Special Electric and Thermo-electric Traction Number

THE BROWN BOVERI REVIEW

The Swiss Federal Railways gas turbine locomotive Ae 4/6 1101 arouses great interest at the Gare de l'Est at Paris.

THE BROWN BOVERI REVIEW

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CONTENTS:

INTRODUCTION.

Some years ago it was decided to issue from time to time special numbers of this journal with a view to giving readers as complete an idea as possible of the state of development of the Company's special lines.

The present special electric traction number was suggested by the very intensive development work undertaken in the electric traction field in the course of the last few years, partly due to conditions imposed by the war.

Together with two articles on industrial locomotives and electric trucks, which will appear later, the contributions presented give an extremely complete survey of the state of development of the traction equipment built by the Company so that further comment would be redundant.

A point of fundamental importance, however, is worthy of special mention.

From the infancy of electric traction it was considered a matter of course that the electrical industry should only design and manufacture the electrical equipment, the design of the mechanical part being left to steam locomotive and coach builders.

From a development point of view this was necessary at the outset and the wide experience of the steam locomotive and coach building firms the played a big part in the development of electric locomotives.

However, this arrangement had certain drawbacks. For instance, the designers were so captivated by the steam locomotive form of driving mechanism with reciprocating motion that they failed to take advantage of the natural rotary motion of the electric motor, which has definitely proved to be a big mistake.

Finally, electric traction engineers were obliged to reach out beyond their normal sphere of activity to tackle the problem of the electric locomotive drive. Their efforts culminated in the modern individual axle drive.

The big part played by the Company in this development with the individual axle drive due to J. Buchli († 1945), introduced towards the end of the first world war, is common knowledge and a number of the following articles corroborate this fact anew.

After the solution of the driving problem, however, the electrical engineer was allowed no time to rest upon his laurels. Due to the demand for lightweight constructions — chiefly for motor-coaches—motor casing shad to be embodied in the vehicle frame design, which in turn affected bogie construction. The problems set here could only be tackled and solved by the traction motor designers, i. e. again the electrical industry. As a result the design of electrical locomotives now lies essentially in the hands of the electric traction engineer, a tendency which is bound to become more accentuated as time goes on. —

It has been asserted that technically electric traction is the most difficult and interesting, but on the score of national economy and ethics, the most noble form of electric motor drive.

Opinions may differ on this point, but one thing is certain: designers and operators of public transport vehicles are more exposed to public critism than any others. If they do not provide absolutely reliable and punctual services and cater for the ever-increasing requirements of comfort and speed with vehicles designed on the most modern lines they will reap anything but praise.

It is this very responsibility to the public at large which gives electric traction its peculiar charm. The extent to which this is realized by the Company is left to traction circles to judge.

K. S. (E. G. W.)

THE Bo Bo LOCOMOTIVES, SERIES 251, OF THE BERNER ALPENBAHN-GESELLSCHAFT BERNE-LÖTSCHBERG-SIMPLON (BLS).

Decimal Index 621.335.2 (494)

Two to four pony axles have hitherto generally been necessary for high-power, standard-gauge, electric express locomotives with an adhesive weight of approximately 80 t. The weight of the locomotive thus varied between 105 and 128 t. In the case of the new series 251 locomotives of the Berner Alpenbahn-Gesellschaft Berne-Lötschberg-Simplon (Lötschberg Railway) progress made in the course of the last few years enabled a power of 4000 H. P. to be lodged in a locomotive with an aggregate weight of only 80 t, a result achieved for the first time in the history of electric locomotive construction. With a load of 20 t admitted on the driving axles it was thus possible entirely to dispense with pony axles and to utilise the whole weight of the locomotive — distributed over four driving axles in two two-axle bogies (wheel arrangement Bo Bo) — for the production of the tractive effort. Notwithstanding the absence of pony axles the locomotive has excellent running properties up to the maximum running speed of 125 km/h. The present article describes in detail how this amazing reduction in weight was achieved.

HISTORICAL.

BROWN Boveri supplied their first 1 B B 1 locomotive to the Swiss Federal Railways twenty-five years ago. One of four trial locomotives, it alone was destined to form the prototype of a whole series finally attaining a total of 41 (series 12,302). The locomotive in question was of the single-phase, bogie type with a total weight of approximately 110 t and an adhesive weight of 80 t. It was intended in particular for hauling express and stopping trains on the Gotthard route. Later on the Swiss Federal Railways acquired a large number of 2 Do1 and 1 Do1 express locomotives (series 10,901 and 10,801). Like the 1 B B 1 locomotives these also had four driving axles and an adhesive weight of 80 t, but were designed for higher running speeds and correspondingly greater powers. The aggregate weights of these more recent locomotives vary between 106 and 123 t, the same as similar single-phase locomotives abroad.

In view of the great progress made in electric machine design in the course of the last few years, especially on the score of material utilization, Brown Boveri have made repeated efforts to force down the weight, and in particular the dead weight, of such single-phase locomotives. Notwithstanding the big weight reductions achieved in the design of traction motors and drives this aim could at first not be attained, since they were insignificant compared to

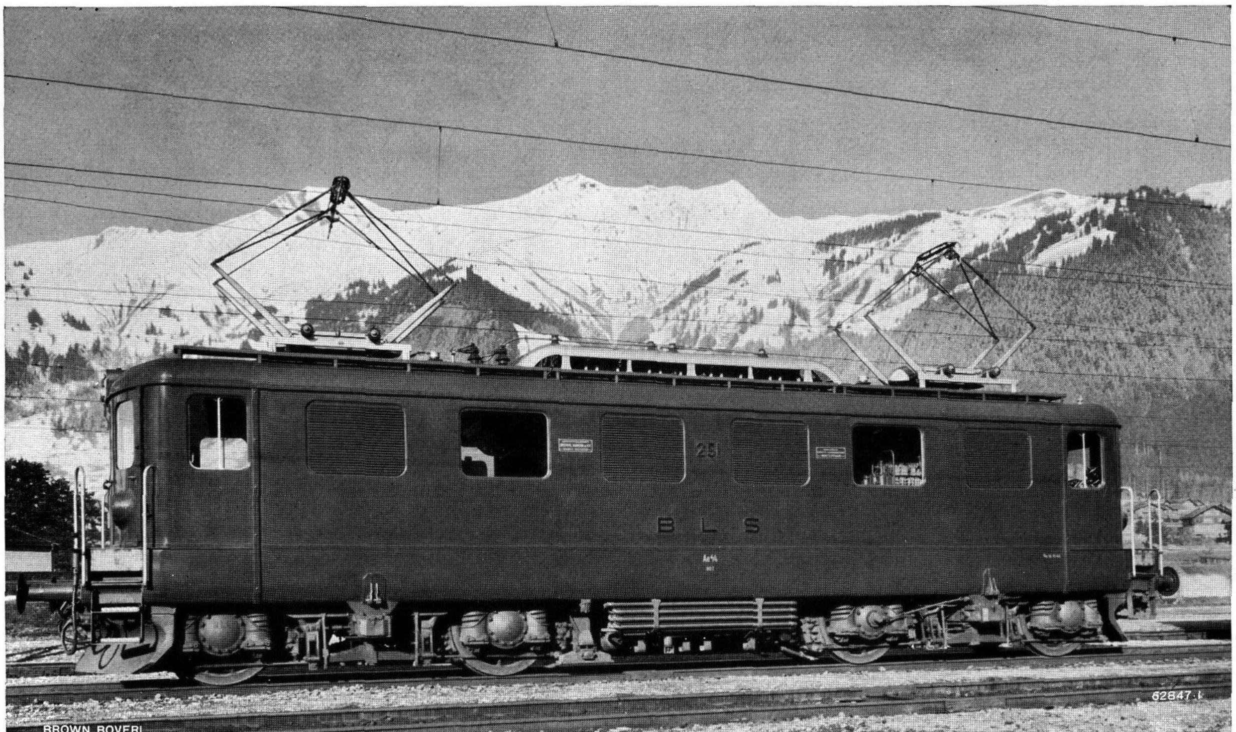


Fig. 1. — Bo Bo locomotive, series 251, of the Berner Alpenbahn-Gesellschaft Bern-Lötschberg-Simplon, designed for an hourly rating of 4000 H.P. at the motor-shaft. Weight in running order 80 t, maximum running speed 125 km/h.

For the first time in the history of electric locomotive construction a power of 4000 H.P. has been lodged in a locomotive weighing only 80 t.

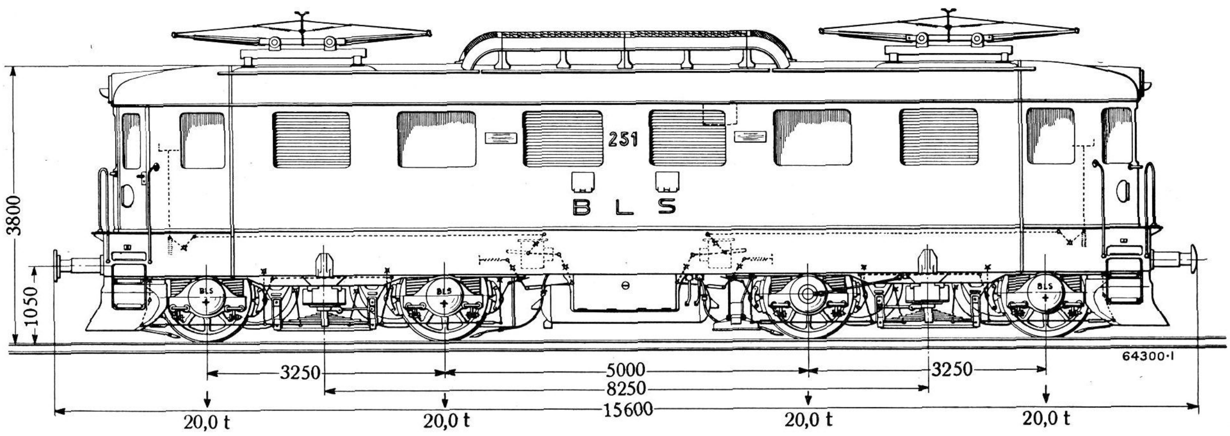


Fig. 2. — Profile of Bo Bo locomotive, series 251, of the Lötschberg Railway.

the total weight of the locomotive. It was not until the advent of the radially laminated transformer that a definite advance could be made in this direction. Compared to locomotive transformers with conventional parallel laminations and of approximately the same rating, the new transformer is about 40 % lighter. With a computed weight of only 38 t for the electrical equipment, including the drives and taking into account recent progress from a mechanical point of view (particularly weight reductions) it was considered possible to build a locomotive with four instead of six axles, i. e. to suppress the conventional pony axles, thus arriving at a bogie locomotive of the Bo Bo type. This aim was attained, both during the design and building stages, by losing no opportunity of introducing new weight-saving features in the mechanical part. The ultimate weight distribution was as follows:—

38 t for the electrical equipment, including drives.
40·6 t for the mechanical part.
1·4 t for tools, sand, and oil.

80·0 t weight in running order, uniformly distributed over the four driving axles.

The pony axles generally have a double purpose: firstly, to take the weight of the locomotive exceeding the admissible adhesive weight; secondly, to give the locomotive good running properties both on straight stretches of track and in curves. They carry a load of approximately 12—16 t.

Since in the case of locomotives with only four driving axles the leading axles are also subject to a load of 20 t doubts were expressed as to the suitability of this type of locomotive, particularly in view of the relatively high maximum speed of 125 km/h. Moreover, no experience with such locomotives was available in Switzerland.

By a lucky coincidence the management of the Lötschberg Railway were investigating at about the same time the possibility of reducing the dead weight of trains, since it had been found that for the case of the international expresses running over the Lötschberg line the dead weight represented 95 % of the total weight of the train. The technical management of the railway immediately showed great interest in the locomotive project and gave their full support to its development.

A contract for one locomotive, followed shortly afterwards by a second, was quickly placed. The railway management drew particular attention to the extraordinarily arduous running conditions involved, which is moreover proved by the fact that between Spiez and Brig the gradient is mostly 27 in 1000 and that the route is single track practically throughout, so that frequent starting from signals on heavy gradients is unavoidable. Moreover, the track abounds in curves and tunnels. The Berne-Thun section of the railway, however, has to be covered at the maximum speed of 125 km/h.

In view of these extremely severe running conditions special guarantees had to be given both for the locomotive as a whole and as regards running properties in particular.

DESIGN DATA OF Bo Bo LOCOMOTIVES.

General:

Maximum gradient	27 in 1000
Contact-wire voltage . . .	15,000 V, 16 ²/₃ ∼
Gauge	1435 mm
Maximum running speed . .	125 km/h

Loads and speeds on the principle gradients:

Gradient	Trailing load	Running speed	Minimum radius of curves
per 1000	t	km/h	m
10	650	90	550
15	600—650	75	300
27	360—400	75	300

Trailing loads:

On the Berne-Frutigen section: 650 t
On the Frutigen-Brig section: 400 t

According to the daily running schedule one and the same locomotive has to haul trains of these weights over the Berne-Spiez-Brig line (Fig. 3) and back three times within twenty-four hours.

Starting time on gradients of 27 in 1000 with a trailing load of 400 t:

$2\,^1/_2$ min. for acceleration of train from 0 to 40 km/h.
5 min. for acceleration of train from 0 to 75 km/h.

Maximum tractive effort at starting: 22,000 kg.

DIRECTIVES FOR PROJECT AND MANUFACTURE.

1. Weights of all individual components of not only electrical, but also mechanical parts to be kept low, e. g. by adopting bogie and locomotive body designs fabricated by welding, employing light metal for parts subject to very little mechanical stress, and utilizing as far as possible roller bearings. Since notwithstanding their great power both the traction motors and their drives can be embodied in the bogie, the supports and bearing points in the locomotive body, otherwise necessary to take the motors, are dispensed with and the design thus greatly simplified. Apart from the apertures in the roof for inspection purposes and the driver's cabs, the locomotive body differs very little from that of a coach and the same light and simple construction can be adopted.
2. Good running properties to be assured by providing practically play-free axle bearings of the self-adjusting, roller type, together with silentblocs. This feature obviates battering of the track, the wheel flanges rolling smoothly along the rails and thus ensuring quiet running of the bogie in the horizontal direction. With a view to enhancing the running properties of the locomotive the mass of the driving axles had also to be kept as low as possible, a condition which was fulfilled by mounting the traction motors directly on the spring-borne frame of the bogie instead of directly on the driving axle, as is often the practice in the case of bogie locomotives. A natural consequence of this arrangement is reduced wear and tear on both bogies and track.
3. Incorporation of features to ensure maximum utilization of the adhesion properties during starting and running.
   (a) Point of engagement of centre pin to be as low as possible to prevent excessive weight transfer from the leading axles due to the tractive effort; the remaining differences in weight distribution to be equalized by means of a special device.
   (b) Master controller to have large number of notches, which is readily feasible with high-voltage control.
   (c) Provision of a so-called anti-wheel-slip brake to counter tractive effort peaks exceeding the limit of adhesion, which are particularly likely to occur at starting.

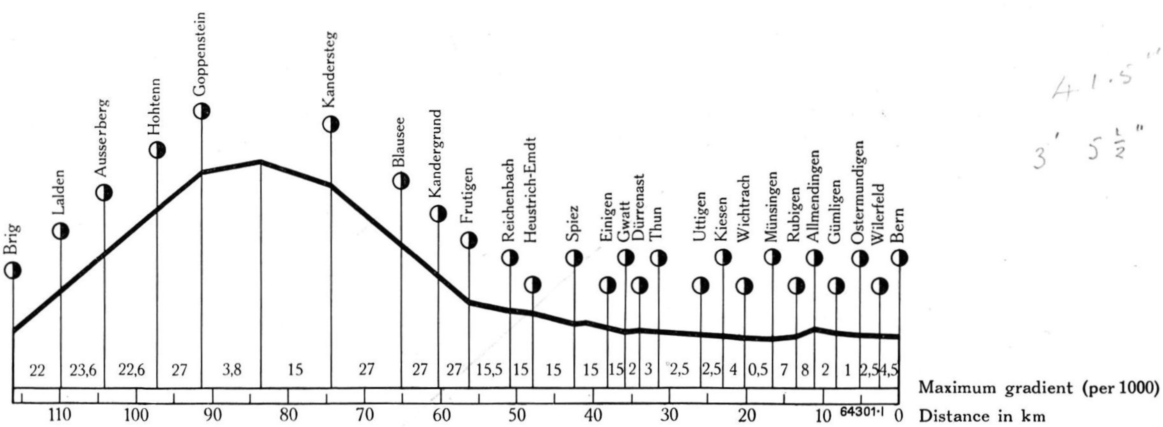


Fig. 3. — Profile of Brig-Berne Line.

CONSTRUCTION OF LOCOMOTIVE.

As general contractors Brown Boveri entrusted the construction of the mechanical part to the Swiss Locomotive and Machine Works, Winterthur, and elected to supply the whole of the electrical equipment, as well as the disc drives, themselves.

(a) *Mechanical Part and Disc Drive.*

The overall length of the locomotive was given by the wheel bases selected and the requisite space for lodging the machines and equipment. Here, too, particular attention naturally also had to be paid to reduction of weight.

As already inferred, the locomotive body, which is of rectangular profile, is integral with the underframe. The latter is reinforced by transverse end and intermediate cross members. All of these parts are of particularly sturdy construction since they not only serve for supporting purposes, but also have to take up the draw-bar and buffing stresses. The bogie bolster is rigidly bolted to the feet of the locomotive body which are supported at four points low down on the side girders of the underframe. In order not to impair the strength of the locomotive body conventional practice was departed from, the sides not being made removable. For the same reason the apertures with light metal covers, serving for the introduction of the electrical equipment, are relegated to the roof. On the other hand, windows and louvred openings for ventilation purposes had to be retained in the side walls. The braking resistances are lodged under a cover over the centre inspection aperture in the roof. Platforms are provided over the coupling and buffer gear in front of the conventional driver's cabs.

The principle factors affecting the design of the bogie were the size and type of the traction motors and drives, and it was these very components which facilitated its construction and contributed to its excellent running properties. The evolution of the cardan disc drive is best illustrated by the diagrams in Fig. 4. Fig. 4 a depicts an electric motor rigidly mounted in the chassis of a trolley bus, the motor driving the axle through the intermediary of a cardan coupling taking the form of discs of rubber or a similar material. Fig. 4 b shows the same drive for a tramcar, but with the motor mounted following standard practice parallel to the axle. The length of shaft between the two couplings, i. e. the cardan shaft proper, is here relatively short. To make it longer and increase its flexibility the cardan shaft is taken through the hollow motor shaft in Fig. 4 c. In this case there is a cardan coupling on either side of the motor, for which at the same time more room is gained in the axial direction. In Fig. 4 d the arrangement of the drive is exactly the same, except that steel discs are substituted for the rubber discs, which are only suitable for low powers. As shown in Fig. 5 the rotor torque is transmitted from the fixed sleeve 1 by the carrier 2 to disc 4 and from here by a second carrier 5, displaced through 90°, to the torsion shaft 6. The right-hand end of the torsion shaft is then flexibly connected

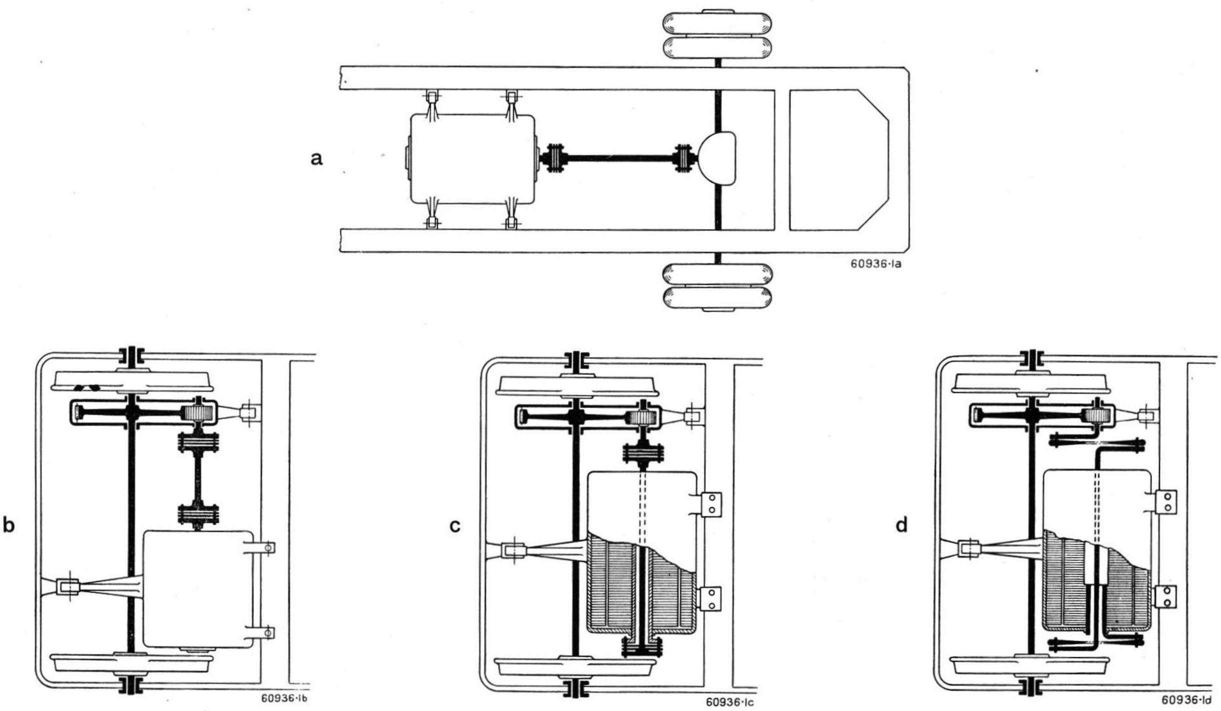


Fig. 4. — Development of disc drive from cardan drive with Hardy coupling.

(a) Drive of trolley bus axle from a motor rigidly mounted in the chasis, through a cardan shaft and two Hardy couplings.

(b) Drive as (a) transmitted to an axle of a tramcar.

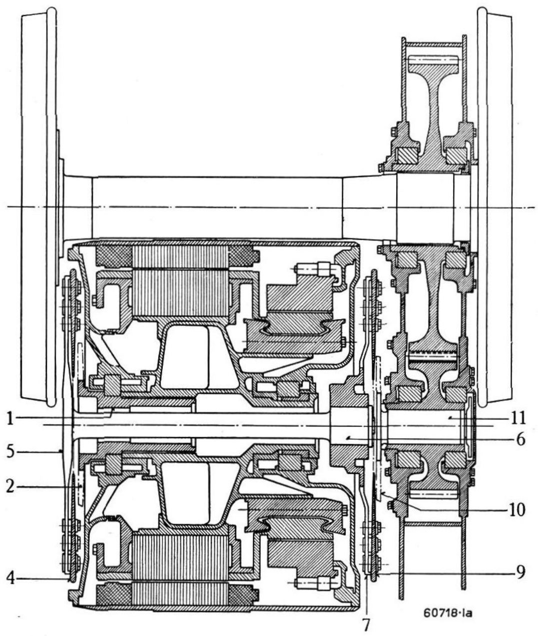
(c) Drive as (b) for motors of higher power; cardan shaft inside quill of rotor (Brown Boveri).

(d) Brown Boveri disc drive.

by the second disc 9 to the pinion shaft 11 through the two carriers 7 and 10, and, in consequence, also with the gearing. Since the traction motor is mounted on the spring-borne frame of the bogie and the large gear-wheel on the non-sprung axle the disc drive has to take up the relative displacement between motor and gearing resulting from the travel of the springs. The gear box, which is of the split type, is of very robust construction since it not only has to protect the gearing, but also to serve as support for the self-aligning bearings of the pinion and large gear-wheel. This arrangement gives the most favourable bearing conditions, the gear-bloc being supported at the gear-wheel end on the locomotive axle, whereas at the pinion end it is suspended from the bogie frame by means of a self-adjusting arm and bolts provided with silent-blocs (Fig. 7). The described disc drive is noteworthy for its low weight and small space requirements. Having no friction parts it needs neither lubrication nor maintenance. The cardan shaft is subject to no bending stresses and can thus take the form of a pure torsion shaft, i. e. be of light construction. Whereas the individual axle drive is generally embodied in the large gear-wheel or in the driving wheel, in this case it is located between the rotor and pinion, i. e. on the high-speed side of the gearing and can therefore be dimensioned for a correspondingly lower torque.

Notwithstanding the high one-hour rating of 1000 H.P. (metric) per motor it was found possible to keep the driving wheels relatively small (diameter 1250 mm) and in consequence light.

The mounting conditions of the motors and drives and the fixing of the diameter of the driving wheels formed the criteria for the new type of bogie built by the Swiss Locomotive and Machine Works (Fig. 7). The box-type bogie frame, which is fabricated by welding, is mounted through the intermediary of powerful helical springs on bracket-like projections of the double roller axle bearing. The cylindrical axle box guides together with the corresponding bronze sleeves lie on the same axis as the helical springs and are each provided with a cylindrical silent-bloc, which gives the bogie its excellent riding properties. The locomotive body is not mounted directly on the bogie, but is supported by the bogie-bolster on the springs suspended from the bogie frame by means of self-adjusting arms. The centre pin is fixed in the centre cross-support of the bogie and transmits the draw-bar and braking forces through the spherical centre pin



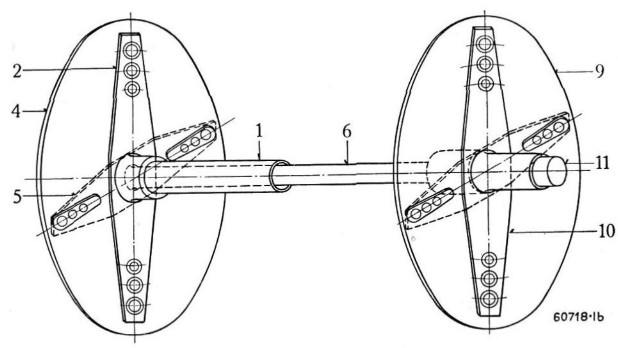


Fig. 5. — Mounting of disc drive in traction motor and pair of wheels.

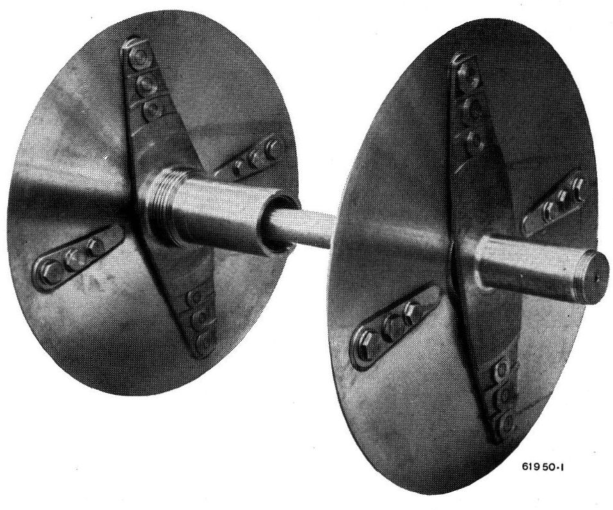


Fig. 6. — Disc drive comprising two flexible steel discs with four carriers and cardan shaft (view from pinion shaft).

The disc drive has no parts subject to wear and therefore requires no attendance or maintenance.

bearing in the bogie bolster to the locomotive body and thus to the draw-bar and buffer gear of the locomotive. The lateral play of the centre pin bearing in the bogie bolster ensures its only having to take up longitudal and not transverse forces.

A transverse coupling between the two bogies, which can be readily coupled and uncoupled, but is only of effect in curves, enables the running properties of the locomotive to be tried out in service with or without it.

selected. The hourly and continuous ratings of these are tabulated below, together with the corresponding tractive efforts and running speeds.

Rating	Referred to one motor					Total tractive effort in kg at wheel tread of locomotive	Running peed km/h
	H. P. (metric)	mkg	R. P. M.	V	A		
Hourly	1000	1000	720	395	2100	13,800	76
Continuous	855	782	780	395	1800	10,800	83

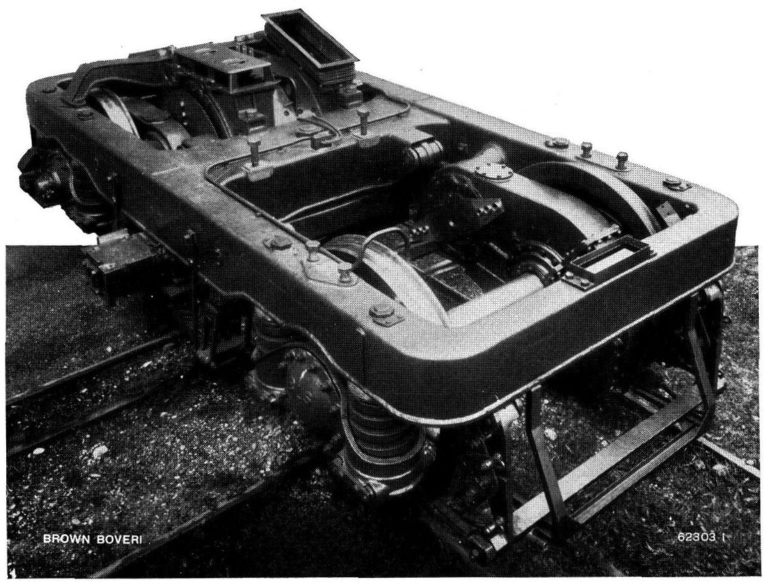


Fig. 7. — Lightweight bogie with longitudinal and transverse hollow girders fabricated by welding. The centre transverse girder carries the centre pin and the bogie bolster.

On the motor on the left will be seen the narrow disc of the drive, while on the right, assembled with the gearing, the carrier for the second traction motor not yet fitted.

Apart from the conventional mechanical brakes, i. e. the Westinghouse, regulating, and hand brakes, the maximum speed of over 110 km/h entailed a so-called high-speed brake with which the brake pressure is automatically increased when braking from speeds of over 80 km/h to ensure the specified braking path being adhered to. On the other hand the big increase in the friction between the brake block and tyre must be taken into account with decreasing speed, otherwise the driving wheels will slip and flats be formed on the tyres. To avoid this drawback, the high-speed brake automatically reduces the brake pressure to normal at a speed of 40 km/h.

(b) *Electrical Equipment.*

The powers were computed from the trailing loads and speeds given on page 331 and in consideration of the specified schedule. On this basis four traction motors with an hourly rating of 1000 H. P. each were

Maximum tractive effort at starting 22,000 kg corresponding to approximately 3000 A per motor. These figures are based on a driving wheel diameter of 1250 mm and a gear ratio of 1:2·22. Rules for temperature rise: Union internationale des chemins de fer.

The starting curves for different gradients and train loads in Fig. 8 are based on train resistance coefficients obtained from experience. Operating results corroborated these curves, resistances of 5 and 6·5 kg/t having been measured at 50 and 75 km/h, respectively, for a train of 480 t on a gradient of 27 in 1000. On the mountain sections the resistance of curves greatly influence these coefficients.

The design of the fourteen-pole single-phase traction motor (Fig. 9) is based on the most recent experience. Both mica-silk and glass fibre were used as winding insulation.

The motor casings with built-on ventilating and inspection flanges and fixing lugs are fabricated by

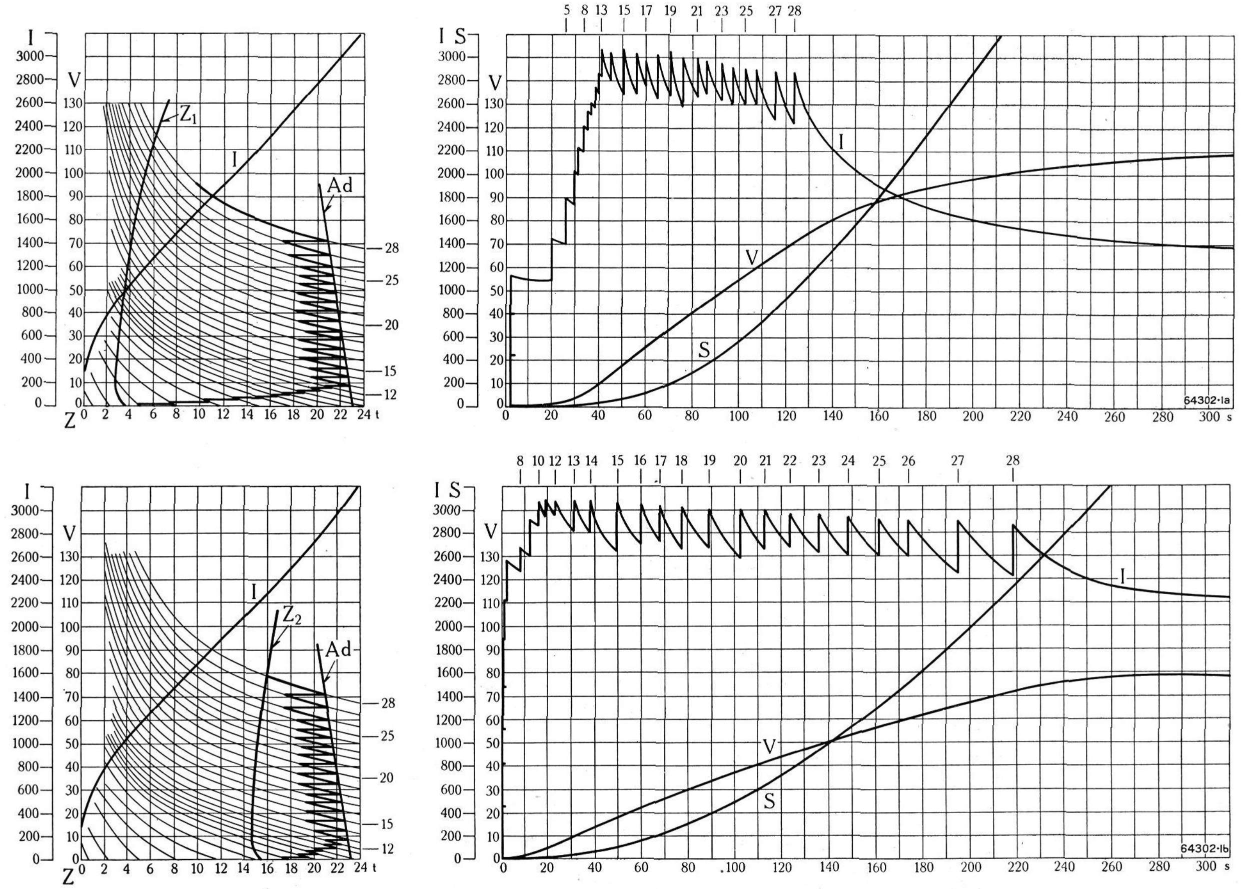


Fig. 8. — Calculated starting curves (top) of an express train with a total weight of 730 t (locomotive 80 t, trailing load 650 t) on the level and (bottom) of a total weight of 480 t (locomotive 80 t, trailing load 400 t) on a gradient of 27 in 1000.

Ad. Limit of adhesion.
I. Amperes per motor.
S. Travel in m.
V. km/h.
Z. Total tractive effort in t at wheel tread.

Z_1. Steady tractive effort on gradient of 0 in 1000.
Z_2. Steady tractive effort on gradient of 27 in 1000.

No-load voltage notch 1 = 25 V.
No-load voltage notch 26 = 451 V.

Due to the high-voltage control the tractive effort varies only very slightly during starting so that the adhesive weight is utilized up to the very limit.

welding, which helped to keep down weight. These lightweight casings are given the necessary mechanical stiffness by the end shields which are of cast steel. On account of the disc drive the rotor shaft had to be made in the form of a quill, the sleeve of the carrier being pressed on to it as shown on the left of Fig. 5. At the same end this shaft runs in a single-row roller bearing and at the commutator end (on right) in a self-adjusting roller bearing in the stator. A torsion shaft is provided with adequate clearance concentric to the quill of the rotor.

The *cooling air for the traction motors* is taken from the interior of the locomotive body so that a bellows device had to be fitted between the traction motor ventilating flange and the floor of the locomotive.

Notwithstanding the fact that the four traction motors are connected in parallel (Fig. 10) and that the current is relatively high only a small amount of equipment is required to control the running speed. In point of fact the motor circuit only comprises essentially the reversing switches for power running and braking and the motor isolating contactors, since control proper is effected in the primary circuit of the transformer. The primary voltage being 15,000 V and the traction motor voltage only about 500 V the current to be regulated on the primary side is approximately thirty times lower, i. e. in the ratio of 15,000/500. This signifies that at starting only 400 instead of 12,000 A and at the continuous rating only 240 in lieu of 7200 A has to be switched. Moreover, by adopting the tap-changing switch principle only two switch units need be designed as power units, whereas all of the others operate off-load and can consist of simple contacts.

In that the tap-changing switch forms a component of the transformer it is necessary at this juncture briefly to touch upon the principle and construction of the radially laminated transformer already alluded to at the beginning of these notes[1]. Radial laminations were first adopted for traction transformers to regulate the voltage of the high-speed two-car motor-

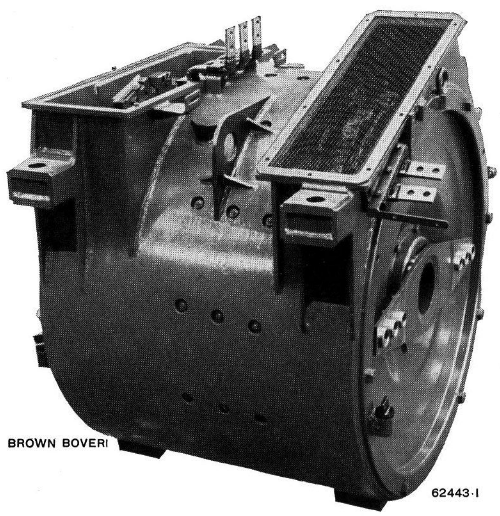


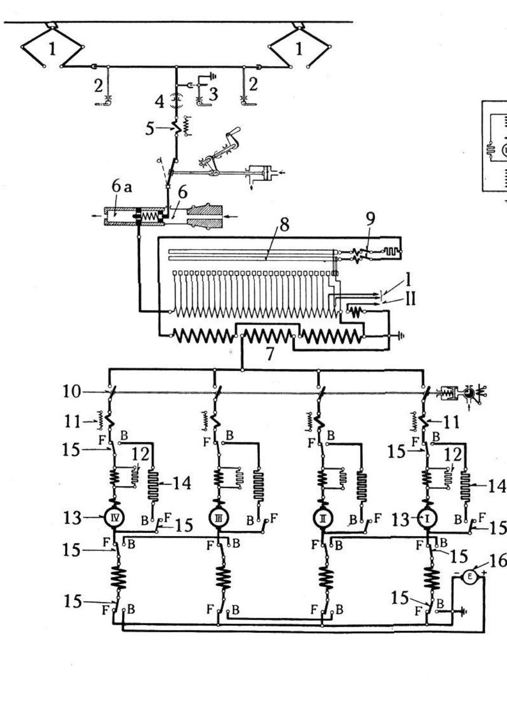
Fig. 9. — Traction motor with an hourly rating of 1000 H.P., 720 r.p.m., corresponding to a running speed of 76 km/h.

Construction with fabricated sheet-steel casing, cast-steel end shields with air inlet branches, commutator inspection opening, and carrier of disc drive.

coach Re 4/8, No. 301, of the Swiss Federal Railways. Thereupon they were also used for choke coils and transformers for land plants and have more recently been applied to traction transformers with tap-changing switches. Since the conditions for the passage of the magnetic flux from the limbs to the yokes are extremely favourable the overall height can be kept lower than with transformers having conventional parallel laminations. The active part of the transformer being cylindrical the tank can also be made cylindrical, so that the space to be filled with oil and in consequence the requisite amount of oil is reduced to a minimum. The weight of the transformer of this locomotive, including high-voltage control gear, is only about 9·5 t, as against the 16 t of a conventional transformer of approximately the same rating. The method of building cores with radial laminations is shown in Fig. 11, the individual laminations being mutually joined by spot welds. The core comprises essentially the cylindrical, radially-laminated main limbs and the yokes bolted to them. Seen in section the core takes the form of a shell type transformer with intermediate yoke. The primary and the two secondary windings of the main transformer are fitted above the intermediate yoke, while the regulating winding is arranged underneath (Fig. 12). Their leads are taken to the tap-changing switch for high-voltage control directly assembled with the iron core.

Although the dimensions of the tap-changing switch with circular contact track hitherto employed for high-voltage control gear are very small they were too large for the new, much smaller traction transformer. A new type of switch (Fig. 13) had therefore to be evolved, which could be fitted on the round transformer tank. The vertical form of the switch moreover facilitates connection to the vertical primary winding

[1] Further particulars of this new design and its application to traction transformers are given in the article by M. Itschner on page 342.



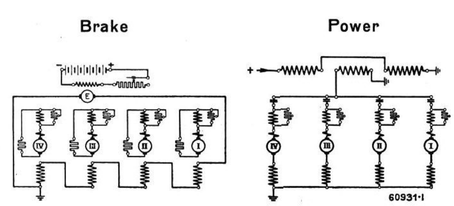


Fig. 10. — Simplified diagram of connections of locomotives.

1. Current collector.
2. Isolating switch.
3. Earthing switch.
4. Bushing.
5. Main current transformer.
6. Main circuit breaker.
6a. Exhaust cooler of circuit-breaker.
7. Transformer with tap-changing switch.
8. Tap-changing switch for high-voltage control.
9. Arc extinction switch.
10. Four-pole electro-pneumatic motor isolating contactor.
11. Current transformer for traction motors (for over-current relay).
12. Ohmic interpole shunt.
13. Traction motor.
14. Braking resistance.
15. Reverser and brake change-over switch.
16. Brake energizing generator.

F. Power.
B. Brake.

I. Train heating.
II. Auxiliaries.

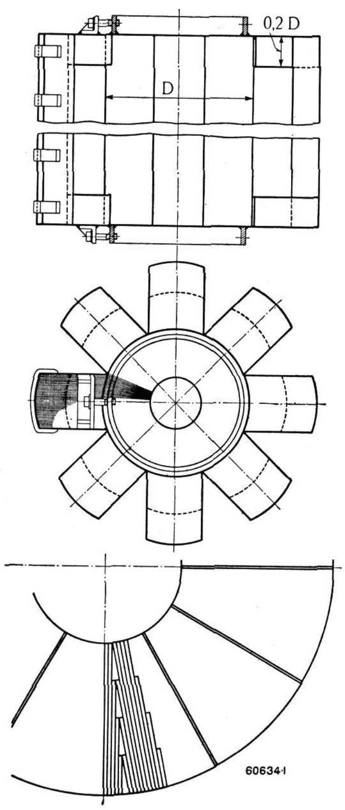


Fig. 11. — Principle of radial core of transformer. Low yoke height in relation to limb diameter, hence reduction of dimensions and weight of whole transformer.

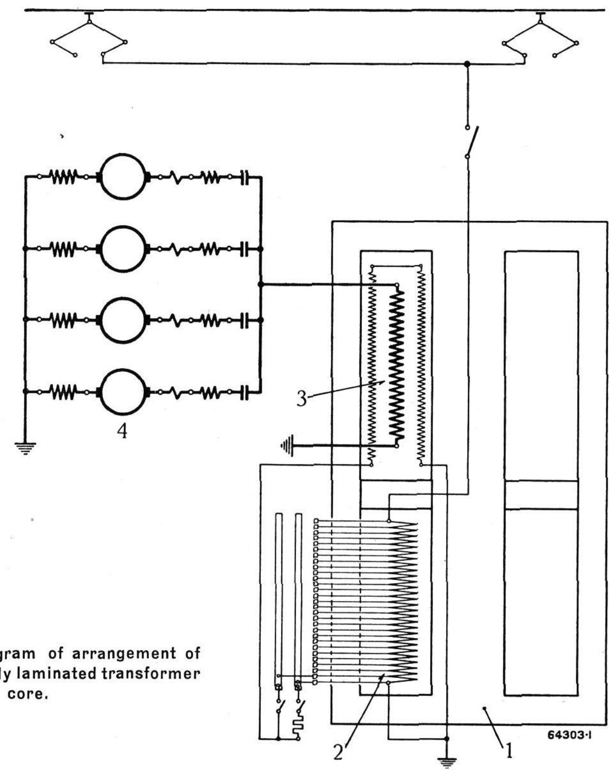


Fig. 12. — Diagram of arrangement of winding on radially laminated transformer core.

1. Radially laminated core.
2. Regulating winding.
3. Power winding.
4. Traction motors.

of the transformer. The contact bars and tapping contacts are lodged in the closed, oil-filled silumin casing. The contact brushes conducting the tapped off voltages to the traction motors, which switch off-load, are moved by a pair of chains. By unbolting the inspection cover of the switch casing the contact track can be inspected without the oil in the transformer having to be run off. The power switch comprises two air-break units which operate as a function of time and of the position of the off-load brushes. The tap-changing switch is driven by a directly built-on d. c. motor which is connected to the 36-V control circuit of the locomotive.

The fact that control is effected on the high-voltage side permits of a large number of steps — in the present case 28 — without any additional apparatus being necessary. As a result, the mean useful tractive effort at starting is higher and the adhesive weight better utilized. This explains why trailing loads of 360 — 400 t can be hauled with twenty-eight power notches as against only 300 — 310 t with eighteen notches, assuming a gradient of 27 in 1000 and an adhesive weight of 80 t.

An arrangement with a mechanically operated selector is employed to control the tap-changing switch motor. When the handwheel of the controller is turned to a certain power notch an auxiliary contact is closed and the control motor thus switched in. As soon as the tap-changing switch has reached the step selected with the controller the contact is opened and the control motor again stopped through the intermediary of a shaft driven by the tap-changing switch itself and which connects the latter to the switch units of the controller. The mode of operation of the control is shown diagrammatically in Fig. 15.

The same shaft can also be employed to operate the tap-changing switch by hand from either of the driver's cabs, e. g. in case of failure of the battery or control motor.

When air-blast high-speed circuit-breakers were first applied to locomotives a design following the lines of that employed for land plants was adopted. For the Swiss Federal and Lötschberg Railways, however, a new type (Fig. 14) specially adapted to locomotive installation conditions was developed. It was possible, however, to take over integrally well-tried components

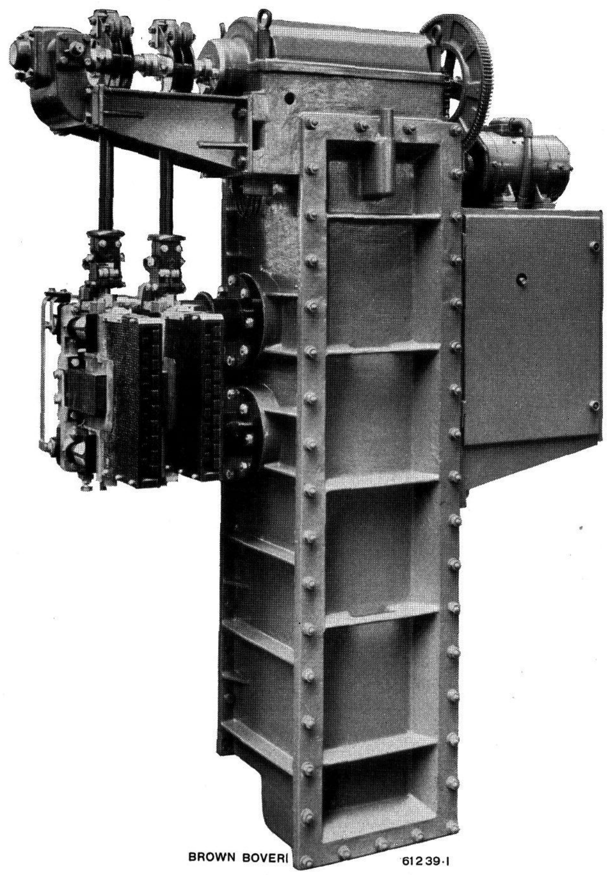


Fig. 13. — Tap-changing switch for twenty-eight power notches, for directly mounting on the cylindrical tank of the transformer.

The extended construction of the tap-changing switch for the Brown Boveri high-voltage control enables it to be harmoniously combined with the transformer, thus saving space (see Fig. 7 on p. 345).

such as the arc extinction and isolating contacts and the control unit. The conventional cylindrical air receiver is replaced here by a tubular arrangement on which the whole active part of the circuit-breaker is mounted and which thus also forms the base-plate. A manual control permits the circuit-breaker to be closed even when no compressed air is available or the air pressure is too low. Notwithstanding the fact that compressed air installations are in any case always available on locomotives some reticence has been shown in introducing air-blast circuit-breakers on locomotives. Now, however, the merits of this class of circuit-breaker are acknowledged by railway authorities and there can be no question of a return to oil circuit-breakers. The advantages of air-blast high-speed circuit-breakers over oil circuit-breakers for locomotive operation are:

Elimination of explosion hazard.

Elimination of labour and trouble in connection with oil.

Rupturing time 0·05 s, i.e. switching speed about ten times greater, therefore better protection of locomotive equipment under severe interrupting conditions.

Elimination of contact blocking at high interrupted powers.

Low weight (about 170 kg as against 480 kg in the case of the oil circuit-breaker).

Locomotive circuit-breakers are subject to frequent operation, due to the fact that there are no automatic switches in the traction-motor and train-heating circuits, but only over-current relays actuating the tripping gear of the primary air-blast circuit-breaker. Moreover, the breaker is often operated by the driver, e. g. when changing cabs, and also opens automatically should the supply voltage fail. From observations in service there is one breaker operation for every 10 km covered by a locomotive, so that from a purely mechanical point of view the circuit-breaker is more heavily stressed than in land plants.

The efforts made to reduce weight and dimensions proved of little success in the case of only one of the important units of the electrical equipment of single-phase locomotives, viz. the reverser. Although this operates off-load and merely has to reverse the direction of travel and change over to electrical braking, it requires more space and is heavier than the much more important tap-changing switch on the primary side. Nevertheless it was found possible to keep the dimensions of the reverser within reasonable limits.

In the case of locomotives of the power in question here the weight of the locomotive itself is chiefly required to be electrically braked on down-gradients. This alone saves a considerable amount of brake block material and no brake dust is produced to dirty the locomotive. The extremely lightweight rheostatic brake

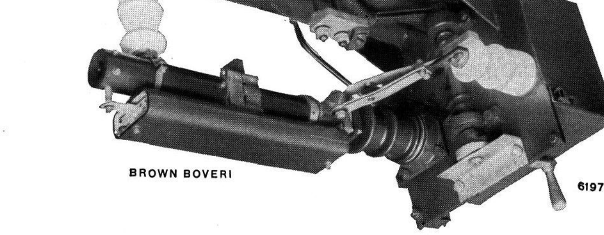
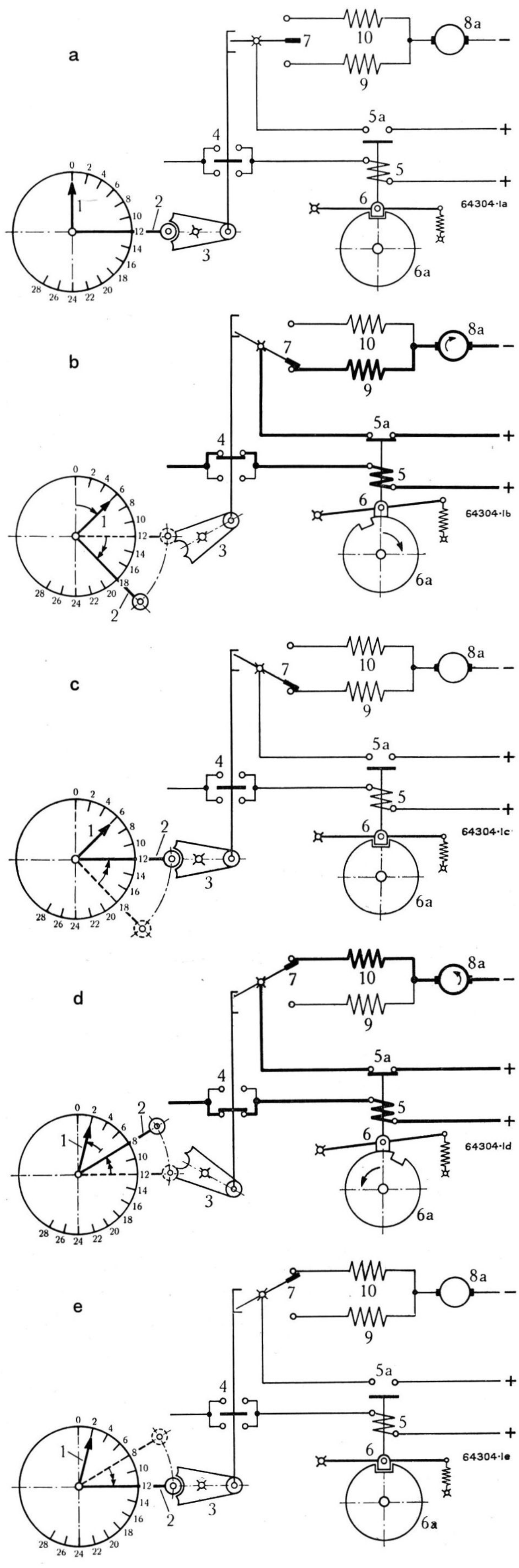


Fig. 14. — Main circuit-breaker.

The air-blast high-speed type of main circuit-breaker gives extremely reliable overcurrent protection on a. c. locomotives and motor-coaches of all classes, since it can cope with all powers which have to be interrupted in service.



employed here meets this requirement in a simple manner, the motors, which are separately excited with direct current, being loaded by resistances on the roof. In point of fact, the entire electrical braking equipment is restricted to the braking resistance, a 3·5 kW excitation generator, and a field rheostat with resistance and commutator-type contact track to obtain a large number of notches on the controller. The resistance is rated approximately 440 kW and permits a weight of about 100 t to be braked on a gradient of 27 in 1000, i. e. apart from the weight of the locomotive about 20 t of the trailing load can also be electrically braked. As long as only the weight of the locomotive and a fraction of the trailing load is required to be braked rheostatic braking is to be preferred to regenerative braking owing to the much lower weight and reduced upkeep involved.

The train heating and lighting equipments, relays, and instruments have no novel features. The desk-like, semi-circular arrangement of the apparatus in the driver's cabs (Fig. 16), which gives an extremely clear layout and convenient operation of the equipment and instruments, is however notable.

A number of special devices already partly referred to in passing must be reverted to here. In the event of difficult starting conditions, wet rails, or badly conditioned track every locomotive is more or less subject to wheel slip. For this reason sanders are provided which apart from the large quantities of sand required, have the disadvantage of operating with very little precision and greatly dirtying both the locomotive and the track, as well as increasing the train resistance, since the sand not only gets under the locomotive

Fig. 15 a–e. — Fundamental mode of operation of remote control with mechanical operated selector switch.

(a) Control crank 1 and thus also tap-changing switch in "O" position.

(b) Control crank 1 turned through angle) to notch 6, lever 2 being entrained by crank 1 and rotated through angle), whereupon fork 3 is deflected downwards; the change-over contact 4 switches in the blocking coil 5, pawl 6 releases the blocking disc 6a; simultaneously rotor 8a of the control motor is switched in through the field winding 9 and interlocking contact 5a of the blocking coil to switch up the tap-changing switch. The tap-changing switch begins switching upwards.

(c) The lever 2 is turned back out of the dotted position by the angle) by the "position indicating shaft" of the tap-changing switch, the fork 3 is moved into the horizontal position, the blocking pawl 6 drops and interrupts the control motor circuit through contact 5a, the tap-changing switch remains in position 6.

(d) Return of control crank 1 to power notch 2 (angle)), lever 2 is turned back by the control crank by the angle), whereupon fork 3 is deflected upwards. The change-over contact 4 switches in the blocking coil 5, the rotor 8a of the control motor is energized through contacts 5a and 7 and field winding 10 to reverse the motor, and the tap-changing switch begins to run back.

(e) Lever 2 is returned to the horizontal position (angle)) by the "position indicating shaft" of the tap-changing switch, as under (c), the blocking pawl drops, the control motor circuit is interrupted, and the tap-changing switch remains on power notch 2.
The same cycle of operations is repeated from notch to notch.

wheels, but also under those of the trailing coaches. A better method of preventing wheel slip, without the above-mentioned drawbacks, is to lightly brake the driving axles mechanically. Fig. 17 shows the admissible limit of adhesion under normal conditions. If now for some reason, e. g. at starting as in this diagram, the adhesion conditions momentarily become worse the normal adhesion limit line is indented and the black tractive effort peaks between Ad_1 and Ad_2 cause the driving wheels to slip. As already inferred this can be readily avoided by momentarily lightly applying the driving wheel brake. For this purpose the driver brakes the driving wheels with reduced pressure through an electro-pneumatic valve. The device has proved very satisfactory in practice and saves sand, which freezes in winter (when wheel skid is most prevalent) and there fore has no effect.

Whereas in the case of a stationary locomotive the weight is uniformly distributed over the four driving axles, this no longer applies when a train is being hauled, weight being transferred from the leading to the rear axles of the two bogies due to the drawbar

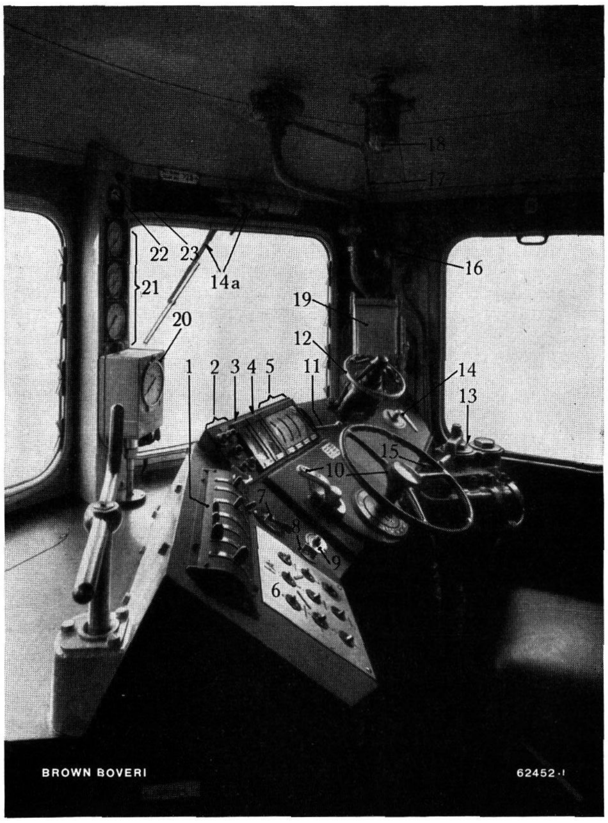


Fig. 16. — Driver's control desk with all handles clearly arranged in semi-circular formation.

1. Control switchbox with switch elements for: Main circuit-breaker, current collector, control current, compressor motor, fan motors, lighting, train heating.
2. Pilot lamps for contact wire voltage-reversing switch "ahead", "reverse", "braking" and "fan on".
3. Voltmeter for contact wire voltage.
4. Ammeter for braking current.
5. Four ammeters for traction motor current.
6. Panel with switch for window heating;
   Switch for pilot lamps;
   Two-way switch for inside lamps;
   Change-over switch for optical day signal;
   Switch for cab lamp and speedometer;
   Twin switches for pilot lamps.
7. Dimming switch with resistance.
8. Vigilance nob with pilot lamp for train control.
9. Push-button for electro-pneumatically operated anti-slip brake.
10. Master controller with handwheel and handle for operating drum of reversing and braking switch.
11. Adjusting lever for axle load equalization.
12. Regulating brake valve.
13. Weibel-Kradolfer brake valve.
14. Cock for windscreen wiper.
14a. Windscreen wiper.
15. Sand cock.
16. Brake change lever with auxiliary contacts.
17. Whistle.
18. Cab lamp.
19. Time-table frame with lamp.
20. Speedometer.
21. Pressure gauge for regulating brake valve, double pressure gauge for braking cylinder and brake air receiver, double pressure gauge for automatic brake.
22. Ammeter for train heating.
23. Voltage indicator lamp for train heating.

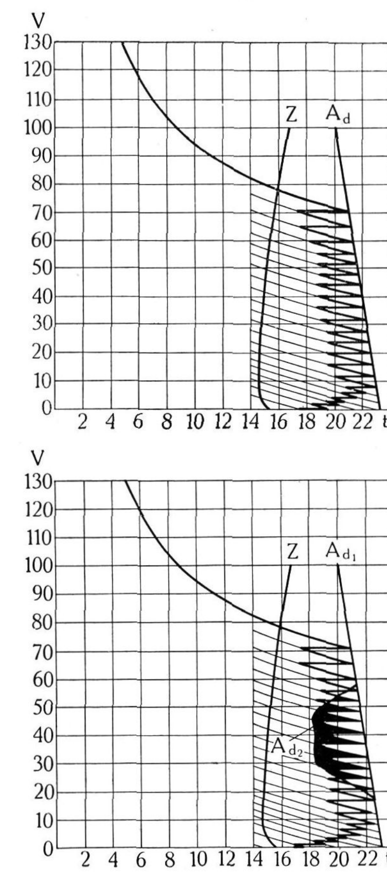


Fig. 17. — Mode of operation of anti-slip brake when danger of wheel slip exists.

Top: Normal starting curve for a train on a gradient of 27 in 1000. V. Speed in km/h. A_d. Adhesion limit with rails in good condition. Z. Total tractive effort at wheel tread.

Bottom: Starting with temporarily poor adhesion conditions as per adhesion curve A_{d2}. The black starting peaks between A_{d1} and A_{d2} are taken up by the anti-slip brake acting on the driving wheels, which do not therefore slip.

pull. This weight transfer becomes all the more pronounced with increasing tractive effort. As a result the driving axles from which weight has been transferred begin to slip first and thus prevent the tractive effort being fully utilized. This disadvantage can be satisfactorily overcome by means of a special load equalizing device comprising four compressed air cylinders fitted on the locomotive frame above the bogie transverse frame. Through the admission of air into these cylinders from the leading driver's cab a part of the weight of the locomotive body is made to bear on the leading bogie transverse beam and thus on the leading axles. The operating lever for the axle load equalizing device directly adjacent to the traction motor ammeter permits this additional loading of the leading axles to be well adapted to the stepwise variations of the tractive effort during the starting process, which are approximately proportional to the deflection of the traction motor ammeter.

Compared to locomotives with pony axles the adhesion conditions of the Bo Bo locomotives are more favourable, in that for the same trailing load 25—30 t less dead weight has to be hauled.

Of the special devices on the locomotive there is finally the contact-wire voltage indicator which informs the driver when insulation fault-finding tests are being carried out and the locomotive circuit-breaker is not to be switched in. The arrangement already employed on the Swiss Federal Railways Ae 8/14 locomotives was retained here in principle, except that instead of a special bushing condenser through the locomotive roof the already existing current collector lead with insulated metallic coating was used as coupling condenser and the indicator lamp no longer switched in directly, but through the intermediary of an amplifier. This indicating device, which only functions when the locomotive circuit-breaker is open, operates with the current collector both raised and lowered.

Operating Experience.

The first of the two new locomotives was taken into service in November, 1944, the second following in March, 1945. To date the locomotives have covered 110,000 and 80,000 km, respectively. Each locomotive weighs 79 t, i. e. 1 t less than guaranteed.

A good idea of the running properties was already obtained on the run from the assembly shop at Münchenstein to the Lötschberg. The route followed included the Jura line to Biel and from there via Berne to Brig and back to Spiez, a round trip of 300 km. The track abounds in curves, but certain sections permit of high speeds being attained. For instance, it was found possible to attain the specified maximum running speed of 125 km/h on the Berne-Thun line, when the remarkably quiet running properties of the locomotive, already evident at the lower speeds, became even more pronounced. On the same section of line the speed was pushed up to 135 km/h for a short period.

The locomotive also ran very quietly on the 27 in 1000 gradients of the mountain section up to the maximum speed of 75 km/h admitted here. The very little wear measured on the wheel flanges indirectly confirms the excellent track properties of the locomotive.

On the score of adhesion the Bo Bo locomotives are at least the equal of the other locomotives with individual axle or side rod drive operating on the same route. In this respect it might be mentioned that the adhesion was sufficient for a train with a trailing load of 435 t on a gradient of 27 in 1000.

Another notable fact is that the commutation of the traction motors compares very favourably with the best d. c. machines.

Recapitulating, it may be claimed that the new Bo Bo locomotives of the Lötschberg Railway have fully come up to the expectations of both the railway management and the designers, even though, as with all technical innovations, initial difficulties were experienced and one detail or the other was found to require improvement.

The following table gives the more important data of the locomotives:—

Driving wheel diameter	1,250 mm
Bogie wheel-base	3,250 mm
Total wheel-base	11,500 mm
Distance between bogie pivots	8,250 mm
Overall length of locomotive	15,600 mm
Gear ratio	1 : 2·22
Total hourly rating at motor shaft	4,000 H. P.
Tractive effort at wheel tread	13,800 kg
Corresponding running speed	76 km/h
Maximum starting tractive effort	22,000 kg
Maximum running speed	125 km/h

Weights:

Mechanical portion (with gearing)	44,350 kg
Electrical equipment (with drive)	34,250 kg
Sundry (sand, oil, tools, etc.)	1,400 kg
Total weight = adhesive weight	80,000 kg

(MS 679) *W. Lüthi. (E. G. W.)*

BROWN BOVERI SINGLE-PHASE TRACTION TRANSFORMERS.

Decimal Index 621.314.21:621.33

The transformer constitutes an essential and – due to the low frequency — relatively heavy component of the electrical equipment of single-phase locomotives and motor-coaches. Lighter locomotives entail above all a lighter transformer. Brown Boveri have therefore devoted much development work to the reduction of the weight of transformers. The following notes give details of the individual stages through which the design has passed, together with particulars of the new types of traction transformer evolved in recent years.

THE following notes are restricted to the development of traction transformers with oil as insulating and cooling agent. In point of fact Brown Boveri has constructed to special specifications a number of air-cooled transformers which have given excellent service. The reduced overload capacity compared to oil-immersed transformers together with the risk of the windings becoming covered with conducting brake dust and moisture, however, were drawbacks which made the air-cooled transformer appear less suitable, especially at high contact-wire voltages, from the very beginning.

The oil-immersed transformers with corrugated tank first constructed for locomotives with Déri repulsion motors need not be gone into either, since the moderate powers involved, with at most three tappings on the low-voltage side, set no design problems.

The first multi-tapping oil-immersed transformers, those for the Be 4/6 locomotives of the Swiss Federal Railways 12,302 series[1] had very much in common with the conventional land transformers of the period. The tapped low-voltage winding was fitted concentrically over the high-voltage winding on adjacent limbs of rectangular cross-section (Fig. 1). By multiple parallel connection of the tapping coils (which was moreover necessary for other technical reasons) it was possible to reduce the asymmetry in the ampere-turn distribution sufficiently to enable the axial thrust occurring under conditions of short circuit to be coped with by clamping rings and tension bolts. The long sides of the rectangular coils, however, had to be secured with strong cast steel beams against the radial forces set up by short circuits. A great number of these transformers have been in service for more than twenty-five years and have proved very satisfactory.

The transformer of the Ae 4/7 locomotives of the Swiss Federal Railways 10,901 series[2] represents the stage of development attained round about 1928. The cores and yokes had undergone very little change. In the interim, however, the already proved disc or pancake winding had been introduced (Fig. 2), which enabled special bracing of the long sides of the coils to be

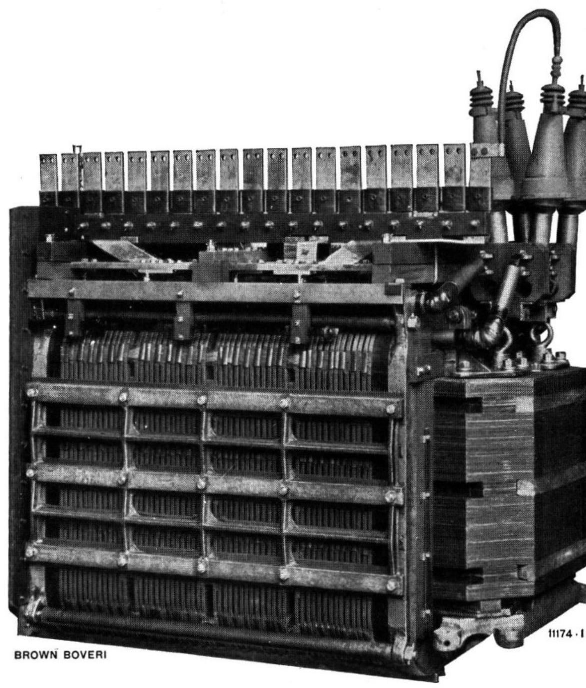


Fig. 1. — 1730 kVA transformer of Be 4/6 locomotive, series 12,302, of the Swiss Federal Railways.

Active part with clamping rings and braces which were still necessary here with the rectangular coil arrangement adopted.

dispensed with. The heavy axial repulsion forces occurring between the high- and low-voltage coils under short-circuit conditions were satisfactorily coped with by clamping rings and tension bolts. The particularly effective vertical cooling ducts between the coils were obtained automatically with the disc winding and horizontal limbs. On the other hand, the lodging of an adequate number of tappings on the low-voltage side had already become a difficult problem here, since

[1] W. Lüthi: "Elektrische Einphasen-Lokomotiven für die Schweizerischen Bundesbahnen", BBC Mitteilungen 1921, No. 9, p. 183 et seqq.

[2] W. Lüthi: "The Single-phase Express Locomotive Type 2 Do 1 with Brown Boveri Individual Axle Drive", Brown Boveri Rev. 1928, No. 2, p. 63 et seqq., Figs. 7—9.

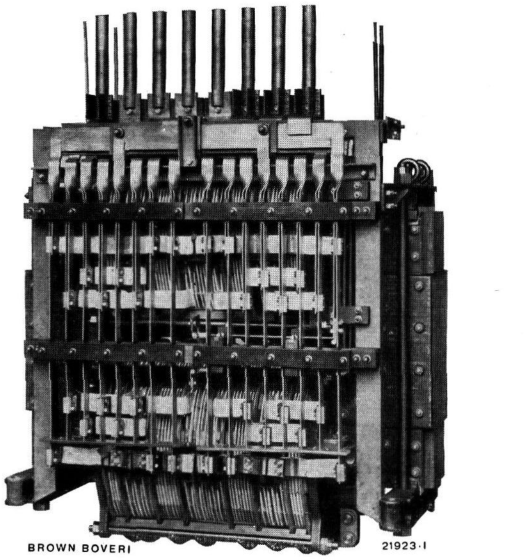


Fig. 2. — 2300 kVA transformer of Ae 4/7 locomotive, series 10,901, of the Swiss Federal Railways.

Active part with secondary leads. The disc winding has enabled the massive braces to be dispensed with (see Fig. 1 on p. 342).

on this locomotive, due to the individual axle drive, all four motors were connected in parallel and as a result the tappings had to be dimensioned for double the current of the transformer (Fig. 1) of the Be 4/6 locomotives of the 12,302 series with two motors permanently connected in series. An added difficulty was that the total number of turns on the low-voltage winding had been reduced because:

1. Due to the higher power the cross-section of the core and in consequence the voltage per turn had become greater.
2. Due to modified dimensioning principles the motor voltage had become lower.

Moreover, an increased number of power notches was desirable. These widely contradictory requirements and conditions led at first to the following arrangement being adopted, without radical modification of the transformer: —

Only seven tappings were taken off the low-voltage winding, an auxiliary voltage supplied by a separate transformer being subtracted or added between the seven main tappings by the control gear, to give a total of twenty-one power notches.

Progress in insulation technique subsequently led to smaller clearances, more compact windings, and lighter cores, while advances in the art of welding permitted the weight of the non-active part and tank to be substantially reduced. This was particularly desirable for motor-coach transformers which, usually having to be lodged under the floor, must be of small dimensions and low weight. Fig. 3 shows such a transformer of very low construction. The two limbs are arranged horizontally side by side.

Already in the case of the transformers for the Ae 4/7 locomotives of the 10,901 series (Fig. 2) the connecting bars for the tappings of the low-voltage winding, together with the auxiliary transformer and the bulky on-load tap-changing gear, had become so heavy and large that the admissible limits were practically attained. With the subsequent development *high-voltage control* was adopted which permits the

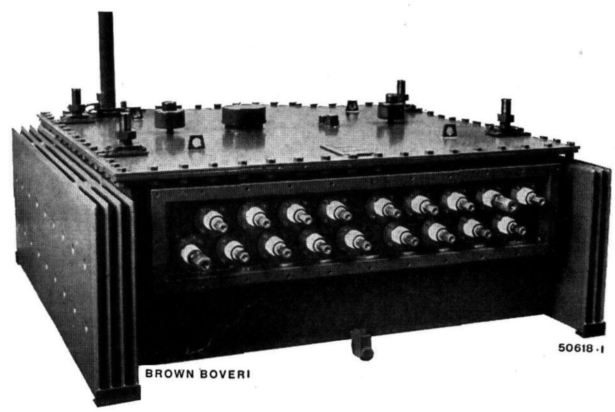


Fig. 3. — 460 kVA motor-coach transformer for suspension under the coach floor.

The flat cooling pockets are subjected to the windage.

The particularly low height required in the case of motor-coach transformers could only be obtained with the core-type transformer by arranging the limb horizontally.

regulating problem to be solved absolutely reliably in an ideal manner with very little extra transformer weight, while space requirements are reduced to a minimum. As will be clear from the diagram in Fig. 4 the tap-changing switch taps variable voltages off a

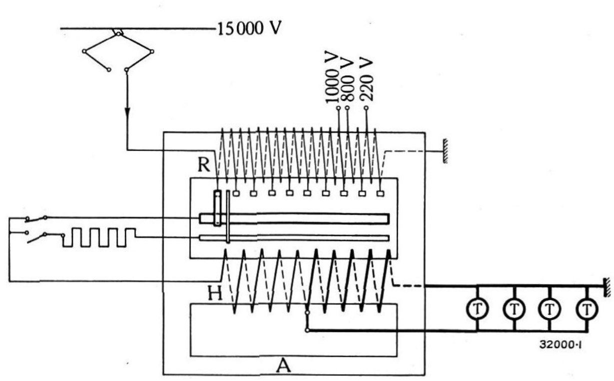


Fig. 4. — Diagram of locomotive transformer regulated on the high-voltage side.

A = Non-wound limb carrying the difference between the fluxes in the limbs R and H.

H = Limb of main transformer with constant transformation ratio and variable flux.

R = Limb of regulating transformer with constant flux.

T = Traction motors.

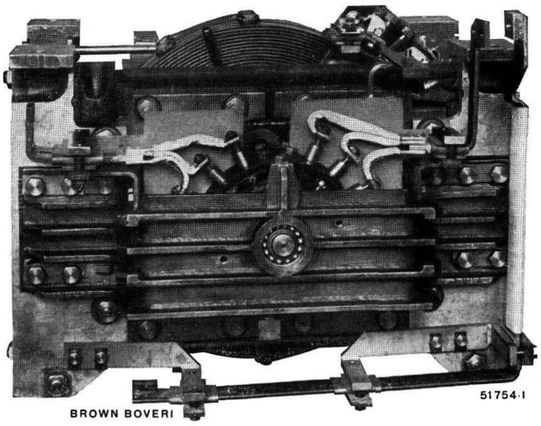


Fig. 5. — Active part of 260 kVA transformer for smooth regulation of two-car high-speed motor-coach Re 4/8 301 of the Swiss Federal Railways.

potential divider R (single-coil regulating transformer) connected between the contact wire and earth. The main transformer H transmits these voltages with a constant transformation ratio to the traction motors.

In lieu of motor currents of the order of 10,000 A only a few hundred amperes have to be switched. For this purpose it is possible to employ a tap-changing switch which is subject to practically no wear, its moving parts with the exception of two arcing switches being incorporated in the transformer tank. This type of switch can be constructed without difficulty for a large number of taps; up to the present a maximum of 28 has been employed. On the other hand, the large number of turns on the regulating transformer permits virtually arbitrary grading of the tappings and this fact, coupled with the large leakage voltages in the lower part of the range of regulation, results in the tractive effort increasing very smoothly at starting and the adhesion weight to be well utilized. The tap-changing connection employed with tap-changing resistances instead of choke coils, for the high-voltage control, also tends in the same direction.

In passing it might also be mentioned that noteworthy tests have been undertaken[1] to regulate the secondary voltage absolutely smoothly, notwithstanding the enormous difficulties the problem presents. Fig. 5 shows such a transformer. The excellent results obtained with high-voltage control subsequently resulted in little further attention being paid to the development of this type.

Even in the case of the transformers regulated on the high-voltage side, the well-known disc winding on horizontal limbs (cf. Fig. 6) was retained for some time. The transformers of the two Ae 8/14 locomotives Nos. 11,801 and 11,851 and the Ae 4/6 locomotives series 10,801 are of this type, the greater part of the latter with aluminium windings.

In the further development of the high-voltage control increased attention was paid to design improvements on the basis of the original connection. Initially, profiting by experience in extra-high-voltage engineering, a cylindrical regulating winding was adopted. This reduced or even eliminated the complicated interleaving, which proved particularly advantageous in the case of low-power transformers. The transformers of the rack-and-pinion motor-vans of the Swiss Federal Railways operating on the Brünig line are of this type.

The transformers to be constructed for the new Ae 4/4 locomotives (wheel arrangement BoBo) of the Lötschberg Railway presented an opportunity to make a radical change in design.

As recorded in another article[2] in this number it was only possible to realize the project by considerably reducing the weight. The transformer described hereafter played a big part in this respect.

[1] F. Steiner: "Der Doppelschnelltriebwagen Re 4/8 Nr. 301 der SBB", Schweiz. Bauztg. Vol. 114, 1939, p. 27 et seqq.

[2] Cf. page 329 et seqq.

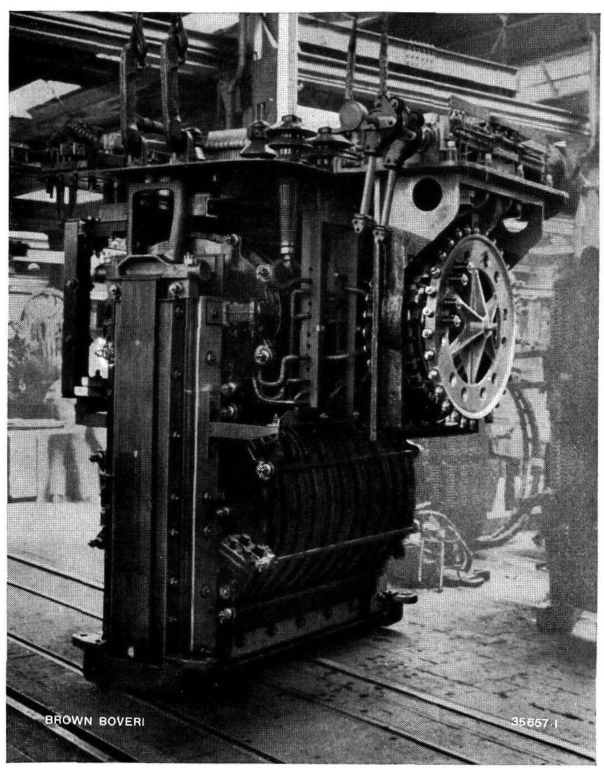


Fig. 6. — Active part of 2900 kVA transformer with tap-changing switch and regulation on high-voltage side, of Ae 8/14 locomotives Nos 11,801 and 11,851 of the Swiss Federal Railways.

The projecting tap-changing switch with circular contact track entailed the transformer tank being shaped accordingly (cf. Figs. 13 and 7 on pp. 338 and 345, respectively).

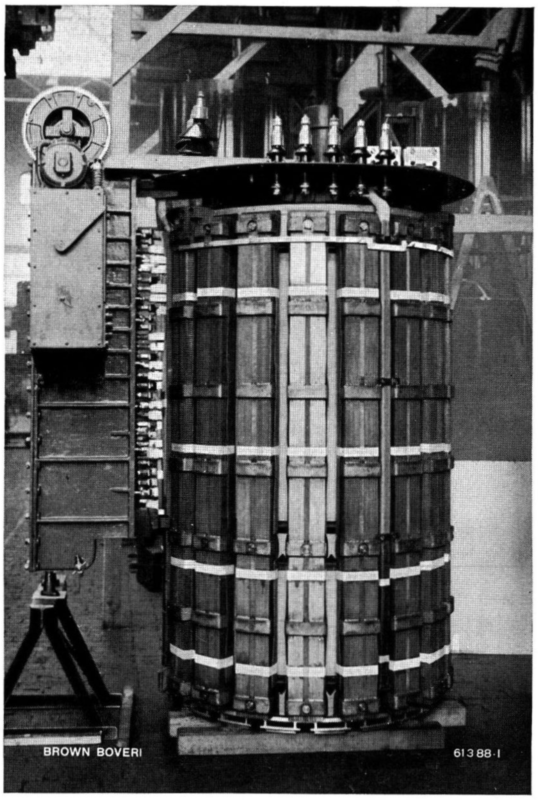


Fig. 7. — 2700 kVA transformer for high-voltage regulation. Active part with radially laminated core and built-on tap-changing switch of the Bo Bo locomotive of the series 251 of the Lötschberg Railway.

Harmonious assembly of transformer and tap-changing switch.

The development of large choke coils had led Brown Boveri to adopt radially laminated limbs with annular yokes[1], an arrangement constructed by Berry more than forty years ago, but which did not find application. Modern welding technique enabled this design to be constructed in a really original manner. It is particularly advantageous for single-limb transformers and is therefore more or less predestinated for single-phase traction transformers. The two windings of the transformer, which is controlled on the high-voltage side, are arranged on a common limb, the main transformer with fixed transformation ratio and variable flux density being at the top and the potential divider constantly energized with the contact wire voltage at the bottom (Fig. 7)[2]. The radially laminated limb projects into a yoke disc top and bottom which conducts the flux to the length-wise yokes arranged around the winding in circular formation. A further yoke disc located between the main and regulating transformers carries the differential flux. The vertical arrangement of the limb does not result in the overall height becoming excessive. The cylindrical windings are of simple construction and can be efficiently cooled. Since there are no irregularities in the axial distribution of the ampere-turns it was found possible to reduce the bracing of the windings to a minimum, with the result that, apart from a few simple yoke bolts there are no further parts of any great weight on the active portion of the transformer. The round tank is inherently strong, so that special reinforcements can be more or less dispensed with. Since the leads lie in recesses between the yokes and only a small clearance is necessary between the earthed core and the tank wall the weight of the oil can be kept small. This naturally involves a reduction in thermal capacity which had to be taken into consideration in both the design of the transformer and the cooler.

The adaptability of the new design is shown up particularly well in the case of motor-coach transformers. It has even proved possible to lodge such transformers with vertical limbs under the low floors of modern motor-coaches (Fig. 8), for outputs up to about 600 kVA. The limbs of these transformers are very short. The [-shaped yokes arranged in circular formation around it only take up a small fraction of the available height; the bolting together of the limbs and yokes only requires a few further centimetres, so that the space is utilized to a maximum. In view of their moderate secondary currents the motor-coach transformers have tappings on the low-voltage side. Potential divider coils lodged in the bore of the transformer limb, serve for tap-changing purposes. They also have a radially laminated core, while their magnetic return circuit is formed by the surrounding limb of the transformer.

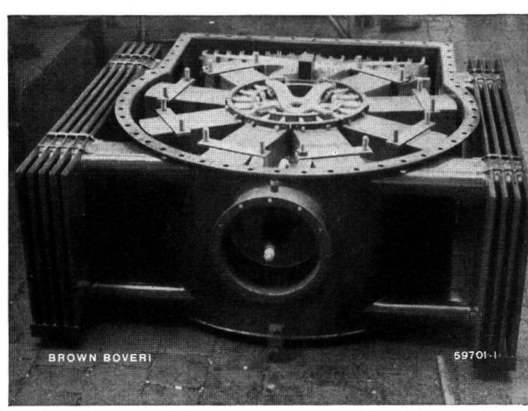


Fig. 8. — 410 kVA motor-coach transformer for suspension under the floor of the coach.

Core radially laminated. Note the particularly low overall height with vertical limb arrangement (cf. Fig. 3 on p. 343).

[1] A. Meyerhans: "New Designs of Transformers and Choke Coils", Brown Boveri Rev. 1945, No. 3, p. 91 et seqq., Figs. 13, 14, and 15.

[2] See also Fig. 13 on p. 337.

so that they do not project in any way. Here, too, the new construction is typified by simple and robust design and low weight. It might be emphasized that the reduction in the weight of traction transformers achieved in the course of the last few years has been effected to a considerable extent on the non-active parts. The electrical and magnetic stressing of the active material has tended to diminish. Nevertheless, the low specific weight of the aluminium employed for

Fig. 9. — **1660 kVA transformer for the new lightweight locomotives of the Re 4/4 401 series of the Swiss Federal Railways.**

Active part with radially laminated core. This new type of transformer played a big part in the reduction of the weight of these 2300 H. P. locomotives to 56 t.

the windings has a favourable effect and the retention of aluminium may prove advantageous in traction transformer construction, even when supplies of copper again become available in pre-war quantities.

Finally there are the transformers constructed for the new lightweight locomotives of the Re 4/4 401 series of the Swiss Federal Railways. These are of similar design to the motor-coach transformers just described, but in view of their higher power and the fact that they are installed in the body of the locomotive are of greater height. They fall within a power range for which high-voltage control can be fundamentally considered the most favourable. For special reasons secondary tappings were specified here, three-part potential divider coils being provided for the change over by contactors. As in the case of the motor-coach transformers these are fitted on a common core inside the limb of the main transformer. Here, too, a simple cylindrical winding with vertical cooling ducts was adopted. Special bracing of the windings is also superfluous in this case, since the strong yokes take over this function. Fig. 9 shows the extraordinarily compact design of these transformers. The tank is so well adapted to the form of the active part that there is practically no space which is not usefully employed. The embodying of the potential dividers in the centre of the main limb enabled the tank to be kept absoluted cylindrical.

In conclusion the development of the *cooling equipment* and the related question of output might be touched upon.

It was at first only natural that the standard cooling practice for land transformers should be adopted, i. e. the transformer tank was made of corrugated plate to increase the available cooling surface. As powers increased this measure no longer sufficed to dissipate the heat generated. Moreover, the corrugated tanks, fabricated in accordance with the state of development of welding technique at the time, proved not to stand up to the vibrations set up in traction service. In the case of low-power transformers, however, this cooling principle was applied with success in the form of a number of flat cooling pockets connected to the transformer by wide connecting branches top and bottom (Fig. 3). The external wall of the outermost pocket is reinforced, which has proved to provide sufficiently reliable protection against damage. In the case of motor-coach transformers which are suspended under the floor of the coach the pockets are arranged in the direction of travel to increase the cooling effect through the windage.

For high powers, i. e. where higher losses are developed, these coolers on the transformer tank no longer suffice, partly because the surface cannot be made large enough and partly because the oil in the coolers circulates too slowly solely under the effect of the inherent temperature drop. As an intermediate solution of the problem a number of Swiss Federal Railway locomotives were provided with very strong tubular oil coolers mounted on the external long sides of the locomotive body to take advantage of the windage. A pump forced the warm oil in a closed circuit through the cooler before returning it to the transformer. Since these coolers are only fully effective at top speed their surface must be made correspondingly large; for this reason they are relatively heavy. The next step was to provide oil coolers with a small surface, but effectively cooled by a separate fan. These coolers have now been developed to have a large capacity with minimum weight.

In connection with the cooling it would not be out of place to refer to the principles on which *transformer ratings* are based.

It was earlier usual, following motor practice, to rate transformers for certain times (e. g. 1/4 h, 1 h) but since the data generally only referred to a fraction of the normal secondary voltage it was mostly impossible to make reliable comparisons between different transformers. Another practice has therefore been adopted for some years past. The requisite transformer and cooler for a certain locomotive or motor-coach is determined on the basis of running schedules and line profiles. Thereupon the current is determined with which the admissible temperature rise of the oil and winding is adhered to on the uppermost tapping with the available cooler. The product of this current and the highest secondary no-load voltage is the *rated power* of the transformer, which characterizes its size. Another condition is naturally that when fulfilling a certain working schedule the transformer must not exceed the specified limiting temperatures.

The foregoing description of the development of Brown Boveri traction-type transformers is naturally far from complete. A whole series of questions which would interest transformer and traction engineers could only be cursorily mentioned or not dealt with at all. It should, however, suffice to show that the Company has always paid particular attention to this special field of transformer design. This tradition is a guarantee that every effort will be made in future to perfect that which has already been achieved.

(MS 668) *M. Itschner (E. G. W.)*

SWISS LIGHT RAILWAYS THE INNOVATIONS INTRODUCED BY BROWN BOVERI AND ANTICIPATED TREND OF DEVELOPMENT.

Decimal Index 625.61 (494)

Practically all of the Swiss light railways had to cope with very intense traffic throughout the war, with the result that their revenue greatly increased. The Swiss Federal Law of the 1st November, 1939 (the so-termed Private Railway Assistance Bill) provided for financial assistance and loans from the Confederation for technical renewals and improvements. In this way they were able to consolidate their financial position and modernize their rolling stock. In the interim, Brown Boveri had developed a whole series of new designs which met the requirements of the light railways for the modernization of their fleets of locomotives and motor-coaches with a view to giving better service to the travelling public.

(a) *Importance and Extent of the Swiss Light Railways.*

The light railways banded together in the "Verband schweizerischer Transportanstalten" (V. S. T.) comprise:

1. All rack-and-pinion and funicular railways and tramways.
2. All narrow-gauge railways.
3. All standard-gauge private railways.

With the exception of the Swiss Federal Railways, therefore, practically all of the Swiss railways are of the "light" class. In many cases, however, they have grown beyond their original purpose. A case in point is the Rhætian Railway which operates a system of about 450 km in extent in the Canton of Graubünden (Grisons). Another example is the Furka-Oberalp Railway running for a total distance of 97 km from west to east and connecting Brig in the Canton of Wallis with Disentis in Graubünden.

The Swiss light railways are operated by 136 companies and cover a total distance of 2890 km, practically as great as that of the Swiss Federal Railways (2894 km). Motor-bus services and trolley-bus routes of an aggregate route length of 520 km, which fall into the same category, are not included in this total.

(b) *Electrification of Swiss Light Railways.*

The Swiss light railways are now practically all completely electrified or in course of electrification. The following are still outstanding:—

Standard railways.

- Sursee - Triengen
- Uerikon — Bauma
- Bulle — Romont
- Porrentruy — Bonfol
- Saignelégier — Glovelier
- Wil — Weinfelden — Kreuzlingen (Mittelthurgaubahn)

Narrow-gauge railways.

- Les Brenets — Le Locle
- Saignelégier - La Chaux-de-Fonds
- Ponts-de-Martel — La Chaux-de-Fonds
- Liestal — Waldenburg (Waldenburgerbahn)

Rack-and-pinion railways.

- Brienz — Brienzer Rothorn
- Capolago — Generoso Kulm (Monte Generoso-Bahn)

The only current systems coming into consideration for the electrification of light railways are either single-phase with a frequency of $16^2/_3$ cycles and a contact-wire voltage of 15,000 V, as in the case of the Swiss Federal, Lötschberg, Emmenthal–Burgdorf–Thun, Lake of Constance–Toggenburg, Swiss South-eastern, and Yverdon–Ste-Croix Railways, or 10,500 V as for the Rhætian, Visp-Zermatt, Furka-Oberalp, and Schöllenen Railways, or d. c. with contact voltages of 550–2200 V or more.

Fig. 1. — Contented passengers become staunch patrons of the railways.

The gauges are 750, 800, 1000, and 1435 mm. The load on the driving axles must not exceed 11 t for the narrow-gauge and 20 t for standard-gauge railways.

Not all railways are worth electrifying. In the very first place electrification is a capital investment, which from a purely commercial point of view can only prove a paying proposition when a certain traffic density is attained or exceeded. Electrification may, however, be necessary due to the shortage and high price of solid and liquid fuels; this has been experienced during war and post-war periods. The Mittelthurgau Railway, for instance, is still not worth while electrifying owing to the slight traffic; the line is at present operated with a small number of steam locomotives and Diesel motor-coaches.

Prior to the war, all local railways, with the exception of those of a special nature, suffered greatly from automobile competition. To-day, with tyres for automobiles and bicycles in short supply, liquid fuels rare and expensive, and the zest for travel growing daily, the light railways are passing through a prosperous period. They can and should modernize their equipment and incorporate as many as possible of the advantages the automobile has brought.

(c) *What Innovations has Brown Boveri introduced on the Light Railways?*

The motto of all branches of engineering would appear to be "Speed and still more *speed*". No matter where we look efforts are everywhere being made to shorten processing times or increase production or transport speeds. This applies naturally in the very first place to railways. On the other hand, there is a greater call for increased *safety* and more *comfort*, a modern requirement for which automobile competition is responsible. Overruling all of these factors is the question of *economy* to which in future greater importance will again have to be attached than in war-time.

It is immaterial whether the transport undertaking is an adhesion, rack-and-pinion, or funicular railway, or a tramway; the chief question is, firstly, how can the speed be increased and rolling stock thus turned round more quickly and personnel and equipment better utilized, and, secondly, how can the travelling public be better served and economy as a whole increased. The deciding factor here is not the maximum speed, but the total time in which the cycle is completed, i. e. the commercial or travelling speed.

Increased running speed not only involves shorter halts at stations – a stipulation which is justifiably made time and again in Switzerland – but also greater acceleration and shorter braking paths. It is very important that after compulsory speed reductions, e. g.

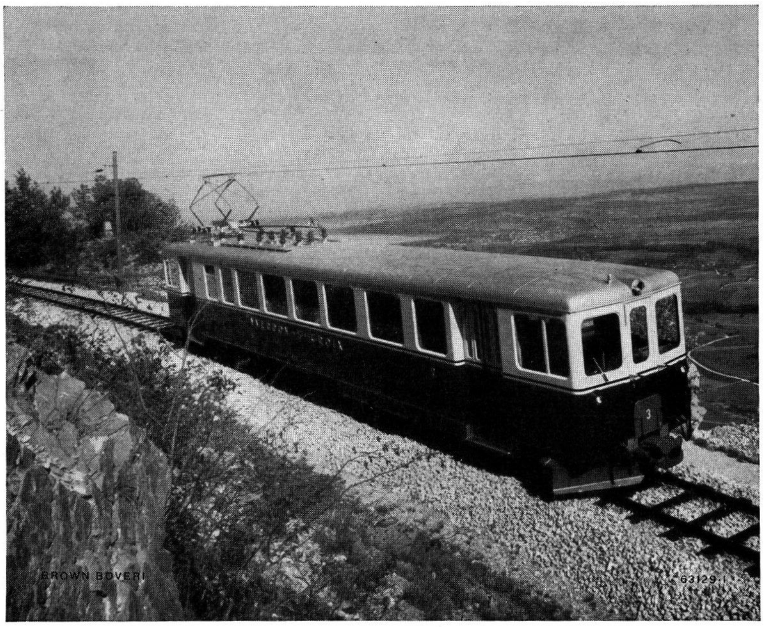


Fig. 2. — Modern passenger motor-coach type BCe 4/4 of the Yverdon—Ste-Croix Railway, single-phase 15,000 V, $16^2/_3$ cycles, gauge 1 m, 620 H.P. at 44 km/h, maximum running speed 65 km/h.

Brown Boveri spring drive, air-blast high-speed circuit-breaker, motor-driven cam-operated tap-changing switch, radially-laminated transformer, regenerative brake for the entire weight of the train. Contact wire system supplied directly from Swiss Federal Railways system.

due to track repairs or adverse signals, the maximum speed admissible for the section of track in question should again be attained as quickly as possible. It is therefore only natural that every effort should be made to reduce the weight of the locomotive or motor-coach and the rotating masses to a minimum and to fit as high a power as possible — or even an excess — to permit the train to be accelerated from already high speeds and thus again be brought up to the maximum admissible speed within the shortest possible time.

There are various ways of attaining these ends, either on the electrical or mechanical sides of the locomotive or motor-coach, or on both sides concurrently. The improvements can be incorporated both in new equipment or when modernizing old vehicles. Modernization schemes were very popular during the war, since they enabled material to be saved, promoted work, and permitted short delivery times to be quoted.

Brown Boveri have systematically developed a number of innovations in an endeavour to meet the foregoing requirements. Details of some of the equipments supplied will be found tabulated overleaf.

(d) *Prospects.*

Mechanical Details. Space will not allow of mountain and funicular railways and thermal and thermoelectric locomotives and motor-coaches to be dealt with, although a large number of the principles given here can also be applied directly to these railways. What form will the future a.c. or d.c. locomotive or motor-coach for local and interurban railways take from the point of view of the designer? In the great majority of cases it will be a bogie vehicle built for high speed with a moderate axle load. All axles will be drivers, the hourly rating per axle 400 – 500 H.P. for gauges up to one metre and up to 1000–1200 H.P. for standard gauge. The bogies will be as far apart as possible and the centre pin located low down, approximately at axle height. The drawbar and buffer gear will be fixed on the cab of the locomotive, the mass of the bogie concentrated around the centre pin. The axle bearings, generally of the roller type, will be linked to the motor-bloc or the bogie frame by levers, no longer being borne in axle boxes gliding in axle bearing guides, which are exposed to

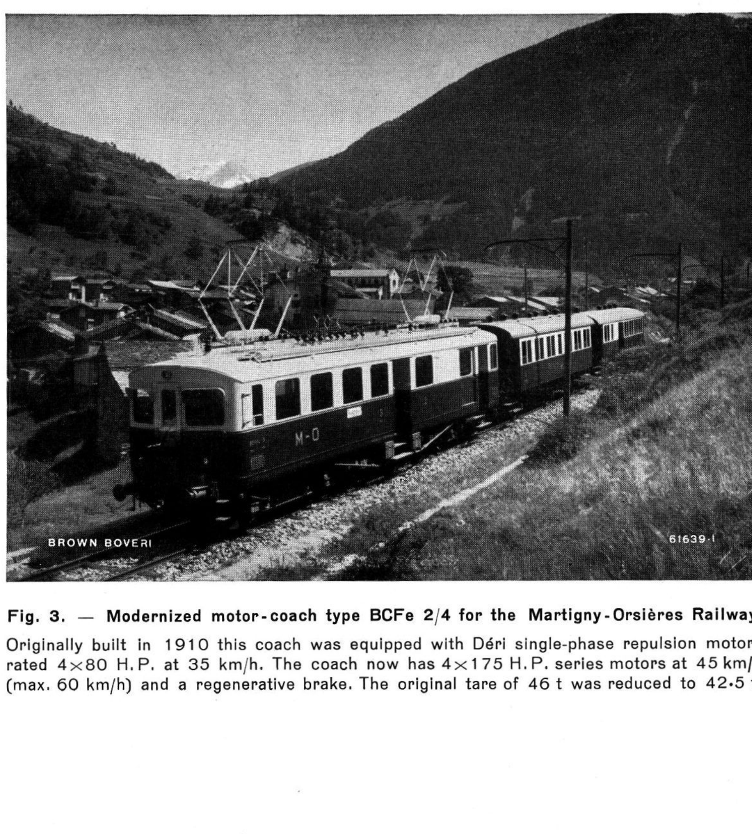


Fig. 3. — Modernized motor-coach type BCFe 2/4 for the Martigny-Orsières Railway.

Originally built in 1910 this coach was equipped with Déri single-phase repulsion motors rated 4×80 H.P. at 35 km/h. The coach now has 4×175 H.P. series motors at 45 km/h (max. 60 km/h) and a regenerative brake. The original tare of 46 t was reduced to 42.5 t.

Characteristic data of a number of Brown Boveri equipments for Swiss light railway locomotives and motor-coaches since 1939.

BB = Brown Boveri. MFO = Maschinenfabrik Oerlikon. SAAS = Soc. An. Ateliers de Constructions Sécheron.

Single-phase

Railway	kV	Gauge m (S = standard)	Year commissioned	Number equipments	Type (Mc. = motor-coach, Loco. = locomotive)	Total hourly rating H.P.	Total weight empty t	Specific power H.P./t (empty)	Max. speed km/h	Overall length over buffers m	Weight per m length kg/m	Current collectors: Number, Mode of operation	High-voltage circuit-breaker or cut-outs	Main transformer: Continuous kVA (REB rules)	Main transformer: Weight kg with oil	Main transformer: Spec. weight kg/kVA (with oil)	Control: Type	Control: Notches Power	Control: Notches Braking	Motors: Number	Motors: Weight kg without drive	Motors: Hourly rating kW	Motors: kg/kW (1 h) without drive	Ventilation	Max. service speed r.p.m.	Drive	Bogie	Electrical brake	Remarks
	General data											Special features																	
Rhætian	10·5	1	1940	4	Mc. BCe 4/4	620	37·5	16·8	65	18	1950	2 pneumatic MFO	Cut-out MFO	350	3670	10·5 with forced cooling MFO	On-load tap-changing sw. electropneum. drive MFO	12	22	4	834 BB and MFO	114	7·3	Self	2470	BB spring drive	—	Rheost. (1)	(1) With motors separately excited by spec. dynamo
Swiss South-eastern	15	S	1940	8	Mc. BCFZe 4/4 CFZe 4/4	980	43	23	80	19·6	2200	1 pneumatic	Roof cut-out	450	4010	9·0 Conventional design	Traction MFO Regen. BB	12	21	4	M F O					Tram-suspension	—	Regen. with condenser (1)	(1) Automatic adjustment by variable condenser
Furka-Oberalp	11	1	1942	2	Mc. BCFe 2/4	584	35	16·8	55 adh. 30 rack	16·7	2100	1 pneumatic MFO	Cut-out	300	3610	12 Natural cooling SAAS	Cam-operated controller with electrical drive	12	26	2	1662	215	7·8	Forced	2250	Tr. susp. with double transm.	—	Resistance (1)	(1) With motors separately excited by spec. dynamo
Bern-Lötschberg-Simplon	15	S	1944	2	Loco. Bo-Bo	4000	80	50	125	15·6	5200	2 pneumatic	Loco. air-blast cir.-br.	2700	9400	3·5 BB rad. lam. core	High-voltage control	28	34	4	4100	735	5·55	Forced	1200	BB disc drive	—		
Martigny-Orsières	8	S	1944	2	Modernized Mc. BCFe 4/4	700	45	15·5	60	17·3	2600		Roof cut-out	410	2650	6·5 BB rad. lam. core	Cam-operated controller hand drive	12	12	4	1100	128	8·7 nose-suspended	Self	2400	BB tram suspension	—	Regen. with condenser (1)	(1) Regenerative equipment rigidly adjusted
Régional du Val de Travers	15	S	1944	2	Mc. CFe 2/4	560	42	13·3	75	20·5	2050	1 pneumatic	Roof cut-out	403	2735	6·8 BB rad. lam. core	Cam-operated controller with electrical drive	12	–	2	1370	206	6·65	Self	2200	BB spring drive (1)	—	—	(1) Drive alone weighs 465 kg
Yverdon-Ste-Croix	15	1	1945	3	Mc. BCe 4/4	600	36	16·7	65	18·8	1900		Roof-mounted air-blast circuit-breaker	430	2735	6·4 BB rad. lam. core		12	12	4	850	114	7·4	Self	2300	BB spring drive (2)	—	Regeneration with condenser (1)	(1) Regenerative equipment rigidly adjusted (2) 360 kg
Yverdon-Ste-Croix	15	1		2	Mc. BCe 2/4	300	25	12	65	14·4	1740			200	2120	8·3 BB rad. lam. core		12	12	2	850	114	7·4	Self	2300		—		
Fribourg-Morat-Anet	15	S	Building	4	Mc. BCe 4/4	1000	56	18	120	22·7	2450	2 pneumatic		650	3700	5·7 BB rad. lam. core		18	18	4	1390	184	7·5	Self	3000	BB spring drive 520 kg	Simplex total 10·9 t		(1) Exciter voltage automatically adjusted with induction regulator
Fribourg-Morat-Anet	15	S		2	Modernized Mc. BCFe 2/4	500	47	10·8	120	21	2250			345	2900	8·4 BB rad. lam. core		18	18	2	1390	184	7·5	Self	3000				(1) Regenerative equipment rigidly adjusted
Rhætian	10.5	1		4	Loco. Bo-Bo	1600	46	35	75	12·1	3800		Loco. air-blast cir.-br.	1132	6200	5·5 BB rad. lam. core	High-voltage control	23	–	4	1400	294	4·8	Forced	2100	BB spring drive 550 kg	—	Regeneration MFO	—
Emmental-Burgdorf-Thun	15	S		7	Mc. CFe 4/4	1120	53	21	90	22·7	2330	2 pneumatic MFO	Roof air-blast cir.-br.	660	4850	7·4 with forced cooling MFO	Contactor control SAAS	18	18	4	1420	205	6·95	Self	2330	BB spring drive	—		—

Direct current

Railway or Tramway	General data: V	Gauge m	Year commissioned	Number equipments	Type Mc. = motor-coach	Total hourly rating H.P.	Total weight (empty) t	Specific power H.P./t (empty)	Max. speed km/h	Overall length over buffers m	Weight per m length kg/m	Special features: Current collectors Number Mode of operation	Control: Type	Number of notches: Series	Parallel	Shunt	Braking	Motors: Number	Weight without drive kg	Hourly rating kW	kg/kW (1 h) without drive	Ventilation	Max. service speed r.p.m.	Drive	Bogie	Electrical brake	Remarks
Zurich Municipal Tramways	550	1	1941 /45	18	Lightweight tramcar Ce 4/4	200	12·9	15·5	60	13·5	960	1 Hand	Electromagnetic contactor	12	8	1	12	4	250	37	6·75	Self	3330	BB disc	Simplex (1)	Rheost. Rail	(1) With 2 motors and drive 2950 kg
Chemin de fer de la Gruyère	900	1	1942	3	Mc. Ce 4/4	550	27·5	20	75	16·7	1650	2 Pneumatic	Multi-notch (pneumatic drive) (1)	15	10	2	15	4	990	101	9·8	Self	2700	BB spring	—	Rheost.	(1) Line-breaker, automatic multiple-unit control
Aarau-Schöftland Railway	750	1	1944	1	Modernized Mc. CFe 4/4	332	25	13	55	15·15	1660	1 Hand	Multi-notch platform controller (1)	12	8	2	12	4	1060	61·2	17·3 nose-suspended	Self	2000	Tram	—	Rheost.	(1) In conjunction with a group of electro-magnetic contactors
Montreux-Oberland Railway	900	1	1944 /45	6	Mc. CFe 4/4	600	35·7	17	75	16·5	2150	2 Pneumatic	Electro-magnetic contactors	12	8	2	12 Rheo. 31 Reg.	4	800	110	7·3	Self	2600	BB spring	—	Rheost. Regen. Rail	—
Wynental Railway	750	1	Building	1	Mc. Ce 4/4	385	25·2	15·3	60	15·8	1600	1 Hand	Electro-magnetic contactors	13	8	2	13	4	870	71	12·4 nose-suspended	Self	2800	Tram	—	Rheost. Rail	—
Lugano-Tesserete Railway	1000	1	Building	1	Modernized Mc. BCFe 4/4	334	22	15	50	15·1	1450	1 Hand	Multi-notch platform controller	13	9	2	12	4	1020	61·5	16·5 nose-suspended	Self	2500	Tram	—	Resist.	—
United Berne-Worb Railway	750	1		2	Mc. Ce 4/4 (1 modernized)	400	23	17·4	60	16·3	1410	1 Pneumatic	Electromagnetic contactors (1)	12	8	2	13	4	510	73·5	7	Self	2800	BB disc	Simplex	Rheost. Rail	(1) Multiple-unit control and double traction

dust and dirt, usually become loose and noisy, and are subject to great wear and require much upkeep. Articulations will be borne in silent-blocs free from play and without chatter. The silent-blocs compensate for small kinematic or assembly errors.

All components will have the lowest possible weight without exaggerated use of expensive light metal alloys, great care being given the question of constructional strength. The rotating masses must be kept as small as possible and the dead weight on the rails reduced to a minimum, possibly being forced down practically to the wheel rims by inserting rubber or springs in the wheels, or eliminated altogether by employing pneumatic tyres.

The drive will be flexible, of the individual axle spring or elastic disc type, the high-speed motors either being mounted on the spring-borne frame or forming a motor-bloc resting on springs on the axles. Parts subject to friction and wear and requiring lubrication should be avoided wherever possible. This reduces the most expensive service item, i. e. maintenance.

The bogie will be of lightweight and sturdy construction. In cases where a frame is provided at all this will be fabricated by welding from channel steel girders to form a two or three-axle motor bogie; in the latter case the centre axle will have limited lateral play.

The complete bogie will be carefully galvanized or metallized if not already chiefly constructed of rustless steel.

The bogie gives the locomotive or motor-coach its excellent running properties, and thus contributes considerably to travelling comfort, as well as having a decisive influence on the cost and maintenance of the locomotive. The motor, drive, and bogie should be supplied by the same makers. It is only in this way that fundamental advances are to be made in bogie design. The firm constructing the best bogie will win the competition for the best locomotive or motor-coach of the future.

The locomotive or coach bogie will have to be made shock and splinter-proof to a higher degree than hitherto, wood being avoided as far as ever possible. All-steel bogies of tubular construction, integral with the frame, will be built. Particular care must be paid to ventilation, heating, and elimination of noise.

For the passengers' safety more and more remote and automatically operated doors must be provided, possibly in conjunction with retractable footsteps which definitely prevent jumping on and off the vehicle while in motion.

Electrical Details. The electrical side is much more comprehensive than the mechanical and affords a larger number of alternatives. In the first place there is the current system. Where the Swiss light railways are concerned this is generally more or less settled. If such is not the case or in the event of modernization schemes it must first be investigated whether amalgamation with other railways is possible or whether the same vehicles may have to run over on to other systems. A case in point is the single-phase system of the Swiss Federal Railways with a low frequency and a high voltage on the contact wire, from which so many light railways have been able to take a direct supply, e. g. the Emmenthal-Burgdorf-Thun, Bodensee-Toggenburg, Swiss South-eastern, Yverdon-Ste-Croix and many other railways. It is possible to travel from St. Moritz or Schuls-Tarasp to Zermatt and Göschenen with the same gauge and the same current system and to interchange the rolling stock of the communicating railways. The main system of the Rhætian Railway and the Chur-Arosa and Bernina Railways have, it is true, the same gauge and are connected together, but have two different electrical systems and three different contact wire voltages. Interchanging of the motive rolling stock here is difficult and involves expensive and complicated equipment. An ultimate change-over from direct current to single phase is hardly conceivable owing to the high cost involved.[1]

Future locomotives and motor-coaches for the Swiss light railways, no matter whether designed for single-phase a. c. or d. c., will more frequently have a single pantograph collector with a double cradle and carbon sliding pieces to save contact wire wear and diminish interference with wireless reception through the reduced sparking. It must be of particularly lightweight and stable design and ensure a constant contact pressure under all contact wire conditions and at the maximum running speeds.

The main circuit-breaker will be of the high-speed type capable of clearing short circuits and overloads in the shortest possible time to keep damage down to a minimum. In the case of a. c., air-blast circuit-breakers will be employed, which eliminate oil and hence the fire and explosion hazard.

Where a. c. systems are concerned the transformer has a large number of tappings and for high power is designed for high-voltage control, the core being of the radially-laminated type and the dimensions and oil content of the smallest.

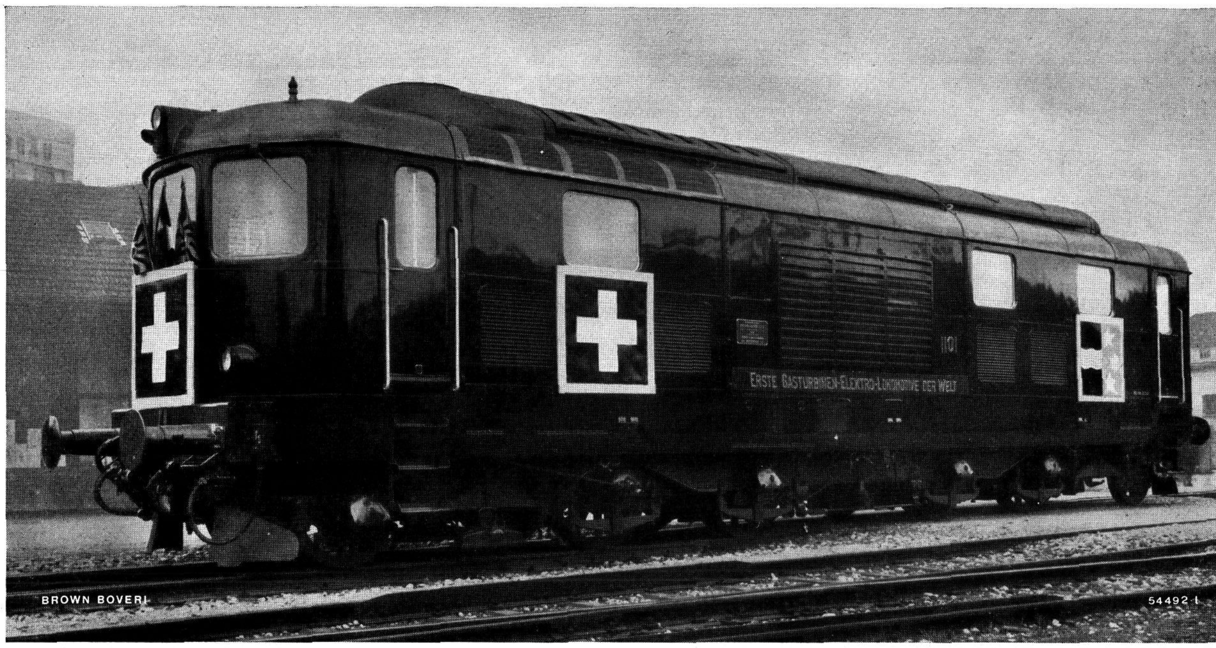
The control gear will comprise a cam-operated controller or be of the contactor type with a large number of steps and operating at high speed. The traction motors will be automatically or forced ventilated, while peripheral speed and temperature rise will be pushed up to the admissible limits, glass fibre being used to insulate the windings. By employing ball or roller bearings and high speeds it is intended to utilize the material to the utmost, although care must of course be taken to allow a certain reserve of power, since occasional heavy overloads are unavoidable on railways. More attention must be paid to quiet running.

Every electrical vehicle should be equipped with an electrical brake, either of the rheostatic or regenerative type, according to the special conditions of the railway in question. There is no more economical and elegant method of braking than the electrical. It wears no material, produces no brake dust (so detrimental to electric machines), is practically noiseless, and requires no maintenance.

Standardization. Standardization will necessarily come more and more to the fore in Switzerland in the post-war period, particularly in the case of the light railways. The country can no longer afford to allow even the smallest railway to order small numbers of vehicles more or less "to measure", to meet their alleged individual interests. Commissions have already been set up which under the auspices of the Swiss Federal Transport Department are hard at work to see whether three or four standard types of tramcars would not suffice and how standard trolley buses can be built which will meet both Swiss and export conditions. It is to be hoped that standardized electric interurban motor-coaches and local railway locomotives will soon follow. It is clear that all of these Swiss standard traction vehicles will have to be constructed in conformity with modern principles, and that their design should to a certain extent be adaptable and capable of extension as well as permit of universal application. It must, however, above all be possible to manufacture them in large numbers, i. e. cheaply for stock.

(MS 671) *E. Schroeder. (E. G. W.)*

[1] The single-phase system with a frequency of 50 cycles with which the German State Railways electrified the so-called Höllental Railway (Freiburg-Neustadt and Titisee-Seebruck) before the war and which appears to attract a number of foreign railways in their rehabilitation programmes, will probably never be introduced into Switzerland.



The first gas-turbine locomotive in the world formed one of the chief attractions of the celebrations in connection with the commemoration of the fiftieth anniversary of the foundation of the firm in 1941.

THE BROWN BOVERI GAS-TURBINE LOCOMOTIVE.

The service results obtained with the world's first gas-turbine locomotive built by Brown Boveri are worthy of special note. The following series of three articles deals with the experience made during the test runs and trial scheduled service, the design problems involved, the development prospects of the gas-turbine plant, and the constructional features and possibilities of the gas-turbine locomotive.

I. SERVICE EXPERIENCE WITH THE 2200 H. P. GAS-TURBINE LOCOMOTIVE SERIES Ae 4/6 No. 1101 OF THE SWISS FEDERAL RAILWAYS.

Decimal Index 621.335.2-833.8

1. The gas-turbine locomotive built by Brown Boveri for the Swiss Federal Railways was described in detail in the May 1942 issue of this journal, particulars of general layout, capacity, and of a technical and economic nature being given; the initial working experience was cursorily referred to on page 85 of the January/February 1944 number. Hereafter, a general survey of results, measurements, special tests, and experience to date is given. It enables conclusions to be drawn as to the merits of the new locomotive from the point of view of service and economy, the fields of application for which it is best suited, and the lines on which development is to be continued. During the building stage considerable difficulty was experienced in obtaining the necessary material, while on the completion of the locomotive the shortage of fuel had become particularly acute. Thanks to indefatigable efforts and the comprehension and courtesy of the Swiss Federal Railways it nevertheless proved possible to make a series of test runs and to operate the locomotive for a long period in scheduled passenger train service.

2. The thermal set successfully passed the official works tests on the 20th May, 1941, while assembly of the entire locomotive was completed on the 1st September of that year. The first runs were made on the same day without incident. The official trials took place on the 5th September, 1941, without any trouble whatsoever, over the Basle-Koblenz-Eglisau-Schaffhausen-Stein a. Rh.-Romanshorn-Winterthur route. On the occasion of the commemoration of the fiftieth anniversary of the foundation of the firm in the early autumn of 1941 the fittingly decorated gas-turbine locomotive (see illustration above) was employed for extra runs from Zurich and Olten to Baden, which proved a notable feature of the jubilee celebrations.

Subsequently, a series of test runs were made according to schedule and without incident, the locomotive completing 2000 km by the end of 1942, fulfilling the specified conditions, and proving its serviceability.

3. The specification called for a combustion chamber designed for Diesel oil, since prior to the war the difference in price between Diesel and bunker or boiler oil in Switzerland was only very slight; as a result it was possible to dispense with the additional equipment necessary for burning bunker oil. From the point of view of export, however, combustion chambers for bunker oil are of much greater importance since in the case of oil-bearing countries or railways in close proximity to the coast heavy bunker oils are much cheaper than Diesel oil. Since bunker oil has a high viscosity (2—30 ^{0} Engler at 20 ^{0} C) it must be preheated, whereas the viscosity of Diesel oil remains sufficiently low (0·5—1·5 ^{0} Engler at 20 ^{0}) for all atmospheric temperatures occurring in Switzerland. To prove that bunker oil can be employed without difficulty, the consent of the Swiss Federal Railways was obtained to fit the requisite preheating equipment in the locomotive. Proper circulation of the bunker oil in the tube system can only be ensured by preheating it to at least 20 ^{0} C by heating elements lodged in the fuel tank, the energy being supplied by the Diesel-driven generator. To obtain satisfactory pulverization of the bunker oil it is necessary to bring its temperature up to approximately 100 ^{0} C; this is achieved with a system of tubes incorporated in the air preheater through which the exhaust is made to pass. Diesel oil is used to take the combustion chamber into service, it being changed over to bunker oil subsequently. On the occasion of a test run with the dynamometer car from Basle via Zurich to Chur and back on the 16th December, 1942, immediately after conversion of the locomotive to bunker oil operation, the specific fuel consumption was found to be the same as with Diesel oil, while proof was furnished that bunker oil can be smokelessly burned at all loads and during all regulating cycles.

During the test run, referred to above, the fuel consumption, with bunker oil grade III having a lower calorific value of 10,000 cal/kg, was found to be 19 g per km/h for the express run Basle-Zurich-Chur (trailing load 488 t; total train weight 581 t) and 20 g per km/h for the express run Chur-Zurich-Basle (trailing load 292 t; total train weight 385 t). The maximum power developed by the gas-turbine set was 2800 H. P. (metric) for a short period, while a speed of 128 km/h was also attained for a short time (designed maximum speed of locomotive 110 km/h).

4. Particularly interesting is the application of the gas-turbine set for braking purposes in conjunction with electrical power transmission on down-grades. With the burner flame greatly reduced or even entirely extinguished the increase in volume of the fuel is considerably diminished or eliminated as the case may be; the output of the gas turbine is thus smaller than the power required to drive the compressor and to maintain the speed of the set, extraneous power must be applied to the gas-turbine shaft.

Tests were carried out on the Münchenstein-Delsberg route with braking equipment provisionally fitted in the locomotive, with the following results:—

With comparatively little additional weight a braking power can be absorbed on a given down-gradient which corresponds to the power output on the same up-gradient. Assuming that no compressor air is blown off a power of approximately 2200 H. P. can be absorbed by the compressor at 5200 r. p. m. with a small burner flame in the combustion chamber. In the case of the equipment tried out the traction motors, which are separately excited in a suitable manner, supply the main generator, which running as series motor drives the gas-turbine set. The fuel supply to the combustion chamber is well throttled, so that the major portion of the blower driving power is supplied not by the gas turbine, but by the kinetic energy of the train on the down-gradient.

5. Careful tests were carried out to clear up the question of the behaviour of the gas-turbine locomotive in tunnels. Points to be settled were whether the intake air quantity (which being of the order of 20 m^3/s is very large) is adequate to restart the locomotive in badly ventilated single-track tunnels and whether the carbon monoxyde content of the exhaust constitutes a danger for the personnel and passengers on the train. A series of test runs made in the single-track St. Ursanne-Courgenay tunnel on the 22nd December, 1942, furnished proof that such is not the case. Special complementary measurements were made by the chemical laboratory staff of the Wimmis Gunpowder Works directly in the exhaust stream, and the following is a translation of an extract from the official test report:—

> "The carbon oxyde concentrations occurring in tunnels are less in the case of the gas-turbine locomotive than with steam operation, i. e. the CO content in tunnels through which the gas-turbine locomotive has passed is less — even under the most unfavourable conditions — than the values determined after the passage of a steam locomotive."

6. When increasing the output of the gas turbine by augmenting the quantity of injected fuel the rise in gas temperature occurring during the acceleration period should be limited to as short a time as possible. This is achieved automatically in that the servo-

field regulator of the main generator temporarily reduces the electrical load and after the higher speed is attained adapts it to the increased turbine output. In this connection test runs were made on the old Hauenstein line via Läufelfingen on gradients of 17 and 21 in 1000 to regulate the control gear to optimum starting conditions in service operation, whereby the specified starting conditions were fulfilled.

7. Shunting service with the Diesel-generator set alone supplying one single traction motor (i. e. without the gas-turbine set in operation) has proved to be extremely practical in service. With this arrangement continuous speeds up to 25 km/h can be obtained on the flat. This method of operation has also been used to determine the track resistance of the locomotive.[1]

8. During the gas turbine locomotive trials and thanks to the courtesy of the Swiss Federal Railways, the rare opportunity was afforded of carrying out special test runs with a dynamometer car to determine the locomotive resistance. The results of these, which have already been published in the pages of this journal,[1] form a valuable contribution to the subject of the resistance conditions of modern locomotives with individual-axle drive, since very few test results are to be found in the literature. These test runs also enabled the excellent running properties of the locomotive to be corroborated.

9. A fair amount of bunker oil having become available it was found possible to operate the gas-turbine locomotive for 297 days between the 23rd May, 1943 and the 18th July, 1944 in scheduled service on the Winterthur-Stein-Säckingen line, the electrification of which had not been completed at the time. During this period the locomotive covered roughly 50,000 km practically without incident, while the combustion chamber was in operation for 1614 hours (passenger and goods train hauling time plus standing times with the gas turbine running) and approximately 1560 starting operations were carried out. The gas-turbine set consumed about 30 l of lubricating oil, but the greater part of this was lost during overhaul work on the tube system. When it is remembered that the lubricating oil has to be changed after only a few thousand service hours, due to ageing, it will be realised that the gas-turbine plant has an extremely low lubricating oil consumption. During the scheduled trial service the gas-turbine locomotive was very poorly utilized due to the working conditions obtaining on Swiss Federal Railways local lines; the mean trailing load was only 100 t (instead of the 700 t necessary for full utilization of the gas-turbine set) and the mean running speed only 28·8 km/h (in lieu of approximately 70 km/h). These working conditions coupled with the frequent stops naturally resulted in a higher fuel consumption than given in section 3. On the other hand, from the point of view of the stressing of the thermal installation and the locomotive equipment (frequent stops and starts, shunting service, i. e. heavily fluctuating loads) this service constituted a far more severe test than express service over long distances with constant load in the vicinity of the normal rating.

The results of the scheduled service runs are very satisfactory. They proved that the features incorporated are fundamentally correct and that no alterations affecting the principles adopted will be necessary in future developments. Having met the specified conditions the locomotive was officially taken over by the Swiss Federal Railways on the 1st October, 1944.

The success of this remarkable technical venture was only possible through the comprehensive collaboration of the technical staff of the Swiss Federal Railways and the designers.

10. As the result of an agreement between the Swiss Federal Railways and the Société Nationale des Chemins de fer Français (SNCF) the gas-turbine locomotive was put into scheduled express service (mean trailing load 600 t) on the Basle-Strassburg line on the 30th October, 1945. The fuel employed is heavy marine boiler oil (viscosity 32° E at 20° C). The mean fuel consumption is 15 g/h/km. Features of operation here are trouble-free service and the very little maintenance required.

The SNCF organized demonstration runs with the gas-turbine locomotive from Paris between the 29th November and the 1st December, 1945, which aroused great interest in railway circles and amongst the public in general. The gas-turbine locomotive hauled regular trains with trailing loads up to 650 t between Basle and Paris; during these demonstration runs it covered roughly 2000 km without the slightest hitch. The locomotive is being retained in service on the Basle-Strassburg route.

11. From experience to date the gas-turbine locomotive is particularly suitable for long distance service in countries and regions with a moderate or cold climate and where cheap oil is available. The gas-turbine locomotive has proved that it is simple to operate and requires little maintenance so that the drivers quickly become familiar with this unconventional traction unit. Initial trouble inherent in all new designs was quickly and appropriately overcome. Experience to date clearly indicates in which direction development has to be continued.

(MS 662a) *A. E. Müller. (E. G. W.)*

[1] Brown Boveri Rev. No. 6, June, 1944.

II. THE LOCOMOTIVE GAS TURBINE.

Decimal Index 621.438 : 625.282

1. *Description and Mode of Operation of Plant.*

PRIOR to dealing with specific problems of the gas turbine it is proposed briefly to sketch the mode of operation of the plant with reference to Fig. 1.

The multi-stage axial-flow compressor C draws in air at 7 and compresses it to approximately 4 kg/cm^2 abs. This air is forced through pipe 8 — which is provided with expansion pieces 9 to take account of thermal expansion — to the tubular air preheater D which is heated by the exhaust of the gas turbine flowing transversally across the tubes. From the preheater the air passes on to the combustion chamber. The air necessary for the combustion of the fuel which is injected at 3 enters the combustion chamber at 1. The remainder of the air (approximately 90 %) is employed to cool the inner walls of the combustion chamber and is mixed with the gases through the slits 2. The air and gas of combustion are mixed at 4. This mixture — the actual driving agent — passes on to the gas turbine B and enters the air preheater D at 5, the exhaust escaping to atmosphere at a temperature of about 250° C through the slits 6. This air and gas system gives a compact installation with very short pipes.

Since the mean volume of the gas turbine driving agent is greater than that of the air in the compressor the power generated in the gas turbine is more than is necessary to drive the compressor. The excess is employed to drive the generator F through gearing E. The set is mounted on the frame G, which itself is only supported at three points in the locomotive, so that the elastic distortions of the locomotive are not transmitted to it.

Since the power which can be usefully employed is the difference between two large powers (assuming the gas turbine output to be 100 %, the compressor input is about 65 %), the thermodynamic efficiency of the compressor and turbine has a big influence on the useful power.

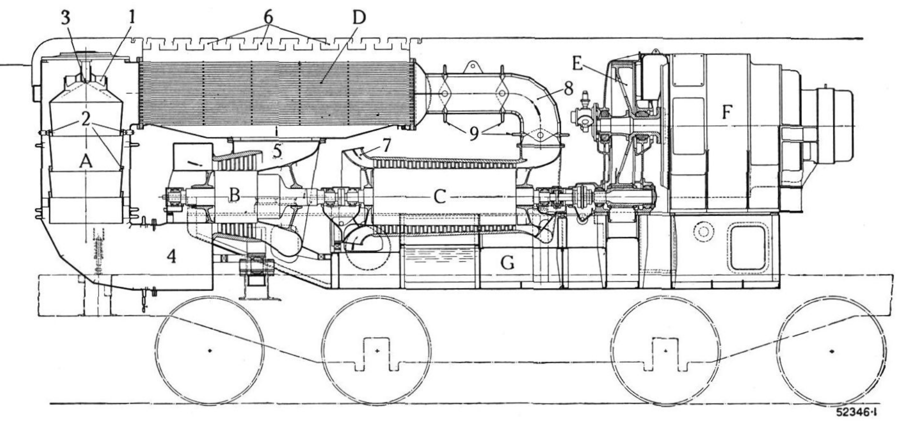


Fig. 1. — Section through gas-turbine locomotive set.

A. Combustion chamber. B. Gas-turbine. C. Axial compressor. D. Air preheater. E. Gearing. F. Generator. G. Machine frame.

The air heated in the preheater is partially employed as combustion air and enters the combustion chamber at (1). The major portion of the air serves for cooling purposes and is mixed with the combustion gases through the slits (2). (3) is the fuel nozzle. The driving gas enters the turbine at (4). The exhaust enters the air preheater at (5) and leaves the plant through the slits (6). The air enters the compressor at (7). The air pipe (9) is provided with expansion pieces (9) to take up the different heat expansions of the gas turbine set.

2. *Computed and Measured Efficiencies.*

From the foregoing section it will be clear that the thermodynamic efficiencies must be accurately known if the dimensions of the machines are to be correctly computed. The great experience obtained by the firm in the construction of numerous gas turbines and compressor sets, together with careful investigations into the individual losses of turbo-machines (losses in blade spaces, diffusors, branch pipes, and bends, as well as clearance losses) permits the thermodynamic efficiences of the machines and the pressure losses in pipes to be accurately predetermined and thus reliable power and thermal efficiency guarantees to be quoted.

The predetermined thermal efficiencies for the 2200 H. P. locomotive set, which were guaranteed are plotted on the graph of the measured values in Fig. 2. The guaranteed calculated values agree very well with the measured values. It must be mentioned here that the measured values were obtained with the same temperature ratio T_1/T_0 as the computed values. (T_1 =

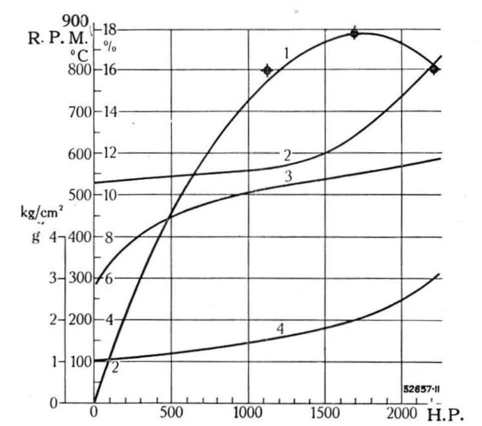


Fig. 2. — Operating data of locomotive set.

Abscissæ: Power at coupling in H. P.

Ordinates: 1. Thermal efficiency at coupling between gearing and generator in %.
2. R. P. M. of generator.
3. Gas temperature at turbine inlet in °C.
4. Air pressure at compressor outlet in kg/cm² g.

The points represent the computed data, the full lines the data measured in the test bay.

temperature at gas turbine inlet, T_0 = temperature of air intake).

The fuel consumption measured at no-load, about 23 % of full-load consumption, is also noteworthy.

3. *Check Measurements after a Year's Service.*

The thermal efficiencies measured after the first setting to work of the plant, referred to in section 2, were checked after nearly twelve months' operation of the locomotive on heavy bunker or boiler oil in normal scheduled service. The tests were made with the locomotive at a standstill, the energy produced by the generator being dissipated in a liquid resistance instead of being supplied to the traction motors. Such check tests are extremely difficult to make under running conditions since a constant load cannot be maintained for the requisite length of time. For accurate fuel consumption measurements, however, a lengthy test with the machine under steady-state conditions is necessary.

The misgivings to be found here and there in the literature that lengthy operation on heavy bunker oil might lead to blade erosion and a consequent increase in fuel consumption proved unfounded in the case of the locomotive set in question. This favourable result was only to be anticipated if it is recalled that the driving agent of the gas turbine is practically 90 % air. According to the size of the air preheater the excess air coefficient of a gas turbine is 8—12. This large excess of air enables the quantity of combustion air to be so selected that combustion is practially complete at all loads.

4. *The Behaviour of the Air Preheater.*

The air preheater gave no trouble as long as combustion conditions were normal. This was the case until the locomotive was placed at the disposal of the French National Railways by the Swiss Federal Railways for normal scheduled service on the Basle-Strassburg route, where it was operated on heavy marine bunker oil.

From experience the quantity of combustion air (i.e. the excess of air) must be adapted to the quality of the oil. For this purpose the ratio of combustion to cooling air can be adjusted by throttle valves. Owing to the cooling air regulating valve having become defective the excess of air necessary for the heavy bunker oil could not be adjusted, and it was not desired to take the locomotive out of service for the requisite length of time to effect the repair. As a result combustion was impaired and the preheater tubes became sooted up.

Notwithstanding the fact that the heat transfer was scarcely affected by the layer of soot and the pressure drop was only increased by an insignificant amount, the preheater was cleaned from time to time. On the eve of one of these periodical cleanings and while the locomotive was stationary a fire broke out in the preheater which damaged some of the air preheater tubes. It was found possible to effect a repair within a short time and the locomotive was again quickly ready for service.

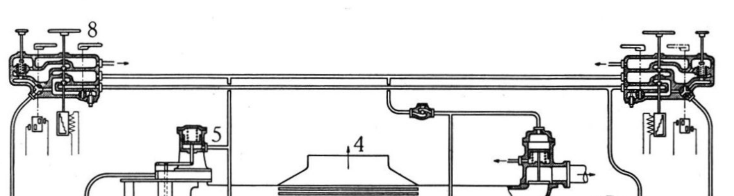


Fig. 3. — Diagram of gas-turbine locomotive control.

1. Gas-turbine.
2. Compressor.
3. Combustion chamber.
4. Air preheater.
5. Fuel nozzle.
6. Governor.
7. Servo field regulator.
8. Controller.
9. Fuel tank.
10. Control and lubricating oil tank.

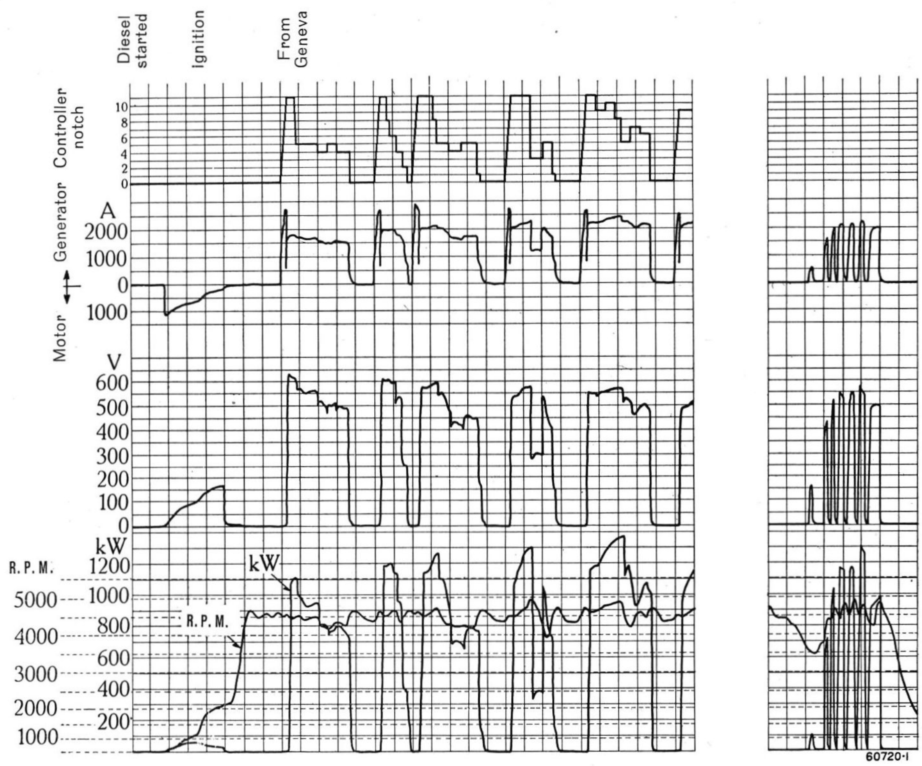


Fig. 4. — Section of chart recorded during the official acceptance tests.

Abscissæ : Time in minutes (one division = 1 minute).
Ordinates : Controller notch, generator current in amperes, generator voltage in volts, generator output in kW, R. P. M. of gas-turbine.

The tests in connection with the air preheater also corroborated the computed heat transfer figures to a high degree.

No traces of rust could be found on the tubes despite the fact that the gas-turbine locomotive was out in bad weather for weeks at a time.

The excellent agreement between the measured and computed values and the good experience made with the air preheater induced the Company to put forward gas turbines with large air preheaters, which have a fuel consumption of $\sim$ 210g/B. H. P/h. Gas-turbine plants with such a low fuel consumption cannot yet be considered for locomotives since it is impossible to lodge the requisite large air preheater in a locomotive. It is, however, probable that the near future will bring higher thermodynamic efficiencies and temperatures, and thus a lower fuel consumption without the necessity of increasing the size of the air preheater.

5. *The Control of the Gas-turbine Set.*

The principle of the control gear is shown in Fig. 3, oil under pressure being employed. The locomotive driver has only one single driving lever to operate (controller). A definite quantity of fuel and speed are adjusted with this lever, this giving a definite output. The servo field reguator protects the gas turbine against overloads. The control gear was exhaustively tested on the test bed. Fig. 4 is a section of the load chart recorded during the acceptance tests.

6. *Starting the Set.*

A Diesel engine of approximately 100 H.P. rating (i. e. of about 4·5 % of the rated output of the gas-turbine set) is employed for starting purposes, the plant being ready for service within about five minutes. The gas-turbine is started on Diesel oil since the heavy bunker oil has to be preheated before pulverization in the nozzle. The gas-turbine exhaust is employed for this purpose, the change-over to bunker oil being effected when the latter has attained the necessary temperature of about 80—100^0 C.

The consumption of Diesel oil is very slight, being only of the order of 1 % of the bunker oil consumption (assuming that the set is started on the average five times a day and is in operation for about ten hours).

7. *Working Experience with the Locomotive as a Whole.*

In conformity with the contract with the Swiss Federal Railways the locomotive had to operate for a whole year in normal service before being finally taken over. During this period, i. e. from the 23rd May, 1943, to the 18th July, 1944, it was taken out of service every month for a short time for inspection. In this time a total distance of 50,000 km was covered, the locomotive being 1614 hours in operation and having been started up 1560 times.

The fuel nozzle was cleaned at intervals of about 100 hours, it proving possible to effect this within the normal lay-over period of the locomotive.

During the whole of the operating period no trouble of any kind was experienced out on the line which involved taking the locomotive out of service.

8. *Comparison of Fuel and Lubricating Oil Consumption with that of Diesel-electric Locomotive. Influence of Air Intake Temperature. Fuel Consumption at Low Loads. Types of Fuel.*

The fuel consumption of the gas turbine is higher than that of a Diesel engine. This notwithstanding,

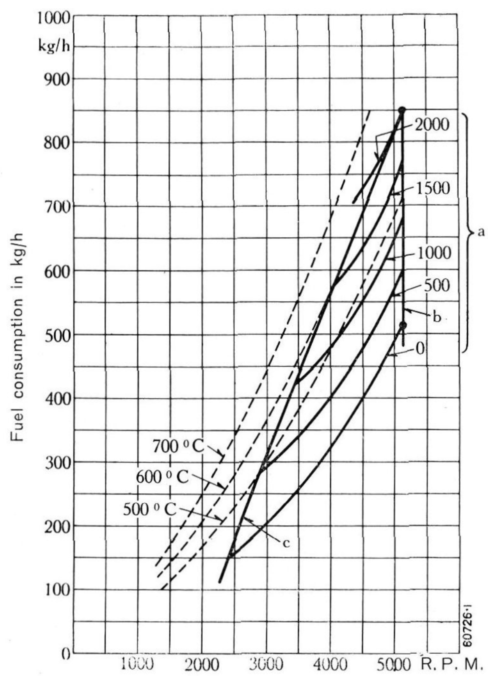


Fig. 5. — Fuel consumption in relation to revolutions, load, and temperature at gas turbine inlet.

Curves a. Power in H. P.
Curve b. Conditions with constant speed at all loads.
Curve c. Conditions with revolutions variable with the load.

It will be noticed that for a given load the fuel consumption is much less at low speeds than high. For instance at no-load and full speed it is about 500 kg/h, whereas at no-load and half speed it is only 150 kg/h.

it is economical, since the fuel is less expensive than in the case of Diesel engines due to the fact that cheap bunker oil can be used instead of Diesel oil, while the lubricating oil consumption is considerably less. Whereas the latter factor represents 10—30 %* of the fuel oil costs in the case of the Diesel engine it is so low in the case of the gas-turbine locomotive as to form an insignificant item on the score of economy. The lubricating oil consumption of the gas-turbine plant is less than 0·05 g/B.H.P./h.

For instance, assuming a bunker oil price of 60 % of the cost of Diesel oil and lubricating oil costs of the Diesel engine approximately 20 % of its fuel oil costs, a gas-turbine plant with an efficiency of 19 % is the equivalent of a Diesel engine with an efficiency of 38 % on the score of fuel and lubricating oil costs. Other points in favour of the gas turbine are the greater power which can be lodged in the locomotive and the lower maintenance costs.

A further advantage of the gas turbine is that its power and thermal efficiency increase with decreasing atmospheric air temperature. With an intake temperature diminishing from + 20 to — 10° C the power increases by about 40 % and the thermal efficiency by approximately 20 %. The excess power can be employed to drive a heating generator. This excess

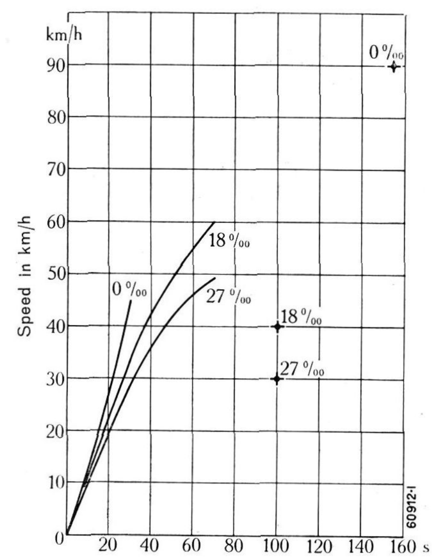


Fig. 6. — Starting tests with the gas-turbine locomotive.

Abscissæ: Starting time.
Ordinates: Speed in km/h.

The figures near the curves show the gradient of the line per 1000.

+ = Guaranteed values.
Measured values = full-line curves.

The trailing load during these test runs was 200 t, which was the guaranteed load.

power of the gas-turbine increases with sinking atmospheric air temperature in the same proportion as the required heating power. In cases where the train is heated electrically the electrical heating energy can be employed directly. Where steam heating is employed the excess energy can be utilized to produce steam in an electric boiler and thus enable the coaches to be heated with steam. The extra power cannot usually be employed to drive the locomotive since it is not

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* E. E. Chapman: "Steam vs. Diesel-electric power", Railway Age, July 26, 1941.

worth while making the generator and traction motors correspondingly larger for the relatively short time coming into consideration.

The fuel consumption of the set at low loads can be kept small if the speed of the gas-turbine is allowed to drop off with the load. In the case of the locomotive in question the revolutions are reduced to about 60 % at no-load. With a new locomotive the speed can be reduced to about 40 % by appropriate means. If this is done the no-load fuel consumption will only be of the order of 16·5 % of the full-load consumption.

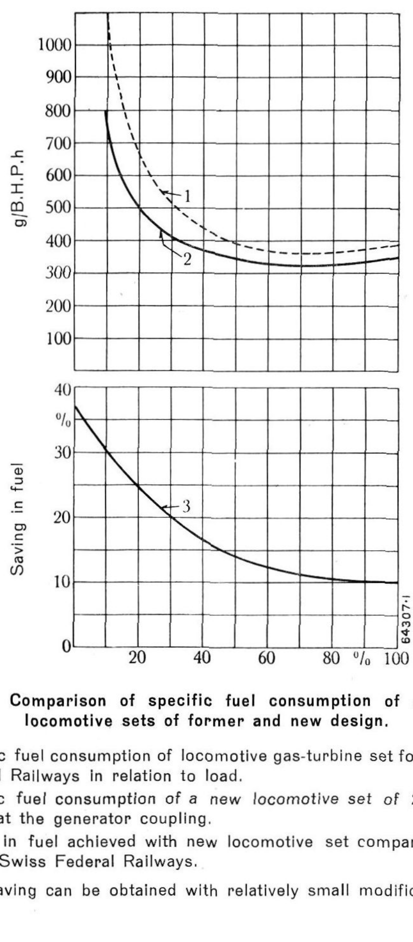


Fig. 7. — Comparison of specific fuel consumption of gas-turbine locomotive sets of former and new design.

1. Specific fuel consumption of locomotive gas-turbine set for the Swiss Federal Railways in relation to load.
2. Specific fuel consumption of a new locomotive set of 2500 H. P. rating at the generator coupling.
3. Saving in fuel achieved with new locomotive set compared to that of the Swiss Federal Railways.

This saving can be obtained with relatively small modifications.

Full-load cannot, however, be developed until the set has been accelerated from 40 to 100 % of the speed. A speed regulating lever on the controller enables the driver to vary the speed independently of the load. In this way the revolutions can be increased just before a higher load is required. The higher load can then be taken up at the required moment without delay.

In this connection the different regulation possibilities of the gas-turbine will now be gone into with reference to Fig. 5.

There are two boundary regulation cases which are employed:—

(a) Load regulation with constant revolutions of the set (vertical straight line b through abscissæ point 5200 r.p.m. in Fig. 5).

Advantage of this method of regulation:

Loads of 0—100 % can be instantly applied since the necessary quantity of air and the requisite speed are always available for all loads.

Disadvantage of this method of regulation:

Large fuel consumption at low loads.

(b) Load regulation by greatly reducing the revolutions at low loads (curve c in Fig. 5).

Advantage:

Low fuel consumption at low loads.

Disadvantage:

Before a higher load can be met the revolutions must first be accelerated to the value corresponding to the higher load, which takes a certain amount of time. The loading speed is thus lower than in case a.

If the locomotive has an additional speed regulating lever, as described above, advantage can be taken of the merits of the two methods of regulation, while the drawbacks are eliminated.

As long as only low loads are required the speed is reduced as low as possible to keep down fuel consumption. When a high load is expected the revolutions can be increased 20—30 s beforehand. As soon as the speed has attained the higher value the higher load can immediately be met. In the case of a locomotive this method of operation is readily possible since the driver can foresee such occurrences. Just prior to the departure of the train, at the approach of gradients, or for the rapid acceleration of the train after a run at reduced speed, the revolutions are increased.

This possibility of regulation makes the gas turbine flexible in operation and enables it to be adapted to the most difficult running conditions. The rate of acceleration is very great, as will be clear from Fig. 6.

In the normal scheduled service of nearly one year duration the locomotive was operated on bunker oil.

Any liquid fuel can be employed. Heavy bunker oil will probably mostly be used, since it is the least expensive in most countries. Vegetable or tar oils, however, can be utilized without difficulty.

9. *Present and Future Possibilities.*

A new locomotive could already now be built with a lower fuel consumption and a somewhat higher power. The new Brown Boveri standard set develops 2500 H.P. at the generator coupling. The reduction in fuel consumption compared with the Swiss Federal Railways locomotive will be seen from Fig. 7. At full-load it is about 10 % and at no-load approximately 37 %.

In the near future it should prove possible to build a locomotive with a rating of 4000 H. P. A locomotive driven by this set would have a weight-power ratio (without fuel) of about 39 kg/B. H. P.

Recapitulating: The gas-turbine locomotive is at present generally superior to the Diesel-electric locomotive when bunker oil costs only 50—60 % of Diesel oil. This factor will become more and more in favour of the gas turbine since the possibilities of this class of machine are very great. It is therefore in the interest of railway companies to become conversant with the gas-turbine locomotive already now, even in countries where its advantages over the Diesel-electric locomotive are not yet particularly evident.

(MS 662 b) *H. Pfenninger. (E. G. W.)*

III. POSSIBILITIES OF DEVELOPMENT OF THE GAS-TURBINE LOCOMOTIVE.

Decimal Index 621.335.2—833.8

1. *General.*

THE development of traffic in general and the consequent increasing competition between the different forms of transport available compel the railways to investigate the possibility of employing every new prime mover in traction service.

In contradistinction to air and road traffic railways involve relatively expensive installations, such as costly track systems, safety equipment, and rolling stock, which enable persons and goods of all classes to be transported to an extent and with a degree of safety scarcely attained by other means of land transport at the present time. The railways, which by reason of their very structure and mode of operation, carry the highest financial charges, are therefore obliged to take advantage of every possibility of reducing working and installation costs, in order to remain competitive.

It is therefore comprehensible that with the advent of a reliable gas turbine this class of machine should also have been tried out in traction service.

It was considerations of this nature which emboldened the Company to take up the study of a gas-turbine locomotive a few years ago and which subsequently led to the placing of the contract for the first gas-turbine locomotive in the world (see illustration on page 353) by the Swiss Federal Railways. As described in detail elsewhere in this number the new type of locomotive has come up to expectations and as a result of the long service period and the fundamental tests carried out provided a means of perfectioning this category of locomotive. The gas-turbine locomotive is a new type of thermal locomotive and, requiring no contact wire, is mainly suitable for service on lines at present operated by steam and Diesel locomotives. A cursory comparison with the latter gives the following striking differences.

The gas-turbine locomotive requires no water (thus eliminating the freezing hasard and avoiding expensive chemical feed-water treating plant) and its most important components are all rotating parts running at high speed, i. e. of light weight, so that it is particularly suitable for high powers. Owing to the motion of its power generating plant being entirely rotary the locomotive runs absolutely vibrationless. It is of very simple design and cheap, low-grade oil can be employed for its operation. Investigations concerning maintenance and running costs have shown that where cheap low-grade oil is available and long runs with high mean loads are possible, the gas-turbine locomotive is an interesting proposition on the score of both economy and service.

Other advantages afforded by the gas-turbine locomotive and which affect its economy are that the lubricating costs of the turbine set are extremely low, while maintenance costs are also less than in the case of a reciprocating engine (steam or Diesel). Experience with a large number of steam turbines, exhaust gas turbines of Velox boilers, and pressure-charging sets of Diesel engines, i. e. turbo-machines of a similar class, has corroborated this fact.

According to the maximum speed, power rating, and tractive effort a locomotive can be put forward which should prove attractive on the score of both weight and price.

The locomotive with electrical transmission built for the Swiss Federal Railways has a rating of 2200 H. P. at the generator coupling.

Improvements in the design of the turbine set now allow the rating to be pushed up to 2500 H. P., whereby the thermal efficiency is increased from 17·5 to 19·5 %.

The question of the most reliable power transmission from the turbine set to the wheels of the locomotive has also been given careful attention. The present stage of development of mechanical and hydraulic gears is not sufficiently advanced to permit their being seriously considered for locomotives of 2000 H. P. or over. On the other hand electrical transmission in all of its forms has been developed to such a high degree of perfec-

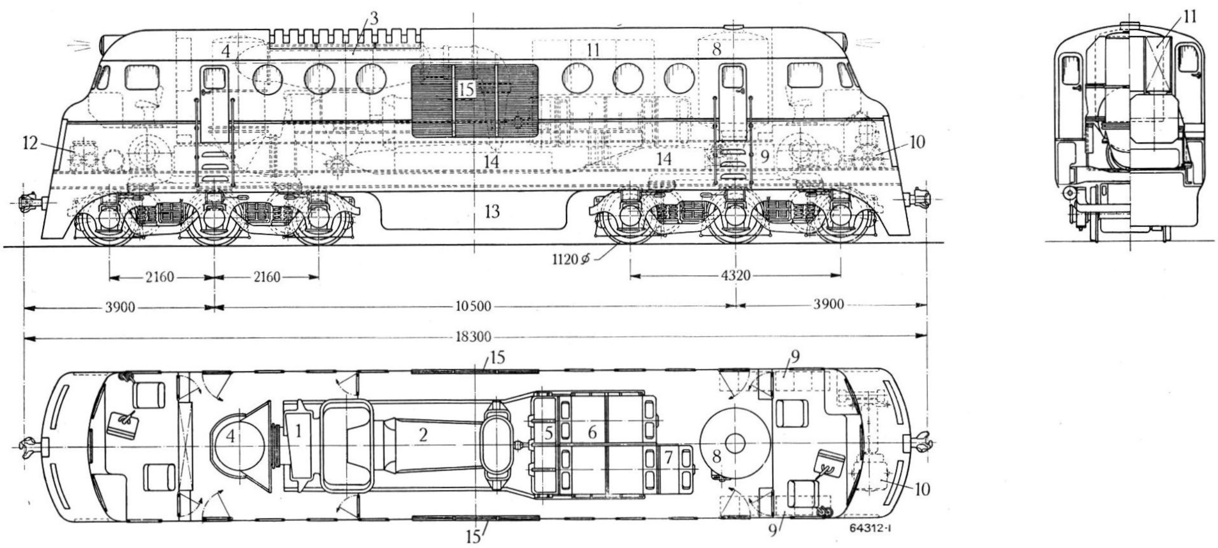


Fig. 1. — 2500 H. P. express locomotive.

1. Gas turbine.
2. Compressor.
3. Air preheater.
4. Combustion chamber.
5. Gearing.
6. Generator set.
7. Auxiliary generator.
8. Steam boiler for train heating.
9. Storage battery.
10. Diesel-generator starting set.
11. Electrical apparatus.
12. Brake compressor set.
13. Water tank for steam boiler.
14. Fuel tank.
15. Lubricating oil cooler.

Principle data of locomotive

Gauge	1·435 m	Weight of locomotive in running order	approx. 141 t
Diameter of driving wheels	1·120 m	Adhesion weight	approx. 94 t
Number of traction motors	4	Load per driving axle	approx. 23·5 t

tion for electric and Diesel-electric locomotives that it can be adopted for gas-turbine locomotives without hesitation.

The mechanical construction of gas-turbine locomotives can follow the general lines of electric locomotives.

The basic designs for the construction of modern gas-turbine locomotives are therefore already available. Experience with the first gas-turbine locomotive are so satisfactory that the Company is now in a position to quote for narrow and standard gauge locomotives for any power at present coming into consideration.

2. *The Development of the Gas-turbine Locomotive.*

The Diesel-electric locomotive — with which the gas-turbine locomotive can best be compared — has become extremely popular, especially in the U. S. A., in the course of the last ten years. Many of the main lines there, particularly in the Middle West and West, are very suitable for Diesel-electric or gas-turbine locomotives. American locomotives of every class are generally much heavier than on other continents, to meet the conditions peculiar to the country.

Even when built for such conditions the gas-turbine locomotive would enable considerable savings to be made, since it is lighter, has lower maintenance and running costs, and coupled with smaller initial outlay, results in lower fixed annual charges.

To obtain good running properties at high speeds motor-bogies are preferable for such locomotives.

Fig. 1 depicts an express locomotive designed for American conditions and for this reason also comprises a steam boiler for train heating.

The locomotive is designed for the following tractive effort and speed conditions:—

Tractive effort at starting	approx. 23,000 kg.
Tractive effort at hourly rating	11,500 kg at approx. 47·5 km/h.
Tractive effort at continuous rating	8,750 kg at approx. 62·5 km/h.
Maximum speed	180 km/h.

This locomotive, developing 2025 H.P. at the wheel tread, is particularly suitable for hauling lightweight express trains. Since such trains have to make long runs and must not lose much time at halts for refuelling, the fuel tanks for the gas turbine and steam boiler are arranged for a full-load run of about thirteen hours. The electrical equipment is designed to enable the gas-turbine set to deliver its full power throughout the entire speed range of the locomotive.

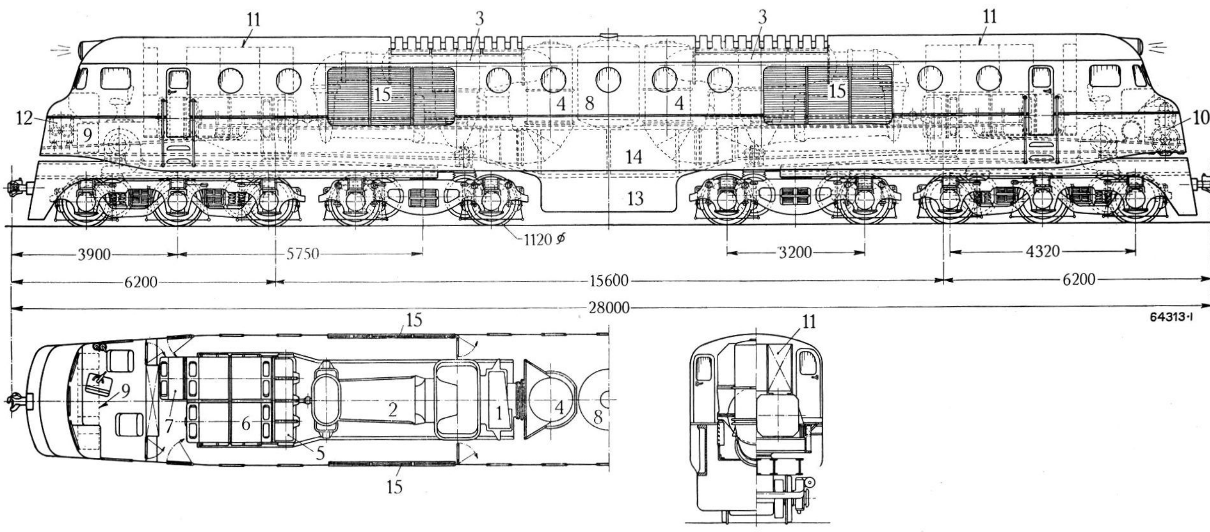


Fig. 2. — 5000 H. P. gas-turbine locomotive.

1. Gas turbine.
2. Blower.
3. Air preheater.
4. Combustion chamber.
5. Gearing.
6. Generator set.
7. Auxiliary generator.
8. Steam boiler for train heating.
9. Storage battery.
10. Diesel-generator starting set.
11. Electrical apparatus.
12. Brake compressor set.
13. Water tank for steam boiler.
14. Fuel tank.
15. Lubricating oil cooler.

Principle data of locomotive

Gauge	1·435 m	Weight of locomotive in running order	approx. 245 t
Diameter of driving wheels	1·120 m	Adhesion weight	approx. 196 t
Number of traction motors	8	Load per driving axle	approx. 24·5 t

A power of approximately 2000 H. P. measured at the wheel tread is, however, very low for present-day railway operation, especially on main lines (most modern steam, Diesel, and electric locomotives have ratings of 3000—4000 H.P. or over) and in many cases it will prove necessary to operate two or more of the locomotives illustrated in multiple-unit control.

A 5000 H. P. locomotive, embodying two similar turbine sets and electrical equipments as the locomotive in Fig. 1, is shown in Fig. 2.

This locomotive is designed for the following tractive effort and speed conditions:—

	For expresses	For freight trains
Tractive effort at starting, approx.	46,000 kg	58,000 kg
Tractive effort at hourly rating	23,000 kg	32,000 kg
at a speed of approx.	47·5 km/h	34 km/h
Tractive effort at continuous rating	17,500 kg	23,000 kg
at a speed of approx.	62·5 km/h	47·3 km/h
Maximum speed	180 km/h	120 km/h

This locomotive develops 4050 H. P. at the wheel tread and is thus particularly suitable for hauling heavy passenger trains or by altering the transmission ratio also for freight trains. The weight of adhesion, representing 80% of the total weight, is thus favourably utilized, eight axles acting as drivers and only two as idling axles. Notwithstanding its great length the locomotive can take curves of comparatively small radius due to the provision of four bogies.

A still more powerful locomotive is shown in Fig. 3. In this case three 2500 H. P. units are controlled from one driver's cab on the multiple-unit principle. Such a locomotive develops about 6230 H.P. at the wheel tread and is thus suitable for hauling the heaviest trains.

A comparison of the three foregoing locomotives gives the following specific weights:—

	Total weight	Weight per H. P.
2500 H.P. locomotive in Fig. 1	141 t	56·5 kg/H.P.
5000 H.P. locomotive in Fig. 2	245 t	49·0 kg/H.P.
7500 H.P. locomotive in Fig. 3	317 t	42·25 kg/H.P.

American Diesel-electric locomotives, with which the gas-turbine locomotives can seriously take up competition, have a weight/power ratio of 70—80 kg/H.P., according to type and application. Considerable weight reductions can thus be achieved with the gas-turbine locomotives which also have a big effect on their cost.

ELECTRICAL BRAKING.

To protect the machinery against brake dust and to diminish wear and tear on tyres and brake blocks,

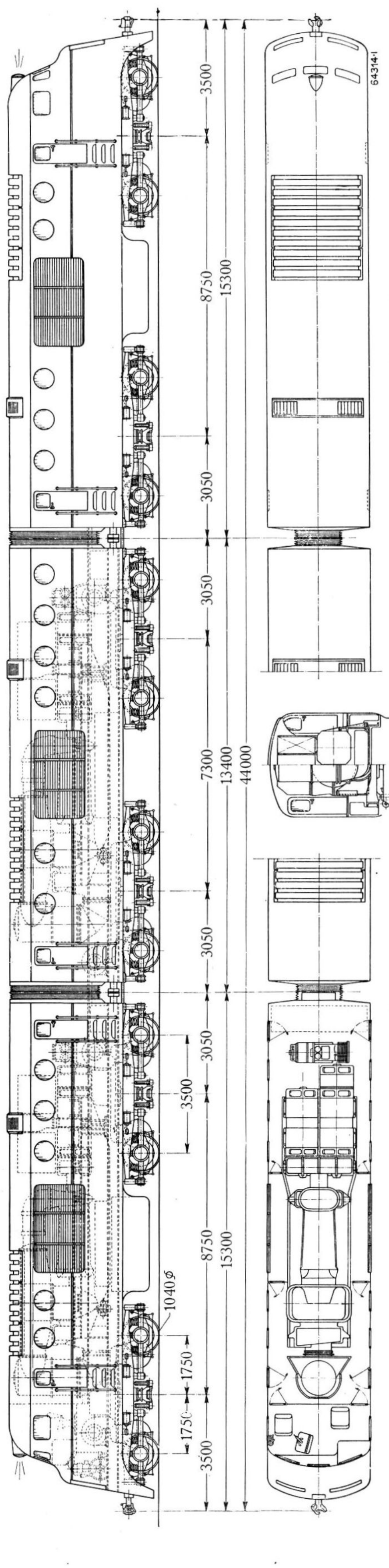


Fig. 3. — 7500 H. P. gas-turbine locomotive.

Gauge	1·435 m
Diameter of driving wheels	1·040 m
Number of traction motors	12
Weight of locomotive in running order	317 t
Adhesion weight	317 t

Tractive effort and speeds

Tractive effort at starting	approx. 46 t
Tractive effort at hourly rating	19 t
at a speed of	approx. 88·5 km/h
Tractive effort at continuous rating	15·5 t
at a speed of	approx. 108·5 km/h
Maximum speed	180 km/h

i. e. to reduce maintenance costs, it is desirable to electrically brake railway vehicles which are provided with electrical transmission. In the absence of a contact wire — the chief field of application of gas turbine locomotives is of course on non-electrified lines — only a rheostatic brake or a brake with which the braking power developed by the traction motors operating as braking generators supplying the turbine set through the intermediary of the main generator operating as motor, comes into consideration. In the case of the gas turbine locomotive it is possible to solve this braking problem at very little additional cost and with only a slight increase in weight, by making the compressor of the turbine set absorb the entire braking power.

At the full-load speed of a 2500 H.P. locomotive gas-turbine set the gas turbine develops a power of about 8500 H.P. Of this the compressor takes about 6000 H.P. so that approximately 2500 H.P. remains for delivery to the generator set. If the turbine set also operates at full speed during electrical full-load braking the compressor will naturally still take 6000 H.P. Approximately 2000 H.P. of this power is furnished by the main generator operating as motor, whereas the air delivered by the compressor, but no longer heated in the combustion chamber, is expanded by the turbine, which supplies the remaining 4000 H.P. To employ electrical braking on short down-hill stretches, all that is necessary is to adjust the fuel nozzle to the minimum rate of fuel with the turbine governor, in order to be able immediately to revert to power running. In the case of long down-hill runs it is desirable to extinguish the flame in the combustion chamber to save fuel. According to the braking power developed the speed of the turbine set is automatically adjusted to a certain balanced value. Upon re-igniting, the change-over to power running can also immediately be made here without the turbine set first having to be accelerated to its ignition speed.

From the described projects it will be seen that the hourly rating lies at a 3·5 — 3·8 times lower speed than the maximum. This involves above all much heavier generators than on the Swiss Federal Railways gas turbine locomotive. However, in order to obtain as light generators as possible each of the above-mentioned locomotives is provided with four high-speed d. c. generators. This arrangement permits one of the four generators to be employed for the excitation of the traction motors during braking and the three others for the transmission of the braking power to the turbine set. In this way the electrical braking of a train entails very little additional electrical equipment. This not-

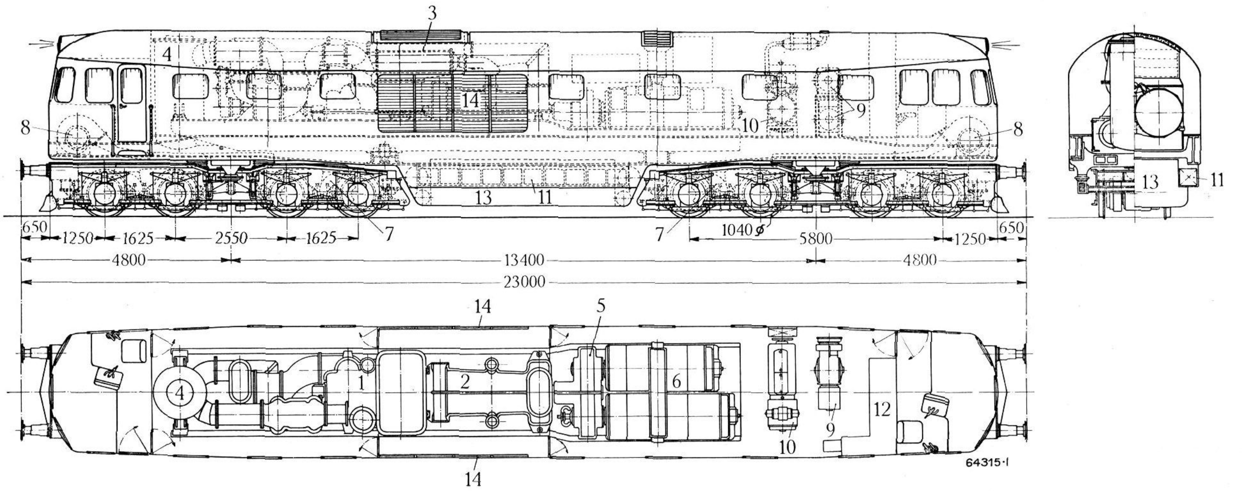


Fig. 4. — 4000 H. P. gas-turbine locomotive.

1. Gas turbine.
2. Blower.
3. Preheater.
4. Combustion chamber.
5. Gearing.
6. Generator set.
7. Traction motor.
8. Fan of traction motor.
9. Brake compressor set.
10. Diesel-generator starting set.
11. Storage battery.
12. Electrical apparatus.
13. Fuel and lubricating oil tanks.
14. Oil cooler.

Principle data of locomotive

Gauge	1·435 m	Weight of locomotive in running order	156 t
Diameter of driving wheels	1·040 m	Adhesion weight	156 t
Number of traction motors	8	Load per driving axle	19·5 t

withstanding, it is possible to brake the same trailing load as the locomotive can haul on a given up-grade at a given speed to the same speed on the same down-grade.

* * *

The locomotives shown in Figs. 1, 2, and 3 are designed for American conditions which permit greater axle loads than 20 t.

The locomotive depicted in Fig. 4, however, proves that it is also possible to build really powerful gas turbine units for railways where the admissible axle loading is restricted to 20 t. The locomotive in question has a continuous rating at the generator coupling of 4000 H.P. All eight axles, split up between two four-axled bogies, are employed for power transmission.

The locomotive is designed for the following tractive efforts and speeds:—

Tractive effort at starting, approx.	37,000 km/h
Tractive effort at hourly rating	20,400 kg
at a speed of approx.	42·5 km/h
Tractive effort at continuous rating	16,400 kg
at a speed of approx.	53 km/h
Maximum speed	120 km/h

Notwithstanding the high power and tractive efforts, which also make the locomotive suitable for mountainous lines, it weighs only about 156 t or approximately 39 kg/H.P., with a length of only 23 metres.

Fig. 5, illustrating a 2500 H. P. locomotive for a gauge of 1 metre, proves that gas turbine locomotives can also be built for narrow gauge railways. The turbine unit is the same as in the locomotives of Figs. 1, 2, and 3. The smaller loading gauge resulting from the narrower track, however, entails modifications to the mechanical portion of the locomotive. Notwithstanding this — for the restricted conditions on narrow-gauge railways — high power of 2500 H.P. the locomotive only weighs about 114 t or 45·6 kg/H.P. in running order.

3. *Economy of Gas-turbine Locomotives.*

It was stated earlier in these notes that when employed under the right conditions gas turbines have big economic advantages over other classes of locomotives. To prove this, exhaustive economy studies were carried out with different trains and loads in freight and express service under different track conditions. The following table shows the conditions to be expected for an express train hauled by a gas-turbine or Diesel-electric locomotive in the U. S. A.

Economy of a gas turbine locomotive in comparison with a Diesel electric locomotive of the same power covering approximately 384,000 km annually (express train in U. S. A.). Power of locomotives 5000 H. P. at the machine shafts, total weight of train about 1235 t.

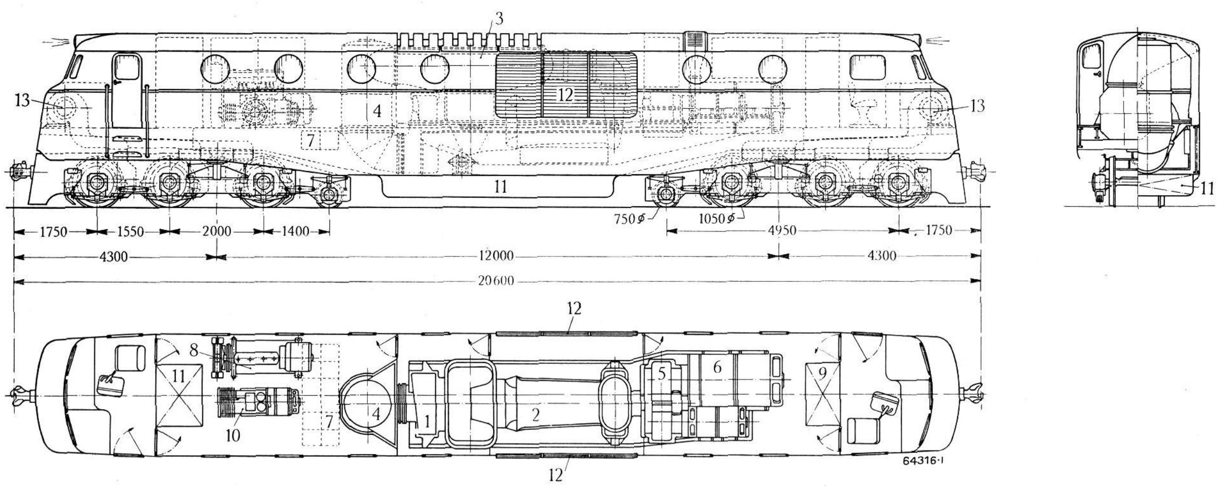


Fig. 5. — 2500 H. P. gas-turbine locomotive for narrow-gauge railways.

1. Gas turbine.
2. Blower.
3. Air preheater.
4. Combustion chamber.
5. Gearing.
6. Generator set.
7. Storage battery.
8. Diesel-generator starting set.
9. Electrical apparatus.
10. Brake compressor set
11. Fuel tank.
12. Lubricating oil cooler.
13. Fan set for traction motors.

Principle data of locomotive

Gauge	1 m	Weight of locomotive in running order	114 t
Diameter of driving wheels	1·050 m	Adhesion weight	90 t
Number of traction motors	6	Load per driving axle	15 t

Tractive efforts and speeds

Tractive effort at starting	approx. 22,500 kg	Tractive effort at continuous rating	12,750 kg
Tractive effort at hourly rating	16,150 kg	at a speed of	44 km/h
at a speed of	34·2 km/h	Maximum speed	60 km/h

	5000 H. P. gas-turbine locomotive $ approx.	5000 H. P. Diesel-electric locomotive $ approx.
Pre-war price of locomotives manufactured in batches	325,000.00	425,000.00
Reduced outlay in favour of gas-turbine locomotive	100,000.00	
Annual charges		
Fixed		
Interest 4 %	13,000.00	17,000.00
Depreciation GT loco. 5 %	16,250.00	—.—
DE loco. $6^2/_3$ %	—.—	28,305.00
Working costs		
Variable		
Maintenance of electrical part	7,887.00	7,887.00
,, of thermal	14,340.00	26,529.00
,, of mechanical part	9,825.00	13,098.00
Fuel	79,920.00	57,687.00
Lubricating agent	2,459.00	8,410.00
Wages	16,800.00	16,800.00
Total annual charges	160,481.00	175,716.00

Annual reduced charges in favour of the gas turbine locomotive $ 15,235.00 or approximately 4·7 % of the initial outlay for the gas turbine locomotive.

Details of Economy Calculations.

For depreciation purposes the life of the gas turbine locomotive is put at twenty and that of the Diesel-electric locomotive at fifteen years.

For the maintenance costs the calculations are based on the following amounts in dollars per mile:—

	Gas turbine locomotive $	Diesel-electric locomotive $
Maintenance of electrical part	0·033	0·033
,, of thermal part	0·060	0·111
,, of mechanical part	0·0412	0·057
Cost of fuel per gallon	0·045	0·067
Lubricating oil for the power unit	0·5 % of fuel costs	0·0288 gall. per km
Lubricating oil for the mechanical and electrical parts of the locomotive	2·58 % of fuel costs	5 % of fuel costs

In the above comparison fuel costs per kg are in the proportion of approximately 2 : 3.

In many parts, e.g. the west of the U. S. A., the price ratio of boiler to Diesel oil, however, is more inclined to be 1 : 2. In this case the reduction in annual charges in favour of the gas turbine locomotive is of the order of $ 36,200.00.

The gas turbines on which these economy calculations are based are designed for maximum working temperatures of 600 ° C. Further greater reductions in running costs will become possible as soon as advances in metallurgy permit of steels for higher working temperatures being used in gas turbine construction, when the efficiency will naturally also be enhanced.

A much wider sphere of application will be thrown open to the gas turbine in traction operation when it becomes possible to operate this class of machine on pulverized coal. Tests in this connection are at present in progress.

BIBLIOGRAPHY.

Brown Boveri Rev. No. 5, May, 1942, p. 115: Ad. Meyer, "The first Gas-turbine Locomotive".

Brown Boveri Rev. Nos. 8/9, Aug./Sept., 1941, p. 183: W. G. Noack, "Pressure-charging, Velox Boiler and Gas Turbine".

Brown Boveri Rev. Nos. 8/9, Aug./Sept., 1941, p. 236: E. Schroeder, "The Gas-turbine Locomotive".

Brown Boveri Rev. Nos. 1/2/3, Jan./Feb./March, 1940, p. 61: "Gas-turbine Locomotives".

Brown Boveri Rev. No. 4, April, 1940: A. Stodola, "Load Tests of a Gas-turbine Locomotive".

(MS 662c) *W. Giger. (E. G. W.)*

PRESENT STATE OF DEVELOPMENT AND FUTURE PROSPECTS OF DIESEL-ELECTRIC RAIL VEHICLES.

Decimal Index 625.28 – 833.6

The economic Diesel-electric vehicle appears to have a rapid development stage ahead of it, especially during the post-war period. On the basis of the literature the state of development at the outbreak of hostilities, as characterized by locomotives and motor-coaches for which Brown Boveri supplied the electrical equipment, is outlined. The article concludes with a survey of development tendencies and future prospects.

A. INTRODUCTION.

The building of Diesel-electric rail vehicles virtually came to a standstill in Europe during the recent world war. The post-war period, and in particular the transition period of the rehabilitation era will, however, see a revival of Diesel-electric traction. The reasons on which this assertion is based are the following:—

1. In the countries directly affected by the war rehabilitation is inconceivable until the badly damaged railway systems and rolling stock are again in working order. Due on the one hand to the shortage of coal, which renders the resumption of steam operation problematical, and on the other to the fact that electrification is only possible in stages, Diesel-electric traction would appear to be the most suitable for the period of transition to normal peace-time working.

2. Another point to be considered is that already before the war there were a large number of steam locomotives in operation which for economic reasons (obsolescence, low efficiency, inadequate power, etc.) were due for replacement. The new rolling stock which the railway companies hesitated to acquire owing to the large sums invested in steam traction have now proved more or less imperative as a result of the havoc wrought by the war.

3. In traction circles it is now realized that Diesel-electric traction is definitely beyond the trial stage and that there is nothing to prevent its being adopted on a large scale. The mere statement of the fact that in the U. S. A. alone, where the land itself was not directly affected by the war, over 3000 Diesel-electric vehicles (of which more than 2000 shunting locomotives ranging from 300 to 1000 H. P. and over 400 main-line locomotives of 2000 H. P. or over) were built between 1930 and the present time, will suffice to illustrate the situation.

4. Liquid fuel supplies for Diesel-electric traction units should cause no difficulties, since war reserves and means of transport are available and could be put to immediate use. In view of the widely recognised importance of coal for the production of synthetic fuels there will be an ever increasing tendency in future to burn less and less high-grade coal with a relatively poor efficiency on steam locomotive grates. Due to this fact coal-bearing, but non-oil bearing countries will be able to provide there own liquid fuels. The steam locomotive will of course also be changed over from coal to oil firing, but this will eliminate none of its operating and economic drawbacks compared with the Diesel-electric locomotive.

This state of affairs leads one to the conclusion that the very economically operating Diesel-electric vehicle is destined to have as rapid and wide development as originally the steam and later the electric locomotive.

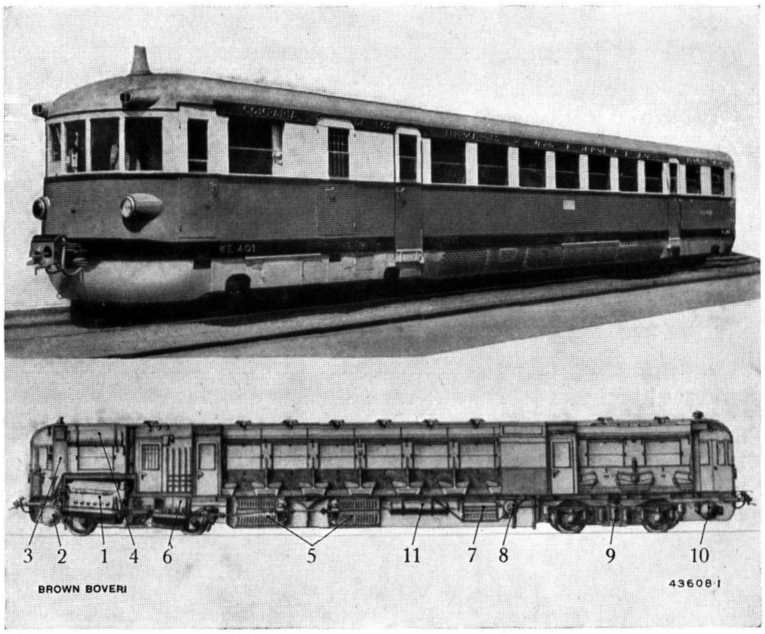


Fig. 1. — 410 H. P. Diesel-electric motor-coach on the Madrid-Zaragoza-Alicante Railway (Spain).

General contractors and makers of coachwork: Compañia Auxiliar de Ferrocarriles, Beasain.

Diesel-engine plants: Maybach-Motorenbau.

Electrical equipment: Brown Boveri.

1 = Diesel engine.
2 = Silencer.
3 = Exhaust pipe.
4 = Fuel tank.
5 = Radiators of Diesel engine.
6 = Generator set.
7 = Storage battery.
8 = Motor-driven compressor.
9 = Motor-bogie.
10 = Oil-fired heating boiler.
11 = Brake air receiver.

B. STATE OF DEVELOPMENT IMMEDIATELY PRIOR TO THE SECOND WORLD WAR.

The active development period of Diesel traction vehicle construction began, both in Europe and North America, around 1930. Electric power transmission was practically exclusively adopted for the high-speed Diesel engines evolved. The extent of this development is really remarkable and is proved by the enormous amount of literature on the subject which is already available (see bibliography at the end of these notes)[1]. Hereafter, a cursory survey of the state of development of Diesel-electric traction immediately prior to the outbreak of hostilities is given, with special reference to equipments partially supplied by Brown Boveri. Many other vehicles worthy of mention could of course also have been included, but this would have led too far.

1. *Motor-coaches and Train Sets for Express Service on Main Lines.*

Fast services on main lines are chiefly coped with by solo motor-coaches, possibly with trailer, for maximum speeds of 100—110 km/h, the rating of the Diesel engines being 400—600 H. P. The Madrid-Zaragoza-Alicante railway commissioned four 410 H.P. Diesel-electric motor-coaches with Brown Boveri electrical equipment in 1935 (1), which have already a remark-

[1] The figures in parenthesis in the text refer to the corresponding numbered publications in the bibliography on page 373.

Fig. 2. — 1950 H. P. Diesel-electric five-car set on Dutch State Railways.

Coachwork: Werkspoor, Amsterdam; JJ. Beynes, Haarlem; Allan, Rotterdam.

Diesel-engine plants: Maybach-Motorenbau und Werkspoor, Amsterdam.

Electrical equipment: Brown Boveri and Heemaf, Hengelo.

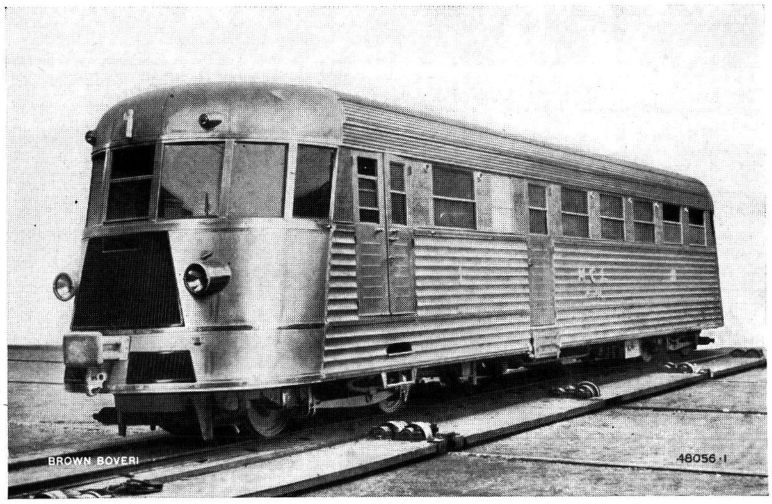
1, 3, 4, and 5 = Passenger coaches.
2 = Motor coaches.

Fig. 3. — 254 H. P. Diesel-electric motor-coach on Calabro—Lucane (Italy) narrow-gauge railways.

Coach body, "Budd" pattern, by Società Piaggio, Genoa.

Diesel engine plants: O. M. Fabbrica Bresciana Automobili (Sulzer licence).

Electrical equipment and bogies: Tecnomasio Italiano Brown Boveri, Milan.



able performance to their credit. The design of these motor-coaches, illustrated in Fig. 1, has proved particularly suitable for the difficult topographical conditions of the railway. Distances of 125,000 km have been attained without overhaul. The mean daily run, taking into account stoppages for overhauls and maintenance, is 328 km. Notwithstanding the enormous amount of dust deposited on the machines and apparatus no trouble has occurred. After every 1500 coach-kilometres the vehicles are taken out of service for one day and the rotary machines and apparatus thoroughly blown out with compressed air. The experience here proves that even under very dusty conditions no difficulties are to be expected with self-ventilated machines given proper care. In the case of the MZAR coaches this applies in particular to the compressors driven by self-ventilated motors mounted under the floor of the coach.

For express services train sets of rigid composition are employed for maximum speeds of 140—160 km/h, the aggregate rating of the Diesel engines being 800—2000 H. P. The most comprehensive motor-coach building scheme in Europe was initiated by the Dutch State Railways in 1933 with the placing of a contract for forty Diesel-electric three-car sets of 820 H. P. [2], which were put into service in 1934. These were followed, at the end of 1938, by a further contract for eighteen Diesel-electric five-car sets of 1950 H. P. each [3]. The invasion of Holland prevented these modern motor-coach sets (Fig. 2) being inaugurated at the beginning of the 1940 summer time-table. However, just prior to the German drive through Holland trials had been carried out with the first motor-coach sets, during which a maximum speed of 178 km/h was attained on the Utrecht-Groningen line.

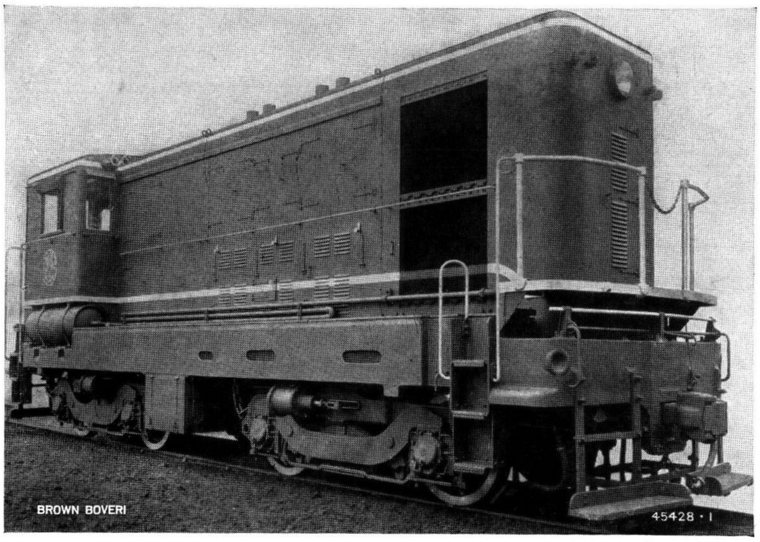


Fig. 4. — 660 H. P. Diesel-electric shunting locomotive built by the Baldwin Locomotive Works.

2. *Motor-coaches for Light Railways.*

In contradistinction to main lines local railways generally have a light track construction, numerous sharp curves, stops at close intervals, and often relatively steep gradients, which factors limit the maximum speed to 60—80 km/h. As a result, the train resistances dependent on the weight, i. e. acceleration and grade resistances, become prominent. Here, therefore, it is the power/weight ratio which is of paramount importance, whereas in the case of high-speed motor-coaches for service on level tracks it is the wind resistance which is the deciding factor. Motor-coaches of lightweight construction are therefore of primordial importance for light railways.

A typical example may be quoted here, viz., the ten 254 H. P. Diesel-electric motor-coaches for the Calabro — Lucane narrow-gauge railway in northern Italy [4]. These coaches (Fig. 3) are designed for a maximum speed of 75 km/h and are operated on numerous, long gradients up to 6 %. Between the 21st April and the end of November, 1937, i. e. during the first seven months of operation, the ten coaches covered an aggregate distance of 430,300 km or roughly 6150 km per vehicle and month.

3. *Diesel-electric Locomotives for Shunting and Line Service.*

Diesel-electric locomotives were first applied to shunting or switching services where their economy and advantages over steam locomotives are particularly pronounced. Due to the little maintenance they require, their simple operation, quick availability for service, absence of smoke, and practically 24-hour operating time Diesel-electric shunting locomotives are finding ever wider application (cf. section A, item 3). The power of the Diesel engines varies between 80 and 800 H. P. The 82/90 H. P. Diesel-electric shunting locomotive built in 1935 for the port of Coruña (Spain) [5] is an example of the simplest construction, where 100 % utilization of the Diesel engine output throughout the entire running speed range is sacrificed to simplicity of equipment.

Fig. 4 depicts the 660 H. P. Diesel-electric shunting locomotive type BoBo built by the Baldwin Locomotive Works, Philadelphia, in 1936, the electrical equipment having been supplied by the American licencees of Brown Boveri [6]. This contract presented an opportunity of introducing the Brown Boveri servo field regulator control into the U. S. A. The electric power transmission of the locomotive shown in Fig. 4 differs from all Diesel-electric shunting locomotives built in the U. S. A. up to that time in that all four traction motors are permanently connected in parallel, which was rendered possible by the servo field regulator control. The permanent connection of all of the traction motors in parallel is particularly important where heavy traction service is concerned, owing to the reduced wheel slip and elimination of the complete or partial interruption of the tractive effort when changing over from series to parallel operation. It was found possible to start the 97 t locomotive with a trailing load of 4000 t on the level, which had never before been achieved in the U. S. A. with any other locomotive of the same type because the control systems employed with a relatively small constant load regulating range render series-parallel connection of the traction motors imperative.

An example of a modern type of Diesel-electric locomotive for line service is shown in Fig. 5 in the form of one of the 1200 H. P. locomotives series Am 4/4 1001 of the Swiss Federal Railways [7]. These locomotives, which have proved satisfactory in every respect, furnish proof of the big part played by Swiss firms in the development of Diesel-electric traction.

The four Diesel-electric locomotives built by Tecnomasio Italiano Brown Boveri for the Eritrea (Massaua-Asmara line) had to satisfy very arduous geographic, climatic, and track conditions (gauge 950 mm, maximum altitude above sea level 2400 m, maximum air temperature in shade 50° C, humidity of air 90 %, very dusty track conditions). The locomotives have a weight in running order of 46 t, while the continuous rating of the Diesel engine is 550 H. P. at 2400 m above sea level with an air temperature of 35° C and 90 % humidity. The Diesel engine is pressure charged on the Büchi principle, while servo field regulator control is provided [8].

4. *High-power Diesel-electric Locomotives.*

Apart from the two high-power Diesel-electric locomotives of the Société Nationale des Chemins de fer français [9] the 4400 H. P. locomotive built for the Roumanian State Railways (Fig. 6) is worthy of special note since it is designed for extremely arduous scheduled operating conditions [10]. This locomotive covered roughly 190,000 km under onerous service conditions on the Bucharest-Brasov route between the 13th July, 1938 and the 7th November, 1940.

C. SUNDRY PROBLEMS, DEVELOPMENT TENDENCIES, AND FUTURE PROSPECTS.

1. Practical experience has shown that it is imperative for Diesel traction vehicles to have an ample reserve of power to ensure a long life and low maintenance costs. In the case of *four-stroke Diesel engines pressure charging* [11] can be employed to obtain a much higher power, usually without entailing any increase in the size of the engine compartment or any sensible augmentation of weight. Exhaust turbo-charging found wide application already before the recent world war, up to the end of 1939 over 600 motor-coach and locomotive Diesel engines having been equipped with Brown Boveri exhaust turbo-chargers. The present stage of development reached by high-power Diesel-electric rail vehicles is due in a large measure to exhaust turbo-charging. In future turbo-charging will also be adopted to an ever increasing extent for low and medium-power Diesel engines. In the case of mountain railways Brown Boveri chargers enable more than the non-supercharged sea-level rating to be attained at altitudes up to 5000 m.

Fig. 5. — Modern lightweight 1200 H. P. Diesel-electric locomotive Am 4/4 1001 of the Swiss Federal Railways.

Coachwork: Swiss Locomotive and Machine Works, Winterthur.
Diesel engine plant: Sulzer Bros., Winterthur.
Electrical equipment: Brown Boveri.

2. Diesel engine *design principles* differ greatly, some engines having plain, others roller bearings. Increasing the speed enables engine weights to be considerably reduced, but at the expense of the life of the machine. High speeds are desirable to keep down the space requirements and weight of the generator set.

In the case of locomotive engines with two crankshafts (Sulzer) the gearing between the shafts can be given a step-up ratio of 1:1·2 or 1:1·33. For large powers of the main generator [12] the double-armature type has to be resorted to.

Efforts have been made to increase the power of high-speed motor-coach Diesel engines with roller bearings beyond the present limit of 650 H.P. to about 1000 H.P. at 1400 r.p.m., but the conventional type of generator will not permit of any notable increase in output beyond the values hitherto attained at 1400 r.p.m. The adoption of a turbo type of generator set with gearing (e.g. planet gearing) to in-

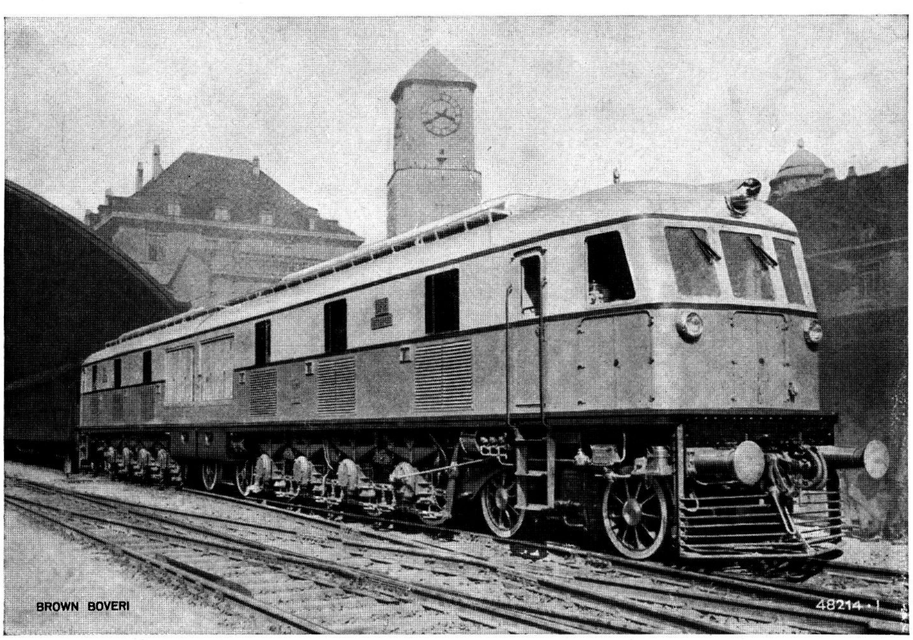


Fig. 6. — 4400 H.P. Diesel-electric locomotive on Roumanian State Railways.

Coachwork: Henschel & Sons, Cassel.
Diesel engine plant: Sulzer Bros., Winterthur.
Electrical equipment: Brown Boveri.

crease the speed would appear to be the best solution here. Generator speeds of 3000—3500 r. p. m. would probably be employed.

Where rigid coupling of the Diesel engine and generator set is concerned close collaboration between Diesel engine builders and electrical equipment designers is imperative to ensure optimum operating conditions for the vibrating system comprising the Diesel engine driving gear, the generator armature, and the shaft.

3. The method of *mounting the Diesel-generator set* has a big influence on the layout of the vehicle as a whole and on accessibility for overhaul and maintenance. As the power increases it frequently becomes impossible to fit the engine in the bogie. The most suitable arrangement of the Diesel-generator set is within the vehicle itself, which saves wear and tear on the Diesel-electric part of the equipment and on the vehicle as a whole. A drawback of fitting the Diesel-generator set in the bogie is that the moment of inertia of the bogie is increased and its running properties thus impaired.

4. The *traction motors* of Diesel-electric rail vehicles are practically exclusively of the nose-suspended type to keep the space above the frame free for the Diesel-generator set, auxiliary machines, and remainder of the equipment. For running speeds from 80 to 100 km/h individual axle drive with the motor entirely spring borne is being more and more widely adopted. The Brown Boveri *spring* and *disc drives* have given excellent results.

5. About ten years ago the Company started employing quick-acting regulators for the *voltage regulation of the auxiliary generator*. This ensures constant voltage conditions under all operating conditions, which is of particular advantage for the charging of the battery.

The voltage regulation also enables several auxiliary generators to be satisfactorily operated in parallel on vehicles with a number of Diesel-generator sets. Three auxiliary generators were first employed in parallel with success on the Dutch State Railways Diesel-electric five-car sets.

6. Much thought and care has been bestowed on the development of *control systems* for Diesel-electric vehicles. A number of satisfactory controls are available which are simple to operate [13]. A method of regulation taking the characteristics of the Diesel engine into consideration in an "ideal" manner must ensure constant speed-torque-power conditions. This requirement is best met with a control automatically adapting the load of the generator set to the instantaneous value of the power delivered by the Diesel engine. Every fluctuation of the working speed due to an increase or decrease in load results in corresponding regulation of the separate excitation of the main

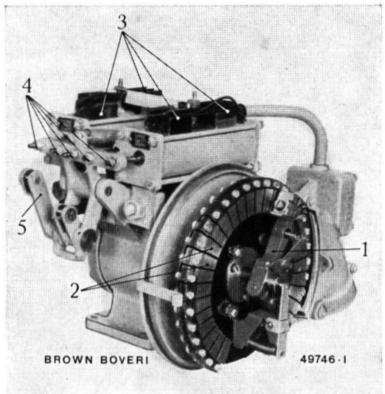


Fig. 7. — Servo field regulator for power control on Diesel engine side with speed regulation of Diesel engine.

(As supplied for locomotive in Fig. 5.)

1 = Brush arm } of field regulator.
2 = Contact track } of field regulator.
3 = Solenoids for torque adjustment.
4 = Set screws for torque adjustment.
5 = End of lever coupled to fuel regulating rod of Diesel engine.

generator (i. e. the output is controlled on the Diesel engine side with speed regulation of the Diesel engine). The *servo field regulator control* [14] developed on this principle has proved to be the best form of control for Diesel-electric traction vehicles. Fig. 7 shows the servo field regulator of the locomotive in Fig. 5.

* * *

The further development of Diesel-electric traction will tend towards higher running speeds (which involves greater powers) and in extensive generalization of this form of traction. Pressure-charging of the Diesel engines permits traction problems on mountain railways in particular to be met in a satisfactory manner. The manufacturers of both the mechanical and electrical equipment are making every effort to develop standard parts for the main equipment of shunting locomotives and motor-coaches. For the more universal application of Diesel traction the retention of electric power transmission is desirable. Its advantages, especially for multiple-unit control, are assumed to be known.

Bibliography.

I. *Detailed Descriptions of Diesel-electric Locomotives and Motor-coaches.*

(1) A. E. Müller: 410 H. P. Diesel-electric Motor-coaches for the Madrid-Saragoza-Alicante Railway.
Brown Boveri Rev. 1934, No. 10, and Schweiz. Technische Zeitschrift 1936, No. 27.

(2) Hupkes: Die dreiteiligen Triebwagenzüge mit elektrischer Kraftübertragung der Niederländischen Eisenbahnen. Organ für die Fortschritte des Eisenbahnwesens 1937, No. 14.
Bolleman Kijlstra, Labrijn und van Lessen: De nieuwe diesel-electrische treinen der Nederlandsche Spoorwegen. Spoor- en Tramwegen, 6th December, 1938.
Also: Brown Boveri Rev. 1933, No. 5, and 1934, No. 7.

(3) De nieuwe diesel-electrische vijfwagentreinen der Nederlandsche Spoorwegen. Spoor- en Tramwegen 1940, Nos. 17, 18, and 19.
Also: Brown Boveri Rev. 1940, No. 12.

(4) A. E. Müller: The 254-H. P. Diesel-electric Motor-coaches of the Narrow-gauge Calabro—Lucane Railway (Italy). Brown Boveri Rev. 1938, No. 9.

(5) Brown Boveri Rev. 1935, No. 12, and 1939, No. 3.

(6) E. Meyer: An American Diesel Locomotive with the Brown Boveri Servo Field-regulator Control. Brown Boveri Rev. 1937, No. 6.

(7) A. E. Müller: The 1200-H. P. Diesel-electric Locomotives Series Am 4/4 Nos. 1001 and 1002 of the Swiss Federal Railways. The Brown Boveri Rev. 1940, Nos. 5 and 6.

(8) M. Grazzini: Locomotive Diesel-elettriche per ferrovie a scartamento di metri 0·950. Rivista Tecnica delle Ferrovie Italiane 1942, No. 1.

(9) Tourneur: Les deux locomotives diesel-électriques à grande vitesse du réseau PLM. Revue générale des Chemins de fer, 1st July, 1937.
Neveux: Les deux locomotives diesel-électriques à grande vitesse du réseau de la Compagnie PLM. Revue générale de l'Electricité, March, 1938, No. 12.
Abry: Les locomotives Diesel-électriques à grande vitesse de la région Sud-Est de la SNCF. Electricité-Science et Industrie, July/August, 1938.

(10) A. E. Müller: The 4400-H. P. Diesel-electric Locomotive of the Roumanian State Railways. Brown Boveri Rev. 1938, No. 10.
O. Schlaepfer: La locomotive diesel-électrique de 4400 ch pour les Chemins de fer Roumains. Revue Technique Sulzer 1938, No. 3.

II. *Design Problems.*

(11) E. Klingelfuss: Increasing the Power of Diesel engines and Aeroplane Engines by the Büchi Process using Exhaust-gas Turbo Supercharging. Possibility of Applying Exhaust-gas Turbo Supercharging to Other Purposes. Brown Boveri Rev. 1937, No. 9.

(12) A. E. Müller: Dimensions and Operating Conditions of D.-C. Generators for Diesel-electric Vehicles in Conjunction with the Control System employed. Brown Boveri Rev. 1940, No. 8.
H. Konrad: Über den Wirkungsgrad von Kraftübertragungen für Motorfahrzeuge. MTZ. Motortechnische Zeitschrift 1941, No. 5.

III. *Control Problems.*

(13) Dr. G. Borgeaud: Grundsätzliche Betrachtungen über die elektrische Leistungsübertragung bei Diesel-Triebfahrzeugen. Schweiz. Technische Zeitschrift 1942, No. 34 and 35.
A. E. Müller: Steuerungen für diesel-elektrische Fahrzeuge. Schweiz. Technische Zeitschrift 1934, No. 42.

(14) A. E. Müller: The Brown Boveri Servo Field Regulator for Diesel-electric Vehicles. Brown Boveri Rev. 1935, No. 12, and 1938, No. 4.
H. Konrad: Der Oeldruckfeldregler, ein neues Steuergerät für diesel-elektrische Fahrzeuge. Brown Boveri Nachrichten 1936, No. 2.

IV. *Diesel-electric Traction in General.*

A. E. Müller: Betrachtungen über den diesel-elektrischen Bahnbetrieb. Elektr. Bahnen 1934, No. 11.
O. Judtmann: Motorzugförderung auf Schienen 1938. Julius Springer, Publishers, Vienna.
Brian Reed: Diesel Locomotives and Railcars. The Locomotive Publishing Co., Ltd., London.

(MS 663) *A. E. Müller. (E. G. W.)*

THE FUTURE OF THE MODERN TRAMCAR.

Decimal Index 621.335.42 : 625.62

Already before the outbreak of the recent war the growth of traffic in large towns had given rise to the question whether increased numbers of solo tramcars or even their exclusive employment would not better meet requirements. Hereafter, it is endeavoured to give a definite answer to this question both from a traffic and operating point of view.

I. ROAD TRAFFIC AND THE AUTOMOBILE.

SOONER or later automobiles of all classes will again be on the road and traffic will become denser and more extensive than ever before. Moreover, due to the advances achieved during the war these vehicles will be cheaper, more comfortable, and speedier, so that the automobile is bound to become more and more popular. The necessity of developing building estates away from business centres and progress made in the erection of cheap, practical dwelling houses will induce town dwellers to live out of town. Many will be compelled to use a car which will increase traffic still further.

Town streets, which cannot be widened without great expense, will soon no longer suffice for this traffic. The growth of automobile traffic will set difficult problems and compel the authorities to take radical measures to cope with the congestion in the centre of towns.

Already before the war tramways formed a big hindrance to the solution of this problem and by reason of their comparatively low speed and frequent halts became unpopular. In a number of cities with populations running into millions it was found possible at a relatively early date to relieve the streets of the major portion of the passenger traffic through extensions to the underground railway and the utilization of its carrying capacity to the maximum. This left the streets much less obstructed for automobile traffic which was able to develop much more freely than in towns of less than a million inhabitants, where an underground railway would not prove a paying proposition. In such cases the tramway represents the means of transport best capable of dealing with dense passenger traffic, provided that modernization of the rolling stock is effected in good time. Thousands of passengers can be conveyed per hour with tramcars which should have the following main characteristics:—

High commercial speed.
High degree of safety.
Quiet operation.

The chief requirement, however, is high running speed to ensure the road being occupied for as short a time as possible. Every stop slows up all road-users; the higher the speed the more vehicles can pass along the road at the same time.

When modernizing a tramway the following questions have to be considered:—

In a large town where the tramway has to cope with the entire passenger traffic are car sets (motor-cars with one or two trailers) running at more or less infrequent intervals to be preferred to solo cars running faster and at shorter intervals? Which of the two methods of operation results in the least dislocation of traffic and which is, at the same time, the more economical?

In the author's opinion cars with trailers have greater drawbacks than merits, because:—

Standing times become longer as the number of trailers increases and the more passengers board or alight from the vehicle.

Roads are occupied for a longer period by a car with trailers.

The long intervals between vehicles results in a large number of people having to wait at halts which tends to obstruct traffic.

A heavy composition, comprising a motor-car and several trailers, cannot be accelerated and braked as rapidly as a single car. The commercial speed is therefore lower the longer the composition.

A car with trailers is invariably noisier than a single car.

Solo cars operating with a higher service frequency have the following advantages:—

Less time is wasted at stops since the driver only has to attend to his own vehicle. Moreover, there are fewer passengers waiting at the halts, so that he can get away again quickly.

The acceleration and deceleration of a solo car can be pushed up to a maximum.

The car can be run at high speed with less risk. The high rate of deceleration possible with a solo car permits it to follow motor traffic closely at approximately the same speed without risk of collision in the event of a sudden stoppage. Roads are therefore occupied for a far shorter length of time.

To facilitate the increasing automobile traffic in large towns it is therefore more advantageous to employ solo cars with a high service frequency instead of trailer sets at greater intervals.

II. THE ECONOMY OF SOLO TRAMCARS WITH A HIGH SERVICE FREQUENCY.

The question now to be considered is whether solo cars operating with a high service frequency are more economical than compositions comprising a motor-car and trailers operating at greater intervals.

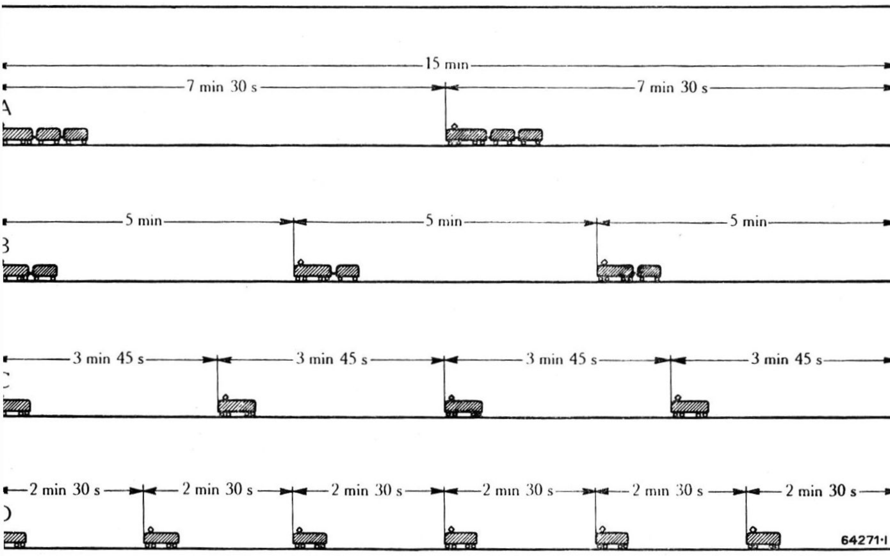
For purposes of comparison the initial outlay for the rolling stock can be assumed as follows:—

Case A: Fr. 340,000.— per set of cars;
for two sets Fr. 680,000.—.

Case B: Fr. 265,000.— per set of cars;
for three sets Fr. 795,000.—.

Case C: Fr. 205,000 per car;
for four cars Fr. 820,000.—.

Case D: Fr. 150,000.— per car;
for six cars Fr. 900,000.—.



Number of men	Weight per car or car set	Passenger carrying capacity of car (s)	Number of passengers conveyed per hour in one direction	Approx. capital investment per car or car set
8	Motor-car 18 t Trailer 11 t Passengers 12 t Total 41 t	80 80 160	1280	Fr. 220,000.— Fr. 120,000.— Fr. 340,000.—
9	Motor-car 13 t Trailer 5.5 t Passengers 9 t Total 27,5 t	80 40 120	1440	Fr. 205,000.— Fr. 60,000.— Fr. 265,000.—
8	Motor-car 13 t Passengers 6 t Total 19 t	80	1280	Fr. 205,000.—
6	Motor-car 9.5 t Passengers 4 t Total 13.5 t	55	1320	Fr. 150,000.—

Fig. 1. — Diagram of tramway operation with various headways.

Fig. 1 shows how a given volume of traffic of approximately 1300 passengers per hour can be conveyed along a road in one direction. Four possibilities are considered:—

Case A: Compositions comprising a motor-car and two trailers for 160 persons with a headway of $7^1/_2$ min.

Case B: Compositions comprising a motor-car and one trailer for 120 passengers with a headway of 5 min.

Case C: Solo motor-cars with a capacity of 80 passengers and a headway of $3^3/_4$ min.

Case D: Solo motor-cars with a capacity of 55 passengers (driver also acting as conductor) and a headway of $2^1/_2$ min.

The number of passengers conveyed in one direction is approximately the same in all four cases:—

Case A: 1280 persons per hour.
Case B: 1440 persons per hour.
Case C: 1280 persons per hour.
Case D: 1320 persons per hour.

Based on the same transport capacity the initial outlay is somewhat greater for the higher service frequency, which was to be anticipated. This greater outlay, however, has little effect on the economy as will be clear from the following considerations:—

The chief item on the expenses side of tramway operation is formed by wages. At first sight, it might be thought that more drivers and conductors would be necessary the more car units are operated, i.e. the shorter the headway. Actually, however, conditions are as follows for the cases we have considered:—

For case A: Eight men for a headway of $7^1/_2$ min.
For case B: Nine men for a headway of 5 min.
For case C: Eight men for a headway of $3^3/_4$ min.
For case D: Six men for a headway of $2^1/_2$ min.

An interesting point here is that although no trailers are employed in case C with a headway of $3^3/_4$ min. the number of men required is the same as for the headway of $7^1/_2$ min. (case A); for operation without conductor (case D) with a headway of $2^1/_2$ min. the number of men required is reduced to six.

The operating costs in francs per car kilometre, estimated from the mean values of the operating costs of large Swiss tramways, are tabulated below:—

Case	A		B		C	D
	1 motor car	2 trailers	1 motor car	1 trailer	Solo motor car	Solo motor-car for operation without conductor
Fixed costs . . .	0·13	0·10	0·12	0·05	0·12	0·085
Wages.	0·32	0·40	0·32	0·20	0·32	0·16
Maintenance . .	0·14	0·08	0·12	0·04	0·12	0·08
Power costs . .	0·15	0·08	0·12	0·04	0·12	0·09
Track maintenance	0·09	0·06	0·07	0·03	0·07	0·055
Interest on capital invested . . .	0·09	0·06	0·08	0·03	0·08	0·065
Depreciation . .	0·07	0·04	0·06	0·02	0·06	0·05
Sundry	0·03	0·02	0·02	0·01	0·02	0·015
TOTAL	1·02	0·84	0·91	0·42	0·91	0·60
per car set . . .	1·86		1·33		0·91	0·60
Referred to the transport capacity:						
Number of car sets	2		3		4	6
Corresponding operating costs .	3·72		3·99		3·64	3·60

From the above it will be seen that the operating costs are practically the same for a motor-car with two trailers and a headway of $7\frac{1}{2}$ min. and a solo car with a $3\frac{3}{4}$ min. headway. For operation with one trailer (case B), however, the costs are somewhat higher, i.e. about 7 %.

The conclusion can therefore be drawn that solo motor-cars give the best results, not only for solving the traffic problem in large towns, but also economically, since operating costs are not higher. Moreover, it can be assumed that the higher service frequency will attract more passengers and thus result in increased receipts.

III. THE COMMERCIAL SPEED OF SOLO MOTOR-CARS.

In large towns it is desirable to keep stops fairly close (at intervals of 200 m at most), so as not to lose the section of the travelling public only having short distances to travel. Power-running and braking curves for a medium-heavy motor-car and two trailers with an aggregate weight of 41 t are given in Fig. 2 and for a solo, lightweight car of a total weight of 19 t in Fig. 3. Given similar conditions a heavy composition covers a distance of 200 m in 29 s, including starting and braking times; on the other hand the solo, lightweight car would cover the same distance

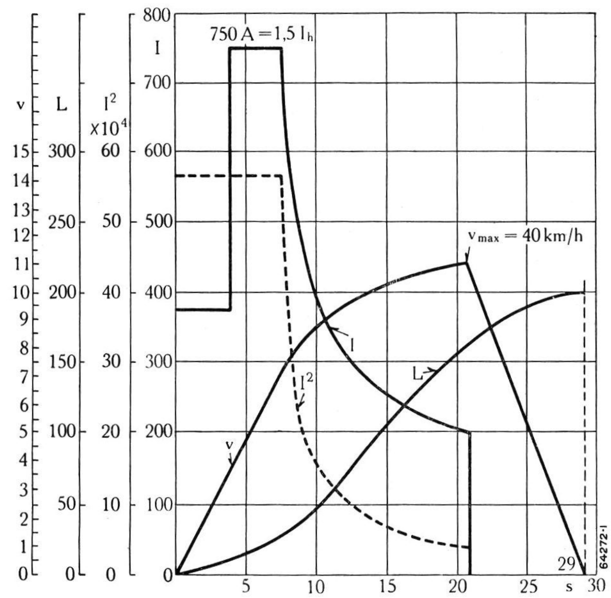


Fig. 2. — Operating curves for a 41 t medium-heavy car set

(18 t empty + 6 t laden) and two trailers (11 t empty + 6 t laden) over 200 m section of track.

L. Distance in metres.

in 26·5 s, and therefore has an approximately 10 % higher speed.

Another point is that longer standing times have to be allowed for trailer compositions with a lower service frequency than for solo cars with a short headway, with which fewer passengers board and alight from the vehicle at the halts. The standing time at each halt can be assumed as follows:—

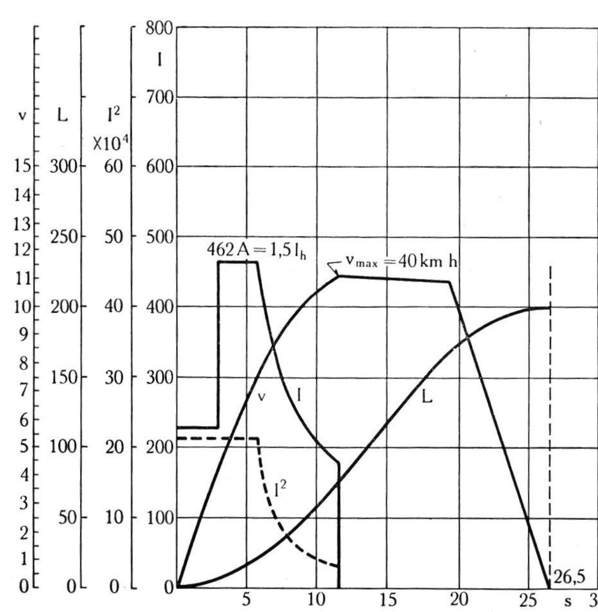


Fig. 3. — Operating curves of lightweight tramcar of 19 t gross weight

(13 t empty + 6 t laden) over 200 m section of track.

L. Distance in metres.

For heavy compositions .	10—30 s
For solo motor-cars . . .	7—20 s,

the longer standing times applying particularly to the halts within the confines of towns.

For a 41 t composition (Fig. 2) and a distance of 200 m the times are as follows:—

Running time: 29 s (excluding stops); mean speed 25·5 km/h

Standing time: 20 s (mean value between 10 and 30 s)

Total 49 s, i.e. commercial speed 14·7 km/h.

For a solo motor-car of 19 t (Fig. 3):—

Running time: 26·5 s (excluding halt); mean speed 27 km/h

Standing time: 13·5 s (mean value between 7 and 20 s)

Total 40·0 s, i.e. commercial speed 18 km/h.

A mean running speed of 18 km/h could therefore be obtained with a solo car, as against 14·7 km/h for a car with trailers, i.e. an increase of 18·5 %. From the graphic schedule of the two compositions in Fig. 4 the time gained by the solo car in the course of several trips is clearly visible. Apart from the reduced time during which the car occupies the road an advantage here is the increased economy, since the number of motor-cars simultaneously in service can now be correspondingly decreased.

Tramways in particular are obliged to investigate every possibility of improving economy. No other class of transport undertaking has so much difficulty in covering the interest on the invested capital as a publicly-owned tramway. The requirements and wishes of the tax-paying travelling public play a big part here. A private undertaking, however, only adopts improvements which pay.

The extent to which solo cars can influence the economy of a tramway, as a result of the increase in commercial speed, will be best realized from an example. Consider a 4·5 km tramway route with the following two possibilities of operation:—

Case A with compositions comprising a motor-car and two trailers operating with a $7^1/_2$ min. headway.

Case C with solo cars operating with a $3^3/_4$ min. headway.

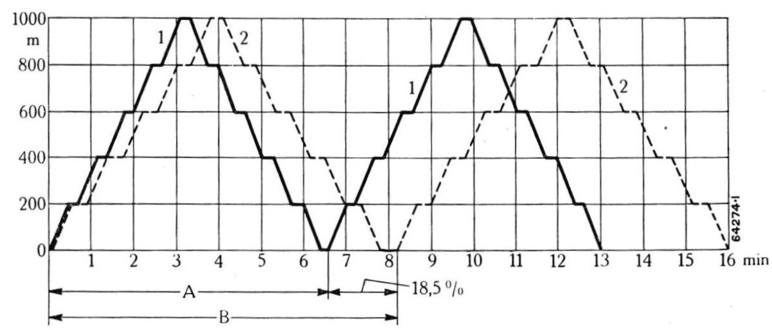


Fig. 4. — Operating curves for a distance of 1000 m with halts every 200 m.

1. Lightweight solo motor-car as per Fig. 3.		2. Medium-heavy motor-car with two trailers as per Fig. 2.	
200 m covered in . . .	26·5 s	200 m covered in	29 s
Standing time 7—20 s, mean .	13·5 s	Standing time 10—30 s, mean .	20 s
Total	40 s	Total	49 s
Commercial speed . . .	18 km/h	Commercial speed . . .	14·7 km/h

Fig. 5 gives a graphic schedule for case A; mean commercial speed 14·7 km/h. For this schedule five sets of cars and trailers are continuously required.

Fig. 6 depicts the schedule for case C with solo cars; commercial speed 18 km/h. From these schedules it is seen that due to the higher commercial speed of the solo cars in case C two cars can be saved, the reduction of the headway from $7^1/_2$ min. to half does not involve doubling the number of cars, *but only increasing them from five to eight.*

As a result of this fact conditions turn definitely in favour of the solo cars:—

	Case A	Case C
Number of cars or sets of cars continuously in service	5	8
Number of men required	20	16

The operating costs per car kilometre (see table on p. 376) were calculated for the same commercial speed.

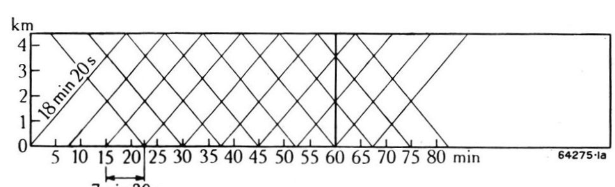


Fig. 5. — Schedule for 4·5 km long tram route with halts every 200 m.

Operation with 41 t composition comprising one motor-car and two trailers; commercial speed 14·7 km/h (five sets of cars continually in operation).

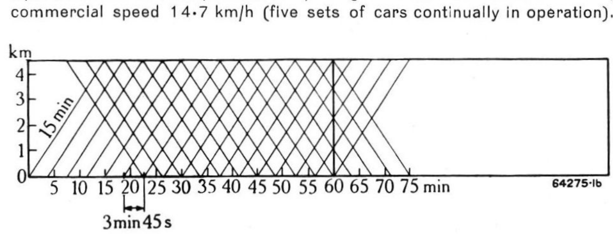


Fig. 6. — Schedule for 4·5 km long tram route with halts every 200 m.

Operation with solo motor-cars weighing 19 t; commercial speed 18 km/h (eight cars continually in operation).

As a result of the foregoing increase the data for case C must also be altered.

	Fr.		Fr.
Fixed costs . . .	0·12	remain unaltered .	0·12
Wages	0·32	reduced in ratio of 20 : 16 . . .	0·26
Maintenance . .	0·12	remains unaltered .	0·12
Power costs . .	0·12	increased slightly to about	0·125
Track maintenance	0·07	remains unaltered .	0·07
Interest on capital invested . . .	0·08	reduced in ratio of 10 : 8	0·065
Depreciation . .	0·06	reduced in ratio of 10 : 8	0·048
Sundry	0·02	remains unaltered .	0·02
	0·91		0·83

Calculating costs for one-hour service give:—

	Case A	Case C
Number of car kilometers	5 × 14·7 = 73·5 km	8 × 18 = 144 km
Costs per train kilometer	1·86	0·83
Total approx.. . . .	Fr. 136.—	Fr. 119.—

Saving with solo cars = approx. 10 %.

Summary.

1. Tramways will be retained in large towns where no underground railway can be built.
2. The future of tramways lies in the use of modern, solo-operating motor-cars which ensure:—
   (a) Diminished dislocation of street traffic due to higher speed possible with solo cars.
   (b) Better service to travelling public due to decreased headway between cars.
   (c) Reduction of noise.
   (d) Increased road safety.
   (e) Greater receipts.
   (f) Decreased operation costs.

In connection with the foregoing a few words on the modern, solo-operating tramcar would not be out of place.

When trailers have not to be hauled there is no need to retain the heavy type of car, and the lighter the car the more economic it will be to operate. The adhesion will always prove adequate for the car alone. Many towns have already changed over to solo cars. For instance, in Europe, the city of Milan has replaced all of its old tramcars by 500 modern, four-axle cars, and no more trailers are employed there. The cars have a rating of 4 × 40 = 160 H.P. (metric) and a weight of 14·7 t. The Genoa Tramways also acquired similar cars, but weighing 16·8 t.

At the instigation of Brown Boveri a lightweight type of car (Figs. 7 and 8) was introduced at Zurich, which has already been described in detail in the technical and daily press.[1] This vehicle, which is of the series 401 and the most modern lightweight tramcar in Europe, has aroused considerable interest in traction circles. Its weight is only 12·9 t. This could have been reduced still further if the car had been built exclusively for solo operation, i. e. if drawbar and buffing could have been dispensed with. (At Zurich, however,

[1] Schweiz. Bauzeitg. No. 20, 18th May, 1940; Wirtschaft und Technik im Transport, Zwischenheft 1940/41; Verkehrstechnik 1942, No. 1; Schweiz. Bauzeitg. No. 23, 6th June, 1942; Verkehrstechnik 1943, No. 6; Brown Boveri Rev., January/March, 1942 (Retrospective number).

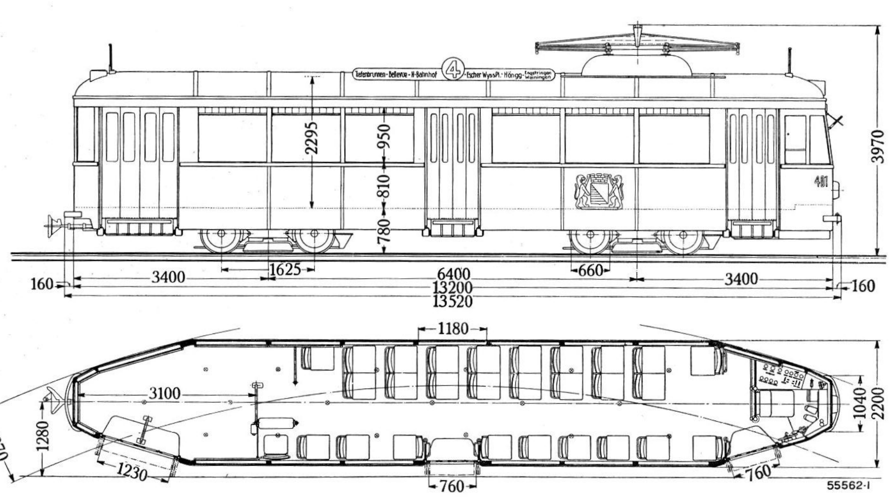


Fig. 7. — Profile of four-axle lightweight tramcar series 401 of Zurich Municipal Tramways.

it is usually running with one trailer and in case of emergency even with two trailers on level routes.) This modern lightweight car embodies all features which can be considered desirable to-day. The advantages can be summarized as follows:—

1. Control is effected with two pedals, one for power running and the other for braking, as in the case of the automobile. Pedal control was not introduced simply as a novelty, but because the foot is quicker to react than the hand, a fact which has played no small part in the development of petrol-driven vehicles. In case of emergency an accident is more quickly averted by the foot than by the hand. Tests have shown that

(a) With foot operation a 8 % higher speed can be attained in the same time.

(b) The reaction time for hand operation is 26·5 % longer than for foot operation, corresponding to a 17 % longer path.

(c) The mean retardation calculated from the speed in m/s divided by the braking time in seconds is 24 % greater with foot operation. From graphs the mean retardation was found to be 23 % higher.

For these reasons the Company preferably provides modern tramcars with pedal control, which also affords a higher factor of safety.

2. The interior of the car is also fitted out on modern lines, thanks to the careful study given the question by the technical department of the Zurich Tramways and the Swiss Car and Elevator Corporation, Schlieren. The car has three electropneumatically operated doors, one at the rear for boarding and one each at the front and in the centre for alighting. This facilitates the passage of the passengers through the car. The fare is collected by a conductor seated near the rear door, so that no passengers can escape paying.

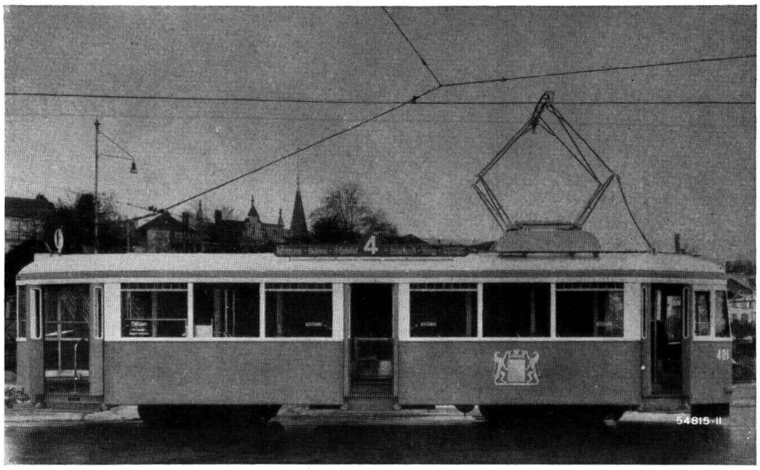


Fig. 8. — The modern four-axle lightweight tramcar, series 401, of the Zurich Municipal Tramways, with Brown Boveri Simplex bogies and a seating and standing capacity of approximately 100.

Total one-hour rating of four motors 220 H.P., running speed with one-hour rating 31 km/h, maximum speed 60 km/h.

3. The electrical equipment comprises four self-ventilated traction motors with an aggregate one-hour rating of 176 kW at 600 V. Two motors are permanently connected in series. The power-weight ratio constitutes a record in tramcar construction. As a result maximum acceleration and a high commercial speed can be attained. Petrol-driven cars scarcely accelerate quicker and are obliged to follow the tramcar in the centre of large towns.

4. The problem of braking this lightweight car was given very careful study to obtain maximum retardation within the limits of passenger safety. Apart from the pneumatic and hand brakes, which actuate

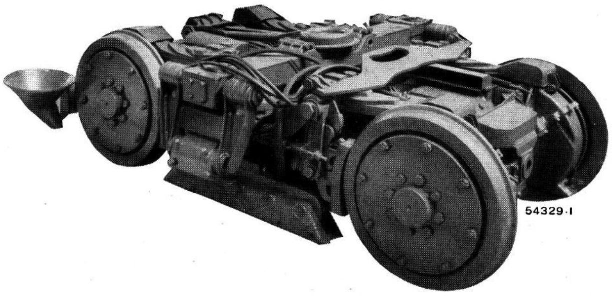


Fig. 9. — The Simplex bogie of the four-axle lightweight tramcar, series 401, of the Zurich Municipal Tramways.

The motors form an integral part of the bogie frame and transmit their torque to the axles through spring discs arranged on the pinion side. (Brown Boveri disc drive as shown in Fig. 4d on page 332.)

four brake blocks per bogie, the car is provided with four electromagnetic rail brakes (two per bogie) and a rheostatic brake. The brake pedal only acts on the rheostatic brake, the rail brakes beginning to function at the end of the action of the rheostatic brake. The pneumatic brake is operated by a hand valve.

5. The bogies (Fig. 9) are of the Company's new pattern with the casing of the motors forming an integral part of the bogie frame. The torque is transmitted through the well-tried Brown Boveri disc drive. The 660 mm driving wheels are rubber cushioned to reduce noise. This wheel arrangement permits points and crossings to be traversed practically at unreduced speed, which contributes largely to the high commercial speed.

(MS 664) *D. Straub. (E. G. W.)*

THE AUTOMATIC MULTIPLE-UNIT CONTROL SYSTEM OF THE NEW FOUR-AXLE MOTOR-COACHES FOR THE CHEMINS DE FER ÉLECTRIQUES DE LA GRUYÈRE.

Decimal Index 621.337.12

Brown Boveri received the contract for the electrical equipment for new lightweight motor-coaches (Fig. 1) for the metre-gauge Gruyère Railways which are operated with 850 V d. c. and have to cope with a large amount of traffic with many halts and gradients up to 3·15 %. These vehicles are equipped with motors having an aggregate rating of 550 H. P. and permit a total load of 100 t to be hauled at a speed of 40 km/h on gradients of 3·15 %. They are also notable in that they satisfy the most exacting requirements on the score of speed and comfort. Their power-weight ratio is double that of the existing motor-coaches on the same railway.

THE new motor-coaches of the Chemins de fer de la Gruyère are equipped with four motors each having a one-hour rating of 102 kW. They are connected in series in pairs and have extremely lightweight control gear which is designed on new principles and can be operated in multiple-unit control with other motor-coaches or actuated from a control car (Fig. 2).

This control gear comprises the following components:—

1. Two master controllers 1 in the driver's cabs (Fig. 3, left) with handwheel *a* for the main control drum with power steps for shunting, series connection, parallel connection, and field weakening, when the handwheel is rotated clockwise out of the zero position. By counter-clockwise rotation of the handwheel first the brake change-over position and then the other braking positions are attained. To the left of the handwheel there is a handle *b* for the reverser operating drum for forward and reverse travel, interlocked in the conventional manner with the main control drum.
2. Two electropneumatically operated contactors, one as line breaker and the other as bridging switch for the change-over of the two sets of motors from series to parallel connection.
3. Two electromagnetically operated contactors for field weakening.
4. A number of relays, of which two accelerating relays and one retardation relay, for automatic starting and braking, with adjustable voltage coil for setting the fall-back current.
5. An electropneumatically operated multi-step master controller for automatic, stepwise starting with fifteen series, ten parallel, and fifteen braking steps (Fig. 4).
6. An electropneumatically operated reverser with forward and reverse positions.
7. An electropneumatically operated brake change-over switch with power and brake positions, of the same design as the reverser, but with eight rows of contacts (instead of four).
8. A hand-operated isolating switch for the arbitrary disconnection of a motor set.

Twelve control wires are necessary to operate the power equipment in multiple-unit control, one for the current collector, two for the electropneumatically operated roof-mounted automatic circuit-breaker, one for the line-breaker, which together with two further control leads also serves for the control of the multi-step controller, and two each for the reverser, brake change-over switch, and the two field weakening contactors.

Moreover, the auxiliary machine sets, i. e. the compressor, vacuum pump and converter sets, the heating,

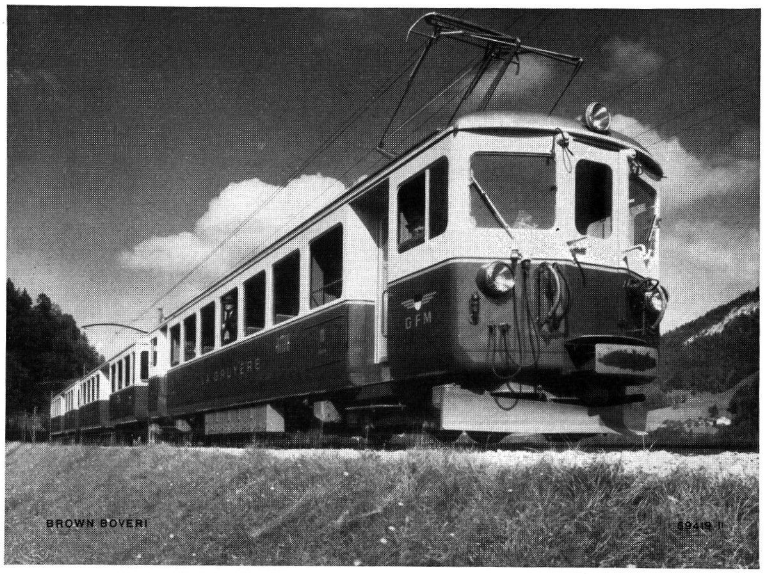


Fig. 1. — New four-axle direct-current lightweight motor-coach with multiple-unit control, type Ce 4/4, of the Chemins de fer électriques de la Gruyère, for hauling trains of 100 t at 40 km/h on 3·15 % gradients. Aggregate one-hour rating 550 H. P.

lighting, and other auxiliary devices, such as pneumatic door-operating gear, sanders, bell system, and departure signal have to be arranged for multiple-unit control, so that altogether there are thirty-six control wires.

The control circuits of the electromagnetically and electropneumatically operated switch equipment are supplied with direct current at 36 V $\pm$ 25 %. The service pressure of the compressed air cylinder is normally 6 kg/cm² abs and must not drop below 4·5 kg/cm² abs.

The apparatus is of extremely light weight, but is of sturdy construction and takes up very little space on the underside of the coach body. Apparatus to which the contact wire voltage is applied are doubly insulated from the earth and the control voltage.

The multi-step main controller for rapid and smooth starting, referred to under item 5 and illustrated in Fig. 4 is worthy of special note since it represents a patented, novel, and simple application of the well-known *line-breaker principle.* In this new design the controller switch units are only operated under load for the stepwise short-circuiting of the starting and braking resistances; for reverse operation of the control from any position the motor circuit is first interrupted by the on-load line-breaker, the controller switch units being subsequently operated *off-load.* Arcing and, in consequence, contact burning is limited to the line breaker. Whereas controls operating on the line-breaker principle hitherto required complicated mechanical or electrical interlocks and nevertheless did not afford full protection against premature opening of the switch units, it is impossible to open the switch units of the Brown Boveri multi-step controller too soon, since the switch cam levers, which take the form of spring-loaded locking pawls, mechanically prevent the controller shaft being turned backwards with the line-breaker closed, on every step of the controller. The switch unit last closed when starting and which is required to open off load, itself thus forms a mechanical interlock against reverse rotation of the controller shaft, independent of the attention of the driver and of the opening speed of the line-breaker and its operating

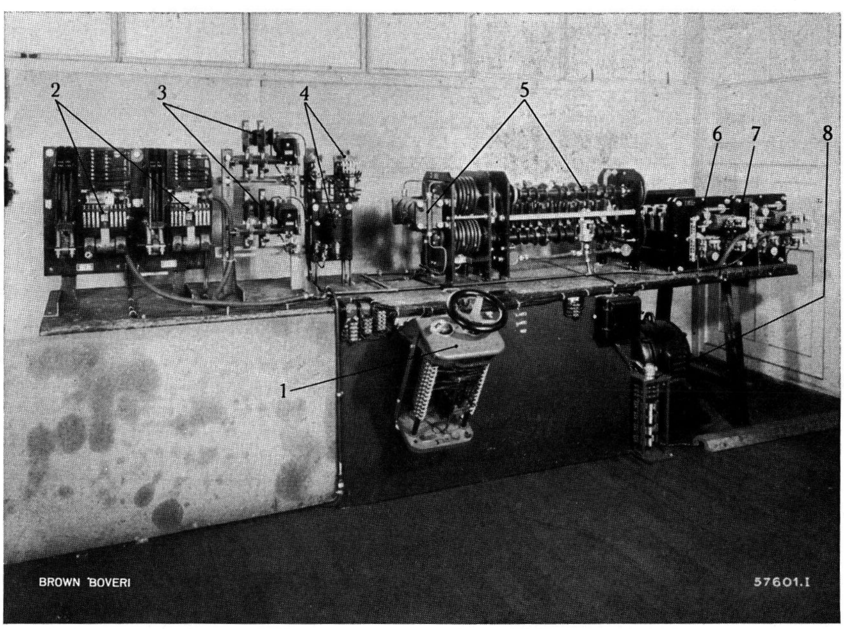


Fig. 2. — Multiple-unit control equipment on test bench.

1. Master controller.
2. Line breaker and bridging switch.
3. Contactors for field weakening.
4. Sundry relays.
5. Multi-step controller.
6. Reverser.
7. Brake change-over switch.
8. Isolating switch for motor sets.

gear. This interlock is not unlatched until the line-breaker has been tripped and at the end of its opening movement actuates a pneumatically operated device; the latter takes care of the off-load opening of the switch units and simultaneously unlatches the controller shaft which is thereupon returned to the zero position by a recall spring.

Fig. 3. — Driver's desk, on left master controller for power running and braking.
Note the space-saving, but clear arrangement.

The multi-step controller (Fig. 4), which is controlled by three electropneumatic valves (two main valves and one auxiliary valve), comprises the main controller and the appertaining selector with built-on pneumatic operating cylinder with double piston. The rack between the two pistons engages in the pinion of the operating shaft, which, in turn, drives the controller shaft for starting, whereas at opening it is returned to zero by its own recall device.

The method of operation of the Brown Boveri automatic multiple-unit control, which is provided with all the necessary interlocks to prevent faulty operation, is the same as with other line-breaker controls. First the reverser operating handle of the master controller is moved to "Forward" or "Reverse", which operation unlatches the main control drum for power running and braking. If, for instance, the handwheel is moved from the zero to the shunting position, a control impulse is imparted simultaneously to the reverser and the brake change-over switch, which brings the former to the "Forward" or "Reverse" position and the latter to the "Power" position, if they were not already in these positions. As soon as the foregoing switches have reached the positions corresponding to the control impulse the "Interlocking relay" automatically switches in the line-breaker and in consequence closes the motor circuit for power running to include all of the starting resistances. The multi-step controller has not yet moved from its zero position, since only one of the two main control valves is energized, so that the operating cylinder is subjected to the same pressure on both sides. If the handwheel is moved to the series or parallel position the control lead of the electropneumatic main starting valve is energized (the air is let out). As a result the pressure on one side of the operating cylinder is about 2 kg/cm^2 abs less than on the other and the multi-step controller begins moving in the notching-up direction. The operating speed of the multi-step controller at starting is so regulated by means of suitable diaphragms fitted in the pipes of the operating cylinder, that the total time from the shunting to the parallel position would be 10 seconds if the accelerating relay were not to come into action. In service, starting and braking are regulated automatically and according to the weight of the train by the accelerating and retarding relays. The driver can arbitrarily alter the adjustment of the fall-back current of the relay to suit the actual weight of the train by operating a small four-step change-over switch to regulate the current of the relay voltage coil. Once the series or parallel position is attained the corresponding control lead of the starting valve on the selector is interrupted by a relay, whereupon the operating piston comes to rest due to the equalization of the pressures.

The starting cycle can, however, be interrupted on any desired intermediate step by returning the handwheel to the shunting position in the series range of the multi-step controller or to the series position in the parallel range. This results in the starting valve also being de-energized and the pressure difference in the air cylinder eliminated. The re-establishment of balanced pressure conditions on either side of the cylinder brings the multi-step controller to a standstill.

For electrical braking the handwheel of the master controller is rotated counter-clockwise. In the brake change-over position the brake change-over switch is first thrown over. Thereupon the line-breaker is automatically switched in and the braking circuit incorporating the braking resistances completed. If the driver turns the handwheel in the braking direction to brake the coach the multi-step controller is automatically cut in until the last braking step is reached. If on the other hand he desires to adjust the braking effect to the train weight and the gradient for continuous braking he brings the multi-step controller to a standstill in the intermediate step already attained by rotating the handwheel back to the brake change-over position.

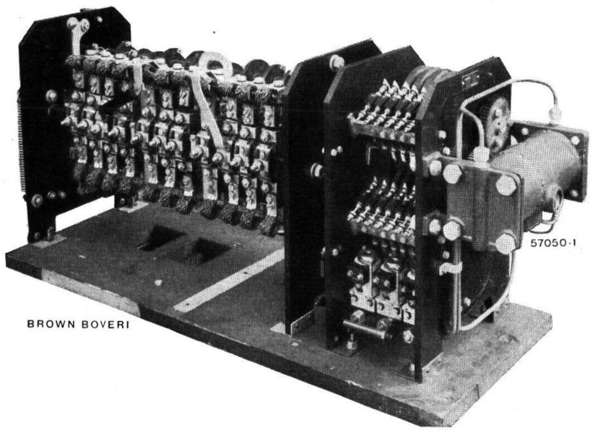


Fig. 4. — Multi-step controller for automatic, stepwise starting with fifteen series, ten parallel, and fifteen braking steps.

In foreground the pneumatic operating cylinder with selector.
Note the compact design and the large number of power and braking steps.

In order to utilize the advantages of automatic control to the full the pneumatic operating cylinder is provided with a third auxiliary valve controlled by the selector, to increase the notching-up speed in the lower part of the series range and when passing through the positions between series and parallel connection.

It is the practice with line-breaker control for the driver to have to return the master controller to the zero position should be ever have to change over from parallel to series connection, i. e. to return from any given step to a lower one. In this case the line-breaker is cut out and the multi-step controller returned to the zero position, due to the de-energization of the control valves. Thereupon a fresh start can be made.

Although the momentary vanishing of the tractive effort when a conventional line breaker is opened and the consequent direct cutting off of the motor current is usually not considered a disadvantage, the control described here has been perfected in this respect in that the line breaker is cut out with a time-lag in three stages, i. e. in two transition stages, with resistances in circuit. In this way, even on steep gradients and with heavy trains the tractive effort dies away to zero smoothly when the line-breaker is opened.

The Brown Boveri multi-step controller, in the design of which special account has only to be taken of the temperature rise of the contacts, has very small breaks, simple switch units without magnetic blowout, and arc chutes. As a result a large number of steps are obtained with the smallest switching angle per step ever attained, together with low weight and small space and power requirements. It therefore constitutes an interesting application of the line-breaker principle. The above-described automatic multiple-unit control with Brown Boveri multi-step controller is also particularly suitable for underground railways where stops are frequent and the method of operation dictated by the schedule has to be rigorously adhered to with rapid, but smooth starting and braking and maximum utilization of adhesion. Moreover, operation must be as simple as possible — as in the case of the present control system — to permit the driver to give his whole attention to the track.

(MS 666) *E. Eugster. (E. G. W.)*

THE TROLLEY BUS.

Decimal Index 621.335.43

The possibilities of this vehicle for transport purposes about towns are described and the different types of motor available for their drive compared. It is shown in particular that a series-wound motor running at low speed when developing the one-hour rating with economic speed regulation affords big advantages for trolley bus operation.

TROLLEY BUSES found wide application for public transport purposes in town and suburban services in the decade prior to the recent world war. It is true that the shortage of copper for the trolley wires and the difficulty in obtaining pneumatic tyres virtually brought this development to a standstill. On the return of more normal conditions, however, interest in the trolley bus is bound to revive, since it will be practically impossible to solve the traffic problem, which is certain to become more and more acute in both large and small towns, without recourse to this class of vehicle. It is for the modernization of transport services in particular, however, that the big advantages of the trolley bus will be turned to account. These may be briefly resumed as follows:—

Manœuvrability over wide range on either side of the trolley-wire position, thus permitting other vehicles to be avoided or overtaken and passengers to be taken up or set down at the curbstone.

No dislocation of traffic.

High rate of acceleration and braking, therefore high commercial speed.

Quiet-running, vibrationless motor.

In contradistinction to the internal-combustion-engined bus no noxious exhaust gases, lower maintenance, and longer period for amortisation.

Spring-borne, like motor bus.

Use of home-produced energy in majority of cases.

Relatively low system costs.

Apart from local conditions which may warrant the adoption of a trolley bus system the question of the class of traction to be envisaged for any given conditions is chiefly a matter of economy. The problem may take one of two forms. Either an internal-combustion-engined bus route which has become unprofitable due to increased traffic density may have to be replaced by a better and less expensive form of transport or it may be required to change over an existing obsolete tramway system with only a small traffic density to another form of traction — trolley or internal-combustion-engined bus — to increase economy.

In the first case the most suitable form of traction can generally be selected without difficulty, since each of the known public service vehicles — tramcar, trolley bus, internal-combustion-engined bus — has advantages for definite traffic densities with which they can cope the most economically in towns and suburbs. Calculations and experience have shown that for large traffic densities with headways of about five minutes the tramcar is by far the most suitable means of transport, followed by the trolley bus for traffic densities up to headways of thirty minutes, whereas for the smallest traffic densities internal-combustion-engined buses become most favourable.

If on the other hand a tram route is required to be put on a sounder financial basis it must be decided whether the whole plant is to be modernized, i. e. whether apart from the acquisition of new cars the track has to be entirely re-laid or whether the latter can be retained and only new cars are required. In the first case the problem is the same as when an entirely new system has to be provided, for which the above-mentioned limits apply for the selection of the most suitable form of traction. In the second case, however, only careful economy calculations will show whether it is worth while purchasing modern cars or whether a change-over to trolley or internal-combustion-engined bus operation would not be the best solution.

The point to be observed is that apart from traffic density the trolley bus is superior to the tram on hilly routes due to the considerably greater coefficient of adhesion between the pneumatic tyres and the surface of the road. The danger of the driving wheels slipping is therefore greatly minimized and higher speeds and shorter running times can be achieved on down-gradients. This fact induced the Lausanne Tramways, for instance, to substitute trolley buses for tramcars on all hilly routes already before the war. Routes aggregating 16 km were changed over in this way.[1] A further reason for the change-over was that trailers could not be hauled on the steep gradients by the tramcars.

A drawback ascribed to the trolley bus is that it is less able to cope with rush-hour traffic than the tramcar. This objection is not quite justified since there is nothing to prevent it being equipped with a sufficiently powerful motor to enable a trailer to be hauled,

[1] See Brown Boveri Rev., March 1938, p. 59.

which given an appropriate coupling tracks up with the trolley bus. This system of operation is already practiced at several places with success.

Three sizes of trolley bus should prove ample for the conditions encountered in service:—

(a) A small trolley bus with a tare of 6—6·5 t, 8—8·5 m long, seating capacity 20—25, standing room for 25—30 passengers, equipped with a motor of approximately 55 kW rating.

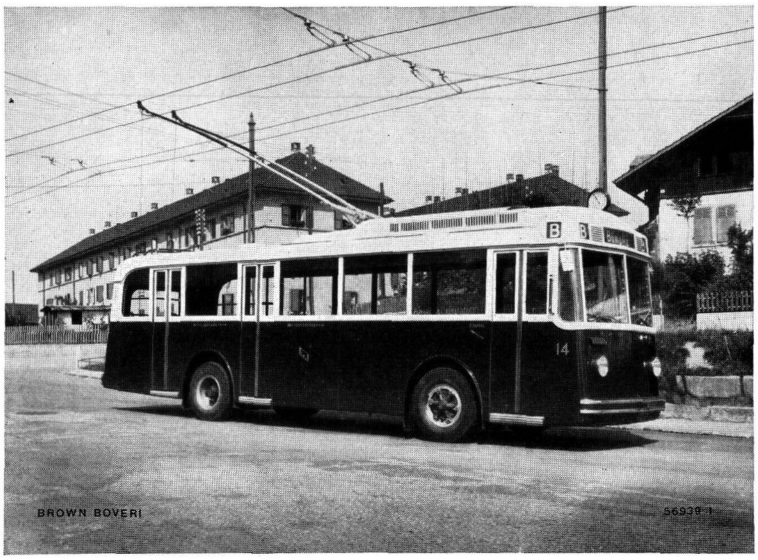


Fig. 1. — Trolley bus owned by Berne Municipal Tramways.

Chassis: A.G. Franz Brozincevic & Co., Wetzikon. Electrical equipment: Brown Boveri. Coachwork: Neue Carosserie A.G. Gangloff, Berne. There are two trolley bus routes at Berne. A trailer is attached to the trolley buses at rush hours, thus greatly increasing the transport capacity.

(b) A medium-size trolley bus with a tare of 7·5—8·5 t, 9·5—10 m long, seating capacity 25—30, standing room for 35—40 passengers, equipped with a motor of approximately 80 kW rating (Fig. 1).

(c) A large trolley bus with a tare of 9·5 t, about 11 m long, seating capacity 30—35, standing room for 40—50 passengers, equipped with a motor of approximately 95 kW rating.

For trolley buses which are to be operated with trailers the above-mentioned motor ratings must be increased by about 20 %.

Trolley buses are generally single-deck vehicles. In the British Empire, however, a standard double-deck type is used, this having a length of about 9 m and despite the large seating capacity of seventy only weighing approximately 9 t. The four-wheeled vehicle with a single-motor equipment is to be preferred, since this results in a simpler, lighter, and less expensive bus requiring the minimum of maintenance. Following tramway practice a voltage of 550—650 V is used. In the case of long routes into outlying districts and interurban routes with dense traffic there is no objection to employing a still higher voltage, i. e. 1200 or even 1500 V. The motor and its equipment can be constructed and reliably insulated for such high voltages without difficulty.

Both series and compound motors are used, the former being in greater favour, although neither possesses such advantages as to give it any claim to general superiority. The chief merit of compound motors is that they permit of regenerative braking, which, however, results in no great saving in energy consumption except on routes with steep gradients. A drawback here is that in the case of dewirements or failure of the supply to the trolley wires electrical braking ceases. The motor then operates unloaded with the result that its voltage rises and must be reduced by a special over-voltage relay switching a resistance into the shunt excitation circuit to weaken the motor field. The same conditions also arise when on the last runs of the day there are no other buses on the line to take the regenerated energy. The trolley wire voltage has again to be reduced by the over-voltage relay here, unless the substation is equipped with reversible mutators or an automatically controlled loading resistance.

Although it cannot be gainsaid that the compound motor affords certain advantages the series motor has not the same drawbacks and, due to its greater insen-

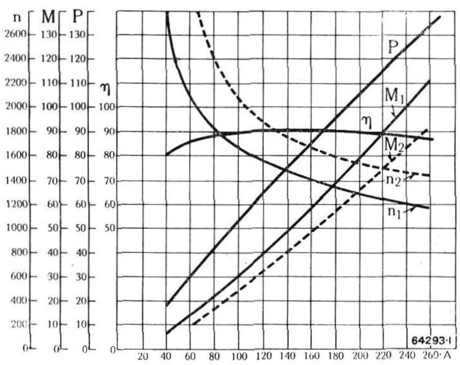


Fig. 2.

——— = Curve with full field.
– – – – = Curve with maximum field weakening.

Characteristic curves of a trolley bus motor with high speed at one-hour rating and relatively small economic speed range by field weakening.

One-hour rating of motor: 80 kW at 1 450 r.p.m., 600 V.

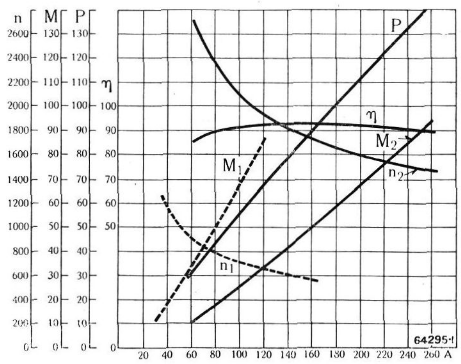


Fig. 4.

——— = Parallel connection.
– – – – = Series connection.

Characteristic curves of a double-commutator trolley bus motor with high speed at one-hour rating. Series-parallel connection of two commutators at starting.

One-hour rating of motor 93 kW at 1 740 r.p.m., 600 V.

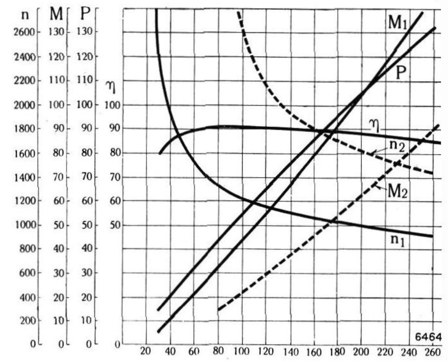


Fig. 6.

——— = Curve with full field.
– – – – = Curve with maximum field weakening.

Characteristic curves of a trolley bus motor with l
speed at one-hour rating and wide economic spe
range by field weakening.

One-hour rating of motor 81 kW at 1 080 r.p.m., 600

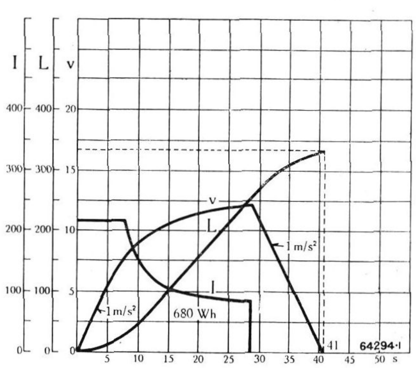


Fig. 3.

Operating curves of a trolley bus having motor in accordance with characteristics in Fig. 2.

Diameter of wheels 975 mm.
Gear ratio 1:9·58.

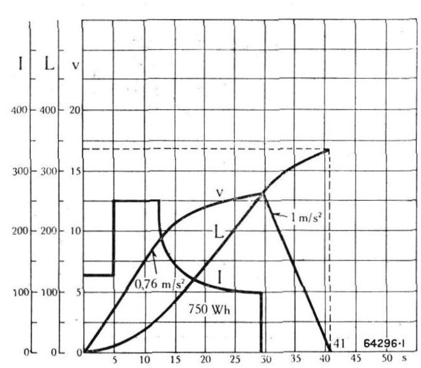


Fig. 5.

Operating curves of a trolley bus having motor in accordance with characteristics in Fig. 4.

Diameter of wheels 975 mm.
Gear ratio 1:8·6.

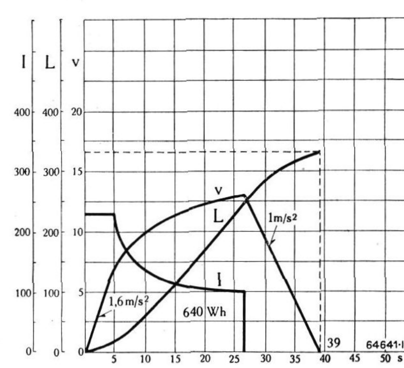


Fig. 7.

Operating curves of a trolley bus having motor in accordance with characteristics in Fig. 6.

Diameter of wheels 975 mm.
Gear ratio 1:10·6.

Figs. 2–7. — Characteristic curves of three trolley bus series motors with approximately the same power and operating conditions over a level section of route 333 m long with a trolley bus weighing 13 t laden.

Comparison of the curves clearly shows the superiority of the motor running at low speed at the one-hour rating and with a wide range of speed control by field variation on the score of energy consumption and running time.

n. Motor speed in r.p.m.
M. Torque at motor shaft in kgm.
P. Power at motor shaft in kW.
η. Efficiency of motors (without gearing) in %.
I. Input to motors in A.
L. Distance covered in m.
s. Running time in seconds.
r. Running speed in m/s.

sitivity to voltage fluctuations and reliability, appears to be more suitable for the drive of trolley buses. Close attention must, however, be paid to design to permit it to compete with the compound motor on the score of energy consumption. This is achieved by building the machine with a low speed at the one-hour rating and providing a large economic speed range through field weakening. It is true that the motor becomes somewhat heavier than a high-speed machine, but this is offset by the higher starting torque and acceleration. The full-field speed being low the starting resistances are cut out earlier during acceleration, and in this way energy saved.

Figs. 2, 4, and 6 give characteristic curves for three different types of series motors of approximately the same rating, Figs. 2 and 4 referring to orthodox motors with a high speed and Fig. 6 for a motor with a low speed at the one-hour rating. This latter design was adopted for the Brown Boveri trolley bus equipments supplied to the Zurich Tramways.[1] In the case of the first motor (Fig. 2) the road speed corresponding to the one-hour rating is 27·5 km/h, i.e. relatively high, and the possibility of economic speed regulation by field weakening is therefore slight. Where the type of motor referred to in Fig. 6 is concerned conditions are just the reverse, i.e. the road speed at the one-hour rating is low, i.e. 18·7 km/h, and, moreover, can be economically controlled within a wide range by field

[1] See Brown Boveri Rev., June 1942.

weakening. In the case of the motor for which curves are given in Fig. 4 the saving in energy consumption during starting is achieved by series-parallel connection of the field and armature windings of the double-commutator motor exactly as though two separate motors were provided. The motor of the last alternative (Fig. 6) is also of the double-commutator type. Since the two commutators are permanently connected in series a higher voltage can be developed during braking without harming the motor.

In Figs. 3, 5, and 7 operating curves are also given for each type of motor with a trolley bus weighing fully laden 13 t on a level route with a distance of 333 m between halts, i.e. three halts per km. As will be clear from these curves energy consumption is least in the case of the third type of motor (Fig. 6) with a low speed at the one-hour rating. Moreover, with the same overload of 50 % over and above the one-hour current rating this motor gives the highest acceleration at starting and therefore the shortest running time. It will therefore be the most advantageous in service. Of the two others the type of motor represented by Fig. 2 has the lowest current consumption for the same running time.

For control purposes Brown Boveri employ electromagnetic contactors actuated by a pedal-operated master controller with direct current at 24 V. The control current is preferably supplied by a small convertor set or charging generator directly connected to the traction motor, in conjunction with a battery which also feeds auxiliaries, such as the lighting system, direction indicator, and klaxon. In the case of the last type of motor considered (Figs. 6 and 7) the control has ten resistance starting steps, one power step at full voltage, and ten further economic power steps with weakened field. Rheostatic braking is effected in eleven steps. Two pedals are provided, one for power running and the other for braking; in the latter part of its travel the brake pedal also acts on the pneumatic brake to bring the bus to a standstill. Control is not automatic and in consequence immediately responds to the movement of the driver's foot, thus permitting of rapid starts and stops. This type of control has proved extremely satisfactory wherever it has been employed.

Fig. 8. — 100 H.P. combined Diesel-trolley bus of the Lucerne Municipal Transport Undertakings.

Seating capacity 34, standing room for twenty passengers, maximum speed 50 km/h.
Electrical equipment: Brown Boveri.
Chassis and Diesel engine: A.G. Franz Brozincevic & Co., Wetzikon.
Coachwork: Swiss Car and Elevator Corp., Schlieren.
A popular vehicle for town and urban services on routes with and without trolley wires.

In conclusion, it might be mentioned that similar equipments were supplied by the Company for four combined Diesel-trolley buses, two of which are operated by the Basle Tramways and two by the Lucerne Municipal Transport Undertaking (Fig. 8). These vehicles are trolley buses equipped with an auxiliary Diesel-generator set. On sections of the route where no trolley wires are provided the driving motor of the trolley bus is supplied by the Diesel-generator set. The same pedals are employed for power running and braking in trolley-bus and Diesel-electric operation. The change-over from one form of operation to the other is effected simply by throwing over a change-over switch. Experience with these vehicles is excellent.

(MS 672) *M. Hiertzeler. (E.G.W.)*

THE ELECTRICAL CONTROL GEAR OF TROLLEY BUSES.

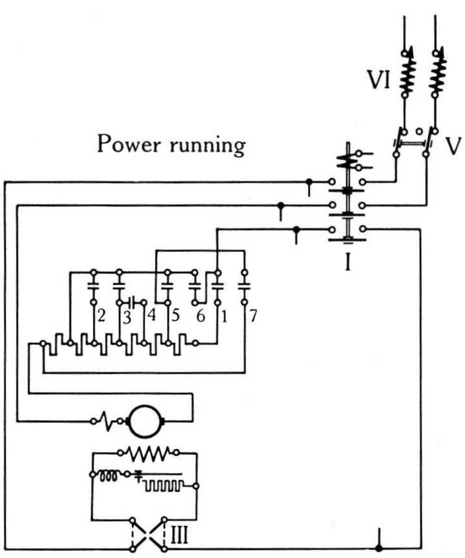
Decimal Index 621.337 : 621.335.43

The following notes are confined to a description of the more important components of the electrical control gear of trolley buses and their location on the vehicle, the economy of trolley bus operation being dealt with elsewhere in this issue.

THE control gear of trolley buses must be of light-weight and compact design. It is imperative that insulation should be of high standard to obviate the risk of leakage and the consequent electrical charging of the coachwork by reason of the fact that the wheels are insulated from earth by the pneumatic tyres. This requirement is given due consideration in the design of the apparatus and machine sets in direct contact with the trolley wire voltage in that double insulation is provided between them and the trolley bus frame. The leakage across the insulation of the apparatus frames and machine casings can be readily checked at any time by means of a terminal board on the control panel.

Nowadays the cable protecting sheath is also additionally insulated in the neighbourhood of the cleats, this either taking the form of an insulating sleeve or supporting insulators. In this connection it might be mentioned that a supporting insulator reinforced with iron and rated 1500 V has recently been developed by the Company for the double insulation of traction motors, auxiliary machine sets, and collector gear of trolley buses.

Power running

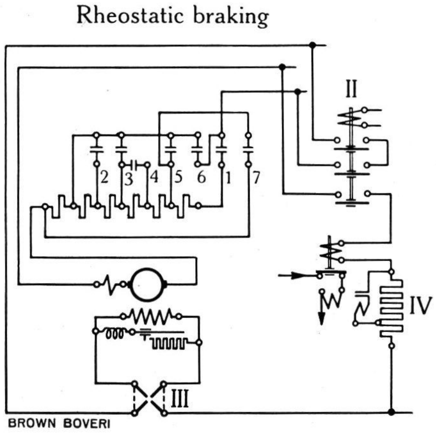


Sequence of contactor switching

O = Closed contactors

Operation with trolley wires or battery											Rheostatic braking									
	Contactors									Field regulation		Contactors								
Steps	II	I	1	2	3	4	5	6	7		Steps	II	I	1	2	3	4	5	6	7
0											0									
1		O	O								1	O		O						
2		O	O	O							2	O		O	O					
3		O	O	O	O						3	O		O	O	O				
4		O	O		O	O					4	O		O		O	O			
5		O	O		O	O	O				5	O		O		O	O	O		
6		O	O				O	O			6	O		O				O	O	
		O						O				O							O	
7		O						O	O		7	O							O	O
8		O		O		O		O	O		8	O			O		O		O	O
9		O		O	O	O		O	O		9	O			O	O	O		O	O
10		O	O		O	O		O	O		10	O		O		O	O		O	O
		O	O		O	O	O	O	O			O		O		O	O	O	O	O
11		O					O	O	O		11	O						O	O	O
		O					O	O	O			Over-travel of brake pedal for operation of pneumatic brake								
		¦					¦	¦	¦											
		O					O	O	O											

Rheostatic braking



Power running with battery

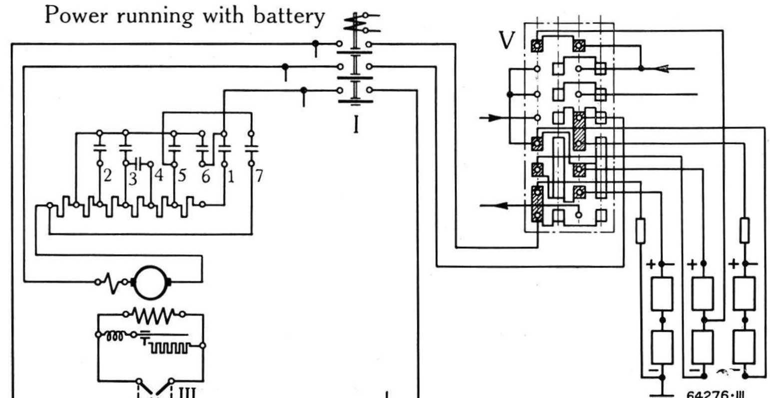


Fig. 1. — Schematic diagram of power and brake circuits of a trolley bus with contactor control gear.

The electrical control gear of a trolley bus with Brown Boveri contactor control gear comprises the following components (Fig. 1):—

Two trolley collectors with insulated shoe and renewable sliding carbons, adjustable for a mean contact pressure of 8—11 kg varying only by ± 1 kg no matter what the height of the trolley wires may be. The trolley base is insulated and equipped with a sliding contact so that the trolley arm may turn in either direction and to any extent about the vertical pivot. The vertical working height of the collector is 1—4 m above the base. The maximum range on either side of the trolley-wire position over which the vehicle can run is 4·5 m. To change the sliding carbons (mean life approximately 3500 km, maximum 8000 km) the collector can be drawn down on the side of the vehicle to a height of about 1·5 m above ground level. The complete collector, including the cable in the pole, only weighs 57·5 kg.

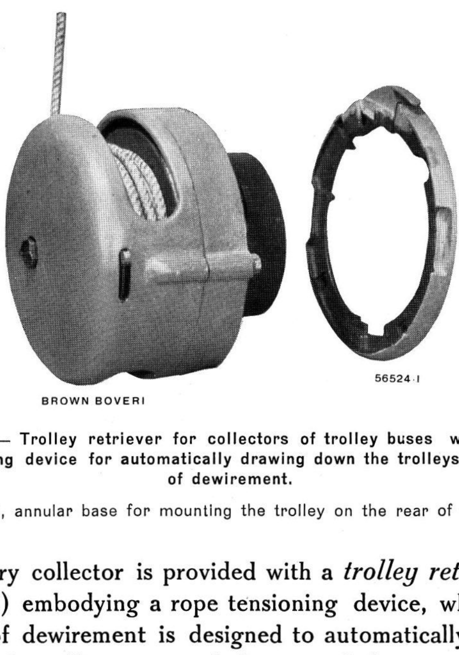


Fig. 2. — Trolley retriever for collectors of trolley buses with rope tensioning device for automatically drawing down the trolleys in case of dewirement.

On right, annular base for mounting the trolley on the rear of the bus.

Every collector is provided with a *trolley retriever* (Fig. 2) embodying a rope tensioning device, which in case of dewirement is designed to automatically draw down the collector out of the way of the span wires. An annular base permits the trolley retriever to be mounted on the back of the bus and enables it to be changed if necessary.

A *radio interference suppressor,* comprising two magnetically coupled chokes and a condenser, is connected between the two collectors and the circuit-breakers on the roof. This suppressor permits the field strength of the interference to wireless reception to be reduced to an admissible limit.

Mounted on the roof are, in addition, two *circuit-breakers* with free-return clutch which permits of automatic opening of the contacts even when the operating shaft is held in the on position. These breakers can be actuated either pneumatically or by hand.

Immediately after the circuit-breakers there is a hand-operated *change-over switch* to permit the trolley bus to be operated from the *trolley-wire* or the *battery*. This switch permits the six 12 V batteries to be connected in series for supplying the motor with 72 V, for instance when turning the vehicle or during manœuvres at the depot with the collectors lowered.

Further apparatus are:—

A hand-operated *reverser* with "Zero", "Forward", and "Reverse" positions.

One *power* and one *braking contactor,* arranged one above the other on a common insulated frame and both electromagnetically operated.

An insulated frame with seven electromagnetically operated *step contactors* for power running and braking.

A pedal-operated, notchless, ten-step *field rheostat* for weakening the motor field by means of a parallel-connected regulating resistance after the last full field power step.

A pedal-operated, notchless *master controller* for eleven power running and braking steps, with magnet-assisted snap-action contacts.

A *set of pedals* for operating the master controller and motor field rheostat, comprising power and brake pedals and contact gear for the control of the power and brake contactors.

A *starting* and *braking resistance* with cast-iron grids for natural air cooling.

A *braking current limiter* to prevent over-braking and thus save wear and tear on the tyres; this comprises a current relay and a current limiting contactor for switching resistance into circuit when an adjusted maximum braking current is exceeded.

The reverser, motor field rheostat, and master controller are concentrated in a common *control unit* and are built into the control panel in front of the driver to the right of the set of pedals. The operating shaft of the control unit is coupled to the pedal shaft by means of a short connecting shaft with universal joints. The pedals, operating shaft of the control unit, and motor field rheostat are spring-loaded. Following standard practice the reverser is mechanically interlocked with the master controller so that the former cannot be changed over with the power or brake pedals out of the zero position. Moreover, the power and brake contactors are electrically interlocked. In consequence, faulty operation due to simultaneous depression of the two pedals is out of the question.

Upon the power or brake pedal being depressed the corresponding pedal contact closes the power or brake contactor and thus the power or brake circuit. Thereupon the resistances are progressively short-circuited by the step contactors and in the final section of travel the field is weakened by the motor field rheostat.

The brake pedal is provided with a certain amount of overtravel to ensure operation of the pneumatic brake pedal after the last rheostatic brake step.

Contactors which remain switched in for long periods are provided with a series resistance to reduce the power consumption of the operating coil.

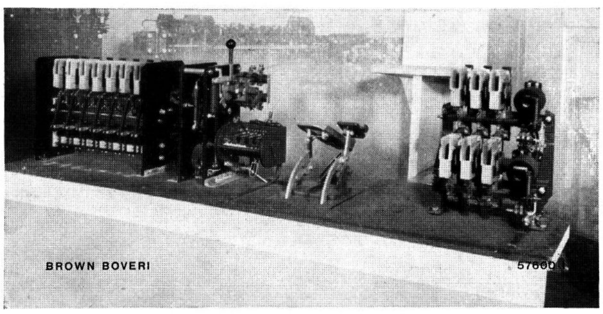


Fig. 3. — Trolley bus contactor control gear on test bench.
From left to right: Step contactors, control unit (combined master controller, reverser, and motor field rheostat), and power and brake pedals and power and brake contactors.

As an example of a trolley bus equipment with d. c. series motor for 550 V, one-hour rating 100 H. P., with contactor control gear for eleven starting, ten field weakening, and eleven braking positions, the trolley bus of the Berne Municipal Tramways with a seating capacity of 28 and standing room for 32 passengers may be taken. Fig. 3 shows the control gear on the Brown Boveri test bench, from left to right: the insulated frame with seven-step contactor and the control unit with master controller and reverser. Opposite this, on the left, fitted on the outer insulated wall, there is a face-plate motor field regulator, but which is not visible in the illustration. Further to the right follows the set of pedals (without pneumatic brake pedal) and finally, on the extreme right, the insulated frame with the power and brake contactors.

Fig. 4 shows the pedals for power running (right) and electrical braking. The pedal contacts for the power and brake contactors are lodged in a box-type bearing pedestal provided with shock-absorbing stops for the pedals. Fig. 5 depicts the driver's seat with the control panel and the pedals under the steering wheel; the pneumatic brake pedal is that on the left.

On the inclined, desk-like control panel are, from left to right, the following:—

The switchboard with tumbler switches for the lighting and auxiliaries, such as motor-driven compressor, converter set, fan, and wind-screen heating elements; then come the audible stop signal, departure signal, and direction indicator switch, pressure gauges for the pneumatic brake and pneumatic auxiliaries with pilot lamp and battery voltmeter. To the right of the steering wheel are the speedometer, a Scintilla switching apparatus and the two tumbler switches for the electropneumatic door-operating gear with pressure reducing valve, then a clock and on the extreme right a hinged cover protecting the leakage testing terminal board and fuses for the 24 V circuits.

To the left of the driver's seat, on the side wall of the trolley bus, are the operating switches for the heating circuits, underneath, the corresponding fuses, together with further 750 V fuses for other auxiliary circuits operated at the trolley wire voltage.

Fig. 6 shows the back of the trolley bus open with, from left to right: various contactors 1 for auxiliaries, the insulated frame 2 with power and brake contactors, further to the right the group of seven step contactors 3, and on the extreme right the battery change-over switch 4 to permit of operation from the trolley wires or from the battery. Above this switch there is the voltage regulator 5 for the low-voltage converter set and the battery fuses 6.

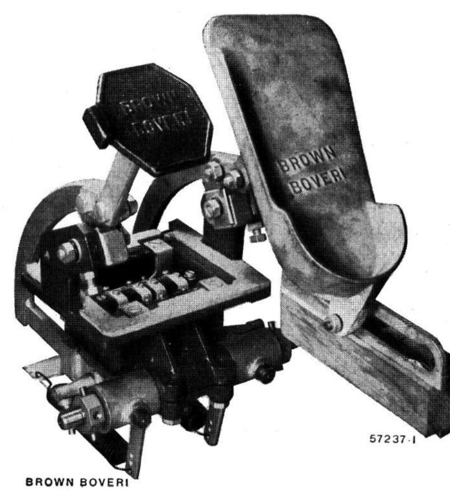


Fig. 4. — Pedals for operating trolley bus contactor control gear.
Right power pedal, left brake pedal, underneath pedal contacts for power and brake contactors.

The layout of the trolley bus electrical equipment selected for the Berne Tramways vehicles and described above has proved very satisfactory in service. The choice of this disposition was guided by the following principles:—

Only those equipment components should be arranged in the vicinity of the driver which have to be continually operated or observed for control and supervision purposes, i. e. in particular the control unit with reverser, the field rheostat and master controller with the set of pedals for operating the last two pieces of apparatus (Figs. 5 and 7), and, to avoid long leads the shunt resistances of the motor field rheostat, whereas the remainder of the control gear, such as the battery change-over switch, power and brake contactor, step contactors, brake current limiter, contactors for auxiliaries, compressor pressure regulator, etc., are preferably lodged at the rear of the bus, where, as shown in Fig. 6, they are readily accessible for inspection from the exterior when the hinged doors are opened.

The starting and braking resistances are advantageously mounted on the roof where they are naturally cooled by the windage and get far less dirty than under the vehicle, without detracting from the external appearance of the latter.

The battery, lighting converter, and compressor set for the pneumatic brake are suspended under the floor of the bus on vibration-damping, insulated mountings.

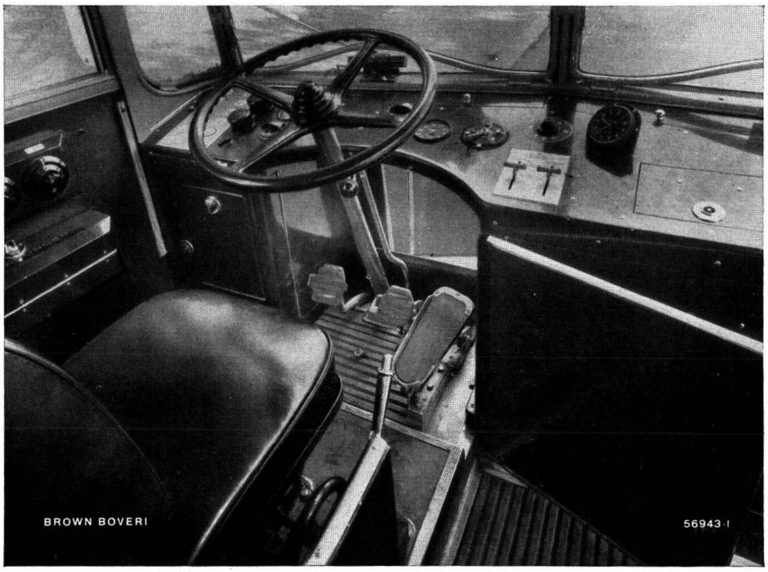


Fig. 5. — Driver's cab with control panel, driver's seat, and steering wheel.

On right pedals for braking and power running, on left pedal for pneumatic brake. Note the ready accessibility of all apparatus.

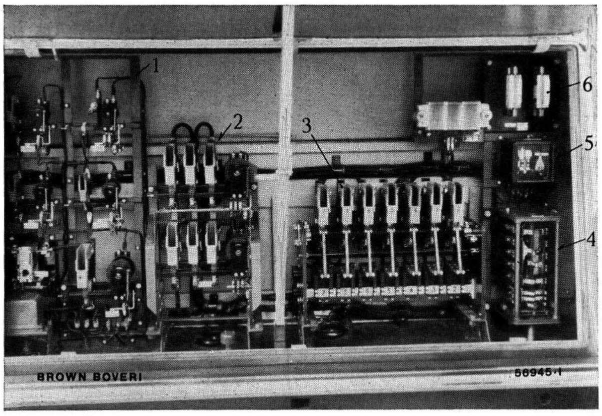


Fig. 6. — Rear of bus open from exterior with various contactors and other apparatus of the power circuits and auxiliaries.

Accessibility of all apparatus is also the keynote here.

1. Contactors for auxiliaries.
2. Insulated frame with power and brake contactors.
3. Step contactors.
4. Change-over switch for trolley wire or battery operation.
5. Voltage regulator for converter set.
6. Battery fuses.

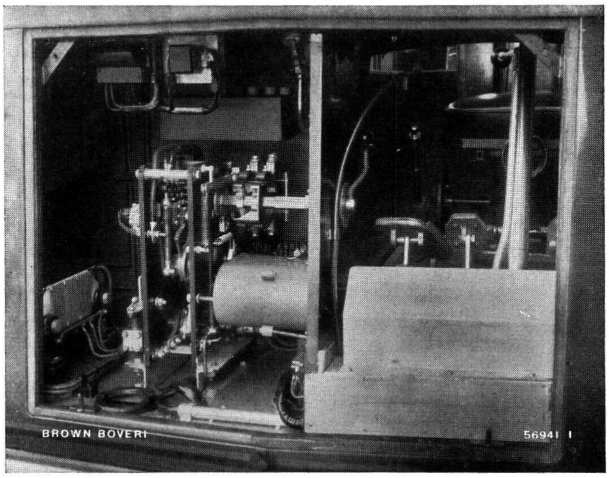


Fig. 7. — Apparatus of trolley bus control panel.

On the left control unit (with reverser, motor field rheostat and master controller), on right power and brake pedals.

Accessibility of all apparatus is likewise a feature here.

The interior of the trolley bus is heated by air heating sets, each rated 2000 W, under the two rows of seats. These comprise heating resistances with motor-driven fan set enclosed in a cylindrical sheet-steel casing. The air is drawn in at the motor end and expelled into the interior of the bus over the resistances. These heating sets result in rapid and uniform temperature distribution and allow the use of thermostatic temperature regulation with a moderate temperature under the seats.

Failure of the contact wire voltage or dewirement of the collectors is indicated by the lighting up of a pilot lamp controlled by a low-voltage relay.

For the sake of completeness mention should also be made of the battery-fed 24 V auxiliary circuits, already referred to in passing. A description of these, however, is beyond the scope of this article. The circuits in question include the accessories for the operation of the pneumatic door operating gear, windscreen wiper, lighting, fans, signals, direction indicator, etc., which have to be continually operated by the driver and for this reason must be installed close to his hand, either on the control panel or on the wall (Fig. 5).

(MS 667) *E. Eugster. (E. G. W.)*

MODERN STANDARD APPARATUS FOR ELECTRIC LOCOMOTIVES AND MOTOR-COACHES.

Decimal Index 621.337

The present article gives design and operating details of modern apparatus and equipment components which have already proved their worth on both electric and Diesel-electric locomotives and motor-coaches. These include single and multi-point couplers, cam-operated tap-changing switches for a. c., servo controls for switches and other applications, as well as a number of special designs of control gear for lightweight motor-coaches.

1. *Couplers.*

APART from affording ready and safe coupling and uncoupling couplers must be mechanically and electrically robust, and as weather-proof as possible. Since many of the couplers on the market do not fully meet these requirements single and multi-point couplers designed expressly for traction service meet a real need. The following range has been developed by the Company:—

Single-point couplers with spring-loaded plug contact (Fig. 1) rated 1500 V d. c. or a. c. and 60 A. This coupler is eminently suitable for lighting, heating, and braking circuits. It comprises a cable holder, cable, plug, plug socket, and dummy socket, and is provided with protective earthing. The contacts are protected against mechanical damage and arranged to exclude accidental contact by the railway staff. A claw fitted on the cover of the coupler socket and which gives way when subjected to excessive pulling forces, prevents the jumper cable sliding out of the socket.

Two-point couplers with spring-loaded plug contacts rated 1500 V d. c. or a. c. and 60 A per point. These are of similar design to the single-point couplers described above.

Ten-point couplers for lighting and control lines rated 20 A per point and 550 V, these consisting of a cable holder, plug with non-sprung pins and cable sealing gland, and a socket with spring-loaded pins and hinged cover with safety fastening.

29 or 37 point couplers for control wires (Fig. 2) comprising two plugs with non-sprung pins and two receptacles with spring-loaded pins and hinged cover with safety fastening, rated 110 V and 14 A per point, suitable for control wires for operating coils of electromagnetically or electropneumatically operated contactors and relays as well as for instrument wires.

61 point couplers for control wires (Fig. 3), of same design as the above-mentioned 29 or 37 point couplers, rating 14 A per pole, 110 V. If all of the points are not employed a certain number of contacts, e. g. for lighting and measuring purposes, can be provided for higher voltages up to 500 V.

2. *On-load Tap-changers.*

Whereas the Brown Boveri high-voltage control is advantageous for high-power locomotives with a large number of control notches, a cam-operated tap-changer for a maximum of twenty notches has been developed for locomotives and motor-coaches of low and medium power. This has met with a good reception in traction circles due to its extremely low weight and the small amount of contact wear. Such tap-changers are available in two sizes, i. e. 750 and 1000 A per switch unit (Fig. 4) or 1500 and 2000 A at the mid-point of the protective choke coil, for approximately 800 V, $16^{2}/_{3}$ cycles, and voltages between tappings of up to about 100 V. The tap-changer mounted horizontally, usually on an insulated base, comprises two rows of horn-gap switches without magnetic blowout, clamped side by side on insulated cross-bars. These are actuated by a camshaft bearing double-acting cams. The fixed contact carriers are provided with terminals for the transformer tapping leads, while the moving contacts

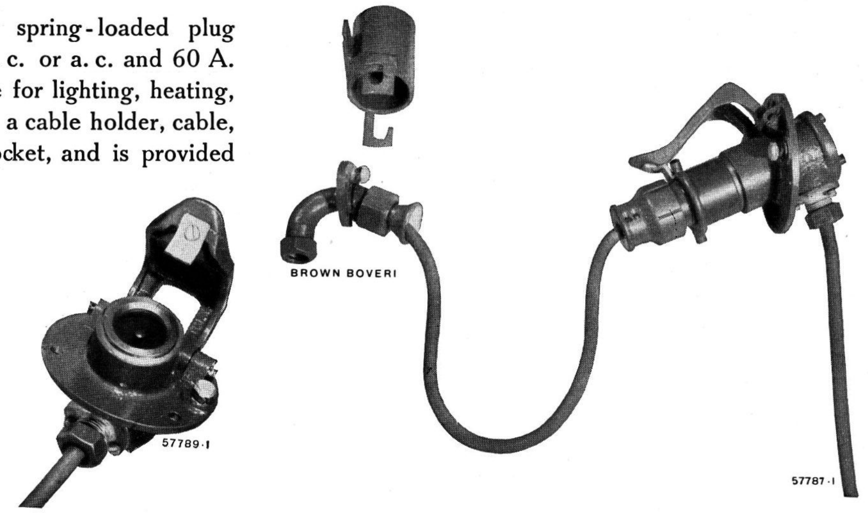


Fig. 1. — Single-point coupler rated 1500 V, 60 A, d. c. or a. c., suitable for lighting, heating, and brake lines.

are connected to the two busbars leading to the protective choke coil by flexible leads. The arc is ruptured by the inherent field of the horn-gap contacts backed up by the special shape of the horns and the composition of the horn material. Experience has shown that the contacts are subject to very little burning, so that even under heavy duty conditions it should not prove necessary to adjust or change the horn contacts for many years. The type rated 2 × 750 A is employed for medium power motor-coaches; it is provided with a casing and mounted under the floor of the coach. The type rated 2 × 1000 A is used for heavy motor-coaches and locomotives, in the latter case mostly without casing for the switch units and connectors.

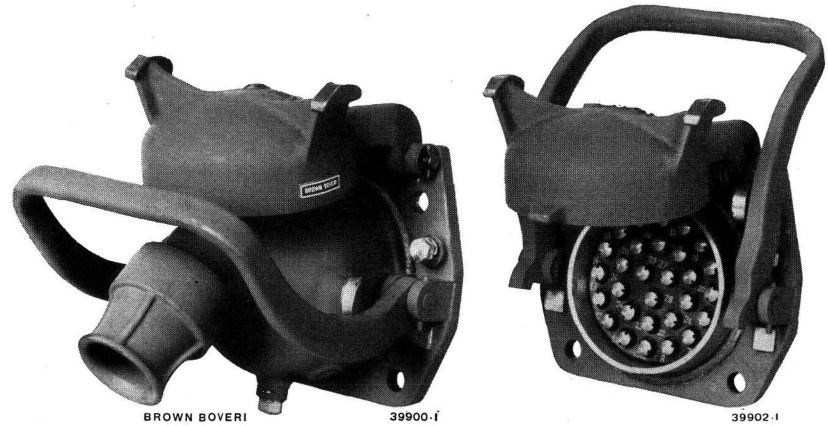


Fig. 2. — 29 or 37 point coupler, rated 110 V, 14 A per pole, suitable for control wires for coils of electromagnetically or electropneumatically operated contactors, relays and measuring wires.

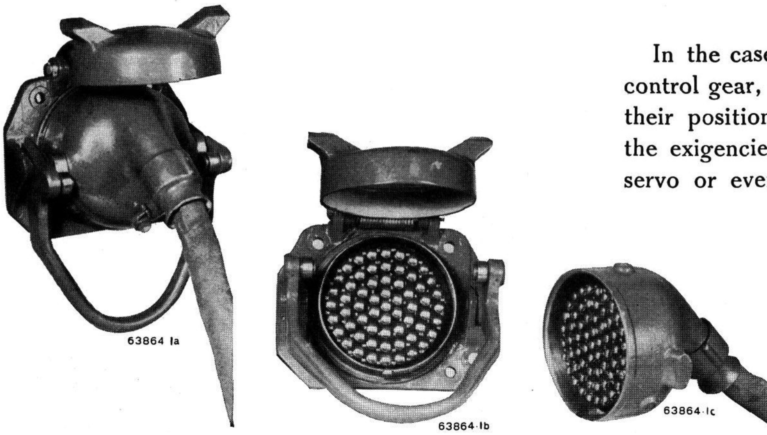


Fig. 3. — 61 point coupler for control wires, rating 14 A per point, 110 V.

These tap-changers are rarely operated by hand through transmission gear with a dummy controller, but on the servo control principle by a remote-actuated power-operated control built on the tap-changer (see section 3). The weights of twelve and eighteen notch cam-operated tap-changers rated 2 × 750 and 2 × 1000 A, respectively, including power-operated control and casings, are 170 and 300 kg, respectively.

To reduce tractive effort fluctuations a resistance can be switched in parallel with the tap-changing choke by a contactor. This resistance is automatically switched in before the tap-changer is operated when going over from one notch to the next and switched out once the operation is completed. The gearing of the control operates in two movements per notch. The short interval elapsing between the two movements has a favourable influence on the quenching of the arc.

3. *Servo Controls.*

In the case of multi-notch controllers, Diesel engine control gear, etc., the effort necessary to operate them, their position on the locomotive or motor-coach, and the exigencies of double or multiple operation involve servo or even multiple-unit control.

Power-operated servo motors type Ma 2 are designed for a maximum of twelve notches (Fig. 5), type Ma 3 for a maximum of twenty. Both types are intended for mounting directly on the cam-operated tap-changer described in section 2 and are designed for notching both up and down. The control motor, designed for 24—220 V, drives the operating shaft of the servo motor through gearing, operating in two movements per tap-changing cycle. The mean ratio between the control motor and the operating shaft is 1 : 600 to 1 : 900 (according to the angle between

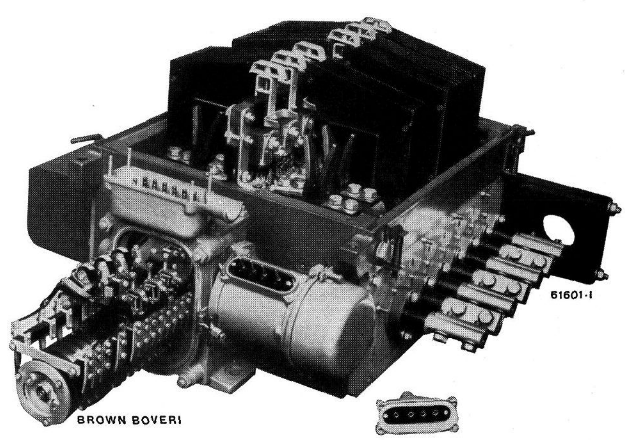


Fig. 4. — On-load tap-changer for about 800 V, 16 $^{2}/_{3}$ cycles and voltages between taps up to about 100 V, rated 750 and 1000 A per switch unit, i.e. 1500 or 2000 A at the mid-point of the protective choke coil. Casings removed.

The Brown Boveri modern a. c. on-load tap-changer for lightweight motor-coaches, is designed especially for mounting under the coach-floor.

notches) corresponding to 12—20 notches, the mean operating speed about 0·6 s per notch, and the torque available on the operating shaft 400—600 kgcm. For the control of the notching up and down coil of the relay group there is a selector drum with contact segments and fingers and a camshaft for the stepwise operation of hammer contacts. The control motor is remote-operated from the master controller through the change-over relay for changing the direction of rotation and controlling the switching-in and braking relays. After the position selected on the master con-

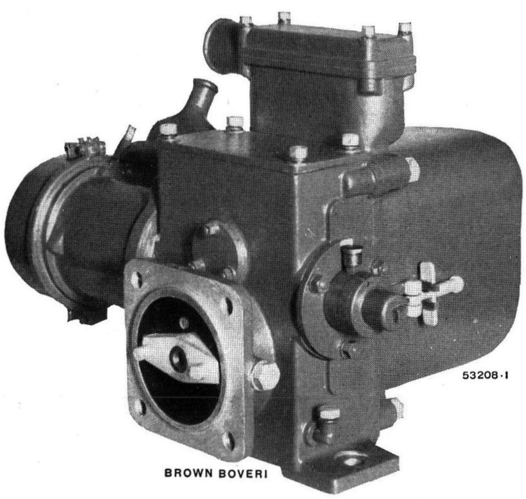


Fig. 5. — Power-operated servo motor types Ma 2 and Ma 3, for a maximum of twelve and twenty notches, respectively, and for direct mounting on the on-load tap-changer in Fig. 4, for notching both up and down.

troller and accurately determined by the gearing is attained and the switching-in and braking relay has dropped back into its braking position the control motor is automatically rheostatically braked. Several such servo motors can be operated in double or multiple-unit control.

Weight of type Ma 2: 34 kg.
Weight of type Ma 3: 45 kg.

Multi-notch power-operated servo motors type NEMOT for varying the speed or injection of Diesel engines comprise gearing with built-on electric motor and a selector with adjustable cams, for a maximum torque of about 100 kgcm on the driven shaft. The maximum switching angle is 330°. With the maximum of twelve notches there is a minimum angle of 25° between notches. The operating time for twelve notches is about 7 s. The torque of the control motor is transmitted to the shaft of the servo motor through gearing and a slip coupling. This coupling permits, for instance, the governor of a Diesel engine to be operated by

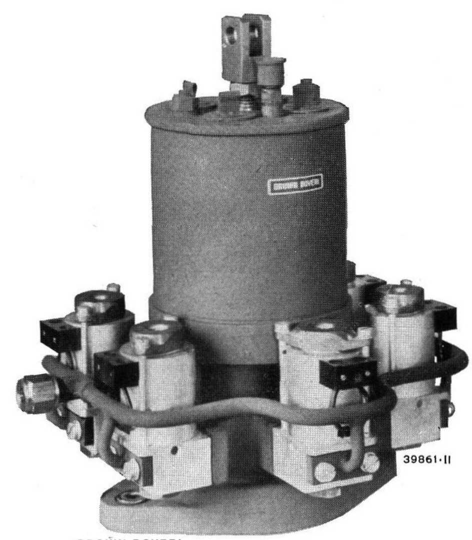


Fig. 6. — Electropneumatic servo motor for varying the speed or injection of Diesel engines size 35/50, aggregate travel 50 mm, with six positions (including zero position). Positions 1—4 adjustable. Force of displacement 10 kg.

hand for servicing without affecting the correct mutual position of the governor and the servo motor. The latter together with the relay set is controlled from the master controller in a similar manner to the control for tap-changers described under the foregoing subheading. The cams for actuating the spring-loaded hammer contacts are individually adjustable on the cam shaft, so that the angle between the individual notches can be selected to suit operating requirements. The control type NEMOT constructed for the first time for seven switch positions for the Diesel-electric five-car sets of the Dutch State Railways weighs 45 kg.

Electropneumatic servo motors size 35/50 (Fig. 6). The five-cylinder servo motor for a maximum pressure of 8 kg/cm², which is normally mounted upright, with five built-on electropneumatic valves for 12—110 V

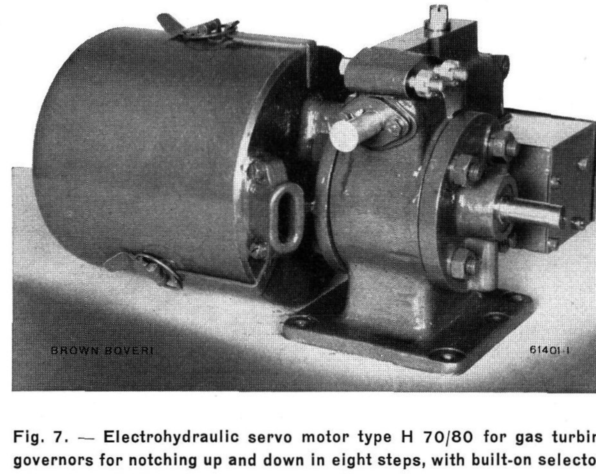


Fig. 7. — Electrohydraulic servo motor type H 70/80 for gas turbine governors for notching up and down in eight steps, with built-on selector.

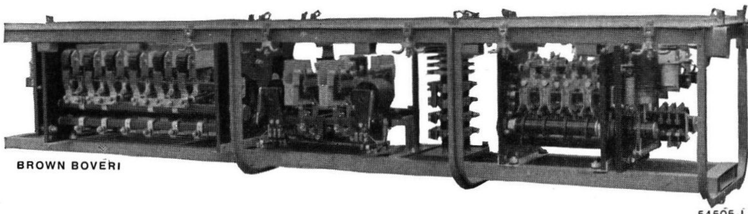


Fig. 8. — Control box for d. c. lightweight motor-coaches, incorporating brake change-over switch, main contactor, motor isolating switch, and reverser.

d. c. also serves as multi-notch control unit, e. g. for adjusting the speed of Diesel engines, the forked head being connected to the control unit to be operated through levers and rodding. The total travel between 0 (initial position) and the last position 5 is 50 mm; positions 1 to 4 can be adjusted to suit requirements. With the minimum pressure of 3 kg/cm^2 g the force of displacement in both the notching up and notching down directions is still 10 kg. The weight of the servo motor is 22 kg.

Electrohydraulic servo motors type H 70/80 (Fig. 7) are designed for notching both up and down for the control of gas-turbine governors in eight steps. The apparatus comprises a cylinder with horizontal rotary piston for an oil pressure of 3—3·5 kg/cm^2 g, the corresponding electromagnetically-operated control piston, and a selector with contact drum and rotary contact finger carrier. A magnetic system controlled from the master controller via the selector drum of the servo motor displaces the control vane out of its central position either in the notching up or in the notching down direction. Once the selected position is reached the vane is automatically returned to its central position where the pressure of the oil on either side of it is the same, so that it comes to rest. The weight of the apparatus is 28 kg.

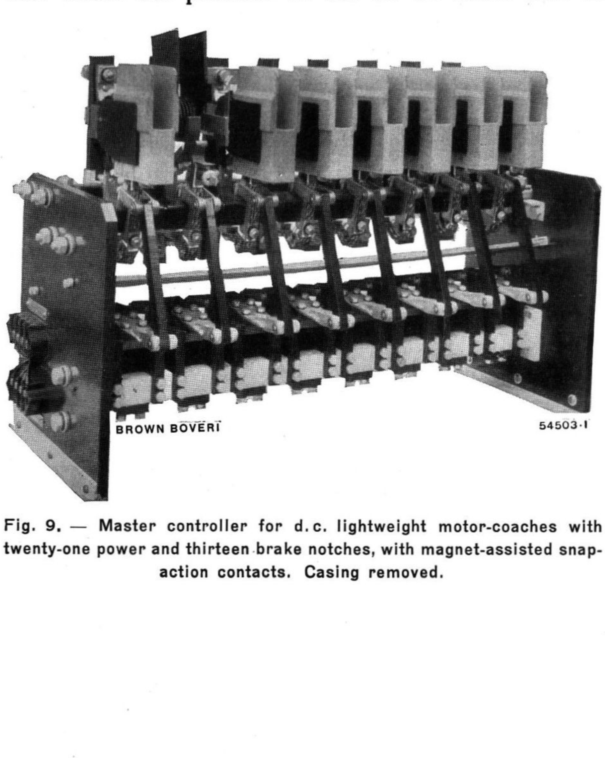


Fig. 9. — Master controller for d. c. lightweight motor-coaches with twenty-one power and thirteen brake notches, with magnet-assisted snap-action contacts. Casing removed.

4. *Power Control Apparatus for Lightweight Motor-coaches.*

Control equipment for lightweight vehicles must above all be of light weight and compact, but robust design. The power control equipment supplied, for instance, to the Zurich Municipal Tramways, comprises a pedal-operated master controller, the main contactor, the grouping contactors for the series-parallel connection of the two sets of motors and the eight step contactors, all electromagnetically-operated, the reverser and brake change-over switch, both electropneumatically operated, and the hand-actuated motor isolating switch.

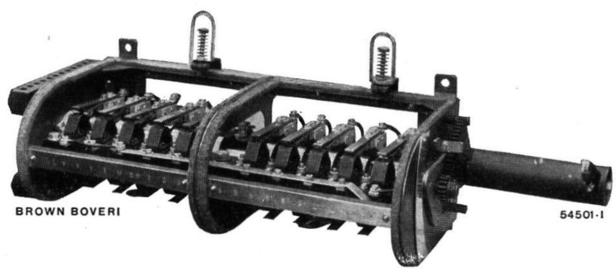


Fig. 10. — Insulating framework with eight electromagnetically-operated contactors for d. c. lightweight motor-coaches.

Fig. 8 shows the large control box, on the left the brake change-over switch, and then in succession the main contactor, the motor isolating switch, and the reverser. Fig. 9 depicts the pedal-operated master-controller for twenty-one power notches (twelve series, nine parallel notches) and thirteen brake notches. This controller is of the cam-operated type provided with magnet-assisted snap-action contacts which facilitate operation, reduce the necessary effort for operation of the controller, and at the same time render marking of the individual steps superfluous. Fig. 10 shows the insulating framework comprising eight contactors for power running and rheostatic braking, as also employed on trolley buses. Apart from the excellent space utilisation for the step contactors which generally have to be lodged in the driver's cab, the concentration of several contactors on a common framework and the locating of the operating coils underneath the appertaining switch units ensures the equipment being less subject to mass inertia effects arising from the motion of the coach body.

(MS 665) *E. Eugster. (E. G. W.)*

MODERN ELECTRIC LOCOMOTIVES AND MOTOR-COACHES FOR RACK-AND-PINION RAILWAYS.

Decimal Index 621.335 : 625.33

Comfortable, high-speed, lightweight motor-coaches of pleasing appearance are also imperative on rack-and-pinion railways if they are to pay their way. The following cursory description of a number of vehicles of this kind supplied, modernized, or in hand gives an idea of the part Brown Boveri have played in this development.

IN recent years a large number of rack-and-pinion railways have been changed over from steam to electrical operation owing to the greatly increased traffic which could only be met by electrification. These include the Vitznau—Rigi (built as early as 1871 by Niklaus Riggenbach), Glion—Rochers-de-Naye, and Furka—Oberalp Railways. Other progressive mountain railways such as the Aigle—Leysin, Wengernalp, and Gornergrat Railways, have decided to acquire modern lightweight motor-coaches in order to be able to meet the prevailing traffic requirements. These modernization schemes gave the engineering industry an opportunity to develop up-to-date rack vehicles embodying many big advantages and certain fundamental innovations compared with the locomotives and motor-coaches in operation on such railways hitherto.

Fig. 1. — Motor-coach of Rigi Railway at Rigi-Kulm.

Electrical equipment: Brown Boveri. Mechanical part: Swiss Locomotive and Machine Works, Winterthur.
This spacious panorama coach smoothly climbs 1311 m in 35 min.

Even on rack railways high-speed, comfort, and safety are the order of the day from the point of view of the passengers, whereas the railway companies naturally attach great importance to maximum

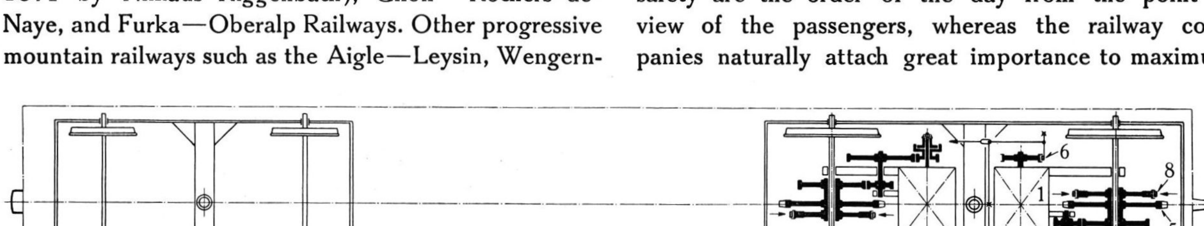


Fig. 2. — Diagram of drive on Rigi Railway motor-coach shown in Fig. 1.

1 = D. C. series motor.
2 = First gear shaft.
3 = Slip coupling.
4 = Second gear shaft.
5 = Rack pinion.
6 = Automatic speed limiting brake, also hand brake.
7 = Speed regulator for automatic brake.
8 = Gear brake with pawl gear only for braking on down-grade.

Left: Pony bogie (Lower end). Right: Power bogie (Upper end).

economy. Such requirements are met with lightweight motor-coaches having a low-built, well-sprung coach body with large windows, comfortable and readily accessible compartments for the passengers — possibly with upholstered seats — liberally dimensioned, high-speed traction motors capable of withstanding heavy overloads, and electrical control gear requiring as little space as possible. These exigencies are met by the vehicles for pure rack-and-pinion and mixed rack and adhesion operation cursorily described hereafter. For reasons of economy therefore solo motor-coaches or a composition of one motor-coach and one single passenger coach are employed. A requirement, however, is that the relatively short routes should be covered as quickly as possible to permit of a fast shuttle service being introduced during the periods of peak traffic. In this way the capacity of the vehicles is well utilized without the electrical equipment and mechanical portion having to be over-dimensioned for the periods of heavy duty service.

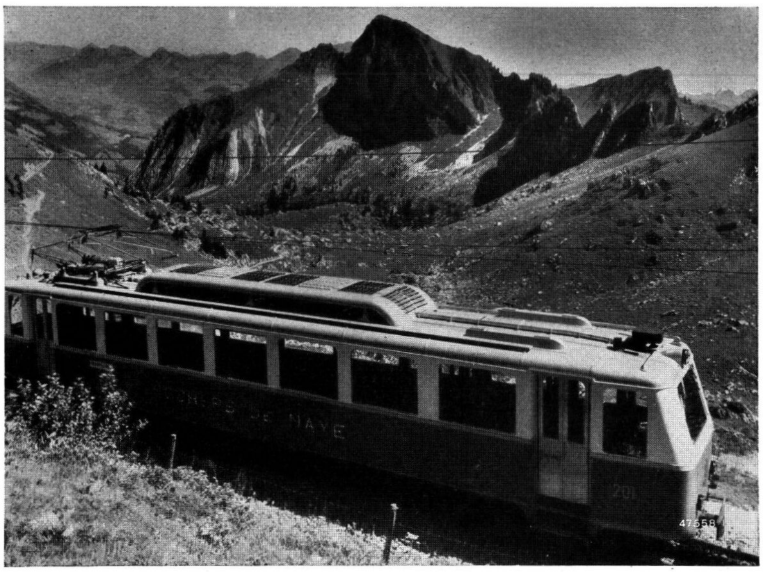


Fig. 3. — Motor-coach of Rochers-de-Naye Railway.

Electrical equipment: Brown Boveri. Mechanical part: Swiss Locomotive and Machine Works, Wintertnur.

Electrical operation has enabled the time taken to climb 1578 m to be reduced from 90 min. with the earlier steam operation to 52 min. with this modern lightweight coach.

1. *The Rigi and Glion—Rochers-de-Naye Railway Motor-coaches.*

Both of these railways are entirely rack operated and have to deal exclusively with touristic traffic. Except for a few weeks of dense traffic in summer and winter the number of passengers carried is small.

The *Rigi Railway* conversion to 1500 V d. c. entailed three motor-coaches and a small locomotive for goods traffic and snow clearance work.

The roomy coach body of steel is of self-supporting construction and rests on the power and pony bogies. The pony bogie, which is at the valley end of the vehicle, is of lightweight construction, while two trac-

Fig. 4. — Diagram of rack drive on Rochers-de-Naye motor-coach.

1 = D. C. series motor.
2 = Flexible coupling.
3 = Slip coupling.
4 = Spur gearing.
5 = Automatic speed limiting brake, also used as hand brake.
6 = Sliding joint.
7 = Cardan shaft.
8 = Bevel gearing.
9 = Rack pinion with two sprung toothed rims.
10 = Gear brake with pawl gear, also used as hand brake on down-grade.
11 = Pony axle.
12 = Hand control of speed limiting brake.
13 = Brake spring with tripping magnet for automatic speed limiting brake.
14 = Lighting set.
15 = Centrifugal switch for speed limiting brake.

tion motors and all of the mechanical brakes are mounted in the power bogie. The buffing and braking forces entailed when propelling an additional passenger car have therefore only to be transmitted by a small part of the coach frame. As a result is was possible to dispense with reinforcement of the remainder of the vehicle and thus achieve a reduction in weight. A single large compartment with upholstered seats provides accommodation for 60 passengers who are able to enjoy virtually a panorama view due to the large type of windows adopted. At the other end of this compartment there is a spacious driver's cab, that at the valley end also being employed as a luggage compartment when necessary. Twelve folding seats are likewise provided in these two cabs, thus bringing up the total seating capacity to 72.

The fact that the railway is of standard gauge (quite an exception where rack railways are concerned) it was found possible to employ nose suspension for the two traction motors. The torque is transmitted through two-stage spur gearing to the corresponding rack pinion. An arrangement adopted by the Company for the first time on the motor-coaches of the Turin-Superga rack railway with a short intermediate shaft for the gearing permits the motor to be lodged close to the rack pinion, thus enabling the latter to be fitted between the centre pin and the pony axle. In this way it was possible to achieve a substantial weight reduction due to the shorter bogie and the motor supports. Moreover, riding properties are improved. The remainder of the electrical equipment comprises essentially a platform-type controller with 15 starting and braking notches in each cab, the roof-mounted starting and braking resistances (the latter designed for the braking of the entire weight of the train), the usual current collection gear, high-voltage lighting and heating equipment, and the conventional safety devices for operation with one single driver.

A notable feature is the low weight of 232 kg per seat, a record which will be difficult to surpass in rack-and-pinion coach construction and for which great credit is due to the firms participating in the building of the coaches.

The locomotive is of the two-axle type and has fundamentally the same mechanical and electrical equipment as the motor-coaches. Since, however, in contradistinction to rack locomotives constructed heretofore the motors are lodged between the pony wheels, underneath the locomotive body instead of in it, the interior of the vehicle is very roomy and goods or even track maintenance men together with their equipment can be transported. For a standard gauge rack locomotive with a one-hour rating of 330 kW and a maximum running speed of 18 km/h the low weight of only 12·6 t is also a feature here.

The motor-coaches built for the *Glion—Rochers-de-Naye Railway* (750 V d. c.) are designed for solo operation and convey the traveller into the mountains as rapidly and comfortably as the familiar alpine road cars. The vehicles are designed throughout with this end in view. The coach body, built to streamlining principles, has an elegant and attractive appearance. It is of steel construction integral with the frame and comprises a third-class compartment with a seating capacity of 41, a second-class compartment for the accommodation of six passengers seated, and two roomy driver's cabs with five seats. In addition, there is room for eighteen passengers standing, thus bringing up the total capacity to 70 passengers, and this for a vehicle with a gauge of only 800 mm! The coach body itself rests on two power bogies each fitted with a traction motor arranged in the lengthwise direction. The narrow gauge no longer permitting of the conventional arrangement with nose-suspended motors parallel to the axles, a well tried arrangement was reverted to with which the motors, arranged along the axis of the coach, are no longer restricted by the gauge and, moreover, are carried by the coach springs. A cardan shaft and joint take up the relative movements of the axles and the motors, which now form part of the spring-mounted portion of the coach. This type of drive was employed many years ago for the motor-coaches of the Stansstad—Engelberg and St. Gallen — Gais — Appenzell Railways, although in the case of the Glion—Rochers-de-Naye Railway the motors are fitted in bogies instead of on the underside of the coach body. The motor fitted at

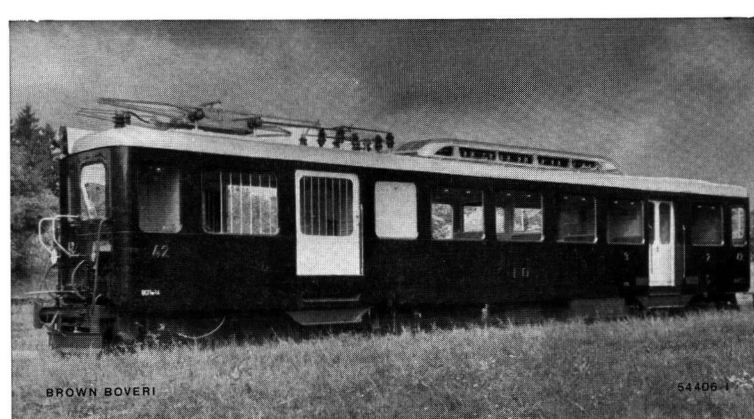


Fig. 5. — Motor-coach type BCFe 2/4 of Furka—Oberalp Railway.

Electrical equipment: Brown Boveri.
Mechanical part: Swiss Locomotive and Machine Works, Winterthur.
The trains hauled by such modern lightweight motor-coaches cover the 97 km between Brig and Disentis in 3 h 25 min., overcoming a total difference in altitude of 2081 m.

the upper end of each bogie drives spur gearing through a slip coupling and bevel gearing via a short cardan shaft, the larger bevel wheel being coupled to the rack pinion. A brake disc for one of the two hand brakes and for the automatic speed brake is provided after the spur gearing. A second independent hand brake for braking the whole weight of the coach on any gradient, in the form of a pawl brake, acts on a braking disc adjacent to the rack pinion; this has two toothed rims. Normal service braking is provided by electric rheostatic braking of the motors. The remainder of the electrical equipment comprises, as in the case of the Rigi Railway, a platform-type controller with 13 starting and braking notches at each end actuated by the seated driver with a large control wheel, the roof-mounted starting and braking resistances, the pantograph current collector, the circuit-breaker, electrical heating equipment for roughly 210 W per m^3 of coach space, the lighting circuit, supplied from a dynamo driven by one of the motors in conjunction with a regulator and battery, the usual safety equipment for operation with one single driver, and special electrical equipment to prevent the running back of the coach on gradients in the event of supply failure. If the maximum admissible speed is exceeded on the down-grade a centrifugal switch closes the circuit of special electro-magnets which apply the speed-limiting brakes on both bogies simultaneously.

2. *The Motor-coaches of the Furka—Oberalp Railway for Mixed Adhesion and Rack Operation.*

In its total length of 97 km this railway includes two passes of 2164 and 2064 m above sea level, respectively. On the run from Brig to Disentis, for instance, there is a climb of 2081 m and a descent of 1607 m. The four modern motor-coaches acquired by the railway on the occasion of the conversion to electrical operation (11,000 V, 16 ²/₃ cycles) in 1942 have to cope with local traffic and haul fast light-weight trains over the entire route. They are also able to operate on the adjacent Visp—Zermatt, Schöllenen, and Rhætian Railways. A fifth motor-coach of similar construction has been put into service by the Schöllenen Railway. This is intended for shuttle service on the 3·76 km long Andermatt—Göschenen line during periods of peak traffic, operating either alone or together with a control car.

The extremely severe operating conditions on this railway and the gradients of 4 % on the adhesion sections entail a very robust and fairly heavy motor-coach. The specification called for motor-coaches with only two traction motors. These are nose-suspended in a single power bogie and drive a gear shaft through spur gearing. On this shaft there are two gear-wheels giving different ratios, the one meshing with the rack

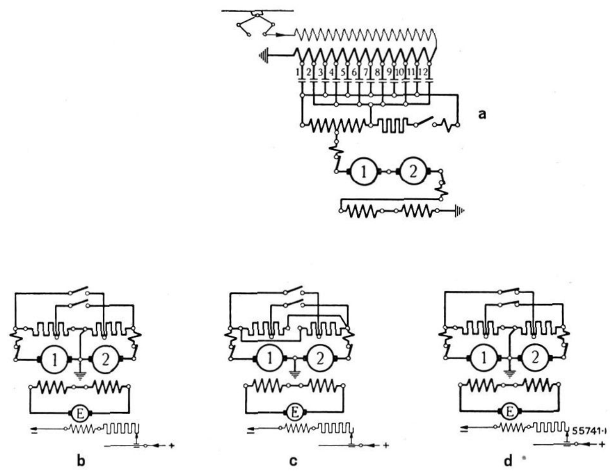


Fig. 6. — Simplified diagram of power and brake circuits of motor-coach on Furka—Oberalp Railway.

a = Power running. c = Braking (rack up to 11 %).
b = Braking (adhesion). d = Braking (rack over 11 %).
1, 2 = Traction motors. E = Exciter.

pinion and the other with the adhesion driving axle. As a result of this combined transmission the adhesion axles also provide a part of the tractive effort on the rack sections of the railway. The coach body is of self-supporting construction and rests on the power and pony bogies. The pony bogie is provided with a braking rack-pinion. Triple springing of the coach body assures smooth and pleasant travelling. Due to the exacting operating requirements the electrical equipment is fairly comprehensive, but on account of the restricted space conditions had to be made of extremely compact design. The traction motors are located within the adhesion axles and not, as for instance in the case of the locomotives of the same railway company, outside in the bogie, an arrangement which results in better riding properties of the coaches on both straight stretches and in curves with consequently reduced wear and tear of the track. The transformer and tap-changer are suspended from the underside of the coach body. The cam-operated tap-changer for twelve tappings with electric servo-motor control and the remainder of the apparatus in the series circuit are actuated by a master controller in each of the two driver's cabs. The entire equipment, however, can also be remote controlled from a control car. On the long down-grades the two traction motors are connected in series to a braking resistance, being excited by a separate convertor set. The widely differing braking conditions entail subdivision of the electrical brake into three groups. The braking ranges thus obtained overlap and are achieved by changing over the connections of the braking resistance. The entire weight of the train is braked electrically, a part of the energy generated being used for heating purposes in winter. The exciter is driven by a single-phase induction motor and the dynamo for the battery charging and lighting

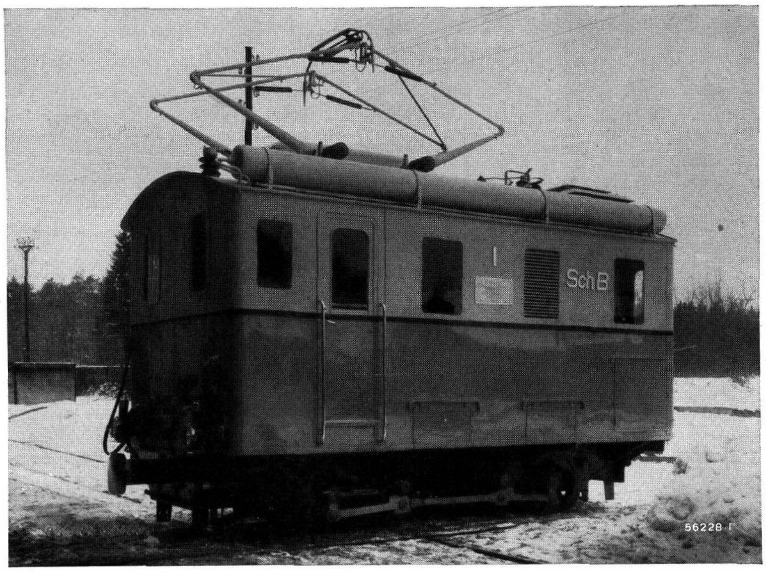


Fig. 7. — Locomotive on Schöllenen Railway converted from d. c., 235 kW, 1200 V, to single-phase a. c., one-hour rating 430 kW, 10,500 V, $16^{2}/_{3}$ cycles.

This represents an increase in power of more than 70 % notwithstanding the addition of a transformer.

is also combined with them to form a self-contained unit. The set is started by the charging machine, which automatically operates as motor in the event of failure of the supply voltage. Electrical braking is therefore always ensured on the down-grade. The remaining auxiliaries comprise essentially a fan set for the traction motors, a combined vacuum and compressed-air pump set for the train and motor-coach brake and the pneumatically operated apparatus, the thermostatically controlled train heating equipment, the lighting system, and the safety devices for operation with one single driver and for limiting the speed on steep down-gradients. The brakes giving the necessary operating safety can be subdivided into the electrical service brake, an automatic vacuum brake for the train, combined with a vacuum-controlled retarded Westinghouse pneumatic brake for the motor-coach acting on the adhesion wheels and the braking rack pinion in the pony bogie, a pneumatic brake acting directly on the rack pinion, and a hand brake for the adhesion axles of the power bogie.

3. *The Locomotives on the Schöllenen Railway Converted for Single-phase Mixed Adhesion and Rack Operation.*

In connection with the electrification of the Furka—Oberalp Railway the Schöllenen Railway was also changed over from 1200 V d.c. to 10,500 V, single-phase $16^{2}/_{3}$ cycles a.c. to facilitate transition of the rolling stock from one railway to the other at the joint station at Andermatt. As a result the four two-axle locomotives of the Schöllenen Railway had to be changed over for single-phase operation. It was desired to retain the mechanical portion, but the complete renewal of the electrical equipment afforded an opportunity of substantially increasing the capacity of the vehicles as the following table shows:—

Current system		Earlier D. C.	Now Single-phase a. c.
Supply voltage . . .	V	1200	10,500
One-hour rating . . .	kW	235	430
Corresponding running speed	km/h	8	14·5
Maximum speed			
on rack section . . .	km/h	10	18
on adhesion section .	km/h	20	30
Weight of locomotive .	t	21·3	24·6
Maximum weight of train	t	55	73

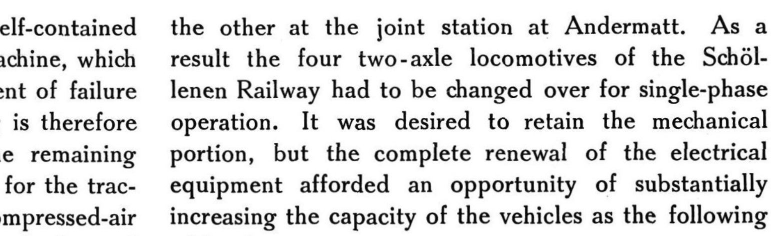


Fig. 8. — Diagram of mechanical drive of locomotive of Schöllenen Railway.

1 = Single-phase series motor.
2 = Slip coupling.
3 = Shaft between first and second gear shafts.
4 = Rack pinion with brake drum.
5 = Adhesion coupling with control by oil under pressure.
6 = Connecting rod of adhesion axles.
7 = Braking pinion.
8 = Automatic speed limiting brake.

Principal Data of New Motor-coaches for Rack-and-pinion Railways.

Railway	Rigi	Rochers-de-Naye	Furka — Oberalp	Aigle—Leysin	Wengernalp	Gornergrat
Method of operation	Rack	Rack	Rack and adhesion	Rack and adhesion	Rack	Rack
Length . . . km	6·86	7·7	97	6·31	10·45[2] and 8·55[3]	9·346
Gauge . . . m	1·435	0·800	1·000	1·000	0·800	1·000
Rack	Riggenbach	Abt	Abt	Abt	Riggenbach	Abt
Maximum gradient						
on rack . . . %	25	22	11 and 17·9[1]	23	19[2] and 25[3]	20
on adhesion section . . %	—	—	40	38	—	—
Maximum weight of train						
on rack . . . t	32·7	21·2	72 and 53[1]	34·2	44·8[2] and 34·6[3]	24·5
on adhesion section . . . t	—	—	100	38	—	—
Current system	D. C.	D. C.	Single-phase	D. C.	D. C.	Three-phase
Mean contact wire voltage . V	1500	750	10,500	1200	1500	725
One-hour rating of vehicle kW	330	150	430	260	440	190
Corresponding running speed . . . km/h	16·4	12·3	26·4	14·0	17·8	14·5
Maximum running speed						
on adhesion section . km/h	—	—	55	23,5	—	—
on rack uphill . . . km/h	18	17·5	30	20	25	15
on rack downhill . . km/h	12—14	13·5—17·5	20 and 15[1]	13—15	12—15	15
Tare . . . t	16·7	15·5	35	21·7	21	15·7
Fixed seating capacity	64	42	40	48	40	30
Folded seats	8	10	—	12	12	26
Standing capacity	8	18	—	20	—	30 110[4]
Luggage compartment . . m^2	5	—	8	4·8	2·9	—

[1] Section of Schöllenen railway. [2] Lauterbrunnen—Scheidegg section. [3] Grindelwald—Scheidegg. [4] For winter sports service.

Apart from the motor casing and a number of unimportant apparatus the electrical equipment is similar to that of the motor-coaches on the Furka—Oberalp railway. This entails only one set of spare parts having to be stocked for the two railways which are both under the same management. The tap-changer of the locomotives is manually operated and the resistances forced cooled. A notable fact is that it was found possible to locate the entire electrical equipment in the restricted locomotive body (superficial area 3800 × 2500 mm), without the clearness of arrangement and accessibility being essentially impaired compared to the former d. c. equipment. The earlier hand operation of the adhesion coupling for the two adhesion axles, which are coupled by a connecting rod, is replaced by an electrically variable hydraulic control; transition from rack to adhesion operation and vice versa is thus greatly facilitated. A small electrically driven oil pump supplies the necessary oil under pressure for coupling the adhesion drive. The locomotive has only one driver's cab which is situated at the valley end.

4. *Conversion of Motor-coaches of Leuk-Leukerbad Railway.*

The 10·4 km long Leuk-Leukerbad Railway has also changed over three d. c. motor-coaches for mixed adhesion and rack operation acquired in 1915 in order to meet as far as possible the new traffic requirements. The original motor-coaches, the first to be built for 1500 V d. c., had two bogies each having a frame-mounted slow-speed motor. Due to this arrangement the compartments behind the driver's cabs had to be employed to lodge the machines and apparatus so that the passenger compartments were only accessible from the outside. The chief advantages achieved through the conversion were a greater motor power with corresponding higher running speed both on the up and down grades, and more suitable arrangement of the interior of the passenger compartments, a corridor being provided between the two cabs through the passenger compartments and more space obtained for the luggage and second class compartments. The more powerful motors are of smaller size than the earlier ones. In lieu of the centrally located controller with mechanical remote control, a platform-type controller is fitted in each cab so that it has been found possible to lodge the whole of the remaining equipment and auxiliaries in a single compartment over one motor. The improvements achieved will be evident from the following table:—

		Earlier	After conversion
Contact-wire voltage . .	V	1500	1500
One-hour rating of motors	kW	2 × 125	2 × 187
Corresponding running speed	km/h	8·5	12·0
Maximum weight of train .	t	60	70
Running speed with full-load on 16 % gradient, up-grade	km/h	8·5	12·0
down-grade	km/h	9·0	16·0
Maximum running speed .	km/h	20	30

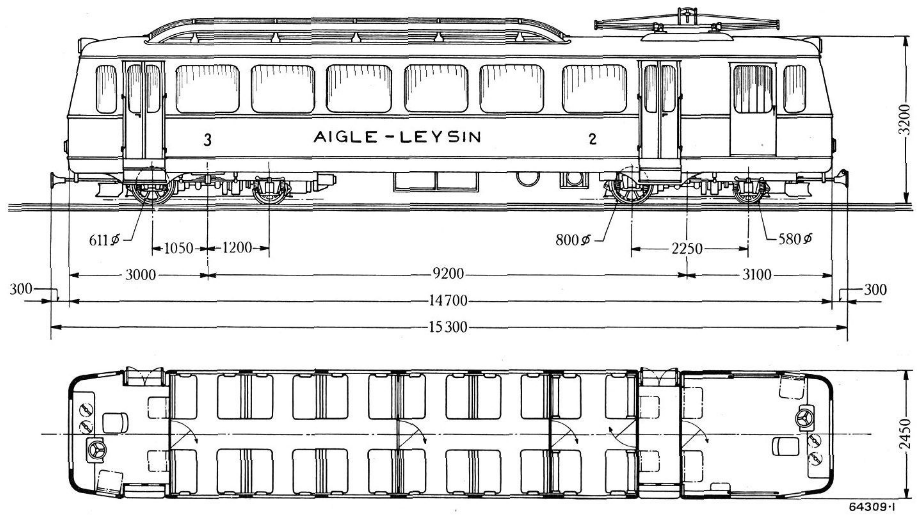


Fig. 9. — Motor-coach for 1300 V d. c. under construction for the Aigle—Leysin Railway.

Electrical equipment: Brown Boveri. Mechanical part: Swiss Locomotive and Machine Works, Winterthur.

The running speed on the up-grade rack section is limited by the capacity of the power station, while due to the unfavourable conditions — numerous short-radius curves with track laid on roads for some distance — it was impossible to raise the speed on the adhesion section. This notwithstanding, the time for the up-grade trip has been reduced from 60 to 45 min and that for the down-grade run from 60 to 35 min, so that the traffic has been considerably speeded up.

5. *Motor-coaches of Aigle—Leysin Railway for Mixed Adhesion and Rack Operation.*

At the beginning of 1945 the Aigle—Leysin Railway (d. c. 1300 V) purchased three new motor-coaches for the modernization of the line. Up to that time the adhesion section of roughly 1 km in length between the depot and the lower end of the rack section had been operated with a two-axle motor-coach hauling one or two passenger coaches at a speed of 12—15 km/h. At this point the coaches were taken over by a rack-and-pinion locomotive and propelled up to Leysin at a speed of 6 — 7·5 km/h. This complicated method of operation on a busy line of only 6·5 km in length is now greatly simplified as a result of the new motor-coaches. The running time is reduced from 55 to 35 min. The motor-coaches are generally operated alone, but sometimes also with a passenger coach ahead of them. They have two power bogies each with one motor arranged lengthwise, as in the case of the motor-coaches of the Rochers-de-Naye Railway already described. For service on the adhesion section the adhesion coupling is coupled up by a hydraulic

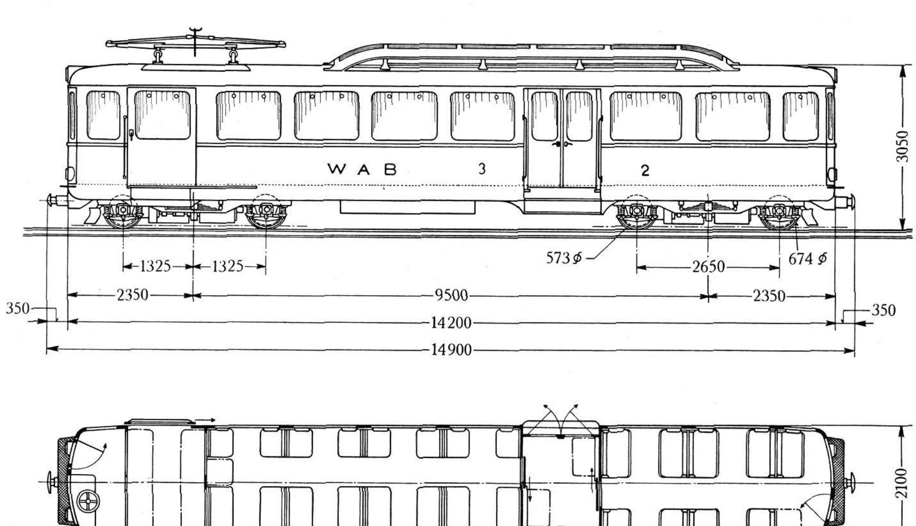


Fig. 10. — Motor-coach for 1500 V d. c. under construction for the Wengernalp Railway.

Electrical equipment: Brown Boveri. Mechanical part: Swiss Locomotive and Machine Works, Winterthur.

coupling in a similar manner to the Schöllenen Railway locomotives. The traction motors and the remainder of the electrical equipment are of well-tried design. The two platform controllers are lodged in the control panels where they can be operated by the seated driver. The vehicle is equipped with an electrical service brake for the down-grade run and pneumatic equipment for the control gear and the usual mechanical brakes.

time taken for the uphill run from Lauterbrunnen to Scheidegg, for instance, with a difference in altitude of 1265 m, is only about 45 min instead of 75 min, while the time for the downhill trip has been reduced from 75 to about 55 min. The four traction motors are arranged in pairs lengthwise in the two bogies. They drive the rack pinion through a cardan shaft and bevel and spur gearing. For the uphill run the motors

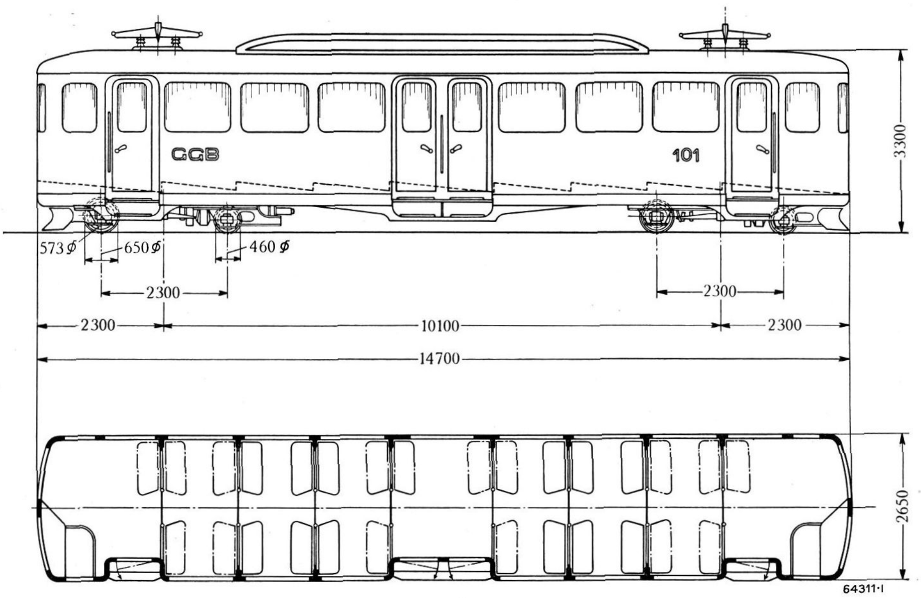


Fig. 11. — **Motor-coach for three-phase 725 V, 50 cycles, under construction for the Gornergrat Railway.**
Electrical equipment: Brown Boveri. Mechanical part: Swiss Locomotive and Machine Works, Winterthur.

6. *Rack-and-pinion Motor-coaches for the Wengernalp Railway.*

This railway (1500 V d.c.) is not only the most extensive pure rack-and-pinion railway, but also has more rolling stock than any other in Switzerland. In the course of a modernization scheme motor-coaches will be substituted for the locomotives exclusively employed up to the present. To this end a lightweight prototype was purchased at the beginning of 1945. The specification called in the very first place for a substantial reduction in running time, a high degree of comfort, and as economic operation as possible for a touristic railway on which traffic varies greatly with the season and the weather.

The motor-coach is therefore of very roomy and comfortable design. Apart from the single driver's cab at the valley end all of the available space can be employed for the accommodation of passengers. Compared to service with the locomotives operated up to the present the running speed on the up-grade is doubled. The speed on the down-grade is restricted by the official regulations, but has been increased by 30 — 60 % according to the gradient. As a result the

are normally connected series-parallel, but can also be operated in series, for instance when the motor-coach has to follow a locomotive-hauled train at reduced speed. On the down-grade regenerative braking is employed; apart from this, rheostatic braking is also possible independent of the contact wire. The motors are controlled and grouped for the different operating conditions with a single platform controller. The change-over from regenerative to rheostatic braking can be achieved without any intermediate manipulation of the reverser. In this way the running speed on the down-grade can be reduced from 15 to 3 km/h entirely electrically. For regenerative braking the four motor armatures are connected in series. The two branches of the fields which are normally connected in series-parallel are split up and separately excited in series from the contact wire. For rheostatic braking all four motors are connected in series. The remainder of the electrical equipment is simple and comprises the heating and high-voltage lighting installations for the interior of the coach, the service lighting installation connected to a battery, the usual safety and supervisory equipment for operation with one single driver and for automatic stopping of the train in the event of failure of the electrical brakes and the maximum admissible speed being exceeded on the down-grade. The guard in the passenger coach can also stop the train at any time. One hand brake acting on the gearing, a second combined with the pawl brake in the rack pinion drums, and an electrically tripped automatic brake in each bogie acting by spring pressure on the gear brake provide the necessary operating safety.

7. *Rack-and-pinion Motor-coaches for the Gornergrat Railway.*

This mountain railway (three-phase a. c., 725 V, 50 cycles), the first rack railway to be operated electrically and for which Brown Boveri supplied the entire electrical equipment of the power station, substations, and locomotives in 1898, serves the finest glacier district in Switzerland. Towards the end of 1946 two new lightweight motor-coaches, again electrically equipped by the Company, will be taken into service. These motor-coaches will be operated solo and their gear arrangement is similar to the Glion—Rochers-de-Naye coaches. The weight must be as low as possible in order to be able to meet the specified operating conditions with the one-hour rating[1] of the vehicle of 190 kW. The coach body is of self-supporting construction and rests on the two power bogies. In summer benches are provided which can be removed in winter to make more room for skiers with their equipment. On a part of the route passing through excellent skiing country the motor-coaches can be run in a shuttle service to rapidly convey the skiers from the bottom of the run to the top. The control gear for starting and regulating the two slip-ring motors is extremely simple. The starter, reverser, and brake and cascade change-over switches are mechanically operated from the two driver's cabs through rodding. The normal speed of 14·5 km/h will be obtained with the motors connected in parallel, while when running behind a locomotive-hauled train the cascade connection can be employed to obtain half speed. Regenerative braking is employed on the down-grade, the motors usually operating at super-synchronous speed. Rheostatic braking can, however, also be employed, when the motors are separately excited by a d. c. generator. The only other electrical equipment provided are the safety devices for operation with one single driver, the lighting for connection to a battery, and the coach heating installation. The mechanical braking gear will be similar to that on the Wengernalp motor-coaches.

In conclusion it might be mentioned that the mechanical part of all of the vehicles described above was supplied or is being built by the Swiss Locomotive and Machine Works, Winterthur.

(MS 669) *E. Hugentobler. (E. G. W.)*

[1] Owing to the very limited capacity of the power station in winter.

REMOTE-CONTROLLED FUNICULAR RAILWAYS.

Decimal Index 625.92

Remote-controlled funicular railways with automatic regulation of the operating cycle are economic in service and increase the capacity of the plant. The system incorporating a braking machine developed by Brown Boveri has proved reliable for both new and converted railways both under normal and dense traffic conditions, It, moreover, meets all working requirements.

FUNICULAR railways provide a means of communication with high or low-lying parts of towns or suburbs as well as serving for touristic and winter sports traffic in mountainous regions. In both cases the traffic density is subject to heavy fluctuations during the day or at certain seasons. The capacity of such an undertaking to cope with the short-period peak traffic is often of primordial importance where its economy is concerned. Working costs must be kept down to a minimum during the periods of light traffic. This can be effected by equipping the railway for remote control from the car and automatic regulation of the operating cycle. The power plant requires no attendance. Since departure signals have only to be exchanged between two points instead of three the trains can be got away quicker. The scheduled running time is shortened by the automatically controlled starting and stopping. Under peak traffic conditions therefore more trips can be carried out. The electrical braking for stopping at the stations reduces wear and tear on linings, so that re-adjustment of the mechanical brakes is only necessary at much longer intervals, which reduces maintenance costs. In case of emergency the drive can immediately be stopped from the car without the waste of time involved by ringing the engine-room attendant or employing the quick-acting brake of the car, which reduces wear and tear on the latter and diminishes the risk of accidents for passengers.

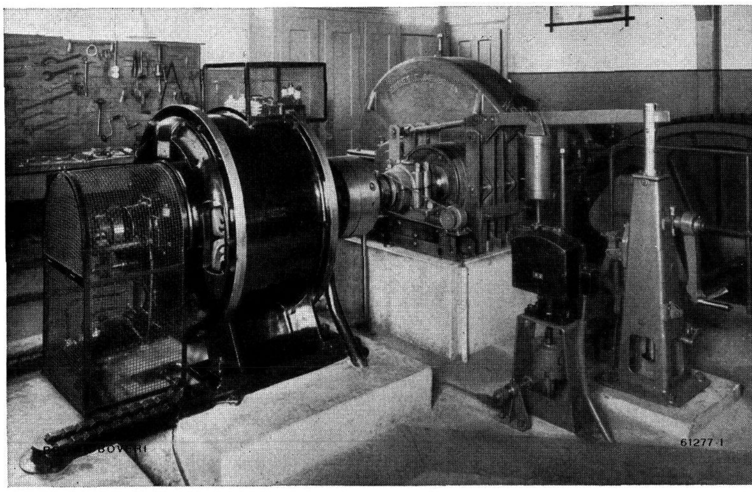


Fig. 1. — Old power plant of Gurten Funicular Railway for three-phase 3000 V a. c. and attended operation.

The Brown Boveri remote control gear with automatic regulation of the starting and stopping periods in the stations has the following features:—

1. Control of the power plant is effected by means of short current impulses via an overhead line or a control wire run along the side of the railway on telephone poles. The fact that contact is only required to be made briefly also ensures reliable transmission of the control impulses in winter and under hoar frost conditions. Different signals can be given over a single line.
2. The braking power to stop the railway is adapted to the car loading, braking virtually always taking place with the same deceleration, rapidly, smoothly, uniformly, and with the shortest possible braking path. The automatic regulation of the braking process enhances reliability which is not dependent on the trustworthiness and skill of the power plant attendant in the manipulation of the control and brake gear.
3. The power necessary for braking purposes is produced by a d. c. braking machine which dissipates the braking current in resistances, so that the braking work is performed without wear and tear on any part of the installation.

Apart from the usual funicular railway drive with three-phase induction motor automatic control involves a braking machine, frame-mounted control gear for checking and adapting the starting and braking process to the car loading, relays for receiving and executing the control orders from the car, and the necessary safety apparatus for the supervision of the regulation of the operating cycle. In the case of new installations the remote control gear can be employed for all working conditions. Existing railways can be changed over to remote control and automatic operation with only a short service interruption. As an example of such a conversion a brief description will now be given of a large funicular railway which was recently changed over with great success.

The Gurten Railway at Berne was built in 1899, being the second funicular railway to be equipped by Brown Boveri with a high-voltage motor (rating 62 kW, 3000 V three-phase a. c.). This simple equipment operated for approximately forty-five years without any trouble of importance, although in 1932 the running speed was increased from 2·0 to 2·5 m/s without modification of the electrical equipment. In 1944, due to the big increase in winter sports traffic, modern cars for a hundred instead of sixty passengers

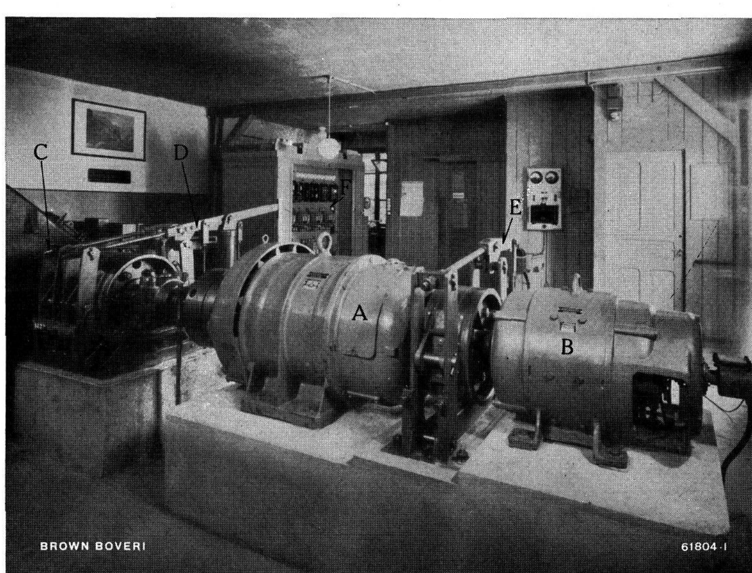


Fig.2. — Converted machine equipment of the Gurten Railway for remote control from the car.

A. Three-phase motor.
B. D. C. machine with built-on centrifugal switch.
C. Electrically operated mechanical brake.
D. Mechanical safety brake.
E. Hand brake for operation of railway with attended power plant.
F. Control panel with control gear and built-on controller for automatic regulation of the operating cycle.

were acquired, the speed increased from 2·5 to 3·3 m/s, and remote control from the car introduced. The new driving equipment with a 103 kW low-voltage motor is designed for automatic operation, with remote control from the car over a control wire running alongside the line on telephone poles. After the exchange of departure signals the driver in the upper car depresses a push-button, whereupon the railway starts up and quickly attains the normal running speed. To stop at the intermediate station the control wire is touched with a contact rod fitted on the front of the car. Prior to reaching the station the railway is then automatically braked to a low speed and stopped at the halts by bringing the rod into contact with the control wire a second time. At the entry to the terminal stations the necessary stopping impulses are automatically imparted by auxiliary contacts on the car position indicator and a limit change-over switch. To ensure correct braking the car loading is just previously checked up by measurement of the power input or output of the motor and the electrically produced braking power correspondingly adapted and controlled. After the entry of the cars into the stations at low speed a mechanical brake, operated by an electrohydraulic thrustor, is finally applied.

The operating improvements achieved are worthy of special note. The scheduled running time for the operated length of the railway of 1064 m has been reduced by about 25 %, while a maximum of 850 (as against 425) passengers per hour, can now be carried. With favourable ski-ing conditions up to 8900 passengers have been conveyed on Sundays as against 5500 earlier.

In recent years the Biel-Magglingen, St.-Imier-Mont Soleil, and Ecluse-Plan Neuchâtel Funicular Railways have been converted to remote control and automatic operation in a similar manner, while the Davos-Parsenn and Unterwasser-Iltios Funicular Railways, which have been in service for a long time, were equipped on this control principle from the very beginning and have consistently proved reliable and economical in both summer and winter.

(MS 670) *E. Hugentobler. (E. G. W.)*

Beckenried-Klewenalp aerial ropeway.

Cabin for twenty passengers.

Brown Boveri supplied the electrical equipment for the winch station at Beckenried.

BRIEF BUT INTERESTING

The Converted 1 B 1 Locomotives of the Rhætian Railway.

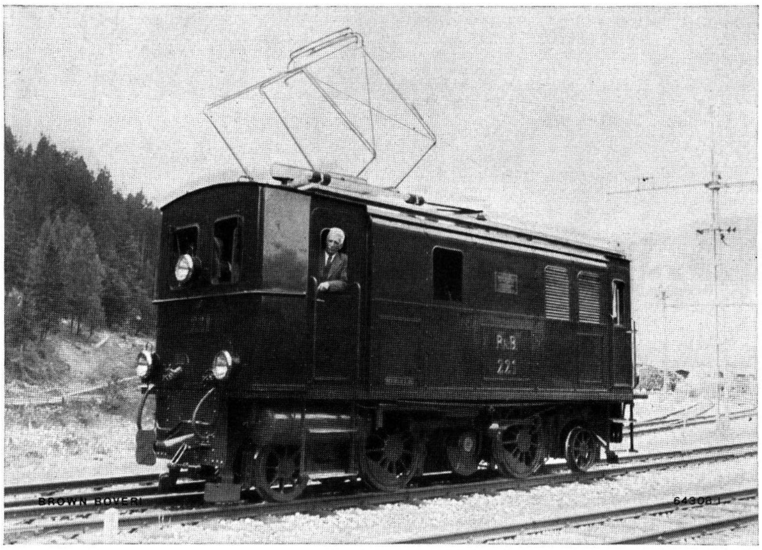
Decimal Index 621.335.2 (494)

FOR the inauguration of electric traction in the Engadine in July, 1913, the Rhætian Railway, disposed, inter alia, of seven small locomotives series 201, wheel arrangement 1 B 1, and one locomotive No. 301, wheel arrangement 1 D 1, for which the electrical equipment had been supplied by Brown Boveri. This comprised in the case of the former, one, and in the case of the latter, two Déri slow-speed repulsion motors for direct drive, each with a one-hour rating of 310 H.P. corresponding to a running speed of 28 km/h. These locomotives constituted an innovation in electric locomotive construction at the time, but in the intervening thirty years or so naturally became obsolete in many respects.

With the extension of electric traction on the 277 km parent system of the Rhætian Railway twenty-two further electric locomotives and four motor-coaches were added in the course of the years. Electric shunting locomotives proper were, however, never acquired and finally the power of the 1 B 1 locomotives proved to be inadequate for the service required of them.

Subsequently, to save solid and liquid fuels for steam shunting locomotives and petrol driven tractors, as well as to reduce costs and building time, three of the seven 1 B 1 locomotives were converted to shunting locomotives — one of which for combined single-phase and battery operation in Chur on the track of the Rhætian Railway (former "Chur—Arosa Railway") — and two to line-service locomotives with increased power.

Details of the shunting locomotives have already been given in the pages of this journal[1].



Line-service locomotive on Rhætian Railway for single-phase 10,500 V, 16⅔ cycle supply converted to develop twice the original power.

	1911	1945
Locomotive numbers	201/02	221/22
Traction motor	Déri	Series
One-hour-rating (at motor shaft)	310 H. P.	612 H. P.
At running speed of	28 km/h	39 km/h
Maximum running speed	45 km/h	65 km/h
Weight	about 36·7 t	about 32 t

In the interim the two line-service locomotives, bearing the Nos. 221 and 222, have been put into service in their new garb. A high-speed series motor has been substituted for the Déri motor which drives the two coupled axles through double gearing. The one-hour rating of the new motor is 612 H.P. (metric) at the motor shaft, corresponding to a normal running speed of 39 km/h (maximum 65 km/h). Power-controlled cam-operated tap-changers giving sixteen power notches and oil-immersed transformers with radially laminated cores continuously rated 453 kVA according to REB (German electric railway) specifications, are further features of the converted locomotives. During electrical braking the traction motor

[1] Brown Boveri Rev., January-April, 1943, pages 54 and 55.

operates as d. c. generator, being excited from a separate exciter and the energy generated dissipated in a resistance on the roof of the locomotive. The braking effect can be regulated in the exciter circuit connected to the battery with the main handle of the master controller.

Through the modernization of these thirty-year old locomotives the power has been doubled, speed and tractive effort increased, and the aggregate weight reduced by 10%. In point of fact, more valuable material was recuperated than the new material required for the conversion, in which, moreover, labour represented a higher proportion than usual of the cost.

(MS 677) *E. Schroeder. (E. G. W.)*

Renewal of Berne Municipal Fleet of Tramcars.

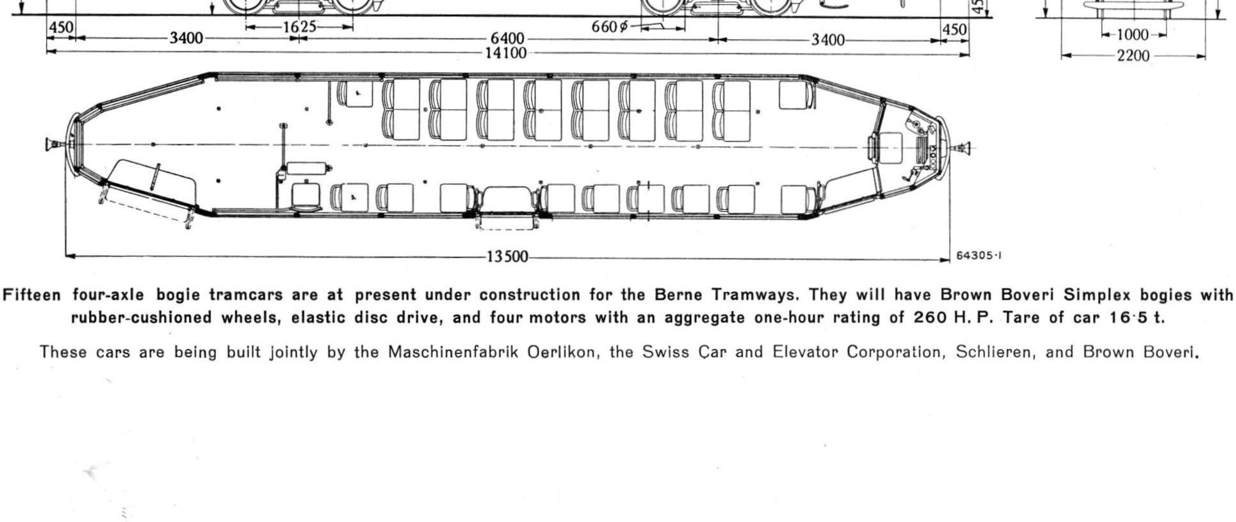
Decimal Index 621.335.42 : 625.62 (494)

THE demands on the Swiss municipal tramway undertakings are greater than ever before and in all probability will increase still further. Most tramways are at present doing good business. The zest of the public for travelling increases daily, while there is less competition from internal combustion engined vehicles, trolley buses, and bicycles, at least temporarily, due to the shortage of tyres. On the other hand pre-war tram fares still prevail in many places, so that trams have developed into a cheap means of passenger transport about towns.

Tramway rolling stock is, for the most part, however, antiquated. The federal law covering tramway operation in Switzerland fixes the life of a tramcar at 33 1/3 years. At Berne, for instance, more than half of the motor-cars have already been in operation for more than 35 years; the same conditions prevail in many other Swiss towns. These antiquated vehicles far from meet present requirements on the score of speed, comfort, and economy, while their reliability is not always as it might be. The cars are too heavy, technically obsolete, and not powerful enough. The tramways are therefore well advised to endeavour to retain their present increased number of patrons through the acquisition of new, modern, lightweight, and roomy cars, otherwise they run the risk of losing them to the afore-mentioned forms of transport when they again become available.

In the U. S. A. the public began foresaking the tramways for internal combustion engined cars and buses over twenty years ago. In an endeavour to put a stop to this tendency the presidents of the large tramway undertakings got together and mobilizing all of the interested circles created a more or less standard tramcar, the so-called PCC (presidents' conference car), which has been constructed in thousands. In Switzerland a similar movement is on foot in that tramway and industrial undertakings are cooperating to create a SST, i. e. a "Swiss standard tramcar", which would be constructed in only a small number of sizes. This would be inexpensive, available from the manufacturers at short notice, of ultra-modern design, meeting all reasonable requirements, and built in large numbers. A special commission of the Association of Swiss Transport Undertakings has been set up to study the question.

To meet post-war requirements the Berne Municipal Tramways require at least twenty-nine four-axle motor-cars. At present only fourteen are available, the lacking fifteen cars having been ordered in June of this year. Cars having the following features have been selected:—



Fifteen four-axle bogie tramcars are at present under construction for the Berne Tramways. They will have Brown Boveri Simplex bogies with rubber-cushioned wheels, elastic disc drive, and four motors with an aggregate one-hour rating of 260 H. P. Tare of car 16·5 t.

These cars are being built jointly by the Maschinenfabrik Oerlikon, the Swiss Car and Elevator Corporation, Schlieren, and Brown Boveri.

Peter-Witt system: All passengers board the car at the rear, pass by the seated conductor, and alight by the centre or front door when arriving at destination. From experience three times as many passengers can be dealt with in this way than with a conductor passing from passenger to passenger down the car. Moreover, it is impossible for any passengers to escape paying their fare.

Single-ended operation, only one driver's platform or seat being provided. Track loops must of course be provided at the termini to turn round the cars.

Brown Boveri Simplex bogie as provided for the Zurich tramcars of the 401 series. Light weight, compact, mass concentrated in centre of bogie, no sliding axle boxes and guides, bogie bolster, small wheel diameter of only 660 mm, low car body, silent-blocks in various articulations. Smooth, quiet running, high-speed lightweight traction motors with Brown Boveri individual axle elastic disc drive.

Pneumatically-operated and remote-controlled doors and footsteps which prevent the dangerous practice of passengers jumping on and off cars in motion.

These features permit the commercial speed to be substantially increased.

The cars in question have a seating capacity of twenty-seven and room for seventy-three passengers standing, a total passenger carrying capacity of one hundred. The one-hour rating is $4 \times 65 = 260$ H.P. at the motor shaft at 27 km/h (maximum 50 km/h) while an electro-pneumatic contactor control gives twelve series, nine parallel, and thirteen brake notches; apart from the rheostatic brake, electro-magnetic rail brakes and the usual pneumatic and hand brakes are provided.

On these cars the Simplex bogie of the Zurich series 401 cars is combined with the body of the medium-heavy type of car to be standardized.

The cars are being built jointly by the Maschinenfabrik Oerlikon, the Swiss Car and Elevator Corporation, Schlieren, and Brown Boveri. It is to be hoped that the same type will find wide application on metre-gauge tramways both in Switzerland and abroad to enable them to be built in large batches.

(MS 678) *E. Schroeder. (E. G. W.)*

Rhætian Railway also adopts High-speed BoBo Bogie Locomotives.

Decimal Index 621.335.2 (494)

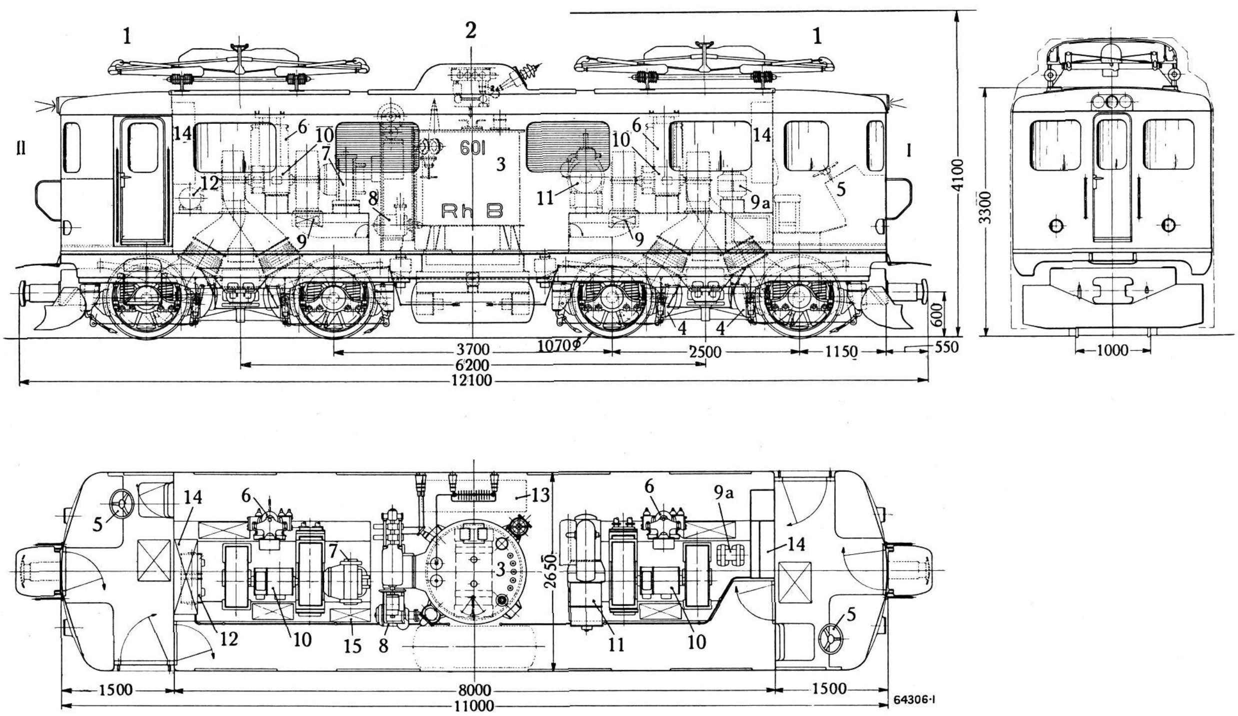
THE fifteen C-C locomotives of the 401 series supplied between 1921 and 1929 have been handling approximately 85% of the entire traffic on the Rhætian Railway. They were originally designed with a one-hour rating of 1200 H.P. at a maximum speed of 45 km/h. Their speed has been gradually pushed up to 55 km/h and they are now used to develop up to 1500 H.P. without a single vital part having been modified in any way, indeed a wonderful testimony to the design of these twenty year old vehicles.

In view of the ever-increasing traffic it appeared advisable to increase the fleet of vehicles after the war. A question which had to be settled was whether the C-C series of locomotives should be continued or whether another type should be adopted.

In the case of the Rhætian Railway — and all other railways for that matter — the real call for increased speed is yet to come. Under certain conditions a maximum speed of 75 km/h is admitted for metre-gauge light railways. The Rhætian Railway already has motor-coaches built for a maximum speed of 65 km/h in service. The next obvious step was therefore to provide new locomotives for a maximum speed of 75 km/h and, in view of the excellent experience with the new BoBo locomotives of the 251 series of the Berne-Lötschberg-Simplon Railway, to adopt four-axle bogie locomotives with individual axle drive equipped for multiple-unit control with regenerative braking.

Subsequently, in June 1945, an initial contract for four such BoBo locomotives was placed. The comparison with the C-C locomotives which follows gives an idea of the progress in locomotive building technique which has been made in the intervening twenty years or so:—

	C-C locomotive series 401	Bo Bo locomotive series 601
One-hour rating at motor-shaft . . .	1200 H.P. at 31 km/h with 9500 kg tractive effort at wheel tread with new wheels.	1600 H.P. at 47·3 km/h with 8850 kg tractive effort at wheel tread with new wheels.
Continuous rating at motor-shaft . . .	1000 H.P. at 31 km/h with 7900 kg tractive effort at wheel tread with new wheels.	1360 H.P. at 51·9 km/h with 6890 kg tractive effort at wheel tread with new wheels.
Maximum running speed	45 km/h	75 km/h
Maximum tractive effort at starting	15,000 kg	about 14,500 kg
Electrical braking . . .	Rheostatic braking with separate excitation	Regenerative braking
Weights:		
Mechanical part . . .	38·1 t	about 24·5 t
Electrical equipment .	27·9 t	about 21 t
Equipment components	—	about 0·5 t
Total weight	66·0 t	about 46·0 t



The Rhætian Railway has also adopted the four-axle bogie type for their future high-speed single-phase metre-gauge locomotives. The increased one-hour rating of 1600 H. P. is achieved with a substantial reduction in weight, this being reduced to 46 t.

1 = Current collector.
2 = Air-blast high-speed circuit-breaker.
3 = Transformer with high-voltage on-load tap-changer.
4 = Traction motors.
5 = Master controller.
6 = Reverser.
7 = Braking choke coil.
8 = Oil pump.
9 = Oil cooler.
9a = Auxiliary choke coil.
10 = Fan set.
11 = Vacuum pump and compressor.
12 = Motor-generator.
13 = Battery.
14 = Switchboard.
15 = Frame for brake fittings.

Supply system: Single-phase	10,500 V, $16^2/_3$ cycles	Continuous rating at 51·9 km/h	1360 H. P.
Gauge	1000 mm	Tractive effort with continuous rating	6890 kg
One-hour rating at 47·3 km	1600 H. P.	Maximum tractive effort at starting, temporarily	14,500 kg
Tractive effort with one-hour rating	8850 kg	Maximum speed	75 km/h

With an approximately 67% higher maximum speed and a one-hour rating increased by one-third it was found possible to keep the weight down to roughly 70% of that of the C-C locomotives, although the adhesion weight and the tractive efforts are naturally lower. The locomotives develop therefore a greater power with a correspondingly increased speed, which was the main stipulation.

Twenty-eight notches instead of eighteen, multiple-unit control, and regenerative in lieu of rheostatic braking are further features.

The locomotives are being built jointly by Brown Boveri, the Maschinenfabrik Oerlikon, and the Swiss Locomotive and Machine Works, Winterthur. Brown Boveri are furnishing a part of the traction motors, all of the spring drives of the type already supplied for the Rhætian Railway motor-coaches alluded to above, the radially-laminated transformers with high-voltage control, and the air-blast high-speed circuit-breakers, the Maschinenfabrik Oerlikon the remainder of the electrical part with the regenerative braking equipment, and the Swiss Locomotive and Machine Works, Winterthur, as usual, the entire mechanical part comprising essentially the bogies and locomotive bodies.

These will probably be the most modern, lightweight, and powerful single-phase locomotives for metre-gauge light railways in existence. For the immediate future they will form the standard motive vehicle on the Rhætian Railway.

(MS 673) *E. Schroeder. (E. G. W.)*

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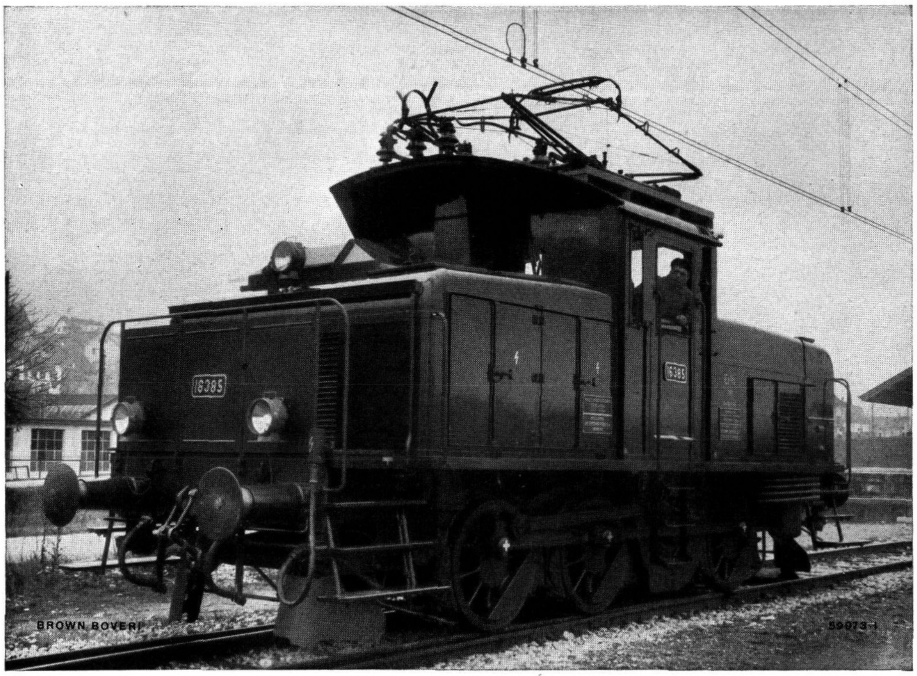
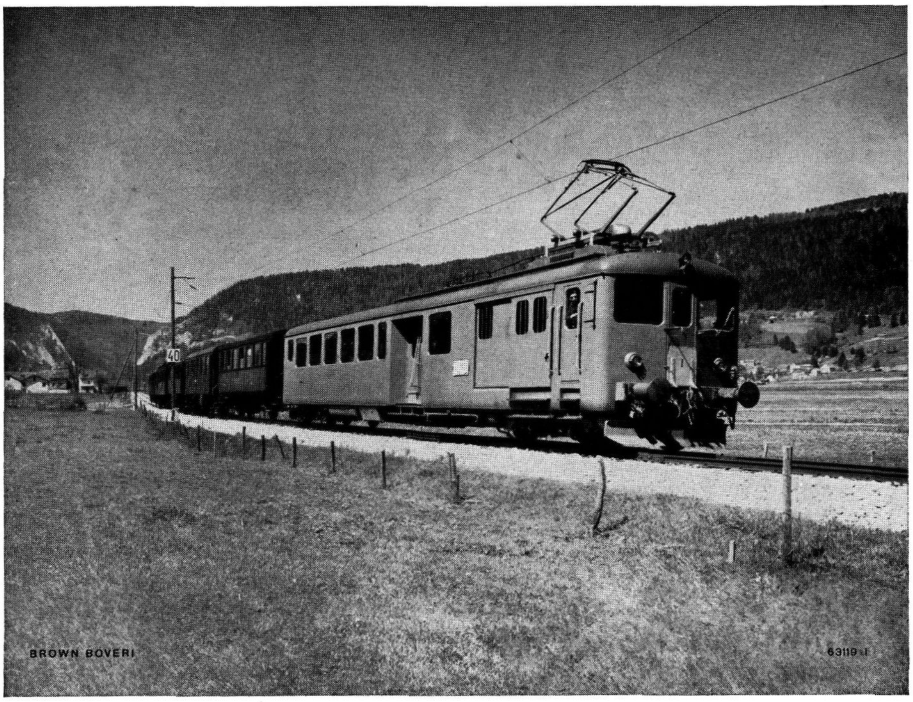


Shunting locomotive Ee 3/3 series 16381 of Swiss Federal Railways.

Shunting locomotives of this type designed by Brown Boveri cope with the major part of the shunting service on the Swiss Federal Railways.



Motor-coach BCFe 2/4 series 101 of the Chemin de fer Régional du Val-de-Travers.

Electric traction will play a big part in the future economic prosperity of the Val-de-Travers due to the resulting more frequent service and reduced running times.

BROWN
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