

## SOME NOTES ON EUROPEAN PRACTICE IN ELECTRIC TRACTION WITH THREE-PHASE ALTER- NATING CURRENTS.

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There have recently been some pretty lively discussions between the advocates of continuous current and those of alternating current systems for electric traction purposes.

Now I wish to state right at the beginning that in the opinion of the author there are certain cases where continuous current is preferable and where alternating currents could not do the work as well, on the other hand there certainly are cases where alternating currents are particularly well adapted to solve the problems in question and where continuous current could not be used advantageously. Each special case should therefore be studied by itself, and the decision as to what system should be adopted ought to be dependent on all the different conditions which might apply to the particular case, viz., profile of the road, speed required, number of stops, traffic conditions, etc., etc. Probably most of us will agree for instance that, taking everything into consideration, the recent decision in the London Underground Railway case was really the best solution of this rather complicated problem.

In America continuous current practice has so far almost absolute sway, and it may therefore be interesting to learn something of what has been done in Europe, and more particularly in Switzerland, in the way of using alternating currents for traction purposes and to hear at the same time something about the practical results obtained on some alternating current roads that have been in operation several years.

Brief descriptions follow in chronological order of some of the most typical roads of this kind including as many details as possible, especially in regard to the Burgdorf-Thun Railway, probably the best example of an alternating current railway installation. The results of some tests made on this latter railway are also given with a few general conclusions as to the applicability of polyphase alternating currents for traction purposes.

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*First Tests by Siemens & Halske.*—The first tests with alternating current traction were made by Siemens and Halske of Berlin, in 1892, in Charlottenburg on a specially constructed track of about 360 m. length with one curve of 40 m. radius. There were two overhead trolleys, the rails forming the third conductor. The voltage was between 500 and 600, the periodicity 50 cycles per second. An open car was used on an ordinary street railway truck, equipped with a three-phase induction motor driving one of the axles by means of a single reduction gear of 1 : 11. The speed of the motor being 1400 revolutions per minute; the maximum speed attained was about 25 km. (15 miles) an hour.

The primary winding of the motor was arranged to allow being connected in delta for starting purposes, while it was changed to star connection for full speed. The starting torque of the motor was therefore made about six times the full load running torque. The motor was also provided with slip rings on the rotor which allowed for inserting resistance into the secondary winding.

These tests showed clearly that an alternating current railway was absolutely feasible, and proved that no serious difficulties would be encountered in regard to the trolley line construction. However, the street railway problems then under consideration did not absolutely require the use of anything else but the well known continuous current system and this is probably the reason why these tests were not carried any further and put into actual practice.

The installation as just described was sent to the Chicago Exhibition in 1893, where it attracted considerable attention, but nothing has been heard of it since.

*Lugano Tramways.*—Brown, Boveri & Co. of Baden, Switzerland, may claim the honor of first putting alternating current into actual use for traction on a commercial scale. The tram-

ways of Lugano, the first three-phase railway, were opened for traffic in 1895. The power station for these tramways is 12 km. outside of town, therefore transmission with 500-600 volts continuous current was impossible. Rotary converters seemed too expensive and thus it happened that all conditions were favorable for an experiment with three-phase alternating currents. The total length of the line is 4900 m. (about 3 miles) with maximum grades on long stretches of 3% and on short stretches of 6%. The transmission voltage is 5000 volts at 40 cycles. Transformers reduce this to 400 volts. Two trolley

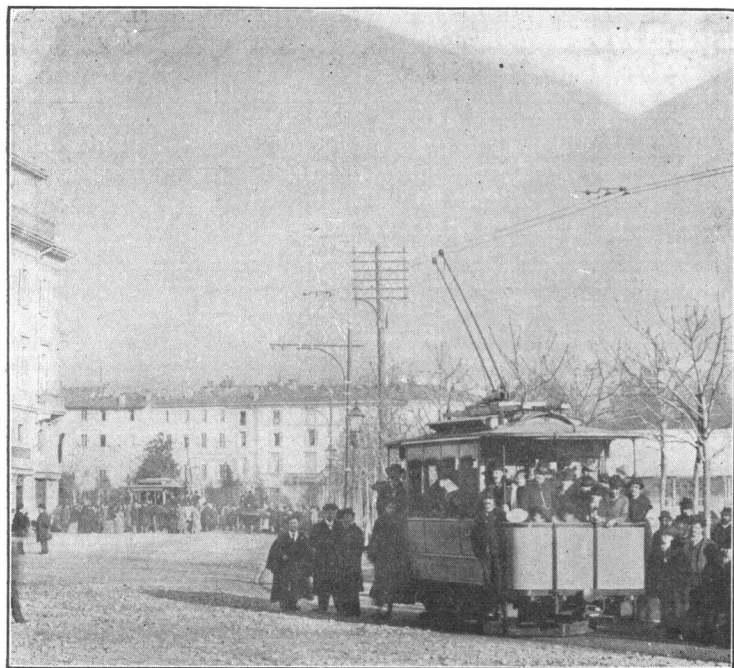


FIG. 1.

wires of 6 mm. diameter 25 cm. apart are used and the rails serve as third conductor. Cars hold 20 persons each. There is one 20 h.p. motor per car, completely enclosed, with single reduction gear 1 : 4. Speed of car 15 km. (9.3 miles) an hour. Two trolleys, one 1 yard behind the other, make contact with the two lines. Motors are started by means of a reversing switch and their speed is controlled by means of a resistance in the rotor circuit. Cars may be handled from both platforms.

Fig. 1 gives a good idea of one of these cars, and shows part of the line. Tests have demonstrated that it is possible to start with ease even on 6% grades and under more than full load.

*Gornergrat Railway.*—After the Lugano plant had thus proved that alternating currents could be applied to ordinary tramway purposes, the Gornergrat road was destined to show that they could also be used to advantage on a much larger scale and under the most severe conditions met on a Swiss mountain road. The total length of this line is 9 km. (5.6 miles). The difference in altitude of the two terminals is 1412 m. (4660 ft.) The maximum grade is 20%, the minimum radius in curves 80m. The gauge is 1 m. (3' 3 3/8") with an Abt rack between rails. The power station generates 5400 volts at 40 cycles.

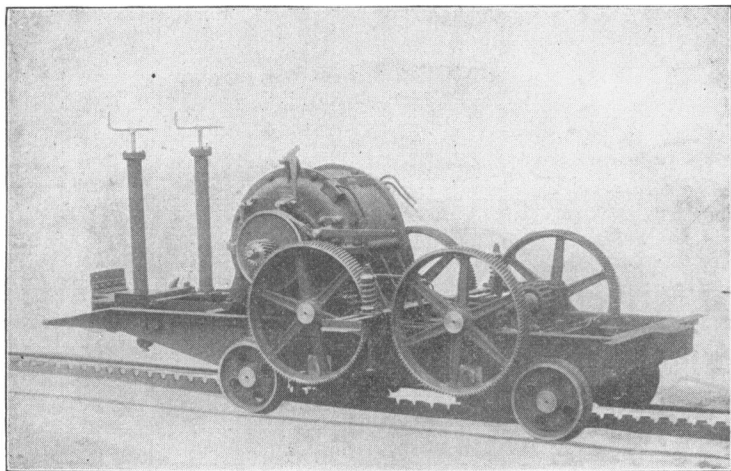


FIG. 2.

Three transformer stations of 180 k.w. each 2, 5 and 8 km. respectively from the beginning reduce from 5400 to 540 volts. The high-tension line follows a separate route. The trolley line consists of two wires of 8 mm. diameter suspended by means of cross-wires from wooden poles every 25 m. the rails forming the third conductor. The speed is 7 km. (4.35 miles) an hour. and there are 5 stations, 2.5 to 3 km. (1.5 to 1.8 miles) apart. The normal train consists of one locomotive, one main passenger car, (60 persons) and one second car (50 persons) added when needed. As a maximum there are two trains up and one down on the road at the same time. The locomotive weighs



10.5 tons, two cars 9.2 tons and 110 passengers 8.3 tons, total for one train 28 tons. The motor capacity is therefore 160 h.p. or about 180 h.p. on axles, and the locomotive is equipped with two motors of 90 h.p. each, running at 800 revolutions per minute. Each motor drives by means of a double gear one of the two cog wheels. The total reduction of gear is 1 : 12. The motors are controlled by a reversing switch through which the stator is connected to the line and by the usual starting rheostat in the rotor circuit. The rheostat is placed on the top of the motors to save space, and the switch, fuses and instruments for the same reason on the side and against the roof of the car. Two trolleys are employed on each line wire on account of the large current and in order to pass switches without making a break. The motors start on any grade under full load without using more current than when running at full speed and full load. They can start under more than full load but with proportionately more current. Fig. 2 shows the truck of the Gornergrat locomotive with one of the motors in its place. This line was completed in 1897 and opened to traffic in 1898.

*Jungfrau Railway.*—Before it was finished, work was already begun on a very similar line, the Jungfrau Railway. The total length of this road is 13 km. (8 miles) with a difference in altitude between the two terminals of 2100 m. (6900 ft.) The grade, almost immediately after leaving the Kleine Scheidegg station, is 10% and this is increased to 20% at about half way to the Eiger Glacier Station. From there on, the grade increases to the maximum of 25% when the line enters the tunnel. The permanent way is of metre gauge with a rack of the Strub system half way between the rails. The sharpest curve on the open section has a radius of 100 m., in the tunnel this is increased to 200 m. Water power is made use of in the valley of the White Lutschine to generate three-phase currents at 7000 volts and 38 cycles, which is transmitted by overhead wires to transformer stations along the line, where it is transformed down to 500 volts. The sub-stations are stone buildings, designed to withstand the action of the most inclement weather. They are fitted each with two 200 k.w. transformers. When the whole line is completed, transformers will be placed about every 1000 yards. There is a double trolley line as on the Gornergrat. The locomotives are very similar to those on the Gornergrat line. They weigh 13 tons complete, and contain each two 125 to 150 h.p. induction motors, driven at 760

revolutions per minute. The motor controlling devices and the contact arrangements are exactly the same as on the Gornergrat road. The cars hold 40 persons each and a normal train consists of one locomotive pushing two cars, the total weight of such a train when filled, being 28 tons as on the Gornergrat road. The speed, however, is 8 km. (5 miles) per hour.

The first section of the Jungfrau Railway to Eigergletscher was opened in September, 1898, the second to Rothstock in April, 1899, since then each year has seen further progress toward the summit, which will probably be reached in five or six years.

*Stansstad-Engelberg Railway.*—The next alternating current

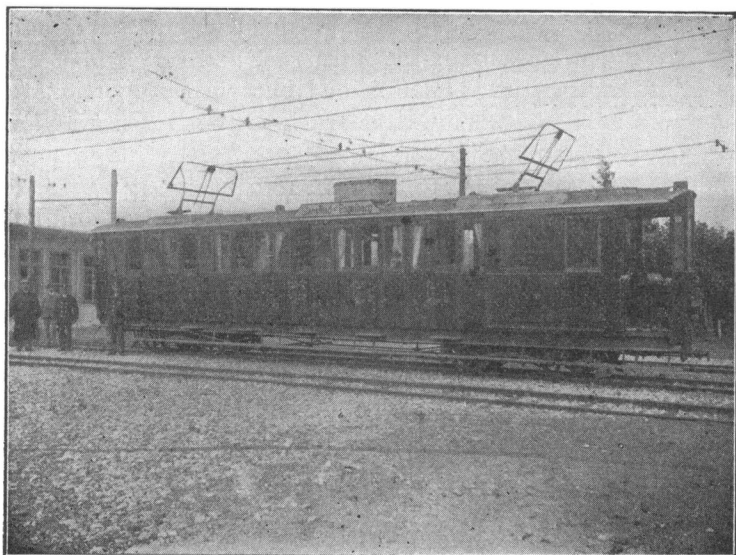


FIG. 3.

railway to be built was the one from Stansstad to Engelberg. This road, although of metre gauge only, approaches in the shape of its cars normal gauge railway conditions. The total length of the line is 22.5 km. (14 miles). The first 15 km. have small grades up to 2%, the next three km. have grades of 2.5 to 5%, then follows a section 1.5 km. long with a grade of 25% and a so-called ladder rack, finally about 3 km. more with grades of 2.5% and less. The minimum radius in curves is 50m. The power station is situated at the beginning of the rack section,

about 18 km. from Stansstad, therefore it is near the point where the maximum energy is used. The voltage generated is 750 volts at 32.5 cycles, and this is fed direct into the trolley line. A 90 k.w. step-up transformer produces 5,300 volts which is transmitted to two sub-stations situated at about 3 and 7 km. respectively from Stansstad and containing each a similar transformer, reducing the voltage again to 750 volts. The trolley line construction is similar to that found on the Gornergrat and Jungfrau Railways. There are nine passenger stations on this road. Three locomotives and seven motor passenger cars are used. The cars, as shown in Fig. 3, are of the double truck type, and their total length is 14 m. Each car weighs 14 tons and

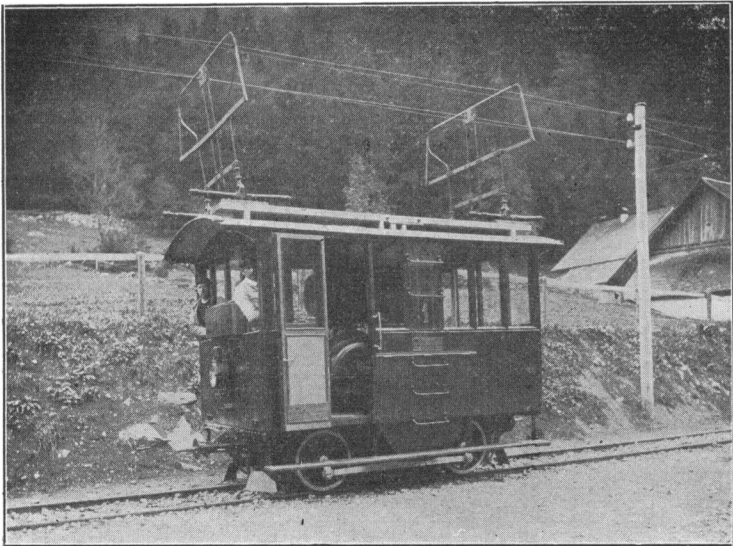


FIG. 4.

has room for 46 passengers besides being provided with a baggage compartment. The front truck carries two motors of 35 h.p. each, running at 400 revolutions per minute, with single reduction for a car speed of 20 km. (12.5 miles) per hour. The contact with the trolley line is made by means of two double contact bars attached to the roof near each end of the car. The cars may be controlled from either end-platform and the control is similar to that already described for the other roads. One automobile car is able to propel itself and to haul a trailer of about

10 tons on grades up to 2.3%. The first 15 km. section, which happens to have the heaviest traffic, is therefore worked with two cars at a speed of 20 km. per hour. The next section with heavier grades up to 5% is traversed by the motor car alone at the same speed, the motors furnishing about 80-90 h.p. for a 16-ton load on a 5% grade. At the beginning of the rack section a locomotive is added which pushes the car up the grade of 25% at a speed of 5 km. an hour. The last stretch with grades up to 2.5% is covered by the automobile alone. The locomotive not only serves for the above mentioned purpose but is destined also to haul freight trains of 20 tons total weight over the lower part of the road at a speed of about 11.5 km. an

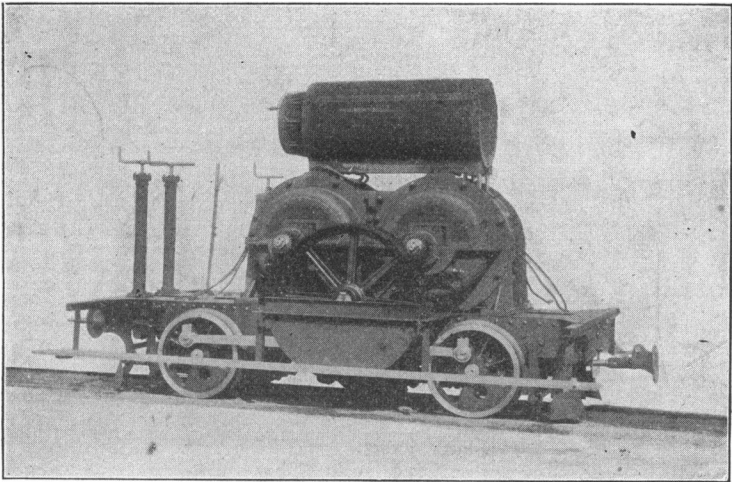


FIG. 5.

hour. Its design, therefore, varies greatly from the Gornergrat and Jungfrau locomotives. Two motors of 75 h.p. each and 650 revolutions per minute drive through a single reduction gear a counter shaft, which by means of two symmetrically placed gears drives the cog wheel placed in the center of the locomotive. This wheel is mounted on a hollow shaft fitted over the crank shaft which in its turn drives the four main carrying wheels of the locomotive. On the rack section the cog wheel alone is driven. In the level country a friction coupling is set in such a manner that the two main axles are driven and the cog wheel is allowed to follow loose. The contact device is similar to the one on the passenger cars. Fig. 4 gives a good

idea of this locomotive and Fig. 5 shows an interior view of its mechanical arrangement, while Fig. 6 represents a locomotive pushing one of the passenger cars up the 25% grade. The Stansstad-Engelberg Railway was opened also during 1889.

*Burgdorf-Thun Railway.*—The Burgdorf-Thun Railway, which was opened in 1899 and which will be described more in detail is not exactly what you would call a trunk line, yet it is of normal gauge and forms a very important link between three of the main steam lines of Switzerland. The service conditions are the same as encountered on the other Swiss railways and it uses the same size and shape of rolling stock as the main

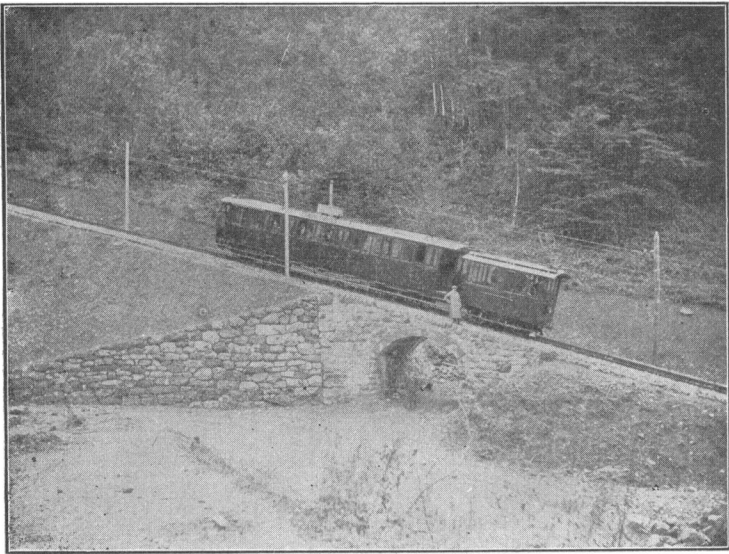


FIG. 6.

steam roads. The total length of the line is 40.3 km. (25 miles). The main reason for adopting electric traction was that the time-table could be arranged much more conveniently than for steam traction. With steam there would have been 5 trains per day in each direction, costing per year at the least 52,000 francs for coal alone and each additional train would have cost 10,000 francs more for coal alone. Now, 50,000 francs allows with electricity as motive power the running of 10 passenger and two freight trains per day in each direction over the whole length of the line, and besides three or four trains per day from Thun to

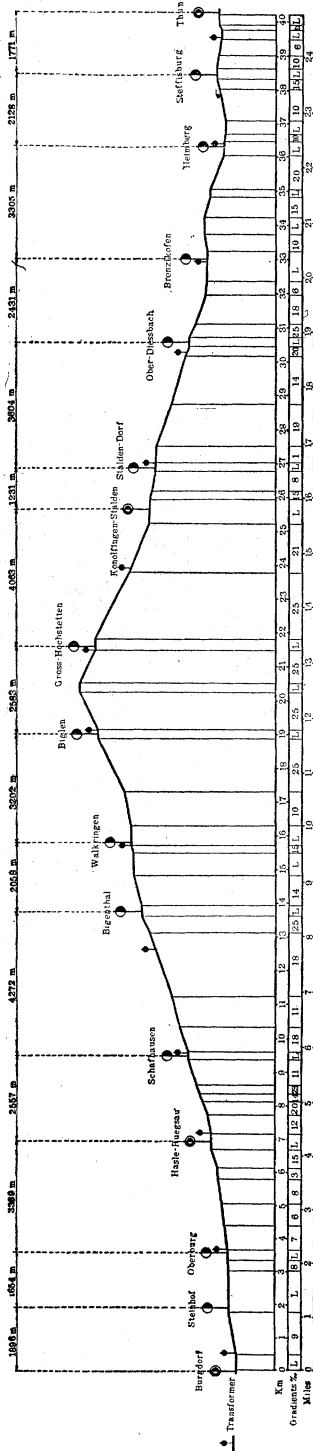


FIG. 7.

Konolfingen and back. Each train consists normally of one motor car and one or two trailers with a total seating capacity of 130-140 passengers. This means that not only is the public benefited by a better service, but the number of passengers actually carried is larger and thus increases evidently the income of the railway by a handsome percentage. Fig. 7 shows a profile of this line. There are 16 stations, four of which have connection with existing steam lines. The gauge is normal = 1.435 m., the minimum radius in curves is 250 m

The road starts at Burgdorf (536 m. above sea) and ascends with an average grade of 1.144% to the highest point almost exactly half way between Burgdorf and Thun (770 m. above sea). Then it descends with an average grade of 1.051% to Thun (561.5 m. above sea). The maximum grade in any place is 2.5%. All stations have a level stretch at least 200 m. long: 64% of the total length is straight line; 36% curves; 24% level; 23.5% on grades up to 1%; 31.5% on grades between 1 and 2% and 21% on grades between 2 and 2.5%. Rails are 12 m. long and weigh 36 kg. per metre: 45% of the track is on iron sleepers weighing 137 kg. per metre track; 55% on wooden sleepers weighing 145 kg. per metre. The normal speed was fixed at 39 km. (24.2 miles) per hour.

The energy is furnished by the power station on the Kander about 10 km. (6 miles) beyond Thun. The primary line voltage is 16,000, the number of cycles 40 per second. Fourteen transformer stations reduce this voltage to the voltage in the trolley lines which was fixed at 750 volts, this being the limit set by the federal authorities at that time. This voltage, however, seems to be increased slightly in actual practice.

The number of transformers along the line was determined by the following considerations:

The distance between two transformers along the line had to be chosen so that the drop in the line voltage did not exceed a certain predetermined value. On the other hand it was desirable to keep the number of stations within a certain limit in order to make the proportion between installed and actually working transformers as favorable as possible. It will be noticed that at any time only those transformers between which trains are actually moving are under load, while the rest are not doing any work. Finally the transformers should be placed

as near the railway stations as is practicable so as to facilitate their inspection. These somewhat conflicting conditions led to the adoption of 14 transformer sub-stations with an average interval of 3 km. from one another, the maximum interval being 3.4 km., the minimum 2.4 km. The two end transformers are 500 m. from the terminals of the line.

The size of each transformer would really be dependent on the grades in its vicinity. As these grades are pretty nearly alike in this case, the capacities of the transformers worked out

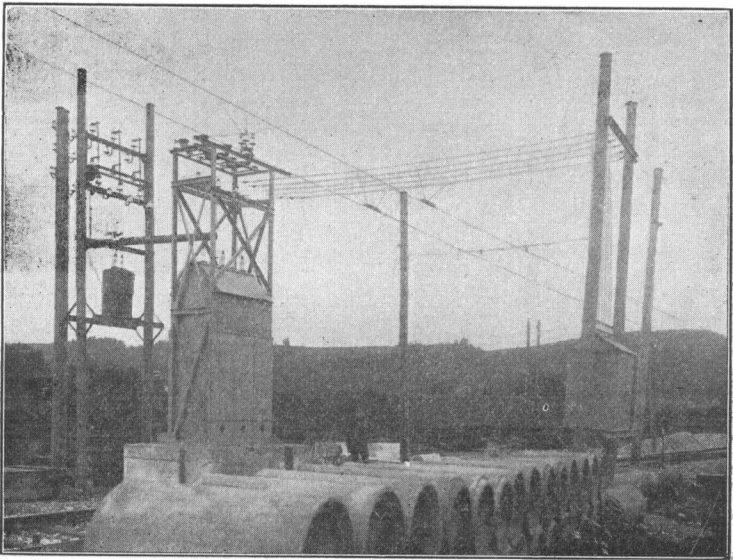


FIG. 8.

to be very much the same also, and it was therefore decided to use only one size of transformer with a maximum output of 450 k.w. This is the power required to move two complete trains. Fig. 8 shows one of the transformer sub-stations.

The high tension line first passes an emergency switch which permits cutting off the whole station. The transformer is placed in a small iron house containing in its upper part primary and secondary fuses; there is also a lightning arrester on the top of each station. The transformers are of the oil cooled type and transform from 16000 volts down to 750 volts. On



the secondary side one pole is connected to earth, viz: to the rails, and the other two are carried over to the other side of the track, where they enter a special small switchboard placed in an iron box which allows cutting off the transformer from the line or else either of the two line sections meeting here from the transformer. The whole length of the line is thus effectively cut up into 15 sections. The secondary box also contains a secondary lightning arrester. Most of the sub-stations are also equipped

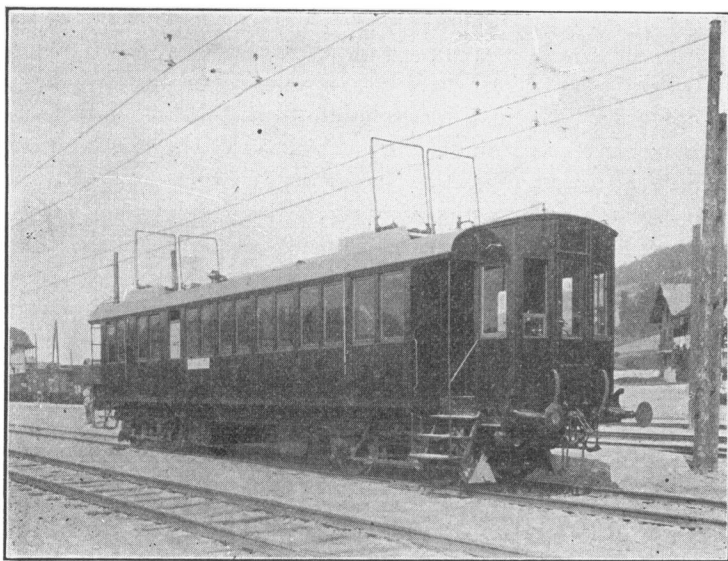


FIG. 9.

with a small 2 k.w. lighting transformer, furnishing the current for lighting the neighboring railway station.

The trolley line consists of two copper wires of 8 mm. diameter suspended by means of steel cross wires from wooden poles placed on both sides of the track. These poles are normally about

35 m. apart somewhat less on curves and grade crossings. The height of the trolley wires above the rails is 5.2 m. (16 ft.) at the most, and at least 4.85 m. The rails form the third conductor and are bonded by means of a special metallic paste.

The contact devices of the cars consist of four steel frames per car as shown on Fig. 9, two on each end of the car roof at a distance of about 9.5 m. (31 ft.) from the other two, the contact bar being a brass roller of special shape. This double set was found to be necessary in order to facilitate the passing of switches without breaking the current. At the switches, the two outer trolley wires are carried right through, while the two inside ones terminate in insulated sections prolonged into a common meeting point and there anchored by insulated guy wires. The distance of 9.5 m. between the two sets of contact devices is just long enough to allow three of the four bars making contact under any condition. There is, therefore no sparking at switches, and it is possible to stop a car underneath a switch and to start it again in the same or the opposite direction.

There are two kinds of motor cars, the passenger automobile and the regular locomotive for freight trains. If this railway had been entirely independent the passenger trains would perhaps consist of one car alone. As it is, the traffic to be handled at the stations having connection with the steam roads necessitated larger carrying capacity of all the trains. The normal train composition comprises one motor car weighing 32 tons, capable of pulling a weight of about 20-24 tons in trailers on all grades and at normal speed. The motor car has seats for 66 passengers and the trailers for 60-70 more, making a total seating capacity for between 130-140 passengers.

A general view of a motor car is given on Fig. 9. It is a double bogie car with a 64 h.p. three-phase motor geared to each axle. The gear ratio is 1 : 3 and the speed of the motors 600 revolutions per minute, equivalent to a train speed of 39 km. (24.2 miles). The four motors are connected with their stators in parallel. The line current passes first through one of the two controllers, placed one on each car platform, then through automatic cut-outs to the motors. The first motion of the controller handle closes the switch shown on Fig. 10 and connects the stators to the line, at the same time cutting in four

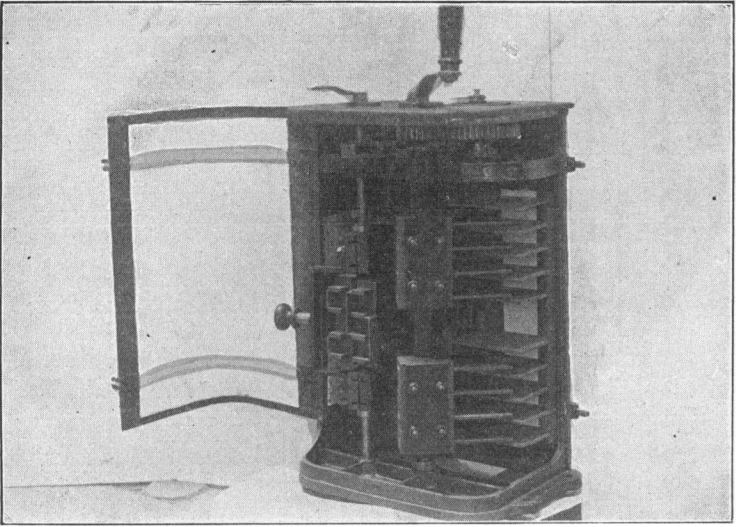


FIG. 10.

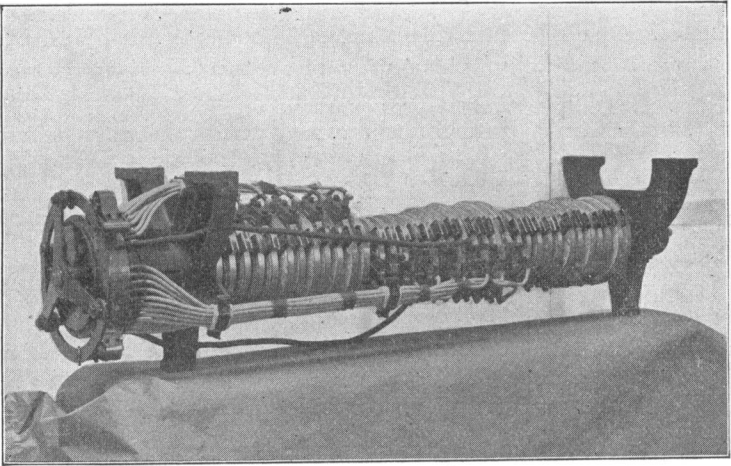


FIG. 11.

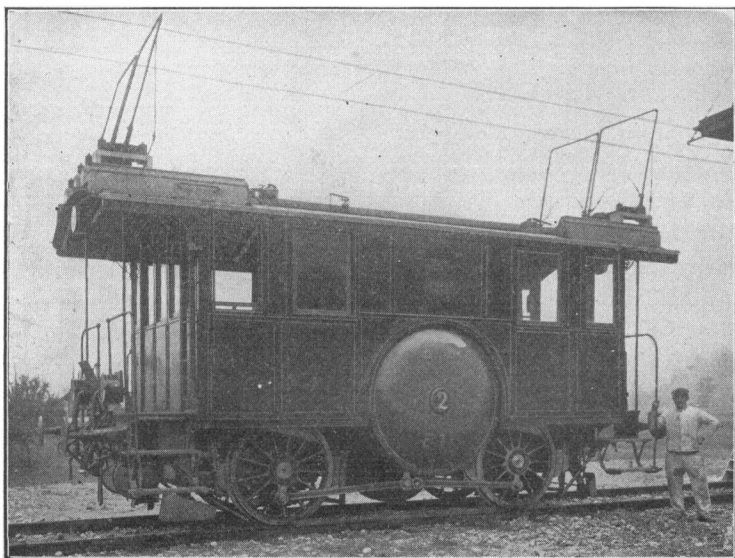


FIG. 12.

rheostats, one into each rotor circuit. Subsequent turning of the controller handle works a combination bevel and chain gear through which three carbon brushes are moved on a sort of commutator attached to each rheostat (see Fig. 11), whereby all the resistance is gradually taken out and the rotors left short-circuited. A second handle on the controller reverses the direction in which the car is going by changing two of the main leads. Each car platform is equipped with two ampere-meters, one

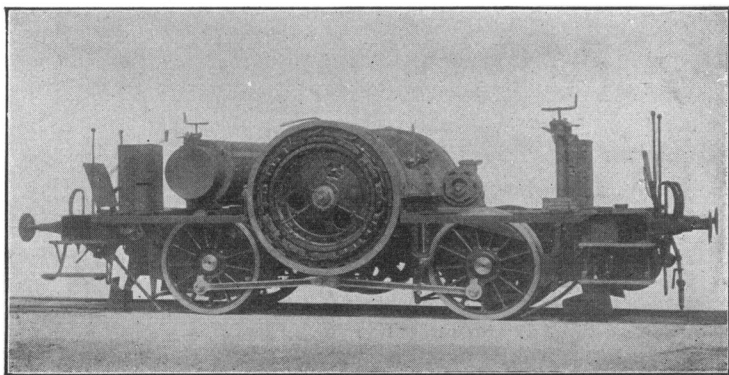


FIG. 13.

voltmeter and a recording tachometer. A Westinghouse brake and an electric lighting and heating installation complete the equipment.

One of the freight locomotives is shown in Figs. 12 and 13. They are designed for a speed of  $19\frac{1}{2}$  km. (about 12 miles) per hour, and will haul a weight of 100 tons (not including their own weight) up the steepest grade of 2.5%. The weight of a locomotive complete is 30 tons, equally divided between two axles. Two motors of 150 h.p. each are mounted on a common shaft half way between these two axles and drive by means of a reduction gear first an intermediary axle, and from this axle by means of connecting rods, all four driving wheels. These are 1.23 m. (almost exactly 4 ft.) in diameter. A common rheostat serves for starting both motors and there is a controller on each platform as in the case of the passenger cars. The same measuring instruments are also to be found, as well as a Westinghouse and an additional hand brake.

This railway has now been in successful operation for almost three years. It was equipped by Brown, Boveri & Co., of Baden, Switzerland, as well as the other Swiss lines mentioned. Later on some actual results obtained on this road will be given, but attention is directed first to three experimental lines recently installed for the purpose of ascertaining the conditions met on long trunk lines with higher voltages and very high speeds.

*Lecco-Colico-Sondrio-Chiavenna Railway.* — In 1901 Ganz & Co. of Budapest finished the electric equipment of what is usually called the Valtellina Railway in the northern part of Italy.

The length of the line from Lecco to Chiavenna is 65 km. (40 miles), the branch from Colico to Sondrio 41 km. (25 miles). The gauge is normal = 1.43 m. The normal speed is 60 km. (37 miles) per hour for passenger trains and 30 km. for freight trains. It is evident that under these conditions it would have been somewhat difficult to handle the traffic with 750 or even 1,000 volts, and it was therefore decided to adopt a higher voltage. Tests made in the Alt-Ofen shipyard near Budapest showed 3,000 volts to be very suitable for the purpose, and this is the line voltage definitely chosen for this road. The power station generates 20,000 volts at 15 cycles per second, 12 transformers of 300 k.w. each, along the line about 10 km. from each other, reduce this to 3,000 volts. For short periods these transformers can give three times their normal output with a 6% drop

in voltage. There are two 8 mm. trolley wires, the track serving as a third conductor. The rolling stock shows passenger automobiles weighing 50 tons, and freight locomotives weighing 40 tons each. Both are of the double bogie type, with one motor of 150 h.p. on each of the four driving axles. The motors are mounted direct on hollow shafts on the axles, driving the latter by means of a flexible coupling. For the passenger cars the so-called "cascade" connection is made use of, two of the motors being connected to the 3,000 volts directly, the other two to the 300 volts induced in the rotors of the first two. Thus

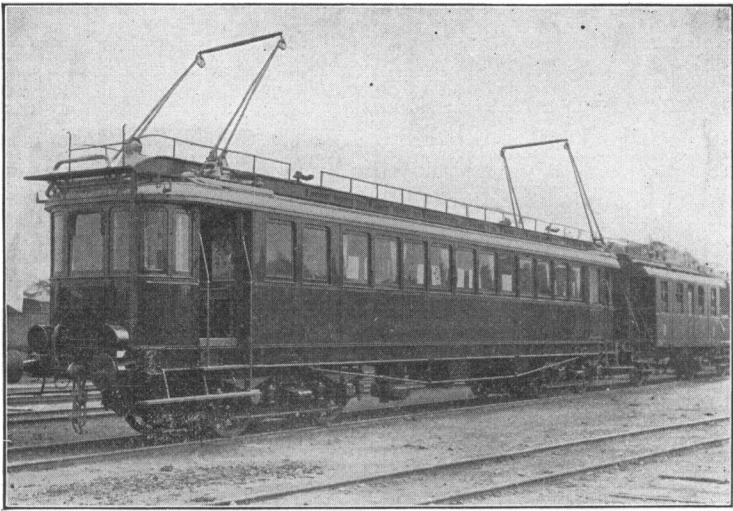


FIG. 14.

half normal speed is obtained and a certain economy in starting. The freight locomotives, however, use resistances only for starting purposes.

Fig. 14 shows one of the passenger cars with a trailer. The contact device is of the roller type, two copper rollers 40 cm. long being separated by a piece of hard wood 12 cm. long, saturated with paraffin under pressure. In the interior of the cars the high tension is carried in iron pipes insulated inside and connected to earth. The current enters the stators of the motors after passing a high tension switch placed in a separate chamber. Thus all possible means have been employed to ensure absolute safety to the passengers. Trial runs have been made on this line but several details seem to need to be perfected, and the line is not yet open for traffic.

*Tests at Grosslichterfelde.*—Still higher voltages were used by Siemens & Halske in 1899 and 1900 during extensive tests made on the Teltower Road between Grosslichterfelde and Zehlendorf on a specially constructed test track a little over one mile long, normal gauge, with curves of 200, 100 and 40 m. radius. On account of the traffic on this public road the contact line had to be placed on one side of the road and for the same reasons a guard wire net had to be fixed under all wires. The main object of these tests was to find a suitable contact device and the best possible line construction to handle a cur-

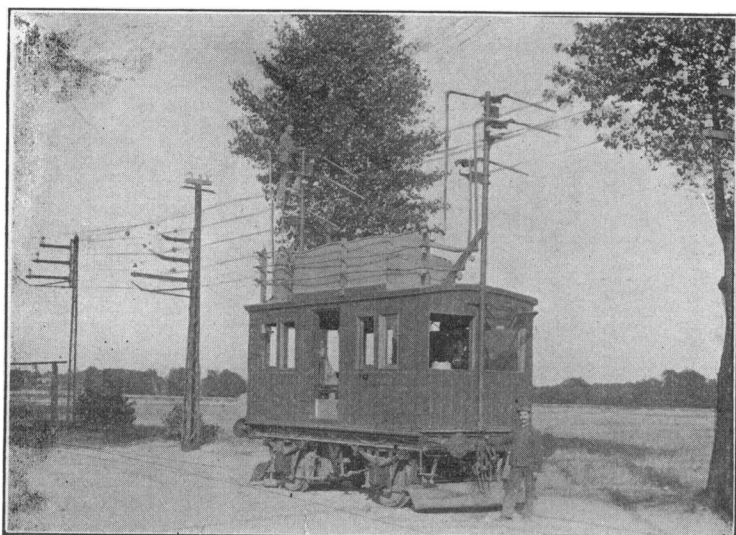


FIG. 15.

rent of 10,000 volts and at car speeds up to 60 km. (37 miles).

The first tests were made with a device making contact with the line from above, as shown on Fig. 15. The line wire was fastened to triple petticoat porcelain insulators by means of special brass pieces. The insulators were mounted on wooden cross-arms of different lengths which were hinged to iron poles in such a way as to permit the tension in the wires to be equalized without difficulty. The three wires formed an inclined plane as may clearly be seen from the photograph.

Later the line construction was changed and arranged for making contact from the side. The three wires were placed in a vertical plane with distances of about one yard from one

another. The wooden cross-arms were replaced by elliptically curved angle irons provided with a guy wire, to which the insulators were fastened inclined toward the track. The line and the corresponding contact devices are clearly shown in Fig. 16.

In both cases tests were made with line voltages of 750, 2,000

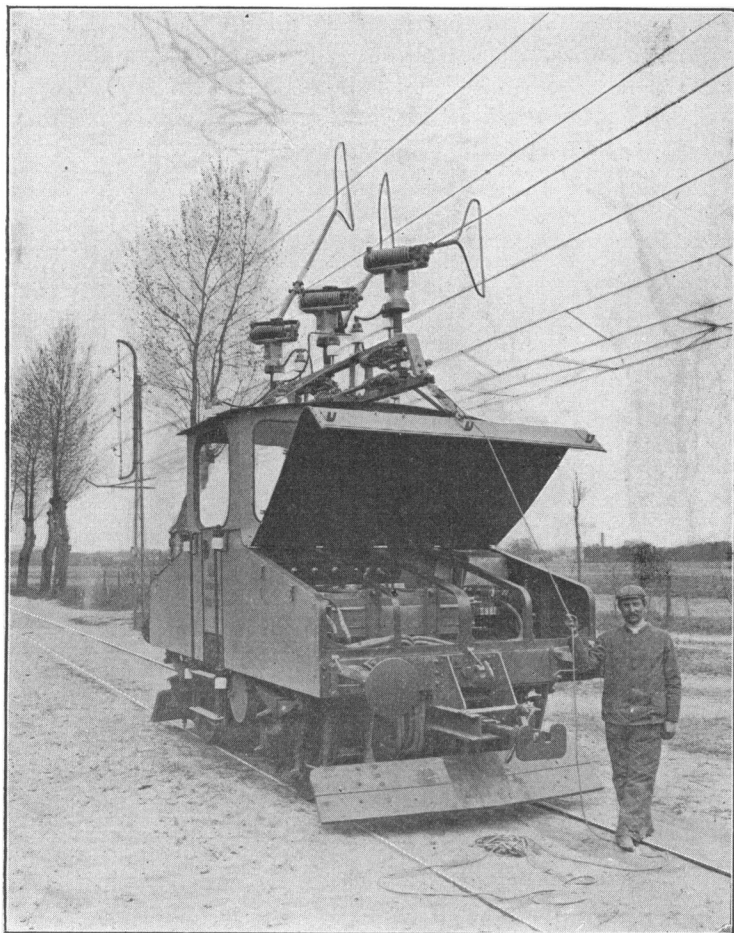


FIG. 16.

and 10,000 volts. The locomotive was fitted with two three-phase induction motors, one on each axle and each for 30 h.p. normal and 120 h.p. maximum output at 650 volts. With 850 volts the output would be increased to 200 h.p. per motor. These motors had interchangeable armatures so that they could



be used for 750 or for 2,000 volts directly with the line voltage. For the tests with 10,000 volts on the line, a transformer was installed on the locomotive to transform down to 750 volts. There were two different reduction gears which could be inserted alternately, one for 40 km. an hour, the other for 60 km. an hour. The total weight of the locomotive completely equipped was 16 tons.

From the tests made the following results were deduced:

1. It is entirely feasible to use line voltages up to 10,000 volts and the necessary energy could be taken from the line in each case without difficulty.

2. The contact from the side is rather the better of the two.

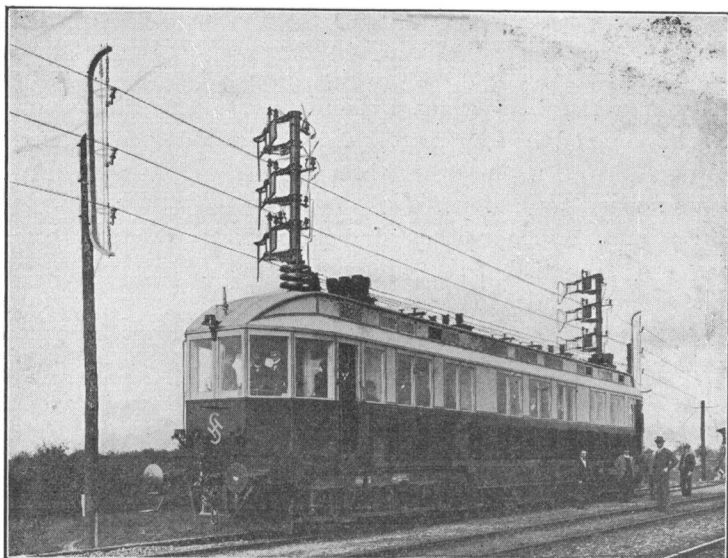


FIG. 17.

*The Zossen Railway.*—These results were availed of for the tests which are now being made on the normal gauge line from Marienfelde to Zossen, about 15 miles long, where the line voltage is 10,000 volts at 45-50 periods per second and the speeds attempted up to 220 km. (135 miles) an hour.

It would lead too far to go into details regarding these tests which have not yet been completed. Suffice it to say that as far as the electric equipment is concerned, they have been entirely satisfactory. The maximum speed obtained thus far is 160 km. (100 miles) per hour.

Fig. 17 shows one of the cars employed, and it will be noticed that line and contact device are shaped after the models used during the tests carried out on the Teltow road. There are 4 motors per car, each of 250 h.p. normal and 750 h.p. maximum output. The car when completely equipped weighs 90 tons and is designed to take 50 passengers.

*Tests on the Burgdorf-Thun Railway.*—Following the program laid down at the beginning, some special tests made on the Burgdorf-Thun Railway will be described.

First the overload capacity of the passenger cars was tried. These cars were designed to haul normally a total train weight of 50 tons on all grades at a speed of 39 km. (24 miles) an hour.

A test train was put together to weigh 70 tons total, i. e., 40% overload, and the motors did their work very well indeed, starting on the 2.5% grade without any trouble whatever. If therefore one of the four motors of a car should ever be temporarily out of order, the other three motors will be able to deal with a normal train alone.

In actual service neither the motors nor the transformers show any appreciable rise in temperature. The transformers are, of course, under load for short periods only, say 10 minutes at a time. Their size was therefore evidently not determined by their heating but by the maximum drop in voltage, which in this case was not quite 10%.

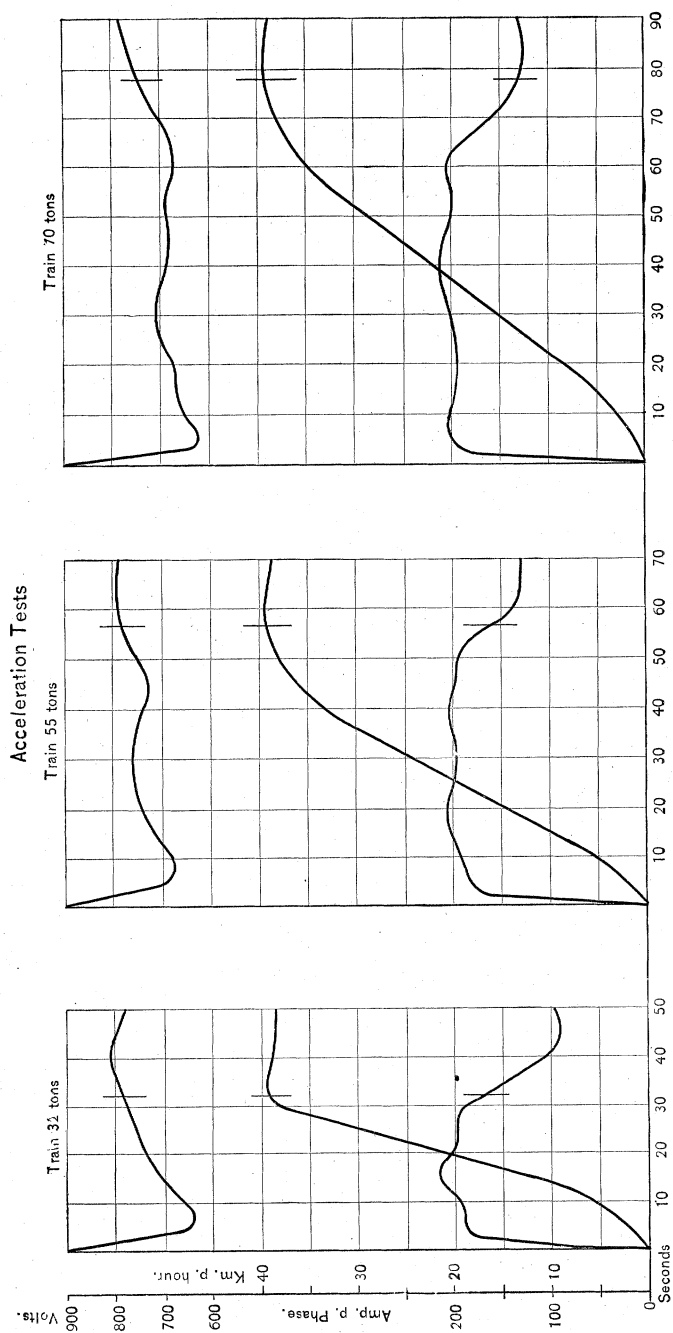
Fig. 18 shows in curve form the results of some starting tests made under three different conditions:

- (a.) One motor car alone weighing 32 tons,
- (b.) One motor car hauling 2 trailers, total weight 55 tons.
- (c.) One motor car hauling three trailers, total weight 70 tons.

The curves show speed, amperes per phase and volts as functions of time. The tests were made on the level and the controller manipulated so as to keep the current as nearly as possible constant at 200 amperes. This represents actual working conditions.

Readings were taken on the instruments mounted on the car at regular intervals of 5 seconds, the usual employe of the road acting as motorman. The automatic speed record made by the speed indicator corresponded very closely in each case with the curves thus obtained.

It will be found that a weight of 32 tons was brought up to a speed of 24 miles an hour in about 32 seconds, a weight of 55



tons in about 57 seconds, and a weight of 70 tons in about 78 seconds.

The total energy input up to the point where full speed was reached, was something like 1,600 watt hours in the first case, 3,000 watt hours in the second case and 3,900 watt hours in the third case, or approximately 52, 55 and 56 watt hours per ton respectively, a power factor of 0.8 being used to calculate real energy.

These results appear to compare very favorably with such as have been recently obtained with continuous current motors and this in regard to time of getting up speed as well as in regard to energy consumed during acceleration.

By the use of the series parallel controller, continuous current motors may be made to consume, I believe, as a minimum about 40-45 watt hours per ton under similar conditions, which would be a little less than 80% of the energy consumed by the above alternating current motors. There is, however, this point to be taken into consideration, that the maximum power input in the case of the alternating current motors is not very much above the average input, while in the case of the continuous current motor the energy curve has a very decided point, making the maximum input always more than 50% and often 100% more than the average input. The times given above for getting up full speed are rather better than have been obtained so far with continuous current motors.

Fig. 19 represents some readings taken during a regular time table run of a normal passenger train weighing 50 tons from Walkringen to Konolfingen, viz: up and down over the highest point of the road.

It will be noticed that very severe grades were encountered. The curves show the normal speed up the grade to be about 38 km., on the level stretch on the top about 39 km. and on the down grade about 40 km. or a slip of about 2% both ways.

The amperes curve clearly shows the difference between energy consumed in going up, and energy returned when coming down. Of course the power factors will be different in the two cases, and the real amounts of consumed and returned energy cannot be calculated from this curve. It is, however, interesting to see how the voltage increases on the down grade, thereby clearly indicating that the load is taken off. This test was made with the brakes wide open all the time and the motor resistances were used for starting purposes only.

A further test showed that by inserting resistance in the motors while on the down grade the speed could be increased materially and the speed reached on this occasion was about 44 km. on a down grade of about 1.4%.

Finally a test was made on a fully loaded train which was going up hill on a 2.5% grade. It was suddenly changed to going down. All brakes were left open and yet the train settled on its downward trip at the normal speed of about 40 km.

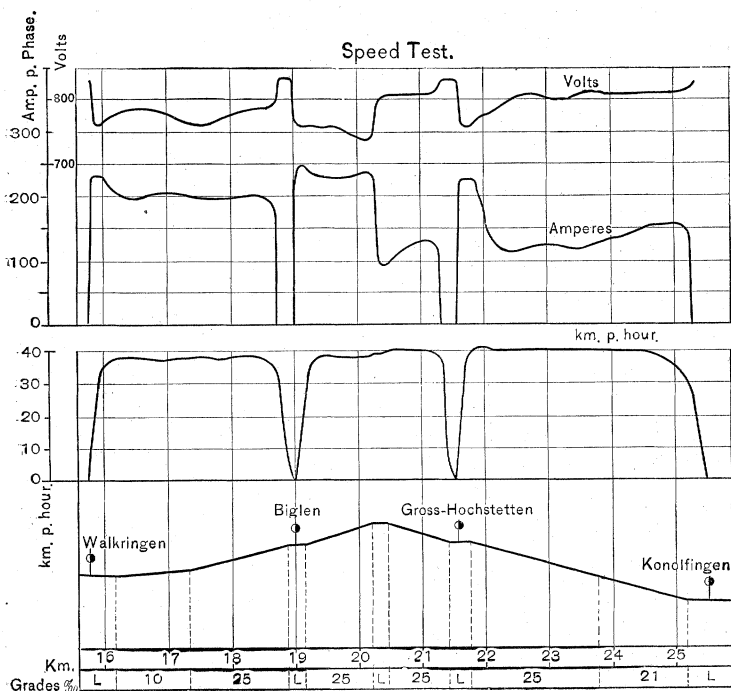


FIG. 19.

which was not exceeded. Then its direction was changed again and the start was made without any difficulty whatever.

*Conclusions.*—From these tests we may draw some very interesting conclusions.

I shall first sum up the results more especially in regard to the motors and the car equipments, which may be formulated as follows:

1. If properly designed, alternating current motors may be made to start under full load with not more than normal full load running current. They will also start under a considerable

overload. The only condition which has to be strictly observed in the case of alternating current motors is that the drop in the line voltage may not exceed a certain percentage, say 15% to be on the safe side. In this respect the continuous current system is more elastic and a continuous current motor will start with full torque even under very low voltages. In practice there is, however, no reason for allowing excessive drops in the line. Besides it would be easy to install on particularly exposed points transformers giving a somewhat higher secondary voltage in order to increase the torque of the motors in these cases.

2. In regard to acceleration we may say that alternating current motors are well adapted for accelerating quickly and uniformly up to full speed. Compared with continuous current motors they show a somewhat better, viz: shorter, time to get up full speed, a somewhat increased amount of energy consumed during the acceleration and a smaller maximum energy input.

3. During the run we find the speed of the alternating current motor to be practically constant on the level as well as on all grades, as it is dependent practically only on the number of cycles of the generators. This means that alternating current motors must be proportioned so as to be able to draw the maximum weight at normal speed on the maximum grade. Continuous current motors need not have the same output, as it is possible, especially in the case of several motors per car, to give the motor momentarily a greater torque by reducing the speed. This, however, is only feasible within certain limits and actual practice has shown that the gain in weight of motor thus obtained is very small compared with the weight of an alternating current motor running always at the same speed. In most cases it will hardly exceed 10-15%. Besides, as pointed out above, the voltage of the line might be increased at the grades in order to increase the capacity of the alternating current motor.

4. On down grades the alternating current motor acts as a generator returning energy to the line. This recuperation of energy is not only theoretically feasible, but is of actual interest in the case of prolonged down grades where the motors thus automatically brake themselves and where the descending trains greatly relieve the power station. In Siemens & Halske's tests, the alternating current generators were driven by continuous current motors from a storage battery. When the car

was going down grade, energy was returned and the storage battery actually charged. The Swiss mountain lines have installed water resistances to use up the excess of energy made free by descending trains.

5. In a mechanical way the alternating current motor is of course superior to the continuous current motor. The absence of the commutator alone is an advantage. Then the voltage in the rotor may be chosen as low as convenient, which makes the rheostats better and safer. All the Swiss roads which have been operated now between 3 and 4 years, the Lugano Tramways even 7 years, report having had practically no repairs whatever on any parts of the electrical equipment, and none whatever on the motors, which is more than can be said of the usual continuous current equipment.

6. Finally the manipulation of the cars is greatly simplified by the constancy of speed which in this connection is a decided advantage. All the motorman has to do is to start his car and bring it up to speed. The car itself will do the rest until it is stopped by the application of the brake. The concatenated motor control although showing a slightly better efficiency during starting makes the controlling apparatus more complicated and it is therefore preferable in most cases to adhere to the ordinary resistance control, which has really proved to be pretty efficient after all.

Now in regard to the line we find:

7. The increased voltage admissible for alternating current systems reduces the dimensions of the line wires. If carried beyond a certain point the insulation will, however, have to be increased. In cases where the energy used is so large that it cannot be taken off the line at voltages below 1,000 volts, alternating current becomes a necessity. I believe that 100-150 amperes per contact device is just about the maximum permissible, although I know that in some cases, especially in America, as much as 300 amperes have been taken off by one trolley wheel.

8. The transformation of the high voltage alternating currents universally used for transmission on long roads into continuous current means the installation of rotary converter substations. For transformation into alternating currents stationary transformers are used which do not call for any particular attendance and, having no rotating parts, do not show any deterioration from use.

Concluding I might now make the following few general remarks regarding the applicability of the two systems for traction purposes:

Both systems are probably capable of satisfactorily doing the work demanded by any traction problem. I therefore repeat that each case ought to be studied for itself in order to find out which system presents the greater advantages.

Very irregular profile and frequent stops, especially if combined with greatly varying speeds as found for instance in congested city street traffic, make a line generally more suitable for continuous current, while a regular profile, even in the case of steep grades, and long runs between stations, would make it better fitted for alternating currents.

Those cases are rare, however, which allow of an *a priori* decision in this respect, and I believe that a discussion on the merits of the two systems in general is a difficult thing.

What I would like to call your attention to, is the fact that the Burgdorf-Thun Railway answers a whole series of questions relating to the application of three-phase alternating current to electric traction, and proves without doubt the possibility of replacing the present steam locomotives by electrically driven vehicles. This, of course, is of special interest to countries like Switzerland, possessing natural resources in the way of water power, but large coal fields may also be put to better use by erecting electric central stations in their immediate neighborhood and transmitting the energy thus generated electrically to the places where it will be used on the cars.

Zurich, Switzerland, April, 1902.