fig. 7a)
  - Slow running: 2 groups in series (Fig. 8a)
  - Regenerative braking: 2 groups in series (Fig. 9a)
  - Rheostatic braking: 2 groups in parallel (Fig. 10a)
- Regrouping the starting and braking resistors from series to parallel connection with auxiliary resistor for the initial transition stage.

The 14 grouping and stepping contactors for the resistors resulted in 21 motoring and braking steps with the connection chosen. The progression sequence is the same for all operating modes.

Motoring

- Connection as for normal traction (normal motoring; basic circuit diagram and Z/v characteristics, see Fig. 7a and 7b).

There are four field-weakening stages for tractive effort control in the upper speed range. Consequently there are 25 steps available for this mode of operation.

- Connection for snow clearance (slow running; basic circuit diagram and Z/v characteristics, see Fig. 8a and 8b).

No field-weakening is used in this mode. Continuous operation is possible in any of the 21 steps.

Braking

- Connection for operation under normal network conditions (regenerative brake; basic circuit diagram and B/v characteristics, see Fig. 9a and 9b).

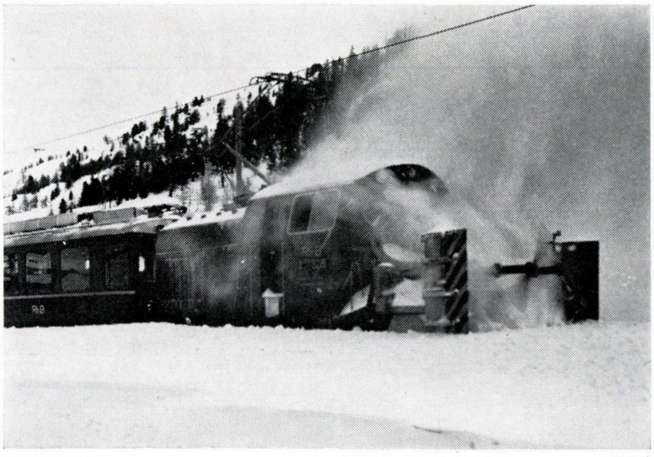
The circuit has the following features:

- Counter-compounding of the exciter
- Combined stabilizing resistor

As a result, braking effort surges due to fluctuations in the supply voltage are largely suppressed. The braking effort is controlled by switching the braking resistors step-by-step and simultaneously matching the separate excitation at the braking generator.

- Connection for operation without supply voltage (rheostatic brake; basic circuit diagram and B/v characteristics, see Fig. 10a and 10b).

Fig. 4 – Rotary snowplough on the Bernina section



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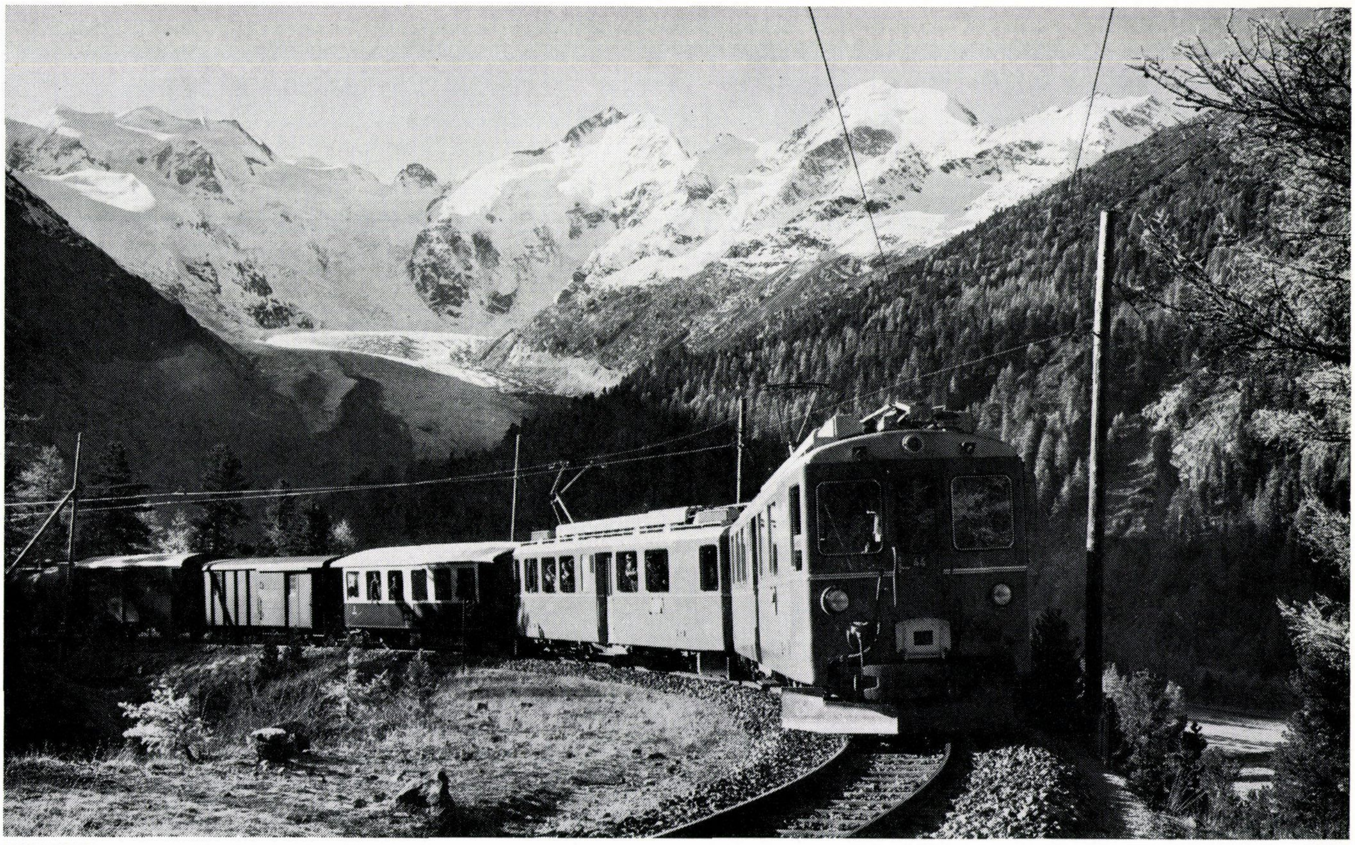

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Fig. 5 – Double-headed train composition on the Bernina section

At voltages of 500 to 1200V across the braking resistor and with the main circuit-breaker open, the vacuum pump and compressor motors can be fed with the braking current produced by the traction motors operating as generators.

Both braking systems are protected by overcurrent and overvoltage relays. If one of these relays trips, the braking current circuit is interrupted and the pneumatic brakes are automatically applied. In addition to the vacuum-controlled air brakes the vehicles are equipped with electro-magnetic rail brakes for added safety.

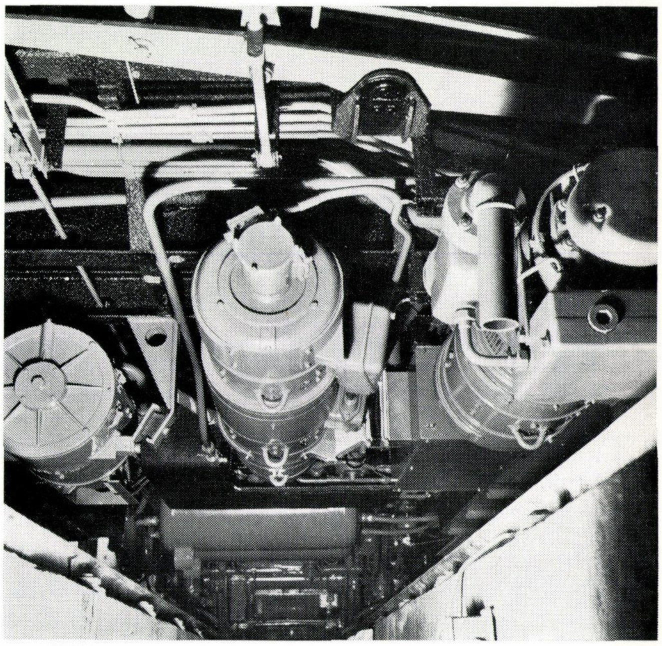
Electrical Components

Because of the various operating modes the electrical equipment for the vehicles is very extensive. In addition to the complex control and monitoring equipment it includes basically:

- A quick-acting d.c. breaker type UR25E20 rated 2000V and 2500A which acts as the main breaker.
- 35 electro-pneumatic and electro-magnetic contactors of various types rated between 600 and 2000V and 10 to 450A.
- Electro-pneumatic switches, one with two positions for reversing and one with four positions for selecting the mode of operation.
- Type 48SF2 vane-type resistors rated 840kW as starting and braking resistors.
- Four type EMR475 traction motors, self-ventilated and with nose suspension bearings.
- A motor/generator set (Fig. 6) comprising:
  - 1000V motor with 16kW one-hour rating,
  - three-phase generator, and
  - braking excitation generator.

Fig. 6 – Auxiliaries mounted beneath the floor of the motorcoach

Right: Compressor set
Centre: Motor/generator set
Left: Vacuum pump set



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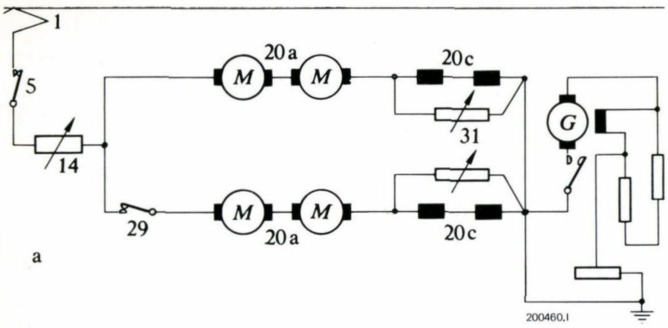


Fig. 7a – Normal traction circuit (BB)

1 = Current collector
5 = Main circuit-breaker
14 = Starting resistor
20a = Traction motor armature
20c = Traction motor field
29 = Contactor for parallel grouping
31 = Field-weakening resistor

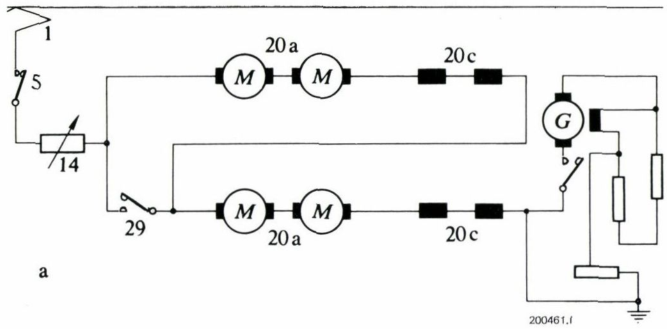


Fig. 8a – Basic circuit diagram for slow running (BB)

1 = Current collector
5 = Main circuit-breaker
14 = Starting resistor
20a = Traction motor armature
20c = Traction motor field
29 = Contactor for parallel grouping

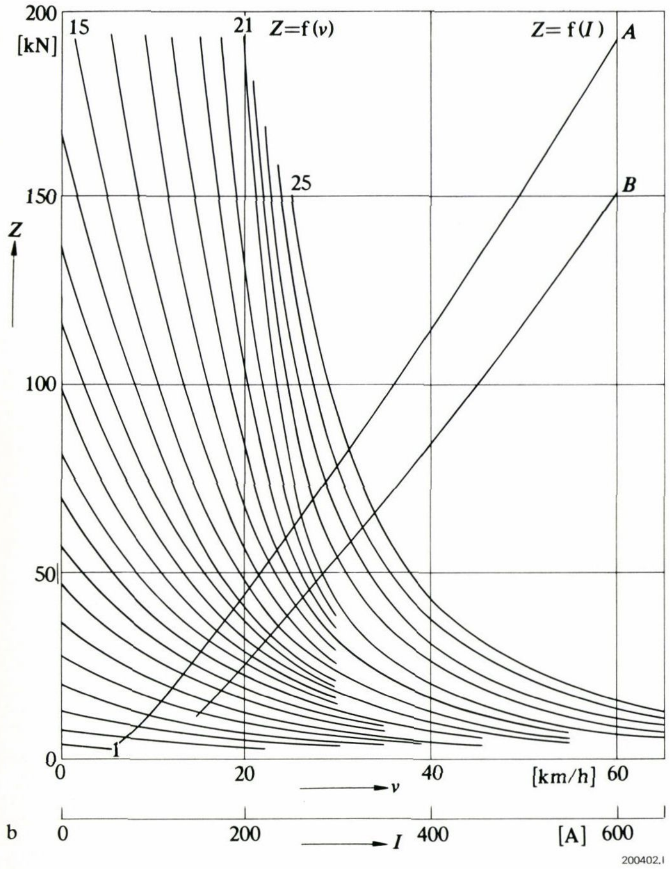


Fig. 7b – Vehicle characteristics, normal traction (BB)

v = Speed
$A = Z = f(I)$ at 100% field
$B = Z = f(I)$ at 50% field
I = Traction motor current
Z = Tractive effort at wheel

1, 15, 21 and 25 = Number of the motoring step

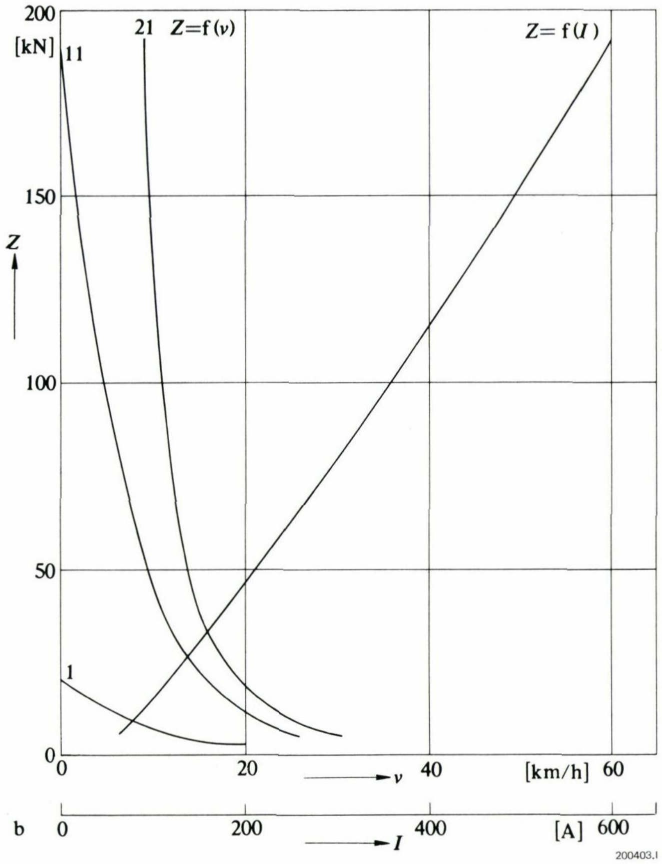


Fig. 8b – Vehicle characteristics for slow running (BB)

v = Speed
I = Traction motor current
Z = Tractive effort at wheel

1, 11 and 21 = Number of the motoring step

- One compressor set comprising:
  - motor rated 845 V and 5·8 kW, and
  - type 2A 70 compressor with a throughput of 720 l/min with a final pressure of 12 kgf/cm².
- One vacuum pump set comprising:
  - 1000 V motor rated 3·7 W, and
  - vacuum pump.

Arrangement and Installation of Electrical Equipment

Various problems were encountered in arranging the complex equipment to facilitate installation and maintenance. The body manufacturers (Swiss Car and Elevator Manufacturing Corporation Ltd., Schlieren-Zurich) were faced with particular difficulties:

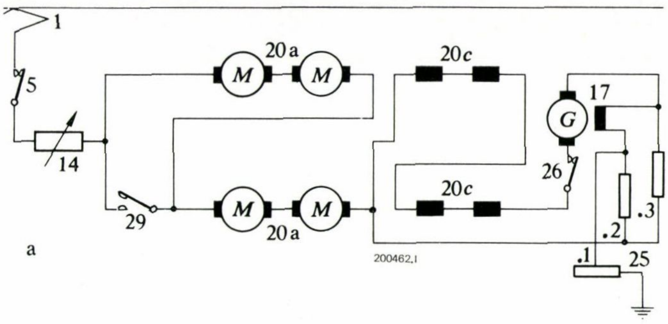


Fig. 9a – Basic circuit diagram for regenerative braking (BB)

1 = Current collector
5 = Main circuit-breaker
14 = Braking resistor
17 = Braking exciter generator
20a = Traction motor armature
20c = Traction motor field
25.1 = Limiting resistor
25.2, .3 = Stabilizing resistors
26 = Contactor for separate excitation of traction motor fields
29 = Contactor for parallel grouping

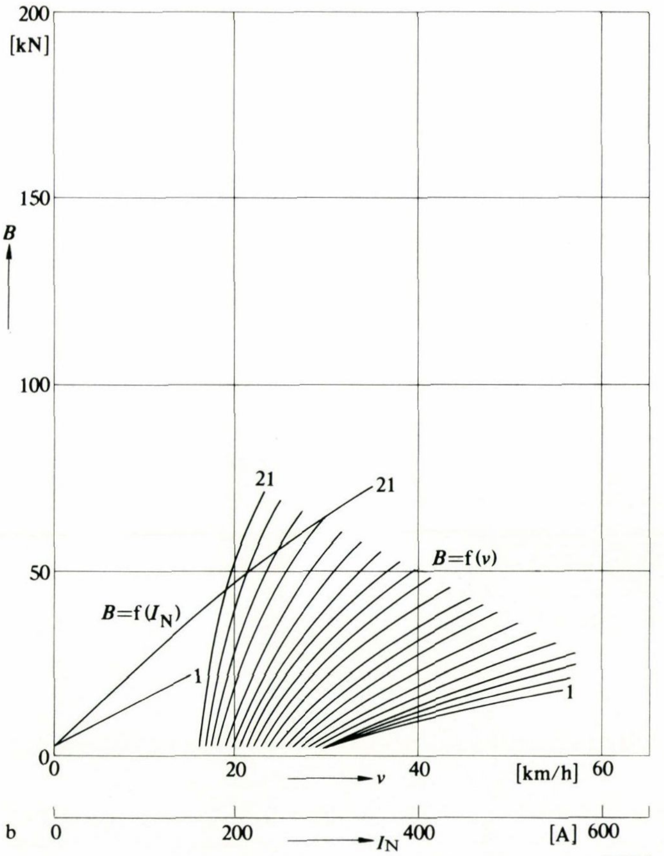


Fig. 9b – Vehicle characteristics for regenerative braking (BB)

v = Speed
B = Braking effort at wheel
I_N = Regenerative braking current
1, 21 = Number of the braking step

- wide doors had to be provided in the side walls of the vehicles for installing and maintaining the equipment (Fig. 11),
- large-section air ducts had to be run from the air inlet louvres at the corners of the roof to the bogies,
- the longitudinal chassis members also act as cable ducts.

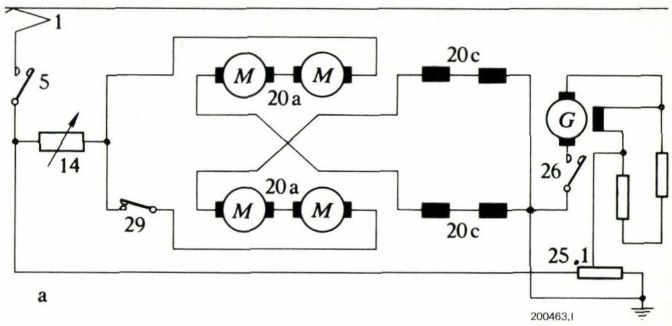


Fig. 10a – Basic circuit diagram for rheostatic braking (BB)

1 = Current collector
5 = Main circuit-breaker
14 = Braking resistor
20a = Traction motor armature
20c = Traction motor field
25.1 = Limiting resistor
26 = Contactor for separate excitation of traction motor fields
29 = Contactor for parallel grouping

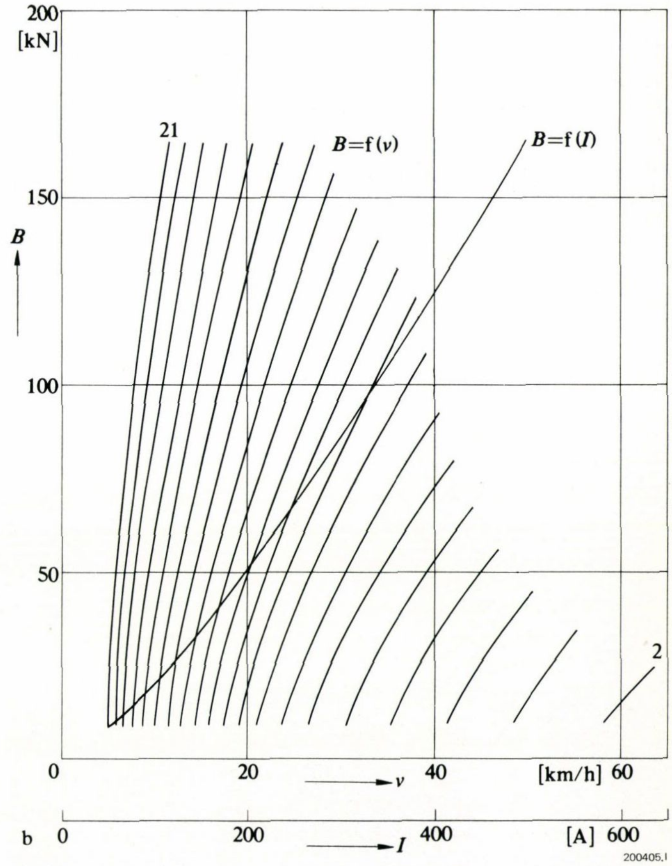


Fig. 10b – Vehicle characteristics for rheostatic braking (BB)

v = Speed
B = Braking effort
I = Braking current
2, 21 = Number of the braking step

Performance

The nine motorcoaches for the Bernina line have so far covered a total of about 4 million kilometres. The vehicles fulfil in every respect the set requirements under operating conditions which are extremely unfavourable as far as both line configuration and climatic factors are concerned.

Motorcoaches for the Chur–Arosa line

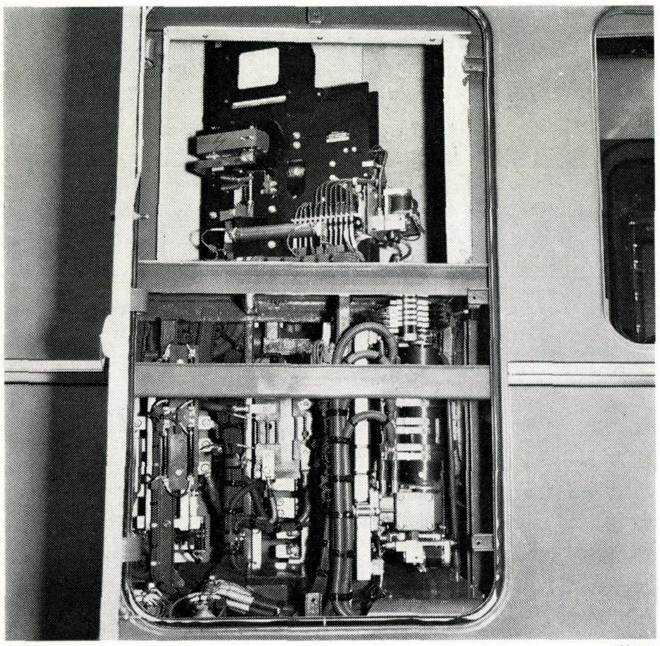
The electrical equipment of the two Bo'Bo', class ABe 4/4 motorcoaches No. 487 and 488 (Fig. 12) commissioned during the autumn of 1973 is fundamentally a replica of that for the six units (No. 481 to 486) built in 1957[1]. However, the electrical equipment had to be installed in a 'Bernina' type body. This was the reason for building five identical bodies (three for the Bernina line and two for the Chur–Arosa line).
It is intended that motorcoaches No. 487 and 488 will operate on the basic network of the Rhaetian Railway during the off-seasons together with driving trailers fitted with a.c. electrical equipment and rectifiers. This is the reason why the facilities for changing over to 1500 V supply (as No. 481 to 486) was retained although, since the Bellinzona–Mesocco line is now closed, this feature was not otherwise necessary.

Motoring and Braking at 2400 V

When motoring on the Chur–Arosa section both motors of each bogie are always connected in series. Starting is performed in 16 steps with the series grouping and 12 with the parallel grouping. Regrouping the motors from series to series/parallel connection is carried out with the short-circuit connection (Fig. 13). There are two field-weakening stages (Fig. 14) available for economical speed control. Electro-pneumatic contactors are used for regrouping the traction motors and for varying the resistance values.
The changeover from motoring to braking is effected by an electro-pneumatically operated drum-type controller.

[1] *A. Bächtiger:* Die stärksten Schmalspur-Adhäsionsmotorwagen der Schweiz für Chur–Arosa. Elekt. Bahnen 1957 193–200.

Fig. 11 – Equipment viewed through the access door in the side wall of the vehicle



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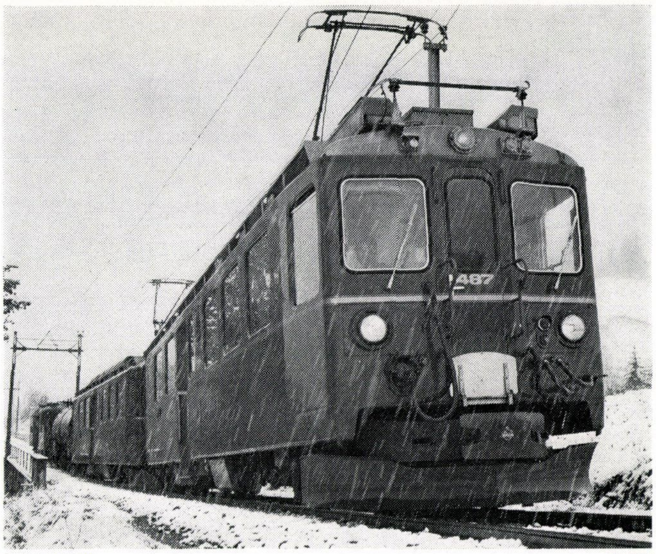

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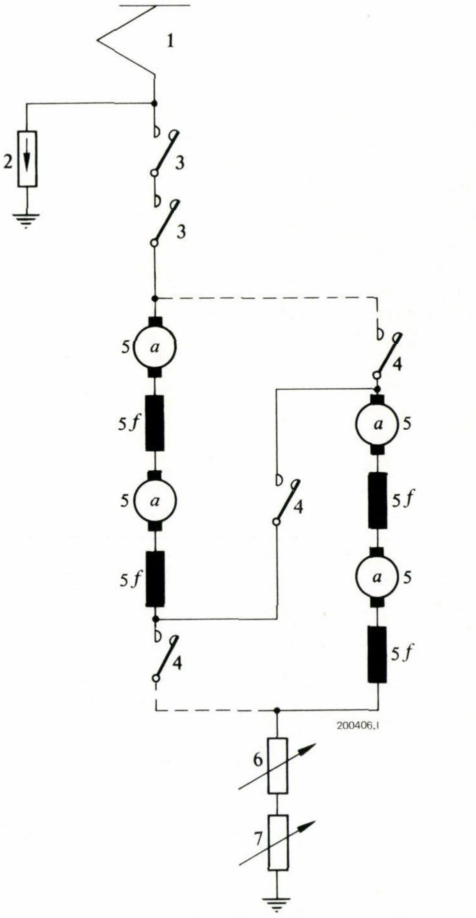
Fig. 12 – Class ABe 4/4 motorcoach of the Chur–Arosa line (double headed)

Fig. 13 – Basic circuit diagram for motoring (ChA)

1 = Current collector
2 = Surge diverter
3 = Main contactor
4 = Grouping contactor
5 = Traction motor
  a = Armature
  f = Field
6 = Starting resistor
7 = Series-connected resistor for traction motor field



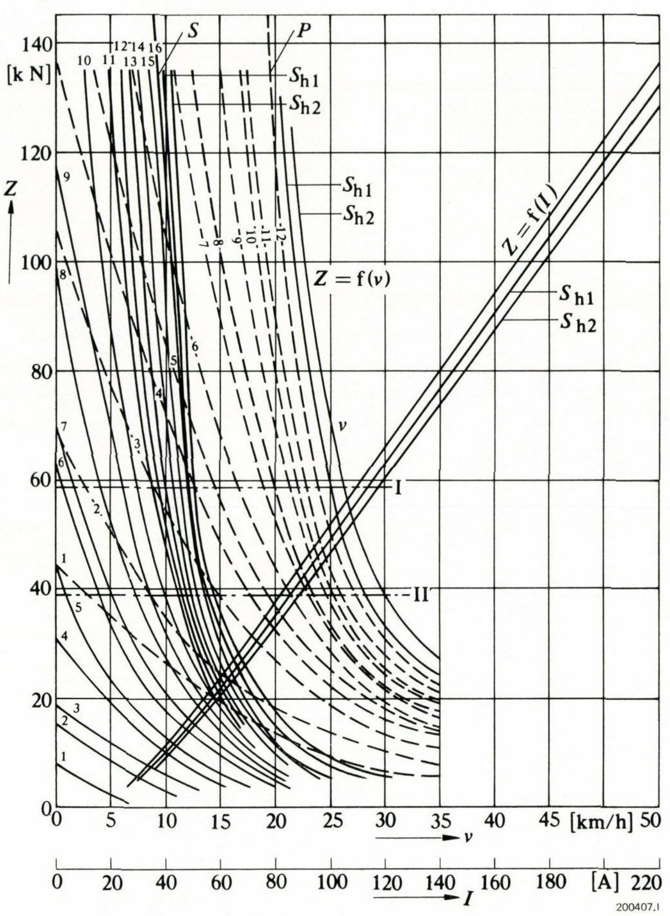
The traction motor armatures are connected in series for regenerative braking. The field windings, which are also connected in series, are excited through a series-connected resistor from the contact wire (Fig. 15). The permissible speed on those downhill runs of the Chur–Arosa line which are suitable for regenerative braking applications is 30 km/h (B/v characteristics, see Fig. 16).
When the braking energy is to be fed to the resistors, the crossover short-circuit braking configuration is used (Fig. 17). There are 14 braking steps available for both braking modes (B/v characteristics, see Fig. 18).
A pneumatically-operated drum-type controller is used for reversing.

Auxiliaries

The heating circuits for the motorcoaches and trailers are fed from the contact wire. A motor/generator set comprising a 2400 V d.c. motor and three-phase generator with series-connected rectifier drives the compressor and vacuum pump. The auxiliary network is rated 300 V. The battery is also charged from the three-phase generator through a transformer and rectifier.

Fig. 14 – Vehicle characteristics for motoring (ChA)

v = Speed
I = Current at traction motors
P = Final parallel step at full field
S = Final series step with full field
$S_{h1,2}$ = Field weakening stages 1 and 2
Z = Tractive effort at wheel
I = One-hour tractive effort
II = Continous tractive effort



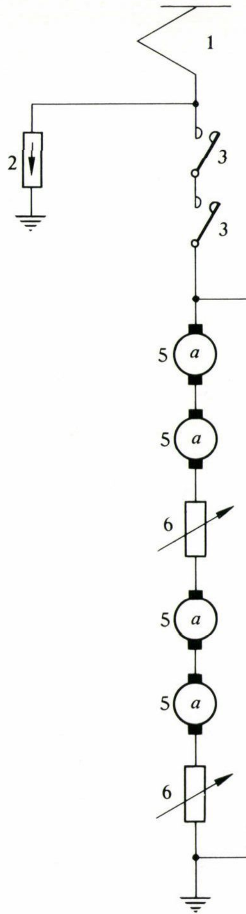
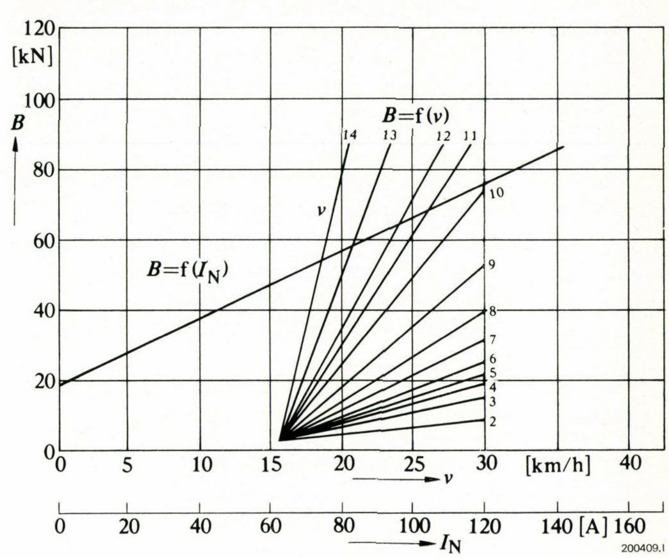


Fig. 15 – Basic circuit diagram for regenerative braking (ChA)

1 = Current collector
2 = Surge diverter
3 = Main contactor
5 = Traction motor
a = Armature
f = Field
6 = Braking resistor
7 = Series-connected resistor for traction motor field

Fig. 16 – Vehicle characteristics for regenerative braking (ChA)

v = Speed
B = Braking effort
I_N = Regenerative braking current



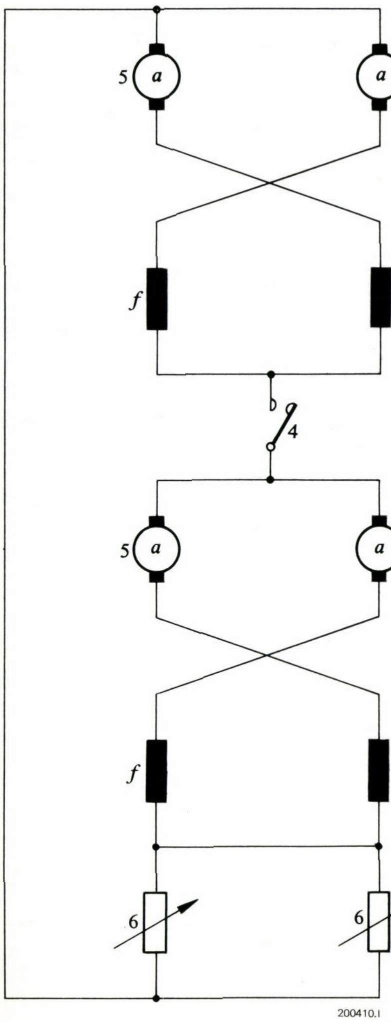


Fig. 17 – Basic circuit diagram for rheostatic braking (ChA)

4 = Grouping contactor
5 = Traction motor
  a = Armature
  f = Field
6 = Braking resistor

Layout of the Electrical Equipment

As the vehicle bodies are identical with those used on the Bernina line the arrangement of the electrical equipment is also similar. The only difference is the roof arrangement; here a supply changeover switch is provided for operation at 1500 V. The train heating couplings are also arranged at the ends of the roofs.

Operation at the Basic Supply (11 kV and $16^2/_3$ Hz)

During the off-peak seasons, i.e. April to June and October/November, not all motorcoaches are required on the Chur–Arosa line. However, during these periods

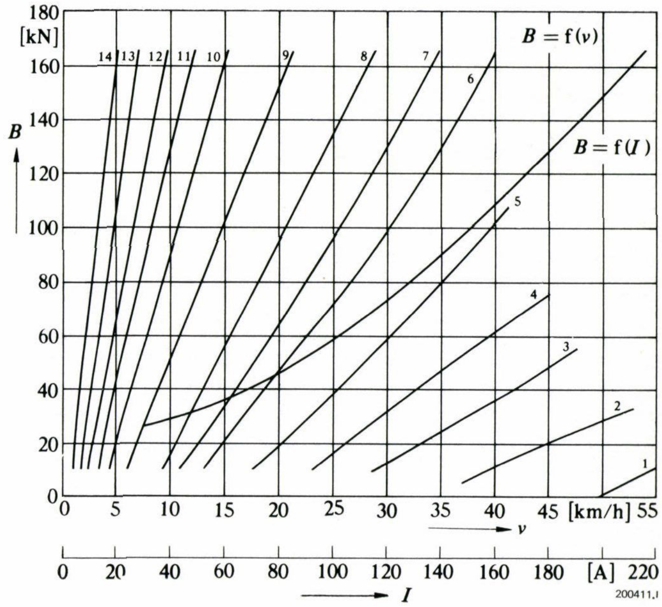


Fig. 18 – Vehicle characteristics for rheostatic braking (ChA)

v = Speed
B = Braking effort at wheels
I = Braking current

there is demand on the Rhaetian Railway system for operating short passenger trains. Consequently the motorcoaches 487 and 488 were equipped so that they can be fed at a constant voltage of 1500 V from the driving trailers with a.c. equipment, rectifiers and smoothing reactors. In this mode the traction motors on each bogie are connected in parallel and starting is performed by regrouping from series/parallel to parallel connection. The changeover to operation with the supply from a.c. driving trailers is effected by manually-operated drum switches.

Electric Motorcoaches for the Dolder Rack Railway, Zurich

T. Šilić

A brief description is given of the electrical equipment for the motorcoaches for the Dolder Rack Railway in Zurich. Built in 1972/73, this rack railway replaces the original funicular.

Introduction

The original Dolder Railway, a funicular from Römerhof square to Waldhaus Dolder in Zurich, was replaced in 1973 by a rack railway and, at the same time, the line was extended to Adlisberg. The original line was 816 m long with a difference of altitude of 100 m.
Investigations into the future of the railway showed that passenger requirements would be better complied with by a rack railway and extending the track to the sports centre and the Grand Hotel Dolder.
The line section from the Römerhof to the Waldhaus generally follows the old funicular track. However, the foundations and permanent way were rebuilt. After extension the line is now 1320 m long, the difference in altitude is 161·3 m and the maximum incline is 1 in 5 (Fig. 1). An Abt single rack system is used. Other data relating to rack conditions are given in Table I.

Fig. 1 – Incline of Dolder Rack Railway

A = Römerhof terminus
B = Titlisstrasse halt
C = Siding
D = Waldhaus station
E = Dolder terminus

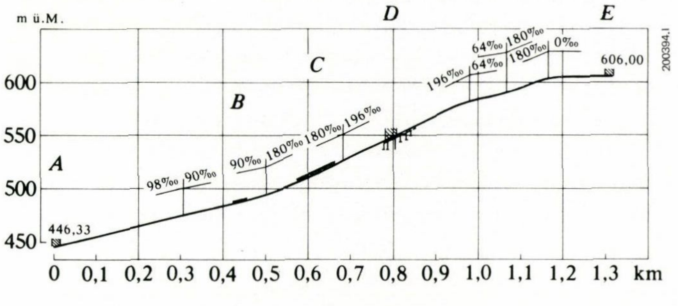


Table I: General data of railway system

Length of track (without siding)	1320 m
Length of siding	107 m
Gauge	1000 mm
Rack	Continuous
Rack system	Abt single rack
Gradients	
0 to 504 m	1 in 10
504 to 1320 m	1 in 5
Smallest radius	Track 200 m
	Points 100 m
Supply	D.C.
Rated contact wire voltage	600 V
Height of contact wire (measured perpendicular to top of rail)	
max.	4·8 m
min.	3·3 m

The Motorcoaches

Weights and dimensions are given in Table II and performance figures of the vehicles are given in Table III (Fig. 2 and 3).

Axles and Drives

The motorcoaches have a driving axle at the downhill end and a brake axle at the other, each having a tangentially suspended pinion. The traction motor is mounted longitu-

Table II: Weights and dimensions

Diameter of traction wheels (new)	690 mm
P.c.d. of pinion	573 mm
Length over buffers	11 520 mm
Width	2 500 mm
Height of vehicle with current collector retracted	3 214 mm
Passenger capacity	26 seated
	74 standing
	total 100
Weight of mechanical equipment and body	11 080 kg
Weight of electrical equipment	3 320 kg
Tare	14 400 kg
Load (100 passengers)	7 800 kg
Gross weight	22 200 kg

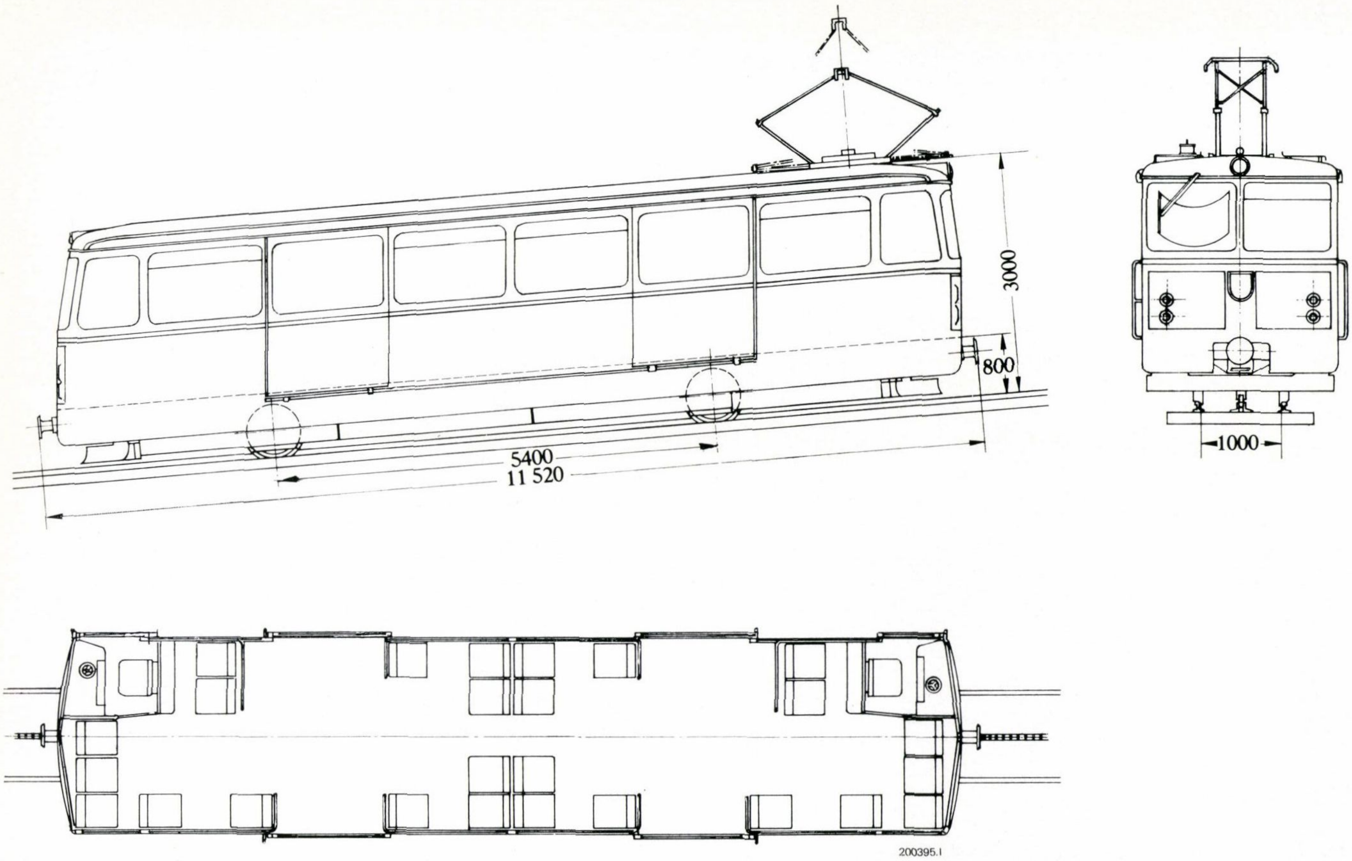


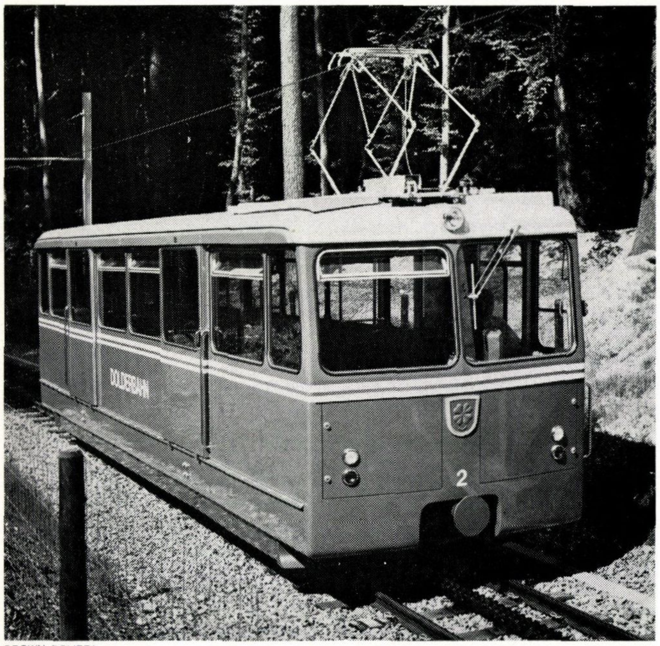
Fig. 2 – Motorcoach

dinally and drives the pinion through a friction clutch, cardan shaft and two-stage bevel gearing.

Pneumatic Equipment

The compressed air for operating the brakes, switchgear and vehicle doors is supplied by a type 2A 40 motor/compressor set. It compresses 380 dm^3 air per minute to 12 kgf/cm^2 at a rated speed of 1330 rev/min.

Fig. 3 – Motorcoach in service



Brakes

The motorcoaches have the following braking systems:

– The rheostatic brake operates as a holding and retarding brake on downhill runs.
– The pinion brake operates on the brakedrum of the uphill pinion and is applied when the train stops.
– The ratchet brake operates on the brakedrum of the downhill pinion, prevents the vehicle from running back on uphill runs and, on downhill runs, supports the pinion brake during emergency braking.

Electrical Equipment

Motor Circuits

The circuitry is shown in Fig. 4. A uniform electropneumatic contactor (type PH 380) is used for motoring, braking, reversing and stepping. This type of contactor is also used in the electrical equipment of tramcars. As a result of the economy circuitry where the individual resistors of the starting and braking resistors are grouped in series or parallel connection, the 12 stepping contactors provide 22 motoring and 23 braking steps (Fig. 5 and 6).
The current is collected from the contact wire by a manually-operated pantograph with carbon slippers. A manually-operated or motor-driven automatic circuit-breaker provides protection against short circuits and overloads.

Table III: Performance figures

	Continuous	1-hour	Maximum (not coincidental)
Output of self-ventilated traction motor [kW]	131·5	149·5	
Tractive effort at wheelrim [kN]	22·8	27·1	65·3
Braking effort at wheelrim [kN]	28·9	34·7	82·3
Speed [km/h]	18·9	18	25
Voltage [V]	600	600	720
Current [A]	240	272	550
Motor speed [rev/min]	1830	1740	2420
Transmission ratio, motor/pinion		10·45:1	
Permissible speeds:			
– downhill, up to 1 in 10		25 km/h[1]	
– downhill, above 1 in 10		16 km/h[1]	
– uphill		25 km/h	
Time to accelerate from 0 to 16 km/h on max. incline		9 s	

[1] In accordance with the Swiss Federal Transport Office Regulations for light railways

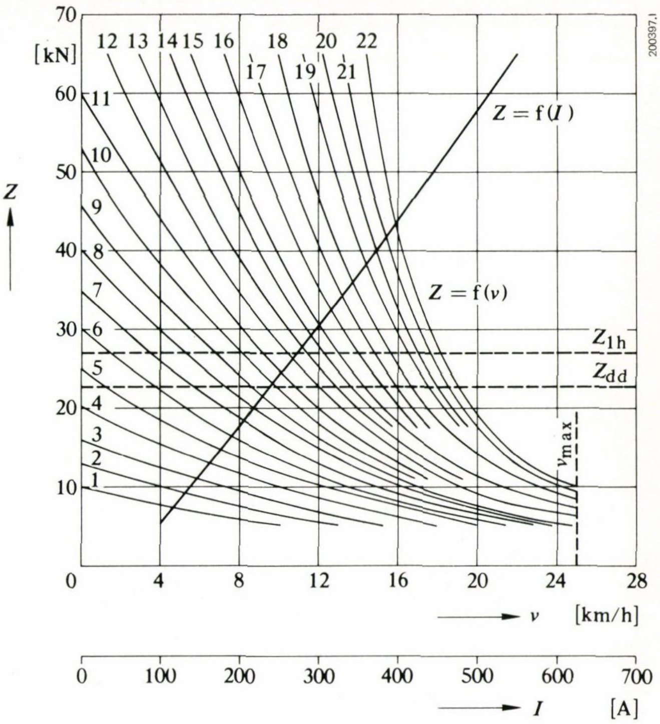


Fig. 5 – Characteristic curves

v = Speed [km/h]
I = Motor current [A]
Z_{dd} = Tractive effort at wheelrim [kN] at continuous current
Z_{1h} = Tractive effort at wheelrim [kN] at 1-hour current
Z = Tractive effort at wheel [kN]

A surge diverter protects the electrical equipment against overvoltages in the contact wire.

Motor/Generator Set for Auxiliaries

A monoblock d.c. three-phase motor/generator set rated 2·15 kVA provides the auxiliaries with 380 V, 50 Hz three-phase supply and a Unitrol 2211 regulator keeps frequency and voltage constant. This three-phase supply feeds the fluorescent lighting, fan motors for ventilating the passenger compartment and also charges the battery through a rectifier bridge. The controls, the emergency and service lighting and also the fan motors for cooling the starting and braking resistors are supplied from the 36 V battery circuit.

Control

The driver can select any motoring or braking stage direct through the master controller, i.e. without any intermediate electronic control equipment. Traction and braking contactors, and also the reversing contactors, are mutually interlocked through auxiliary contacts in such a manner as to preclude wrong manipulations, thus eliminating short circuits.

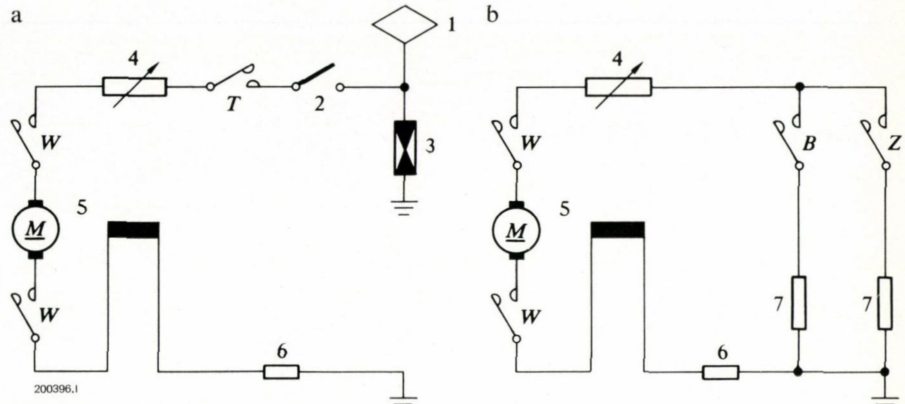
Towing

The motorcoaches are designed for one-car operation. However, each is capable of towing the second car should it develop a fault, provided that both are unladen. Towing is permissible only in braking steps 20 to 23 at speeds

Fig. 4 – Main current diagram

a: Motoring uphill
b: Braking downhill

1 = Current collector
2 = Circuit-breaker
3 = Surge diverter
4 = Motoring and braking resistors
5 = Traction motor
6 = Shunt for measuring motor current
7 = Additional braking resistors
B = Braking contactor
T = Traction Contactor
W = Reversing contactor
Z = Additional braking contactor



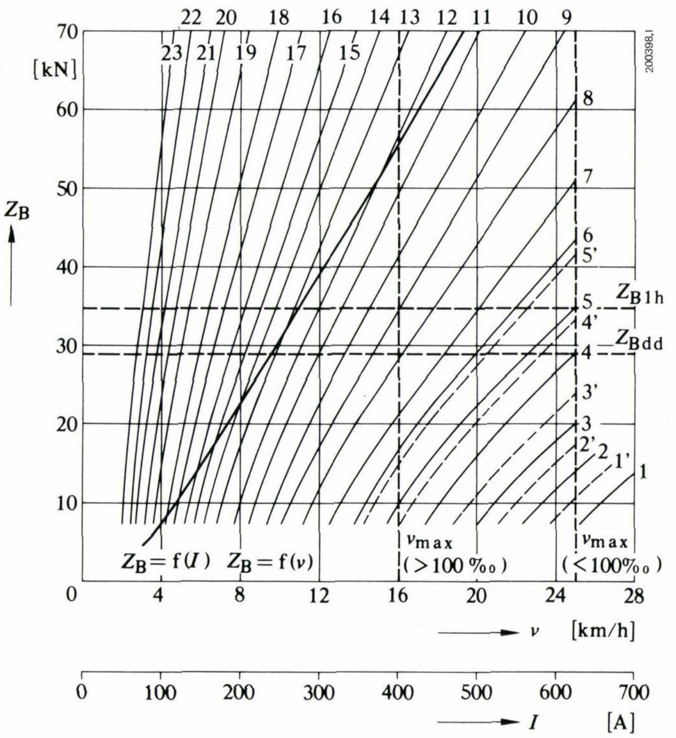


Fig. 6 – Braking characteristics

v = Speed [km/h]
I = Motor current [A]
Z_{Bdd} = Braking effort at wheelrim [kN] at continuous current
Z_{B1h} = Braking effort at wheelrim [kN] at 1-hour current
Z_B = Braking effort [kN]

of 3 to 6 km/h. Motoring duty is permissible only in the last three motoring steps, which correspond to speeds of 13 to 18 km/h.

Suppliers

The equipment for the two motorcoaches, which have been in operation since 1973, was supplied by the following manufacturers:

Chassis:	Swiss Locomotive and Machine Works, Winterthur
Body:	Carrosserie Gangloff AG, Bern
Electrical equipment:	BBC Brown, Boveri & Company, Ltd., Baden

Power Supplies for Passenger Trains

P. Strub

Coaches fitted with air conditioning and other services require an extensive and high-capacity power supply system to feed the lighting and heating, refrigerating plant, fans providing forced ventilation to the passenger compartments, hot water storage tanks and, in coaches with sleeping berths or couchettes, the refrigerators.

General

The energy for train power supplies can be generated separately in each coach or centrally in the locomotive, either from a transformer, direct from the contact wire or a diesel generator.
The first group includes systems with

- generators driven from the coach axle [1] and
- fuel-powered generators in the coach.

The second group is becoming more important as power requirements increase. It requires a busline which runs throughout the length of the train. This is already present in most coaches, in the form of a heating cable. The various loads are connected to this bus either direct or through converter equipment in the coach (Fig. 1a, b).
Individual power generation from the coach axle is a possibility, provided the power requirement per coach is restricted to less than 10 kW and as long as the train speed is not higher than 160 km/h. This system is inexpensive and for this reason is very widespread. But the energy drawn from the axle by means of d.c. or a.c. generators must first be produced in the locomotive in the form of motive power. An additional load is thus imposed on the main traction motors. The appreciable rotating masses of the train lighting generators necessitate extra tractive effort to accelerate the train, and must also be retarded on braking. A further point to note is that energy obtained from the coach axle is no longer available when the train stops. This means, in particular, that preparatory heating and air conditioning of the coaches is not possible. All these drawbacks work in favour of a centralized supply system via the train busline.

Train Busline

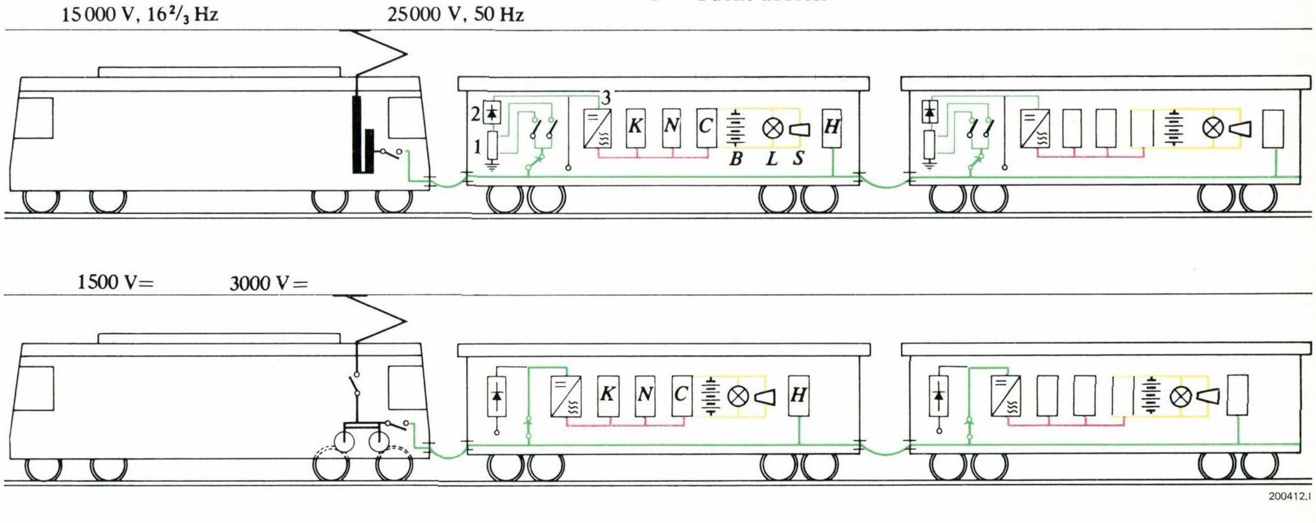
For historical reasons the voltages and systems available for the busline are not uniform throughout Europe. The

Fig. 1 – Power supply to a train with four-system coaches

a: A.C. contact wire
b: D.C. contact wire

Green: High-voltage system
Red: Medium-voltage system
Yellow: Low-voltage system

1 = Transformer 1000/1500/1700 V
2 = Rectifier
3 = Motor-generator 1500 V or 3000 V d.c./220 V, 50 Hz, 3-phase
B = Train lighting battery
C = Battery charger
H = Heating
K = Chiller unit of air conditioning system
L = Train lighting
N = Standard loads (hot water tanks, domestic appliances)
S = Public address



a

b

four voltages specified in the RIC[1] are used by the following railways, among others:

1000 V	$16\frac{2}{3}$ Hz	German Federal Railway (DB) Austrian Federal Railways (ÖBB) Swiss Federal Railways (SBB)
1500 V	50 Hz	French National Railways (SNCF)
1500 V	d.c.	French National Railways (SNCF) Netherlands Railways (NS)
3000 V	d.c.	Belgian National Railways (SNCB) Italian State Railways (FS)

All rolling stock operating across national frontiers must be able to handle these systems, and have to be fitted with four-system converter equipment.
The ORE[2] commission B108 (standardization of electrical equipment for passenger coaches), set up by the various railway authorities, specified the following supply networks for air-conditioned vehicles:

- high-voltage network for heating
- medium-voltage network for refrigeration
- low-voltage network for lighting, for supplying the battery and for loads connected to the battery.

The medium and low-voltage systems are supplied from the high-voltage network.
It is best to distinguish between coaches which operate on only an a.c. system (e.g. with a train bus for 1000 V, $16\frac{2}{3}$ Hz), and those for mixed systems (e.g. 1500 V, 50 Hz and 1500 V d.c.).

Coaches for a Single AC System

The diagram in Fig. 2 shows the method of feeding the loads from the busline. The heating part of the air-conditioning system is supplied direct from the 1000 V, $16\frac{2}{3}$ Hz high-voltage network. The motor for the compressor of the refrigeration system, which uses a halogen-based refrigerant, is connected through a rectifier. This motor has an output of about 14 kW with undulating current at 900 V, and is built as a series motor. The circuit arrangement is such that variations of load and voltage have no significant effect on speed or, consequently, on the output of the chiller plant.
The 220 V, $16\frac{2}{3}$ Hz medium-voltage system feeds the air-conditioning fans and the hot water storage tanks. It is connected to the h.v. system through a transformer. In an air-conditioned coach fitted with a single-duct system [2], the heater units in the compartments can also be fed from this network.
The medium-voltage system, operating through a controlled solid-state charger, charges the battery and feeds the low-voltage loads, such as lighting, public address system and other auxiliary services.

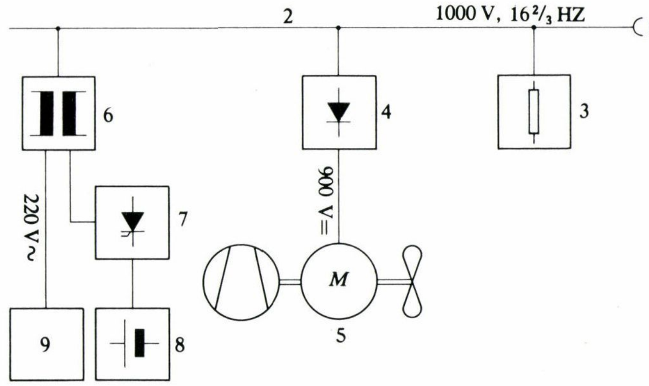
Vehicles for AC/DC Service

The heating section of the air-conditioning plant presents no serious problems, as the air heater can be fed direct with either d.c. or a.c. The voltage can be easily adapted to the levels of 1000, 1500 and 3000 V by arranging the heating elements in suitable groups. In this way each heating element is always at its nominal voltage. The question of the compressor drive is more complicated. Since the voltage of the train's h.v. system can be 1000, 1500 or 3000 V it is not possible to build a reliable motor at reasonable cost for the relatively low output of 14 kW. The battery charging system is also made very expensive by the need to handle 1500 or 3000 V d.c.
Brown Boveri therefore decided to develop a *three-phase medium-voltage train-mounted power system* for four-current vehicles. To this are connected not only the motor of the refrigerating compressor, but all motors installed in the coach, together with the heating elements of the hot water tanks and the supply to the low-voltage loads.

The Three-Phase Train-Mounted Power System

A motor-generator set, which operates on all the power systems feeding the train busline, supplies a three-phase network in the train with $3 \times 220/380$ V, 50 Hz. This is connected either direct or indirect to all loads, with the exception of the electric air heater, as shown in Fig. 3.
A monobloc converter set, comprising a double-commutator undulating-current motor and a three-phase synchronous generator, operates at 1000 V, $16\frac{2}{3}$ Hz and 1500 V, 50 Hz via a single-winding transformer and a single-phase rectifier with the rotor winding grouped in parallel. In the case of d.c. the motor is fed direct, at 1500 V with the rotor winding in parallel, and at 3000 V in series.
Figure 4 shows the converter set specially constructed for four-system service. It has an output of 25 kVA at the generator terminals. The two-phase double-commutator motor has excellent characteristics up to a supply voltage of 4000 V d.c., even when subjected to transients. Rotor and stator are each insulated for a test voltage of 8 kV.

Fig. 2 – Power supply system for single-voltage a.c. vehicles
1 = System connection
2 = Busline
3 = Air heater
4 = Rectifier
5 = Refrigerating plant
6 = Transformer
7 = Static battery charger
8 = Train lighting battery
9 = Auxiliaries



[1] Regolamento Internazionale Carrozze
[2] Office de Recherches et d'Essais

Speed control of the series machine requires a circuit of the kind shown in Fig. 5. A variable boost current is fed to the exciter field to prevent the speed from rising as the load on the motor falls or the supply voltage increases. This circuit has proved its effectiveness in many applications and is protected by patent.
The multi-system selector tests the voltage and system applied to the busline. With an a.c. supply the motor is connected through the rectifier to the bus, the transformer being switched to 1000 or 1500 V, depending on the system.
When running on d.c., the selector allows the motor to be fed direct from the busbar and groups the rotor windings in series or parallel to suit the voltage. The selector also controls the grouping of the heating elements in the air heaters according to the voltage on the train bus.
The voltage of the three-phase system is regulated as a function of battery charging current within the ±6% range permissible for three-phase motors. This amount of voltage variation is sufficient to limit the charging current. A separate controlled charger is therefore unnecessary.
An electronic speed-monitoring device, which is checked automatically at each start, prevents the converter set from running away if the speed governor system fails.

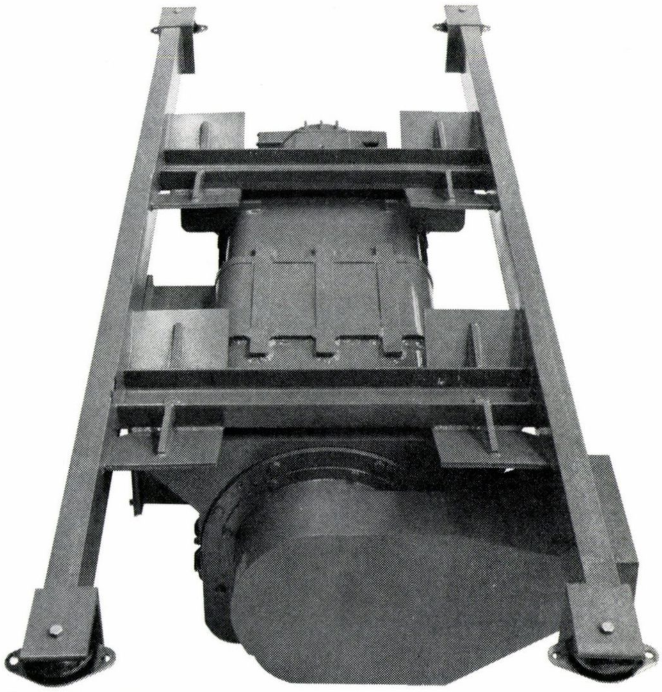


Fig. 4 – Four-system converter set
Power output 25 kVA

The DC Train-Mounted Power System

In cases where the coaches are fed from only a single a.c. system (e.g. 1000 V, 16⅔ Hz) it is possible, as mentioned above, to drive the refrigeration compressor with an undulating-current motor obtaining its supply from the h.v. system through a rectifier. If rolling stock thus equipped is to be used for unrestricted international service, i.e. on railway systems with a contact wire voltage of 1500 or 3000 V d.c., an additional d.c./a.c. converter set is required [3]. As with the three-phase system, the motors are grouped in series or parallel, depending on the contact wire voltage. The three-phase generator voltage is so chosen that 1000 V is available after the rectifier. Speed regulation of the converter set is not necessary with this system. Since there is no actual medium-voltage supply the hot water tanks and the radiators outside the passenger compartments have to be connected to the high-voltage system.
The low-voltage network is fed from a controlled charger in the case of a.c. systems, and from a separate winding in the generator when the supply is through a converter.

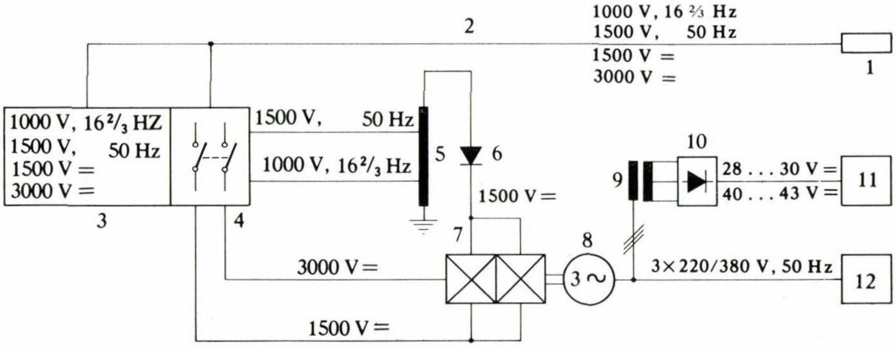
As can be seen in Fig. 6, vehicles fitted with only one set of electrical equipment for a train bus voltage of 1000 V, 16⅔ Hz can be converted to multi-system service by adding the equipment contained in the box.
A variation on the d.c. system is the variable-frequency three-phase network employed in the four-system dining cars of Swiss Federal Railways. A converter set, similar to that in a constant-frequency three-phase system, produces from its generator a controlled voltage of 3×380 V, 50 to 100 Hz. The galley equipment is fed direct from the three-phase system, while the compressor of the air-conditioning plant is connected via a three-phase rectifier [4].

Advantages of the Three-phase Medium-Voltage System

The voltage and frequency of a medium-voltage train-mounted system are the same as those in stationary

Fig. 3 – Power supply to four-system coach with three-phase train-mounted supply network

1 = System connection
2 = Busline
3 = Voltage and system selection
4 = Grouping selector
5 = Autotransformer
6 = Single-phase rectifier
7 = Double-commutator motor
8 = Synchronous generator
9 = Battery-charging transformer
10 = Charging rectifier
11 = Battery and battery-fed loads
12 = Three-phase loads (air conditioning)



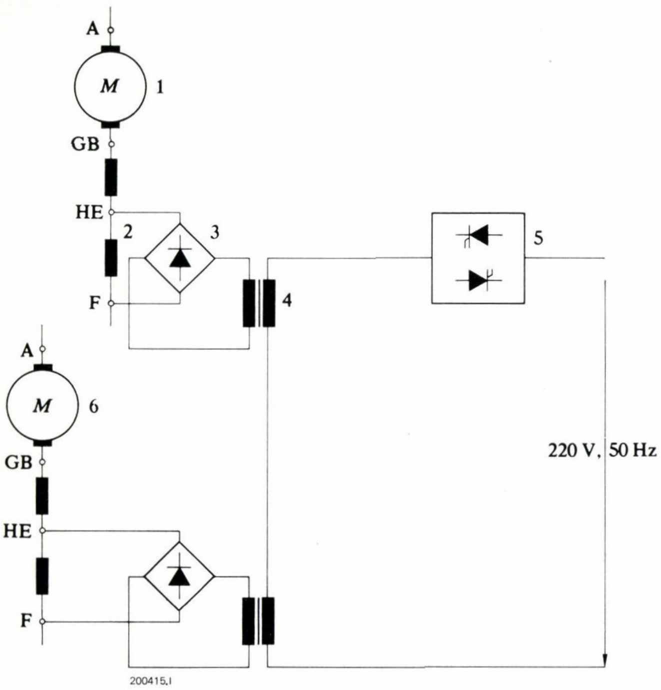


Fig. 5 – Basic circuit of converter speed control system

1 = Motor I
2 = Series field
3 = Rectifier
4 = Isolating transformer
5 = Frequency regulator
6 = Motor II

installations. This means readily available equipment and motors can be used, thus avoiding the need for expensive purpose-built components. This is particularly important as regards maintaining stocks of spares. With a three-phase system one can use induction motors which require very little care and servicing. In the case of equipment for rolling stock especially, lack of space means the motors often have to be in places that are not easily accessible. The induction motor is at a particular advantage in this respect. The design of the refrigeration system benefits in the following ways:

– The compressor-condenser unit can be fitted with a semi-hermetic glandless compressor. This is driven by an integral, low-maintenance induction motor and requires no coupling between itself and the motor.
– The air requirement of the condenser, and hence its power consumption, can be matched at any time to the refrigerating capacity demanded from the compressor by means of a separate pole-changing motor.
– With a three-cylinder compressor with valve-lift, for example, cooling capacity can be turned down to ⅓ full load virtually without loss.
– The busline is largely relieved of the starting current inrush of the compressor motor.
– The refrigerating unit is much lighter and cheaper than with an open-type compressor.

There are also great advantages for the other electrical loads in the coach:

– A power supply system of standard voltage and frequency is available for the heater units in single-duct air conditioning systems, for radiators near doors, hot water tanks, refrigerators and vacuum cleaners. Normal industrial products can therefore be used.
– In the case of coaches left standing in stations for any time, or being carried on ferries, the medium-voltage system can be fed from the local supply. Chilling plant and battery chargers can therefore remain operating in the absence of a locomotive.

If there is no train-mounted three-phase system, not only do the advantages listed above not apply, but also the following disadvantages must be taken into account:

– Because a commutator motor is used, the refrigeration plant can only be equipped with an open-type compressor. In addition, the commutator motor has to be a high-voltage machine.
– The refrigerating capacity could indeed be controlled by means of valve-lift. But this reduces the driving power and the series motor increases speed, which must be kept constant within certain limits by automatic control.
– The current spikes occurring when the compressor starts act directly on the busline. The d.c. motor, with its greater inertia, requires a higher starting torque than the smaller induction motor.

The fact must not be overlooked that with today's air conditioning systems the chiller unit has to operate even

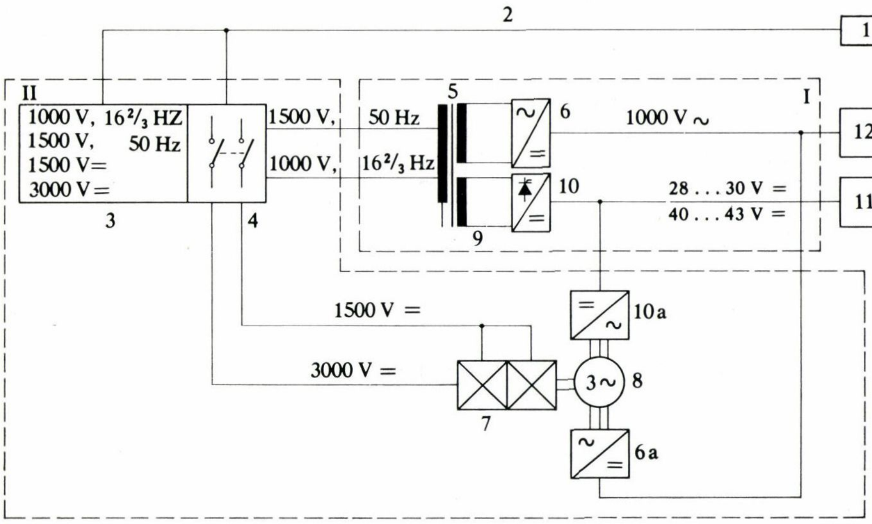


Fig. 6 – Power supply for passenger coach with d.c. power system

1 = System connection
2 = Busline
3 = Voltage and system selection
4 = Grouping selector
5 = Three-winding transformer
6 = Rectifier (single-phase)
6a = Rectifier (three-phase)
7 = Double-commutator motor
8 = Synchronous generator
9 = Winding for charging battery
10 = Battery-charging rectifier
10a = Converter-fed battery-charging rectifier
11 = Battery and battery-fed loads
12 = Air conditioning, hot water tanks, etc.

when the outside temperature is as low as about +5 °C, and thus for some ⅔ of the days in service per annum. On systems with a d.c. supply to the contact wire there are then two high-voltage motors running; the motor of the converter set and the compressor motor. If the power supply is based on the three-phase system, however, a single-voltage vehicle can very easily be converted to multi-system operation by adding a transformer/rectifier set.

The Future

The three-phase power systems used in passenger rolling stock are at present still equipped with rotary converters. Suitable motor-generator sets have proved to be reliable. The only drawback is the need to check the commutator motor regularly. For traction vehicles, the change from commutator machines to induction motors is well under way [5]. In the future, too, static frequency changers can be expected to replace the rotary converter for supplying power to multi-system coaches. Existing rolling stock with a three-phase system can then be modernized at reasonable cost by replacing the motor-generator with a static frequency changer.
The three-phase power supply system for passenger trains can thus be viewed as the most favourable solution, both now and in the future.

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Climate in Passenger Trains

F. Thomann

Whether a train journey is pleasant for the passenger depends greatly on climatic conditions in the compartment. In a train with good lighting and good climatic conditions one can travel not only safely, but also in comfort. The quality of the atmosphere is much more important on long journeys than for short trips. However, the cost of modifying these conditions rises sharply with passenger requirements. Warm-air heating and forced ventilation are at present considered sufficient for journeys of less than an hour. Modern suburban trains are therefore fitted with equipment of this kind. Long-distance coaches are today usually equipped with air conditioning systems which, in addition, include refrigeration facilities for cooling and drying the air.

Human Response to Climatic Factors

If a person is to feel comfortable under given climatic conditions, his body must be capable of maintaining its heat balance without difficulty. The generation of heat within the body and any supply of heat from outside must at all times be held in balance through dissipation of heat to the surroundings by convection, radiation and evaporation.

The amounts of heat dispersed in these ways must also bear a certain relationship to each other. In indoor air of average temperature and humidity, a normally clothed person at rest emits heat by convection, radiation and evaporation in roughly equal proportions. As shown in Fig. 1, this ratio obtains at a room temperature of about 24 °C. At higher ambient temperatures the removal of heat by convection and radiation falls sharply, so that the body is forced to let more moisture evaporate from its surface. At 36 °C heat dissipation takes place almost entirely through evaporation.

Whether the human body can maintain a comfortable relationship between the three forms of heat removal depends on the climatic factors of

- air temperature
- relative humidity of the air
- temperature of the surrounding surfaces
- air movement in the room

The relative influence of these factors on comfort varies widely between individuals, and so is difficult to establish numerically. Average values determined from a large number of test subjects and related to outside temperature yield recommended values for room temperature, humidity and air movement, Table I. Here it should be noted in particular that room temperature has to be increased slightly as the outside temperature rises above 20 °C. At the same time, however, the air movement may also be increased. Nevertheless, the air velocities of more than 0·25 m/s given in Table I should be avoided as far as possible because they are felt to cause an unpleasant draught, even when the heat balance is in equilibrium. Local jets of air can chill the body in places. They are felt to be most unpleasant and must be eliminated if a favourable climate is to be achieved.

Important Factors Affecting Heat Balance of the Body

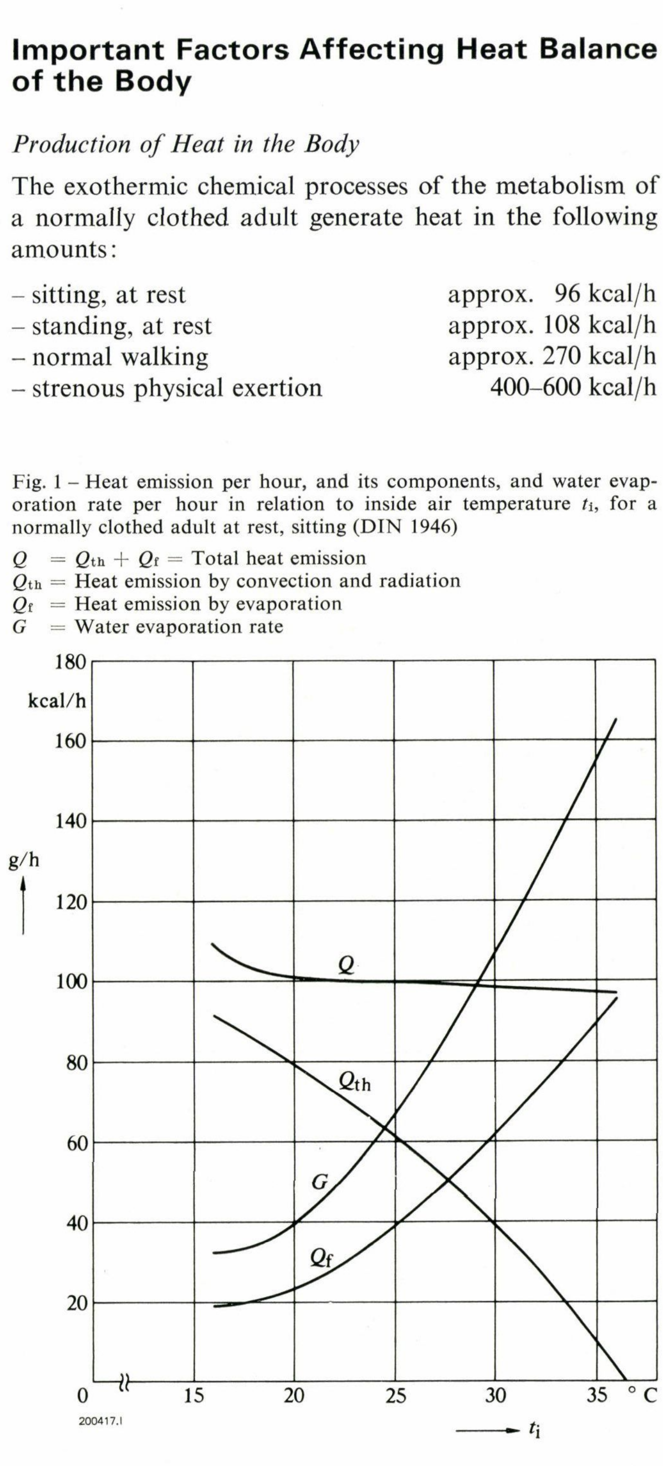
Production of Heat in the Body

The exothermic chemical processes of the metabolism of a normally clothed adult generate heat in the following amounts:

– sitting, at rest	approx. 96 kcal/h
– standing, at rest	approx. 108 kcal/h
– normal walking	approx. 270 kcal/h
– strenous physical exertion	400–600 kcal/h

Fig. 1 – Heat emission per hour, and its components, and water evaporation rate per hour in relation to inside air temperature t_i, for a normally clothed adult at rest, sitting (DIN 1946)

$Q = Q_{th} + Q_f$ = Total heat emission
Q_{th} = Heat emission by convection and radiation
Q_f = Heat emission by evaporation
G = Water evaporation rate



Heat Input from Outside

Since the human body temperature is a constant 37 °C, the body is heated by convection from outside only in the rare case of an ambient temperature higher than 37 °C. On the other hand, very substantial quantities of heat can be received by radiation, either through direct solar irradiation or from warm surfaces. Uncovered parts of the body are heated direct by radiation. Articles of clothing are heated by radiation, and so hinder the emission of heat from the body.

Heat Dissipation

At exposed parts of the body, heat is dissipated direct to the surroundings, while at clothed portions it first disperses by conduction through the insulating layer of air trapped in the clothing. With intensive thermal radiation on to clothing the temperature difference between the body and the surface of the clothes can become very small, and thus the heat flow between body and clothing surface is also very small.
Convective heat removal depends not only on the temperature difference relative to the ambient air, but also on air movement in the room, which is why moving air always feels cooler.
Bodies of all kinds radiate heat, the radiation energy increasing rapidly with temperature. Any human body, and its clothes, therefore radiates heat to its surroundings, but at the same time absorbs heat radiated by every surrounding surface, walls, ceilings, floors, furniture and, through the windows, by the outside world. The essential factor for our bodies is the balance of radiant heat absorbed and emitted. When there is no direct sunshine, more radiant heat is usually emitted than is absorbed. If we are to feel comfortable, the surplus dissipated by radiation must be roughly equal to the quantity of heat imparted to the air by convection. At average room temperature, the temperature of the surrounding surfaces has as great an influence on comfort as the room temperature. For example, with a surface temperature of 20 °C and a room air temperature of 20 °C the same degree of comfort is felt as with a surface temperature of 19 °C and air temperature of 21 °C .Therefore, not only the air temperature is important for comfort, but also the temperature of the bounding surfaces of the room.
The evaporation of water is a very effective way of dispersing heat. When the air is circulating the water vapour is removed continuously, and the skin surface and clothing remain dry. The latent heat of evaporation is withdrawn from the body. The amount of evaporation depends on the temperature of the air, its humidity and movement. In still air of high humidity, the evaporation of moisture from the skin is impeded and the skin becomes wet. Moist skin is always a sign that the removal of heat from the body is not sufficiently effective.

Temperature Regulation System of the Human Body

Our nervous system ensures that the temperature of our bodies remains constant at 37 °C. It responds not only to the temperature inside the body, but also to the temperature at the skin surface and particularly to its rate of change. This is why rapid changes in climatic conditions are always felt to be unpleasant. Identical conditions during a downward trend are felt to be cooler than when they are constant or even tending upward. In control terms we are here confronted with a typical proportional plus derivative action. At low ambient temperatures the generation of heat in the body is adjusted accordingly. Through greater or less constriction of the blood vessels the transport of heat to the body surface can be varied, thus influencing heat dissipation by convection and radiation. Especially at high ambient temperatures, when heat is dissipated mainly through evaporation, the body temperature is held constant by varying the amount of water secreted at the skin surface. Apart from this, we consciously protect ourselves against excessive temperature differences by means of clothing, heating and air conditioning [1].

Technological Means of Influencing the Climate in Trains

The climate in a train is influenced partly by the heat and moisture dissipated by the passengers, and partly by the temperature and humidity of the outside air, solar irradiation through the windows, solar radiation on the roof and sides, heat sources such as lighting or hot meals and drinks in the dining car, etc. Other factors are the speed of the train, the natural wind speed, the orientation of the train with respect to the sun, and air movements through cracks and open doors and windows. All or any of these can change within a short time. Consider travelling along a route with many curves and tunnels, for instance. External influences are particularly apparent by the windows, the seats people generally prefer. Both in summer and in winter unpleasant draughts can be experienced from windows not completely closed. In summer the passenger by the window can be exposed to strong direct sunshine, while in winter the marked radiant heat loss to the side of the coach, and hence to the outside, can cause discomfort.
Unlike normal rooms in buildings, the compartments of rail coaches have a very small volume per person. If heating surfaces are to be provided to heat the compartments, this gives rise to high concentrations of power under the seats or on the walls. Owing to the restricted natural circulation of air over the heating surfaces, the

heat supplied to them is dissipated to a small quantity of air. The result is very high local temperatures.
The delivery of fresh air and removal of used air is difficult because the air inlets and outlets can only be positioned a short distance from the passenger. The likelihood of exceeding the maximum values given in Table I for air velocities in the space occupied by the passengers is thus very great. When feeding in air with temperatures lower than the inside temperature, therefore, thoroughly mixing with the room air is most important. Otherwise there is a danger that cooler air near the ceiling will in some places fall at relatively high speed, owing to its higher specific weight, and so cause draughts. But with the restricted space and a headroom of 2 to 2·4 m, it is hardly possible to provide sufficiently large mixing zones by using conventional techniques. Consequently, air change rates are subject to limits.
The heat transmission coefficients of the outer surfaces are generally between 1·8 and 3 kcal/h m² deg. C. In winter this means high heat losses from the inside air and cold interior surfaces. This in turn is why high specific heating capacities per cubic metre of volume are necessary.
Sunshine on the roof and sides of a coach heat these surfaces to well above the outside temperature. The temperature rises given in Table II are virtually independent of the outside temperature. Because of the mainly convective heat transmission to atmosphere from the outer surface of the coach, however, they are very much affected by the train's speed.
In the case of trains on local services with low average speeds and frequent stops, the usual minimal insulation and correspondingly high transmission coefficients of the walls and roof result in a massive influx of heat into the coach. Apart from the consequent rise in inside air temperature, the radiation from the ceiling and inner wall surfaces, as mentioned earlier, has a great influence on comfort. Without suitable countermeasures, conditions in a coach in summer can be most uncomfortable, even with moderate outside temperatures.
The heat storage ability of passenger rolling stock is small, so there is no significant smoothing effect when large changes in inside or outside conditions occur,

Table I: Recommended atmospheric conditions for rail vehicles, from UIC[1] data sheet No. 533

Outside temperature t_a	[°C]	≤20	22	24	26	30	32
Inside temperature t_i	[°C]	22	22	22	23	25	26
Relative humidity inside (max.) φ_i	[%]	70	70	70	65	60	60
Air movement (max.)	[m/s]	0·24	0·24	0·24	0·29	0·42	0·5

[1] Union Internationale des Chemins de fer

Table II: Temperature rise of roof and one side of a passenger coach relative to outside air temperature at different train speeds
Solar radiation at 45° inclination and at right angles to direction of travel

Train speed	[km/h]	0	10	20	40	60	80
Temperature rise	[°C]	58	32	26·5	20	16	13

whether short-lived or extending over hours. This imposes severe demands on the plant control systems.
Positioning the equipment correctly is difficult because there is very little space available, either in the passenger space or outside it in the ceiling, walls or under the floor.
There are still many coaches in service today equipped with convector heating systems of the kind extensively used for a great many years. Air extraction vents are mounted on the roof. Their cowls and the slipstream together create a suction effet from the coach interior. The extracted air is replaced by outside air flowing into the passenger space through cracks round the doors and windows.
Brown Boveri recognized the merits of warm-air heating at an early stage, and development has been focussed on this system. Fresh air is used as the heating medium. This is heated outside the passenger space and introduced via distribution ducts, without causing draughts. The main advantages are:

- the system and regulation are simple, hence very reliable and requiring practically no human intervention
- efficient air circulation eliminates local overheating
- uniform heating of the whole passenger space, including seating
- short warm-up time
- good controllability and fast response to changes in required output
- year-round draught-free admission of fresh air at suitable points and prevention of inward leakage of cold air [2, 3, 4, 5]

A need to provide a much greater flow of fresh make-up air at outside temperatures of over 5 °C has become increasingly apparent recently. Otherwise the inside temperature becomes uncomfortably high if the coach is well filled and the sun is shining. Opening the windows is not an acceptable remedy, because of the draught with relatively low outside temperatures.
How important this extra air is, even in coaches working short distances, is illustrated by the shuttle-service trains of the Vereinigte Bern–Worb-Bahnen (VBW) and the Solothurn–Zollikofen–Bern-Bahn (SZB) [6].

The coach data governing the climatic conditions are:

Length of passenger space	17120 mm
Width of coach	2680 mm
Height of coach	2210 mm
Volume	≈ 100 m³
Max. number of passengers	110
Min. volume per passenger	0·91 m³

The following figures were used in calculation:

Total surface area for heat transmission losses	167·5 m²
Window area per side	11·4 m²
Area for transmission of solar radiation	72·3 m²
Average train speed, including stops	20 km/h
Heat transmission coefficient	1·8 kcal/h m² deg. C
Heat and moisture emission per person	as per Fig. 1
Solar radiation through windows	400 kcal/h m²
Temperature rise of external surfaces due to solar radiation	as Table II
Barometric pressure	730 mm Hg
Outside air conditions	as Table III

For example, for an inside temperature of 20 °C, the calculated heat input to the passenger space is:

Heat from occupants with 110 passengers	8690 kcal/h
Solar radiation through windows	4560 kcal/h
Influence of solar heat on transmission	3450 kcal/h
Total	16700 kcal/h

With higher inside temperatures the heat from occupants falls to 1210 kcal/h at an inside temperature of 35 °C, while the total influence of the sun remains unchanged.

The transmission heat loss from the passenger space is:

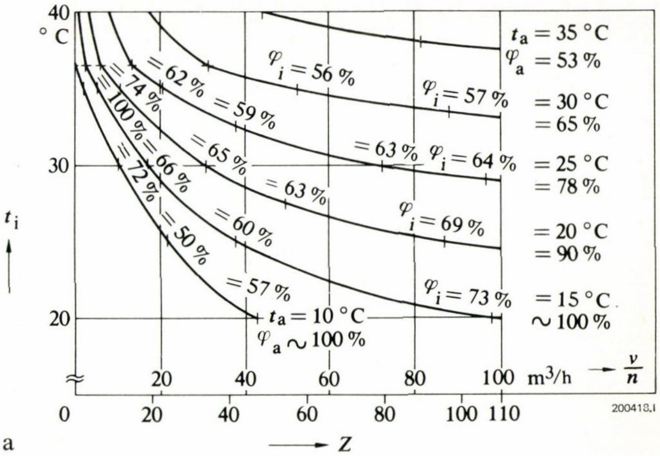
for an inside/outside temperature difference of 5 deg. C	1507 kcal/h
for an inside/outside temperature difference of 15 deg. C	4521 kcal/h

The heat remaining in excess of the heat input must be removed by air change or refrigerating plant. The moisture emission of the passengers, which is 16940 g/h at an inside temperature of 35 °C, must be withdrawn by the same means.

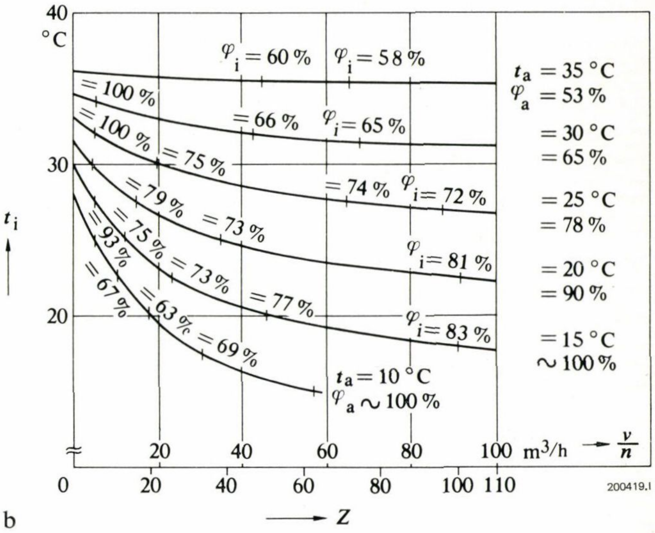
The resulting inside temperatures and some corresponding relative humidities are shown in Fig. 2a (with solar radiation) and Fig. 2b (without solar radiation) in relation to hourly air change rate and air flow rate per hour and passenger. The curves show clearly that without air renewal, or with the air flow rates of 20 to 30 m³ per hour and person customary in the past, the resulting conditions would not be acceptable today.

Our aim has been, by adopting suitable measures, both to cut down the supply of heat to the passenger space and to increase the heat removal.

Possible ways of reducing solar radiation through the windows include grey or green-tinted heat-absorbing glass or gold-coated reflecting glass. But grey, blue or green glass affect colour perception, while gold-coated glass, though the most effective, is very expensive [7]. Sunblinds inside the coach certainly protect the passenger against direct sunshine, and they can act as good reflectors, but a large part of the heat is transferred to the inside air by convection.



a



b

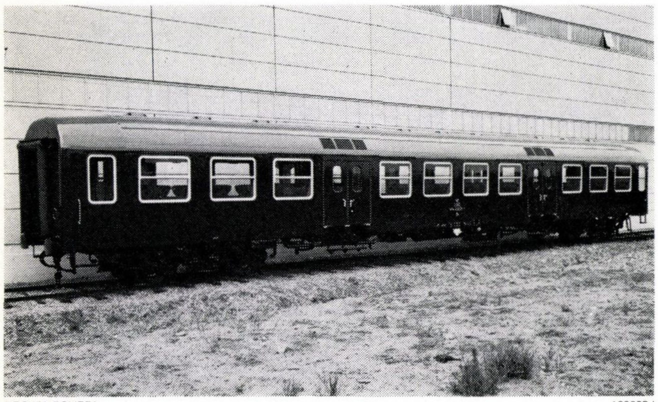
Fig. 2 – Inside air conditions at different outside air conditions in relation to fresh air flow rate per hour and person and to air change rate, referred to t_a, barometric pressure = 730 mm Hg, fully laden with 110 passengers, average speed 20 km/h

a: With sunshine
b: Without sunshine

n = Number of passengers
V = Fresh air rate, m³/h
$\frac{V}{n}$ = Fresh air rate per person, m³/h
Z = Hourly air change rate
t_a = Outside temperature, °C
t_i = Inside temperature, °C
φ_a = Relative humidity of outside air, %
φ_i = Relative humidity of inside air, %

The input of heat through the roof and walls due to heating of the outside surfaces when the sun shines can be remedied by improved insulation.

For reasons of cost these features could not be incorporated in the compositions of the VBW and SZB. However, the exhaust air from the passenger space passes between the inner ceiling and the outer insulated roof so that it flows along under the roof. The heat coming through the roof is thus intercepted and removed by the exhaust air, without affecting the inner ceiling or the space beneath. This not only lowers the inside temperature, but also eliminates unpleasant radiation from the otherwise hot ceiling.



BROWN BOVERI 166063.I

Fig. 3 – Passenger coach for suburban traffic with warm air heating and supplementary ventilation, built by Scania-Randers A/S for Danish State Railways

BROWN BOVERI 166064.I

Fig. 4 – View of passenger compartment of vehicle in Fig. 3 showing perforated ceiling and fluorescent lighting

The total quantity of fresh air delivered by fans to the coach is 5200 m^3/h. This gives an air change rate of 52/h, or an air throughput of 47 m^3 per hour and person when the coach is full. Owing to the restricted space, introducing so much new air presents serious problems, since the fresh air must be well mixed with the inside air and draughts must be avoided. This is achieved through a specially designed air distribution system and perforated ceiling. In order to supply sufficient fresh air to the standing room by the doors, and at the same time greatly extend the area through which air can be fed, the perforated ceiling runs the whole length of the coach. The warm-air heating units and make-up ventilation equipment are located in the roof over the entrances, so they must be easily accessible through flaps in the ceiling. The whole space between ceiling and roof is thus used as a pressurized plenum chamber.

The narrow-gauge coaches for local service in the Bern area are a good illustration of the importance railway companies attach to providing pleasant conditions in their trains, even when the journeys are only short.

Table IV summarizes the data of a number of passenger coaches which have recently been equipped with warm-air heating and make-up ventilation.

Table III: Outside humidities at different outside temperatures and their average hours per year

Outside temperature t_a	[°C]	10[1]	15[1]	20[1]	25[1]	30[1]	35[1]
Outside r.h. φ_a	[%]	100[1]	100[1]	90[1]	78[1]	65[1]	53[1]
Mean duration per year	[h]	–[2]	–[2]	120	60	10	5

[1] according to ORE
[2] not available

Table IV: Data of some completed systems

	V m³/h	$\frac{V}{n}$ m³/h	Z
Suburban trains Be 4/8 of the Vereinigte Bern–Worb-Bahnen	5200	81[1]	52
and Solothurn–Zollikofen–Bern-Bahn		47[1]	
Suburban trains RABDe 8/16 of Swiss Federal Railways, built 1974			
– 1st class compartments	5005	83	52
– 2nd class compartments	6715	84	46
Passenger coaches Bn, An and BnS for surburban trains of Danish State Railways (Fig. 3 and 4)	6800	98	62
Passenger coaches A with corridor for long-distance service on Danish State Railways	5360	112	62

V = Max. fresh air rate per hour
$\frac{V}{n}$ = Fresh air rate per hour and person
Z = Hourly air change rate

[1] including standing room

When very high outside temperatures combine with high humidity, simple make-up ventilation is not sufficient to provide comfortable conditions inside the coach. The climate in passenger trains can be improved by cooling and dehumidifying the air. Today there is a well marked tendency towards using air-conditioned rolling stock for long-distance trains. The cost of providing such comfort is certainly high, but coaches equipped in this way are attractive for people who travel long distances. But the passenger who makes only short trips of 15 to 30 minutes also appreciates the pleasantness of additional ventilation. This is considerably less costly than air conditioning and serves as an economically acceptable step towards a full air conditioning system.

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Air Conditioning Systems for Passenger Rolling Stock

F. Thomann

Air conditioning systems in trains have to satisfy a great number of different requirements, determined on the one hand by the construction of the coach and the degree of comfort demanded and on the other by economic considerations. The basic technical ways of solving these problems are similarly varied. The article shows that the needs of the railways can each be met satisfactorily.

Introduction

Fitting air conditioning systems in passenger trains began much later in Europe than in countries with a tropical climate. At first, systems already well established were adopted for a few luxury coaches and for special vehicles, such as saloon coaches, dining cars and sleeping cars. Air conditioning was introduced on a broad scale, especially for medium-distance and long-haul traffic, once it was realized that an air conditioning system with a refrigerating section is not only necessary on the few very hot days, but also, by cooling and dehumidifying the air, makes travelling more pleasant on some two-thirds of the days in a year. Various systems differing by country, railway operator and available space have been used and refined in Europe over the years.

Principal Technical Features Required of an Air Conditioning System

– The system must maintain a pleasant indoor atmosphere in the coach throughout the year. Both temperature and humidity must be kept within acceptable limits.
– Fresh air must be introduced in sufficient quantities without noise and without creating draughts.
– Local temperature differences must be avoided.
– The inside temperature must be constant within defined limits. Small temperature fluctuations should also be eliminated as far as possible.

All these requirements must be met without unnecessarily high consumption of power.

The Basic Types of System

Air conditioning systems can be divided into two main groups. The fundamental difference between them is the way the air is introduced:

– the classical method of air supply,
– systems in which air is introduced on the induction principle.

Classical Method of Air Supply

The various system types in the first group are summarized in Fig. 1. The classical method of air supply has been widely used since the air conditioning of passenger coaches started, mainly in tropical regions. The air is blown downwards into the coach through a duct in the ceiling (Fig. 2a and 2b). It is cooled as required and at the same time dehumidified, or heated slightly in winter. A system of this kind is adequate for tropical countries, where the heat demand in winter is, at the most, very small (Fig. 1, A).
In cases where a substantial amount of heat is needed, this system is supplemented by background heating (B). The purpose of this is to supply heat near the floor, because it is not possible to feed in the necessary heat

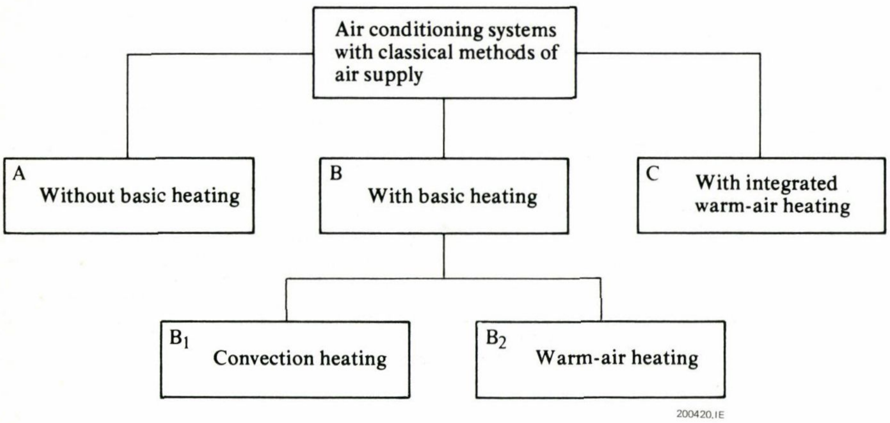

Fig. 1 – Air conditioning systems with classical methods of air supply
The different versions.

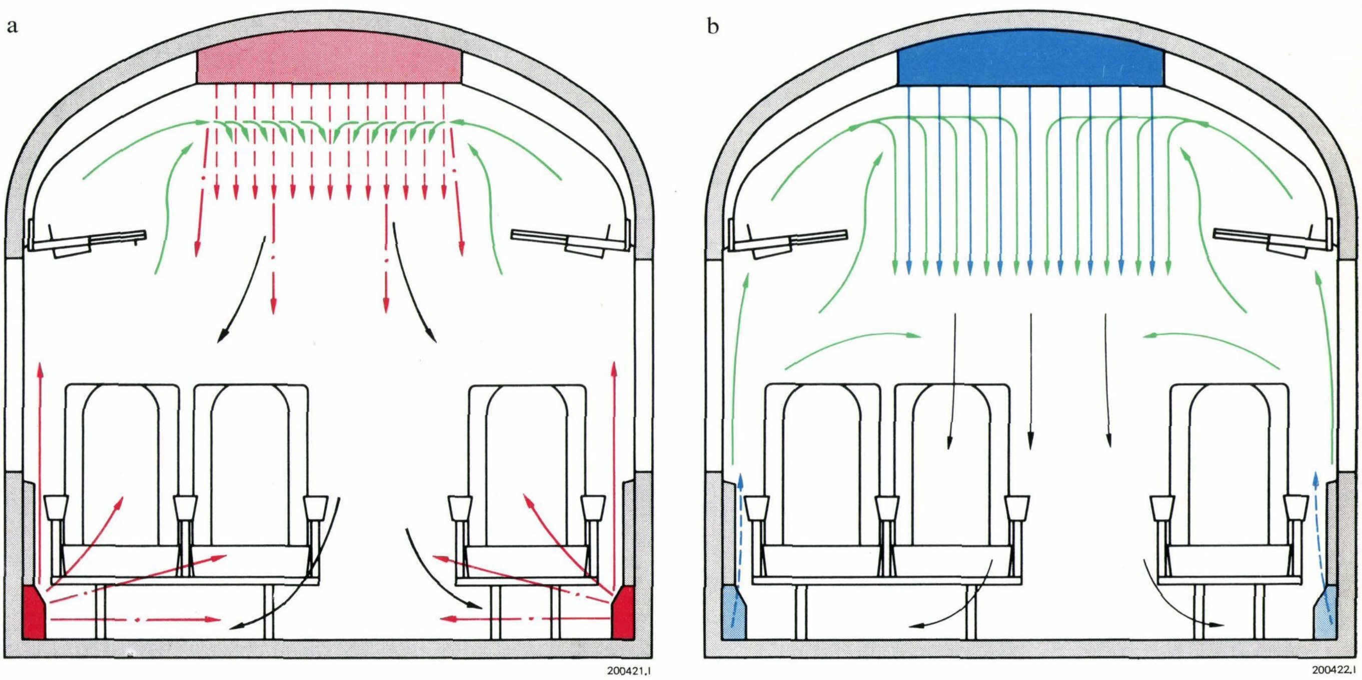

Fig. 2 – Air conditioning system for coaches with centre gangway

a: Heating
b: Cooling

Black: ——— Room air
Red: ——— Greatly heated air
—·—·— Thermal radiation
— — — Slightly heated air
Blue: ——— Cooled air
— — — Dehumidified air
Green: ——— Secondary air

from the ceiling. Warm air coming from this duct would stay in the upper part of the coach, while the temperature over the floor would remain low.

The background heating system has to be controlled separately from the supply air temperature. This presents serious control problems and requires correspondingly more equipment. The background heat can be provided by convection, as with an ordinary coach heating system, using steam or electricity (B_1).

In view of the good experience gained with our warm-air heating systems in some 2000 coaches of Swiss Federal Railways (SBB) and other railway operators, it was logical to use the warm-air system for background heating in air conditioned coaches (B_2).

Brown Boveri went a step further and integrated the warm-air system into the air conditioning plant (C).

This arrangement has other advantages:

– Only one air heater is needed. It heats the supply air in the ceiling duct to a little above room temperature, irrespective of outside temperature, and at the same time raises the warm air in the distribution ducts above the floor to temperatures which depend on the outside value.

The temperature of the warm air in the distribution ducts is raised if the outside temperature falls, this compensating the increasing heat losses from the coach.

– Temperature control is no longer separate but the same for the ceiling duct and the integrated background heating system. The heat output can be varied by:

- adjusting the resistance of the heating element in steps,
- switching the entire heat output on and off intermittently, and
- stepless current regulation, using thyristors.

– There are no control dampers to affect the air temperature in the ceiling duct or warm-air branch ducts. The air circuits remain unchanged throughout the year and in all modes of operation.

– The control system for the room air has a cascade action. The room temperature influences only the set point for regulating the duct temperatures. Depending on demand, a thermostat keeps the duct temperature at the desired value by altering the evaporation rate or the output of the air heater. In this way the output of both the evaporator and the air heater can be varied between 0 and 100% without being influenced directly by the room temperature thermostat.

– A cold coach can thus be preheated automatically at maximum heat output. There is no need to switch over, or provide a special operating mode, for preheating or precooling. Only the temperature of the floor duct is

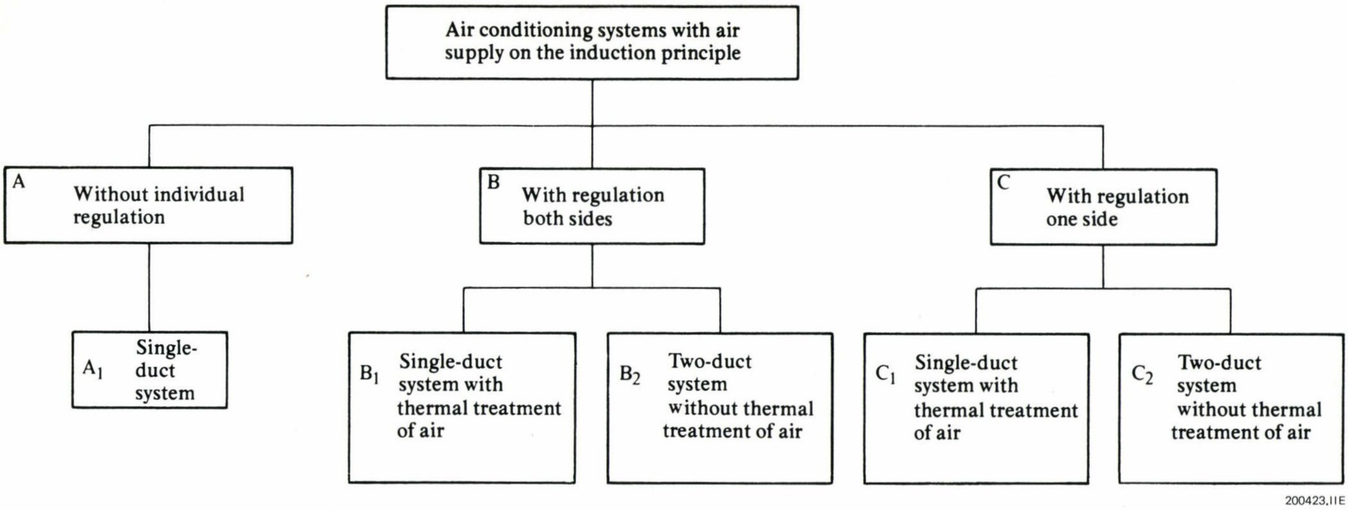

Fig. 3 – Air conditioning systems with air supply on the induction principle
The different versions.

greatly increased during preheating. Once the room temperature is within a few degrees C of its set point, the temperature in the floor duct begins to fall and approaches its continuous-duty value asymptotically, while the temperature in the ceiling duct remains constant. Only then does the room thermostat start to act by influencing the set point of the duct-temperature controller.

– To avoid any temperature shock on entering or leaving the train, the regulations state that with outside temperatures of over 20 °C the room temperature must be allowed to rise to the mean value between 20 °C and the outside temperature. If the outside temperature is 34 °C, for instance, the temperature in the air conditioned coach should be 27 °C. This rise in temperature must be achieved by means of a sliding control set point for the room temperature. If it were to occur simply because the refrigeration plant reaches its maximum output, the room temperature with a high outside temperature, high humidity, sunshine and a crowded coach would become much higher than with lower outside humidity, no sunshine and few passengers, but the same temperature outside.

– Air conditioning systems working on the classical air supply principle can handle large air flow rates. Consequently, the air rate in the evaporators can be so chosen that both dehumidification and the thermal effect on room temperature are matched as closely as possible to requirements under all operating conditions. If the air flow is too small, the necessary thermal effect on room temperature can be achieved only by cooling the supply air so much that an unnecessary amount of moisture is removed.

Compared with earlier systems employing the classical method of air supply, the space required and the quantity of materials needed for the ceiling duct and air supply system have been greatly reduced.

The design of the perforated ceiling ensures that the incoming air is evenly mixed with the room air. This allows both higher air flow rates and lower supply air temperatures than would otherwise be acceptable. Even with a room temperature of only 20 °C the passenger space can be sufficiently cooled in this way, without any danger of causing localized draughts due to falling masses of cold air.

Control systems, including those with a sliding set point for the room temperature, were at first equipped with perfectly normal electromechanical thermostats. All that is then needed for control itself is a four-step thermostat for the room temperature, a two-step thermostat for duct temperature and an outside thermostat. Other limiting and protection functions require a maximum thermostat for the air heater and a second contact on the outside thermostat to prevent the refrigerating compressor from starting up when the outside temperature is below a specified limit value.

A batch of 68 coaches now being delivered to the SBB, following satisfactory proving trials with a series of prototypes, includes five dining cars with the same system, but with electronic control.

Equipment Layout

The combined compressor/condenser unit is always placed under the coach floor. In this way, as with similar earlier installations, the air treatment unit (air heater, evaporator, filter and fan) can be arranged in various places, depending on the available space and the way the passenger space is divided up. In non-partitioned coaches, for example, with one single large space for passengers, the equipment is preferably combined in one unit in the roof of the vestibule and in coaches with one section for smokers and one for non-smokers, in two independent units above the doors. But layouts exist where all the equipment for the air conditioning system is centralized under the floor, with several ducts for fresh air, return air and supply air passing through the outside walls and the floor. The choice depends on the builder of the coach and its construction.

In operational terms, using the roof space has the advantage that inspection and minor maintenance are possible when the coach is standing outside, even in bad weather and in the winter. Swiss Federal Railways make use of this fact. When the plant is under the floor, such jobs can be carried out only from the pit, and not outdoors when the weather is bad.

Air Conditioning Systems Employing the Induction Principle

In installations of this kind the air is introduced exclusively through floor-level ducts running along the outer walls. The air emerges through nozzles into the space behind a panel extending to the bottom of the window frame (Fig. 4a, b). Owing to the high discharge velocity of the air from the nozzles, roughly the same amount of secondary air is entrained from near the floor and blown up through the gap together with the supply air. The air velocity at the top of the gap beneath the window is made high enough to carry the air up to the ceiling. Cooled air then descends from the ceiling by itself, owing to its higher specific weight, and flows through the compartment. It is either drawn in again as secondary air or leaves as exhaust air.

In coaches with corridors the cool air descends chiefly near the compartment doors; in open coaches, in which the air is fed in on both sides, it comes down mainly in the middle. In winter, when the temperature of the supply air is considerably higher than the room temperature, the warm air tends to stay in the upper part of the coach. Only as it becomes progressively cooler does it descend to replace the secondary and exhaust air extracted below. To avoid the risk of cold feet, therefore, the floor has to have very good thermal insulation. In corridor coaches, the temperatures in compartments with different numbers of passengers can be compensated only by the supply air flow rate, and not by the recirculated secondary air. This primary air flow is only 30 to 50% of the flow rates usual in systems using the classical form of air supply. The room temperature differences in compartments with different numbers of passengers would become excessive if nothing were done about them. Various methods of individual adjustment are therefore employed.

Systems supplying only one large open space need no provision for terminal adjustment because the supply air is already brought to the required temperature by the air-handling plant. Such systems can be termed single-duct systems without terminal adjustment (Fig. 3, A).

In the case of coaches divided into two large compartments the equipment can be in two independently controlled units with no subsequent adjustment, or in one central unit with terminal adjustment in the two compartments (Fig. 3, version B or C).

Methods of Terminal Adjustment

Terminal adjustment systems can be divided into two groups: those with two-variable regulation (Fig. 3, B) and those with single-variable regulation (Fig. 3, C).

In both these groups, a distinction is made between systems with subsequent thermal treatment of the supply air, termed single-duct systems (B_1 or C_1) and those without further treatment, known as double-duct systems (B_2 or C_2).

In a system with single-variable terminal adjustment the quantity of supply air for the whole coach is conditioned continuously in the central plant to a temperature corresponding to the minimum energy requirement of one compartment. This energy requirement occurs with a full complement of passengers and the minimum desired temperature. Extra heat has to be supplied to compartments with fewer passengers and to those in which a higher temperature is demanded. In heating operation such systems work very efficiently, as the required energy is supplied to each compartment only through heating. When cooling, however, the air treatment plant has to cool the supply air for the whole coach. Thus, on the one hand, a high refrigerating capacity is necessary, while on the other, heat is expended in those compartments with a higher energy demand.

In systems with two-variable adjustment the energy is transported by flow media (water or air) at different temperatures. To raise the temperature in a given compartment it is possible to increase the effect of the flow medium at the higher temperature level, and at the same time reduce that of the medium at the lower temperature. To lower the temperature in the compartment the effect of the higher-temperature medium is reduced and that of the cooler medium increased. In this way the required energy can be supplied direct to each compartment, without having to add heat to compensate excessive cooling. With systems of this kind, therefore, the energy consumption in cooling operation is less than with comparable systems having single-variable adjustment.

The manner in which the different terminal adjustment systems operate is described briefly below.

Single-Duct System with Two-Variable Adjustment (Fig. 3, B_1)

Secondary thermal treatment is usually by means of heat exchangers mounted behind the panel under the window. Water cooled or heated centrally flows through these, depending on demand in the respective compartment. They thus provide individual cooling or heating of the supply air. Systems of this kind require water circuits with flow and return piping for both hot and cold water. Such installations are relatively costly, and to find a way round, techniques have been used where direct-contact evaporators provide secondary cooling, and reheat is supplied by electric elements.

Single-Duct System with Single-Variable Adjustment (Fig. 3, C_1)

The central conditioning plant continuously brings the air for the whole coach to a temperature corresponding to the minimum energy requirement. In compartments with greater energy requirement the supply air is reheated by electric heaters with a capacity of about 1 kW per compartment of six seats. To save energy the terminal reheaters could be blocked during cooling operation. But unacceptably large temperature differences between compartments with different numbers of passengers would then have to be taken into account, and equally it would be impossible to select the individual compartment temperature.

Single-duct systems with single-variable adjustment are

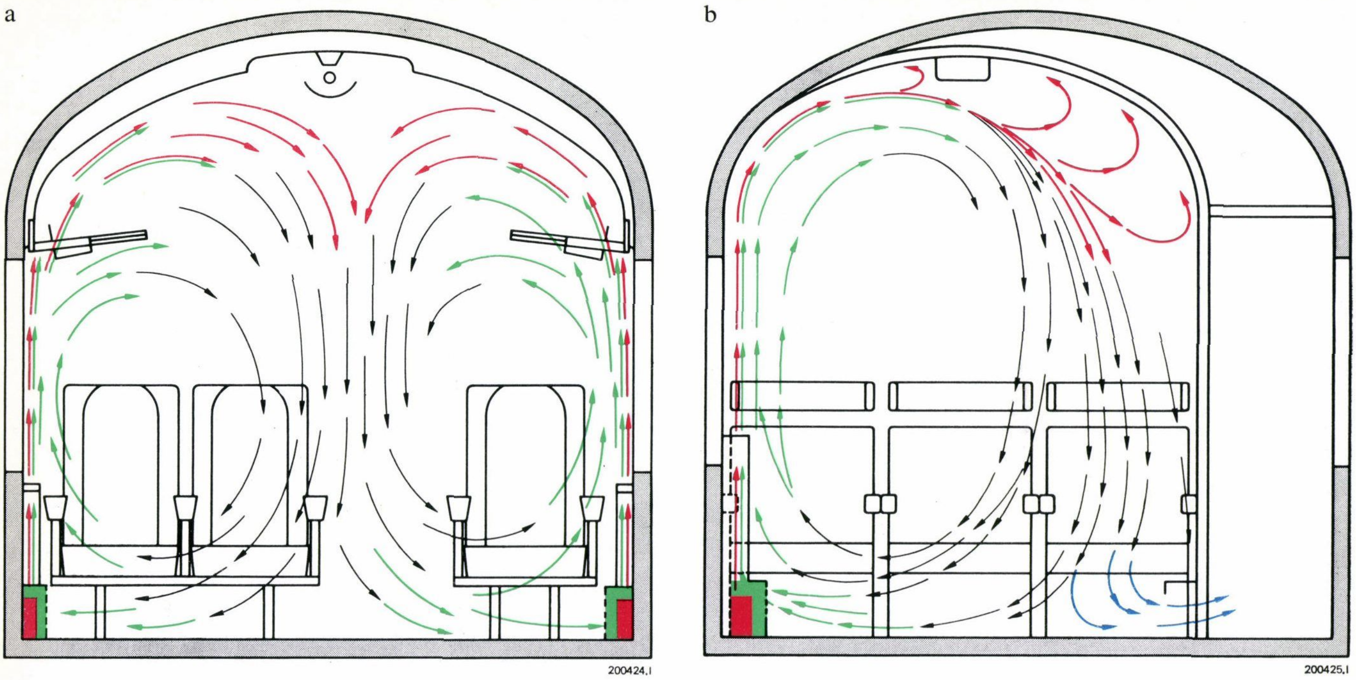

Fig. 4 – Air conditioning systems employing the induction principle
Air flow patterns when heating.
a: Coach with centre gangway
b: Coach with corridor

Red: Heated air
Green: Secondary air
Black: Room air

being installed by Brown Boveri in six AD type corridor coaches for the SBB. These coaches, with a corridor, five passenger compartments and a large luggage compartment, are part of the SBB order mentioned above for 68 coaches of standard type III. It is likely that this type of coach will remain the exception as far as the SBB is concerned, and so the actual plant of the air conditioning plant has been made the same as for coaches fitted with the classical air supply system. The location of the air-handling equipment above the vestibule has also been retained without modification. Only the ducting has been altered slightly to suit the single-duct system. This greatly simplifies maintenance and the stocking of spares.
Control is entirely electronic. The output of the terminal reheaters is continuously regulated by means of thyristor control elements. The supply air temperature in the duct is constantly adapted to the demand in the compartment with the lowest energy requirement, so that the air is not cooled unnecessarily and then has to be heated again in all the compartments.

Double-Duct System with Two-Variable Adjustment (Fig. 3, B_2)

Air from the central plant is fed along a double duct to the individual compartments. The air in the cold duct is continually brought to a temperature corresponding to the minimum energy requirement of a compartment. In the hot duct, on the other hand, the temperature is high enough for a compartment with the maximum energy requirement. The induction nozzles are designed so that they mix supply air from both ducts to meet the demand in each respective compartment, the total air flow remaining roughly constant. An advantage of this system is that when the energy requirement of one compartment rises, not only is the air supply from the hot duct increased, but at the same time the flow from the cold duct is reduced. System efficiency is thus improved. If desired, a further saving of energy is possible by automatically matching the temperatures in the two ducts continuously to the minimum or maximum demand at any moment.

Double-Duct System with Single-Variable Adjustment (Fig. 3, C_2)

Supply air flows through a double duct from the central plant to the compartments. The air flow into each compartment from the primary duct is constant. The primary air temperature always corresponds to the minimum energy requirement of a compartment. The auxiliary duct carries hot air at the maximum permissible temperature. The amount of hot auxiliary air fed to each compartment is variable according to the compartment energy requirement. The total quantity of air delivered to each compartment is therefore not constant. It must be increased for compartments with few occupants and a high energy demand. As in the case of the single-duct system with single-variable adjustment of the air by means of terminal reheat, energy consumption is higher when cooling is employed.
If the temperature of the primary air is not continually matched automatically to the actual requirement at any time, but kept at preset values in relation to outside temperature, not only will energy consumption be higher owing to single-variable adjustment, but also sunshine has to be compensated by progressively lower temperatures in the primary duct. When the sun is not shining,

even more energy is then needed to heat the hot auxiliary air.
To help prevent cold feet in winter, some of the air can be introduced under the seats instead of towards the ceiling through the injection nozzles, in the same way as the warm-air heating systems.
Each of the systems described has its particular merits, but also its drawbacks. Which is the most suitable depends not only on the operating conditions of the coach and the atmosphere required inside it; the construction of the coach and the space available also play an important part.

Conclusion

Brown Boveri are not tied to one particular system, and are therefore able to offer a widely varied range. The systems available at the moment comprise:

1. Air conditioning systems employing the classical method of air supply
   - without background heating
   - with convective background heating
   - with integrated warm-air heating
2. Double-duct systems with two-variable adjustment
3. Single-duct systems with terminal reheat
4. Single-duct systems without terminal reheat

Fluorescent Lighting for Passenger Coaches

K. Tapavica

The demands to be met in respect of good train lighting in passenger coaches are discussed and the advantages to be gained by using Brown Boveri transistor inverter ballast units with fluorescent lighting are reviewed.

Introduction

At the beginning of the '60s Swiss Federal Railways (SBB) carried out their first investigations with a view to changing over from their hitherto exclusively bulb-type lighting to fluorescent tubes with Brown Boveri transistor inverter ballasts. Today over a thousand passenger coaches, belonging to Swiss Federal Railways and a number of privately-owned railway systems in Switzerland, are equipped with this form of lighting. Experience gained in practice has enabled the technical data of the transistorized unit to be considerably improved. From the outset, Brown Boveri have always supported the system with individual inverters; the features are discussed in the following. The European Company for the Financing of Railway Rolling Stock (EUROFIMA) has recently stipulated this system for the standard European passenger coach.

General

In order to more clearly understand the specific problems involved in providing electric lighting in railway carriages attention is drawn to certain basic principles [1, 2, 3]:

- The human eye is more adaptable to its surroundings than any other sensory organ. It is capable of detecting even a slight difference between two degrees of illumination, but cannot judge their absolute values.
- In spite of its enormous flexibility the human eye has certain limits. Inadequate lighting not only restricts vision but easily leads to mental and physical tiredness. On the other hand, big differences in the intensity of illumination within the field of vision have a dazzling effect on the passenger.
- The response of the eye to 'bright' and 'less bright' is affected not only by the light intensity but also by its spectral composition.
- The best artificial lighting is similar to daylight (colour, shade) which is a combination of indirect or diffused light (sky) and direct light (sun).
- The main objective is to ensure that the source of light is not in the direct field of vision so that only light reflected by the interior components of the coach reaches the eye. The interior decoration of the coach (colour scheme, materials) has a considerable influence on the quality of the lighting.
- Not all passengers read during the journey. The lighting must be adequate for those who do wish to read but it must not disturb those who do not.

The introduction of the electric light bulb brought with it many advantages over gas lighting, the major being more agreeable light, instant readiness and greatly reduced maintenance. However, the efficiency of even the most up-to-date bulb is relatively modest. In the case of those types used for passenger vehicle lighting it is only about 12 to 14 lm/W. In view of the increase in power consumption for heating and air conditioning [4, 5] and the restricted power available per vehicle [6] means had to be found of improving the lighting comfort without increasing power consumption. This has been achieved by introducing fluorescent tubes whose light output varies between 36 and 60 lm/W depending on hue (these values apply for a 40 W/1200 mm tube including the transistor inverter ballast).

Lighting in the Type I, II and RIC[1] Standard Coaches of Swiss Federal Railways

The vast difference between bulb-type lighting and fluorescent lighting is best demonstrated by the results of measurements made in standard and RIC coaches of Swiss Federal Railways. The original bulb lighting was removed from several coaches of these types and replaced by the same number of fluorescent tubes with Brown Boveri ballasts without altering the interior of the vehicles. The results are given in Table I. The end effect was double the light emission with a reduced power consumption, and this was achieved with fluorescent tubes of 'warm deluxe' hue. Although this type offers excellent colour reproduction it has lower light emission than the 'warm' type tubes (1900 lm as against 3000 lm). Whereas the bulbs are installed naked the fluorescent tubes have plastic diffuser covers with an absorption of 15 to 20%.

If one also takes the losses due to bulb voltage control into account, in this particular case about 6 W per bulb, and which is completely eliminated by the ballast for the fluorescent tubes, the light emission per unit power consumption is even better in the case of fluorescent tubes.

In addition to this, further advantages were found after these two types of coaches had been converted to fluorescent lighting. Because of the considerably larger light emitting surface of each fitting (approx. 3000 cm² in the standard vehicles and about 2350 cm² in the RIC coaches) it was possible to reduce the light density to a much lower

[1] Regolamento Internazionale Carrozze

Table I: Comparative values for standard and RIC coaches of Swiss Federal Railways equipped with bulb-type and fluorescent lighting with Brown Boveri transistor inverter ballast units
Light intensity measured in each case in a horizontal plane 0·8 m above the floor and 0·6 m from seat backrest (data supplied by Mechanical and Electrical Engineers Dept., Swiss Federal Railways)

Type of vehicle	Type of lighting	Values apply to: – one section of standard coach – one compartment of RIC coach } blinds not drawn						
		No. of lamps	Type of lamp	Rating per lamp[1] (at 36 V)	Measured values			
					Supply voltage	Power consumption	Output	Average illumination intensity at reading level
				W	V	A	W	lx
Standard coach type II (A)	Bulbs	8	Opalized bulb naked	50	38	12	456	70 to 80
	Fluorescent lights	8	1×40 W/ 1200 mm tube with opalized plastic cover	47	38	9·7	368	160 to 180
RIC coach (A)	Bulbs	2	Opalized bulb naked	50	38	3	114	100 to 110
	Fluorescent lights	2	1×40 W U-shaped tube with opalized plastic cover	47	38	2·42	92	230 to 240
Standard coach type III (A)	Fluorescent lights semi-indirect	14	1×40 W/ 1200 mm tube with opalized plastic cover	47	38	18·1	688	320
		2	1×20 W/ 590 mm tube with opalized plastic cover	24				

[1] For fluorescent lamps incl. transistor inverter ballast unit

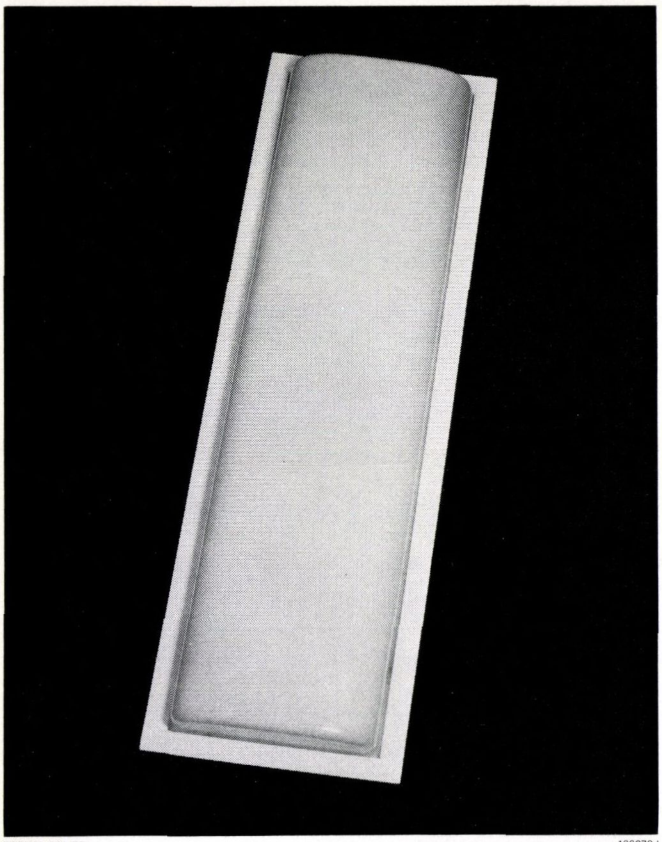

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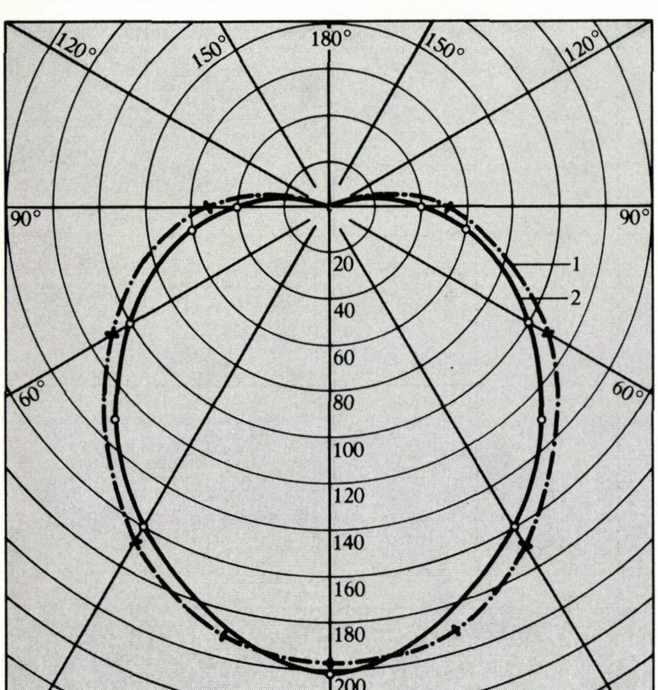
Fig. 1 – Fluorescent light fitting supplied by Fluora GmbH, Herisau, Switzerland, for a U-shaped 40 W tube as installed in the RIC coaches of Swiss Federal Railways

The light fitting for a 40 W, 1200 mm tube is of similar shape but has different overall dimensions.

Fig. 2 – Light distribution curves for a fitting with a U-shaped, 40 W fluorescent tube (1) and a 40 W, 1200 mm (2) both related to 1000 lm, measured centrally, perpendicular to the longitudinal axis of the light fitting (data supplied by Fluora GmbH, Herisau, Switzerland)



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level in spite of the much higher luminous flux of the lamps. This avoids dazzling the passengers. The light diffuser covers are about 50 mm from the vehicle roof and this provides a certain amount of indirect lighting as the light is reflected from the light-coloured roof surface. Finally, the simple but functional shape of the lights (Fig. 1) add to the general aesthetic appearance of the coach interior. The light distribution curves of these lamps are shown in Fig. 2.

Type III Standard Coaches of Swiss Federal Railways

The excellent properties of the Brown Boveri fluorescent lighting system with transistorized inverter ballast units have been put to even better use in the type III standard coaches of Swiss Federal Railways. In the type I and II standard coaches the fluorescent lights form discrete units placed between the bench seats (Fig. 3). In the case of type III standard coaches they form two continuous rows parallel to the longitudinal axis of the coach. The main data for the lighting in this type of coach is also listed in Table I to provide a direct comparison. Although the power consumption in Type III coaches is only about 50% greater than in type II coaches with bulb lighting, and a large portion of light is emitted by indirect means, and consequently partially absorbed, the illumination is quadrupled at reading level.

Intensity of Illumination

The spectral characteristic of a fluorescent tube of 'warm deluxe' hue corresponds approximately to that of a black body at about 3000 °K. According to Kruithof a

Fig. 3 – Arrangement of fluorescent lights in the passenger area of a Type II (A) standard coach of Swiss Federal Railways

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Table II: Main technical data of Brown Boveri transistor inverter ballast unit for individual supply for fluorescent lamps

Type	TWV 42/...				
Rated supply voltage	24 V	36 V	72 V	110 V	220 V
Range of operating voltage for guaranteed light current	20 to 30 V	30 to 45 V	60 to 90 V	90 to 150 V	180 to 300 V
Current consumption at U_n	2 A	1·3 A	0·7 A	0·4 A	0·2 A
Lamp current	0·35 A	0·35 A	0·35 A	0·35 A	0·35 A
Light current	Φ rel = 1·0 $\pm$ 0·1 (all types)				
Preheat time	approx. 1 s (all types)				
Operating frequency	> 16 kHz (all types)				
Permissible operating temperature:					
– Maximum	+ 60 °C (all types)				
– Minimum	— 20 °C (all types)				
Fuse	4 A	2 A	2 A	2 A	2 A
Dimensions	300 × 65 × 27 mm (all types)				
Weight	approx. 0·8 kg (all types)				

light intensity of between 120 and 500 lx is recommended for light of this nature and is designated 'comfortable sensation'. Accordingly, reference sheet No. 550 of UIC (Union Internationale des Chemins de fer) recommends 150 lx as the minimum light intensity at reading level for passenger coaches in international operation equipped with fluorescent lighting, and 0·77 as the minimum value for the equality factor. The equality factor is the quotient of the minimum and mean light intensity.

The fluorescent lighting equipment supplied by Brown Boveri complies with these requirements in all three types of coach.

Transistor Inverter Ballast Unit

The necessity of increasing the voltage from the train lighting battery and converting the d.c. into a.c. results on the one hand from the fact that the battery voltages (generally 24 V but in Switzerland 36 V) are too low and, on the other, from the advantages in respect of operation and maintenance offered by a.c. supply. The $16^2/_3$ and 50 Hz frequencies encountered in a.c. traction are not suitable for connection through an appropriate transformer because the stroboscopic effect at less than 80 Hz is disturbing [7].

From the outset Brown Boveri have always supported the single inverter system where each 40W fluorescent tube or pair of 20 W tubes gains its supply from an electronic unit. This concept has the following advantages over the arrangement with a central inverter:

- Each unit functions regardless of the number of lamps switched on. The lamps are ignited individually.
- The power consumption of the complete installation is proportional to the number of lamps switched on. This results in higher efficiency.
- The system remains functional even if one unit develops a fault.
- Older rolling stock with bulb-type illumination can be easily converted.

The transistor inverter ballast unit is shown in Fig. 4. Its small dimensions permit it to be mounted on the back panel of the fitting or possibly inside it. The unit operates on the principle of a square-wave generator with two transistors and simultaneously ignites the lamp and stabilizes its current. Three particularly important features of the transistor inverter ballast unit are demonstrated by Table II and Fig. 5, i.e.:

1. High Operating Frequency

Consequently it is silent in operation and the light efficiency of the fluorescent tube is improved by about 12% as opposed to 50 Hz operation. Also, the power consumption of the installation is reduced for the same illumination intensity.

2. Safe and Sure Ignition of the Tube even at —20 °C

Each time the tube is ignited the electrodes are preheated with a cold-start protection system which prevents excessive wear. This increases the life of the tubes, considerably reducing operating costs. No wear has been detected in the tubes after 100000 ignition cycles.

3. Virtually Constant Light Emission (Light Current)

even if the supply voltage fluctuates by $\pm$ 25% from the rated value. Additional voltage control, such as is required for bulb-type lighting, is eliminated. While the battery is being charged the d.c. consumption of the transistor in-

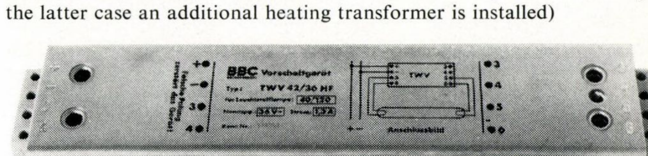

Fig. 4 – Transistorized inverter ballast unit type TWV 42/36 for service with a 40 W, 1200 mm fluorescent tube or two 20 W, 590 mm tubes (in the latter case an additional heating transformer is installed)

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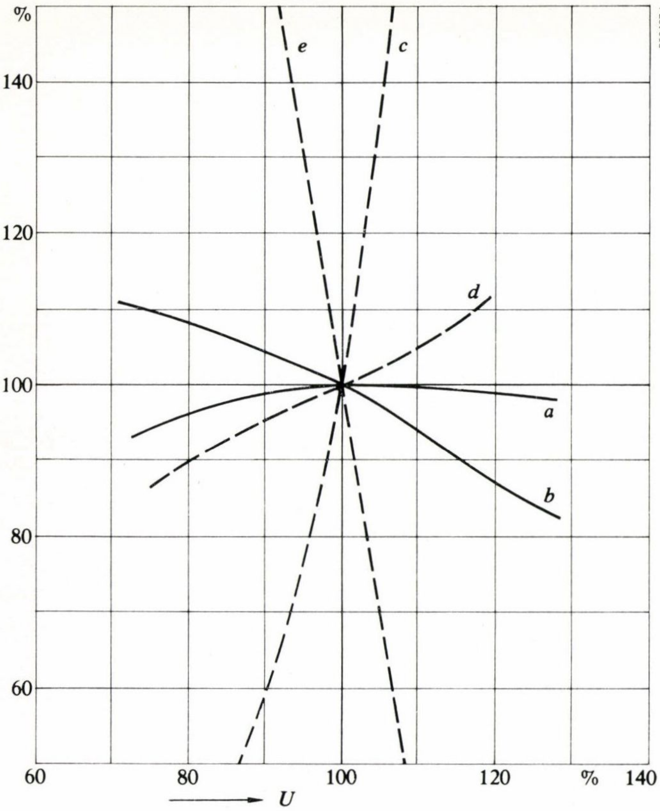


Fig. 5 – Effect of fluctuations in supply voltage on:

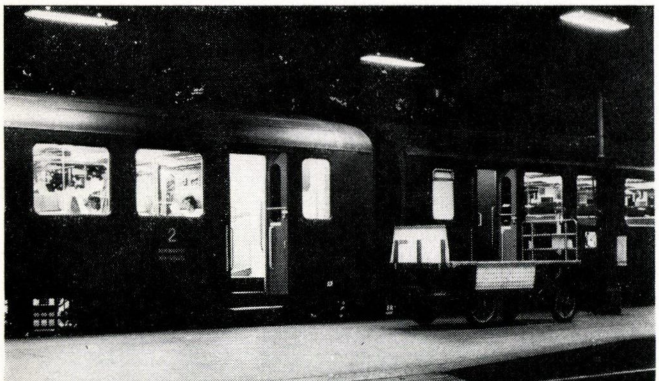
a = Light current, b = Current consumption: Brown Boveri transistorized inverter ballast unit type TWV 42/36

c = Light current, d = Current consumption, e = Life: 36 V, 50 W bulb

verter ballast unit reduces with rising voltage. This favours the battery charging process without the charger being designed for higher rating.

The feature of the ballast unit mentioned under 3 above results in a slightly higher power consumption when the lighting is being supplied from the battery. This is of no significance for carriages fitted with a charger. In this case the battery is being charged for the majority of the time it is in service [9]. It has been shown that even in the case of power supply from axle-driven generators, the battery is not overstressed. Swiss Federal Railways statistics show that the batteries of carriages fitted with transistor inverter ballast units do not have to be exchanged more frequently than those in carriages with bulb lighting. The effect of constant illumination becomes particularly obvious at night on secondary-line passenger trains if they have to stand in the station for any considerable time; passengers in the rolling stock fitted with Brown Boveri fluorescent lighting can still read, which is often not the case with bulb-type lighting, particularly immediately before the journey is resumed (Fig. 6).

Fig. 6 – Train on secondary line with coaches fitted with bulb and fluorescent lighting



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Solid-State Battery Charger for Passenger Rolling Stock

K. Tapavica

A charger for supplying the low-voltage system in passenger rolling stock is described.

Electric traction enables the electrical systems installed in passenger vehicles for lighting, heating, ventilation, etc., [1, 2, 3] to be supplied from the train bus, regardless of the train speed. A. C. traction provides particularly advantageous conditions for charging the train lighting battery. The relatively low d.c. voltage level required can be attained by means of a transformer with a controlled rectifier connected in series. Favourable electrical properties and virtually no maintenance in service are features of such a system. The Brown Boveri solid-state charging unit type SLG 36.060.01.02 is fitted to the series III standard coaches of Swiss Federal Railways.

The task of this unit is to maintain the charge of the 36 V vehicle battery from the low-voltage network to enable it to supply the lighting and, where applicable, the ventilation plant, for a period determined by the battery capacity, should the train bus supply fail. As the railway operator requires maximum battery life and minimum maintenance, the criterion is optimum charging. Here, the following must be considered:

- type of battery
- installed capacity of consumers
- temperature conditions
- available charging time

In addition to the battery charging current, the unit also supplies the full 36 V d. c. requirement for the l. v. consumer network. Consequently the battery is discharging by the consumers only if the train bus supply fails. The permissible voltage limits of the consumers must be taken into account when determining the charge voltage.

The principle of the charging unit is illustrated in the basic circuit diagram (Fig. 1). Fundamentally the unit comprises a semi-controlled rectifier bridge, an electronic grid control set (as the regulator) and a smoothing reactor. It is connected to the 1000 V, $16^2/_3$ Hz train bus through a separate matching transformer. The voltage at the output terminals is regulated by means of phase-angle control. The current is limited in similar fashion. The units operate according to a modified voltage/current characteristic with slight positive-sequence compounding in the voltage regulating range; this is a characteristic which has returned excellent results with power supply systems using axle-driven generators (Fig. 2). However, because of the considerably longer charging times involved, the maximum charge voltage was lowered accordingly [4]. The unit automatically adjusts the charging voltage relative to the temperature so that the battery remains in a well-charged condition, even in the winter.

The charging unit is designed for traction applications and operates in the broad range of 80 to 130% of rated voltage. Collector jumps or sudden fluctuations in contact wire voltage have no detrimental effect on the unit. Large voltage fluctuations due to changes in load are rapidly

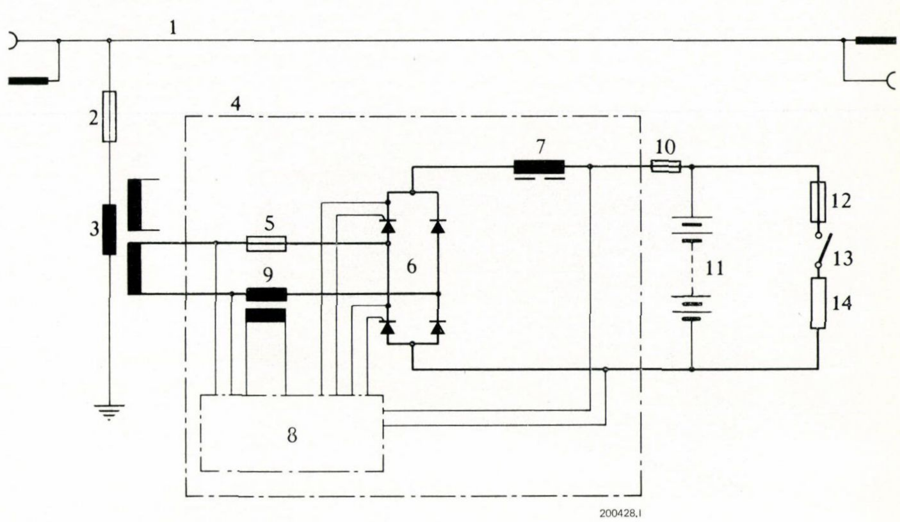


Fig. 1 - Basic circuit diagram

1 = Train bus
2 = High-voltage fuse
3 = Matching transformer
4 = Solid-state charger
5 = Charger fuse
6 = Semi-controlled rectifier bridge
7 = Smoothing reactor
8 = Electronic grid control set (regulator)
9 = Current transformer
10 = Battery fuse
11 = Battery
12 = Consumer fuse
13 = Consumer switch
14 = Consumers (36 V)

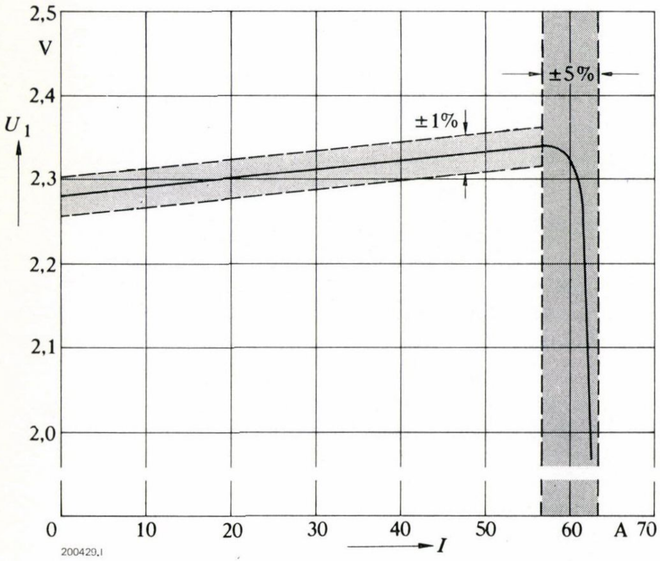
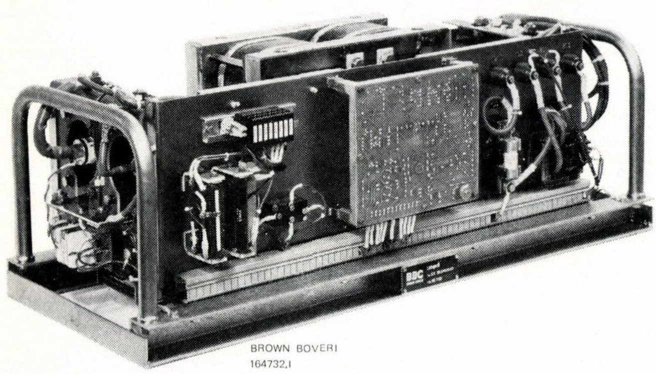


Fig. 2 – Typical charging characteristic for a solid-state charging unit
Voltage per cell (U_1) in relation to charger output current (I)

compensated. The smoothing reactor is designed such that there is no temperature rise at the battery due to charging current ripple. Voltage ripple is additionally reduced by a separate filter for the fluorescent lighting in the type III standard coaches of Swiss Federal Railways [5].

The unit (Fig. 3) is suitable for mounting in a cubicle under the vehicle floor.

Fig. 3 – Solid-state battery charger unit



Main Technical Data

Type	SLG 36.060.01.02
Rated supply voltage (separate transformer)	1000 V
Operating voltage range for maximum d.c. (60 A)	800 to 1300 V
Frequency	$16^2/_3$ Hz
Rated battery voltage	36 V
Type of battery	Lead/acid
Max. charge voltage	41 to 43 V (with fine adjustment)
Max. continuous d.c.	60 A
Control accuracy	
voltage	± 1%
current	± 5%
Dimensions (approx.)	950 × 390 × 330 mm
Weight (approx.)	140 kg

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