

(Paper No. 2310.)

"Electrical Tramway in Hamburg."

By J. L. HUBER.

MANY efforts have been made of late years to adopt electricity for working tramways. Overhead and underground conductors have been, and are still, employed; but the difficulty is to find a substitute for horse-power in the crowded streets of large towns, where overhead conductors are not admissible, and where those laid underground are exposed to a multiplicity of evils only known to those who have endeavoured to cope with them. In this field the storage-battery alone could compete with horse-power, and then only when the energy is stored in a properly controllable form. The Author ventures to say that every practical engineer, knowing the conditions which exist in large towns, will agree with him that any vehicle destined principally for the transport of passengers should be, when possible, independent and self-contained in its motive-power. It is inadvisable to depend upon an engine located at a distance, a breakdown in which, or defects in the leads, would interrupt the service of the whole line. These views influenced him in choosing the Julien system for introduction into Hamburg. A Paper read before the Society of Arts by Captain Douglas Galton, on the 20th of January, 1886, fully describes the Julien system.¹ The speciality of the system is that accumulators, in which the energy is stored, are used in different groups, which may be placed in parallel or in series, according to the power required. This is accomplished by a special switch under the control of the driver, and without any artificial resistance. Only one electric motor is necessary, the power from which is transmitted by ropes to a counter-shaft, and from this by a pitch-chain to one of the axles.² Plate 5, Figs. 1, 2, 3, represent the first car (No. 61) in use at Hamburg; it is similar to that exhibited at Antwerp in 1885. The weight of this car is, ready for service, 4·83 (metric) tons, of which

¹ Journal of the Society of Arts, vol. xxxiv. p. 157.

² Elektrotechnische Zeitschrift, Berlin, 1887, p. 222; and Zeitschrift des Vereins Deutscher Ingenieure, 1887, p. 332 and Plate 9.

the accumulators come to 1·2 ton, and the weight of the series-wound motor of Messrs. Siemens Brothers, London, to 572 lbs. The accumulator-battery is placed in eight drawers, with slide contacts; in each drawer there are four boxes, with three cells, and with fifteen plates in each cell, consequently there are ninety-six cells. The whole battery is divided into four parts of twenty-four cells each; these four parts may be arranged, by simply turning the Julien switch, either (1) all four in parallel, giving a current of $24 \times 2 = 48$ volts tension; or (2) two and two parallel, and then in tension = 96 volts; or (3) two in parallel behind the two others, in tension = 144 volts; and (4) all four in tension = 192 volts. The capacity of each cell is 92 ampere-hours, and consequently the amount of stored-up energy is $192 \times 92 = 17,664$ watt-hours. The tramway-line selected for the trials with the electrical traction extends from the Rathhausmarkt, in Hamburg, to the Berthastrasse in Barmbeck, and is 5,360 metres (5,862 yards) long. The steepest incline on the line is 1 in 40 and 100 metres long, but only about 800 metres are level, the remainder being more or less steep inclines, with numerous curves. Thus this line, of which the route for nearly 2 miles lies through crowded streets, presents all the difficulties which tramways have to overcome in large towns, and as the trial has been extended over eight months, May to December 1886, on a common public road, it may be considered a very fair one. During the whole of the trial the engineer in charge recorded the number of watt-hours charged on each battery, to find when it needed re-charging, and the time and length of way which the car had run with the battery before this became necessary. By always putting fully-charged batteries into the cars, the amount of watt-hours put into the accumulators, to replenish them, after having done a certain service, gave a full account of the work done. It showed the energy required for the work, and the variations between the different loads, or the difference of power required to run the car. Before commencing the regular service, the Author made trial trips at night with the car No. 61 from the Berthastrasse to the Rathhausmarkt and back. During these trial trips the car was loaded with iron bars, to represent the full weight with passengers in regular service. The current passed through one of Paterson and Cooper's ampere-meters; the revolutions of the motor were indicated by a tachometer of Buss and Sombart, and the tension of the current was controlled by one of Paterson and Cooper's volt-meters. The weight of the car was, on all the trial trips, 7 tons, of which

4.83 tons represented the weight of the car proper, and the remainder that of twenty-nine passengers, one driver, and one conductor, or thirty-one persons at 154 lbs. each. The result was that in running up the main inclines 10,700 watts were used, *i.e.*, 54 amperes at 192 volts; further, that on the level 1,800 watts, namely, 19 amperes, multiplied by 96 volts, were required, and that the dynamo made then 900 revolutions. The ratio between the dynamo and the driving-axle was 1 to 10, the diameter of the wheels being 736 millimetres (29 inches), and the circumference 91 inches. Thus at 900 revolutions of the motor the speed of the car was—

$$\frac{900 \times 2.312}{10} = 208.080 \text{ metres,}$$

or about $3\frac{1}{3}$ metres in one second = 12 kilometres ($7\frac{1}{2}$ miles) in one hour. The speed allowed for the tramcars is 12 kilometres an hour in the town, and 16 kilometres in the suburbs. As the trial trips were made during the night, the Author drove the car at a higher speed. As tractive power he calculated 10 kilograms for every ton of weight, plus 1 kilogram for every millimetre of grade per metre, and per 1 metre of speed per second, or—

$$T = \{(t \times 10) + (g \times s)\} s,$$

where T is the tractive power, t the weight in tons of 1,000 kilograms, g the grade in millimetres per metre, and s the speed in metres per second. This formula gives very fair results when the rails are in good condition; but to allow for curves, as well as for dirty rails, it is necessary to multiply the values given by the formula by 1.5. The journey from the Berthastrasse to the Rathhausmarkt and back to the Berthastrasse, equal approximately to 11 kilometres (6.8 miles), occupied fifty-five minutes, and $96,802 + 94,652 = 191,454$ watt-minutes were indicated, or 3,481 watts per minute, or 17,405 watt-minutes = 290 watt-hours for every kilometre. As during the trial the accumulators were in first-rate condition, an efficiency of 80 per cent. could be reckoned on, and thus the accumulators required a charge of 362 watt-hours for every kilometre of way made by the car (7,000 kilos) on the line in question.

As stated above, the output of the accumulators was 17,664 watt-hours, and thus, in every 290 watt-hours per kilometre, 60 kilometres might be run with one load; but as at any moment something might occur on a tramway, and more power might be required to overcome it, the Author did not consider it advisable to allow the accumulator to run so far down; and besides, the

life of accumulators is prolonged when they are never fully discharged.

The annexed Fig., p. 308, gives the daily expenditure of energy in watt-hours employed to drive the car 1 kilometre, from the 1st of July to the 24th of December, 1886. The shaded parts of the Fig. represent Sundays; one day in each week is missing, which was either a holiday for the men, or was employed in overhauling the installation. The mean energy expended in volt-amperes to reload the accumulator was: In July, 392·16; August, 354·72; September, 441·49; October, 417·87; November, 701·92; and December, 561·374. The lowest amount of energy for 1 kilometre employed in one day, when only one car, No. 61, was running, was 280 watt-hours, on the 23rd of August, and the highest to the end of October 630 watt-hours. This enormous difference, as well as the daily variations, were due to the state of the rails and the traffic, which were both influenced by the weather. During summer, and in fine weather, the rails are clean, and in Hamburg the streets are well swept and watered; besides, the traffic is small, and the public evenly distributed on both platforms; but if the weather is misty, the rails are slippery, the cars more fully occupied, and the passengers avoid the forward platform and crowd on the hind one. This, when the driven axle is foremost, occasions loss of energy. The worst is when the grooves of the rails are filled with frozen dirt, and this happens in Hamburg when, during the night, sudden frost sets in, and the cars have to commence running before the salt-car, or before the salt has sufficiently acted; such a day was the 8th of December, when the average energy rose to 890 watt-hours.

Now, with an average of 362 watt-hours per kilometre, 19 amperes at 96 volts are employed on the level, and 54 amperes at 192 volts on different inclines, so that there must be, when 630 watt-hours are necessary, an expenditure of at least

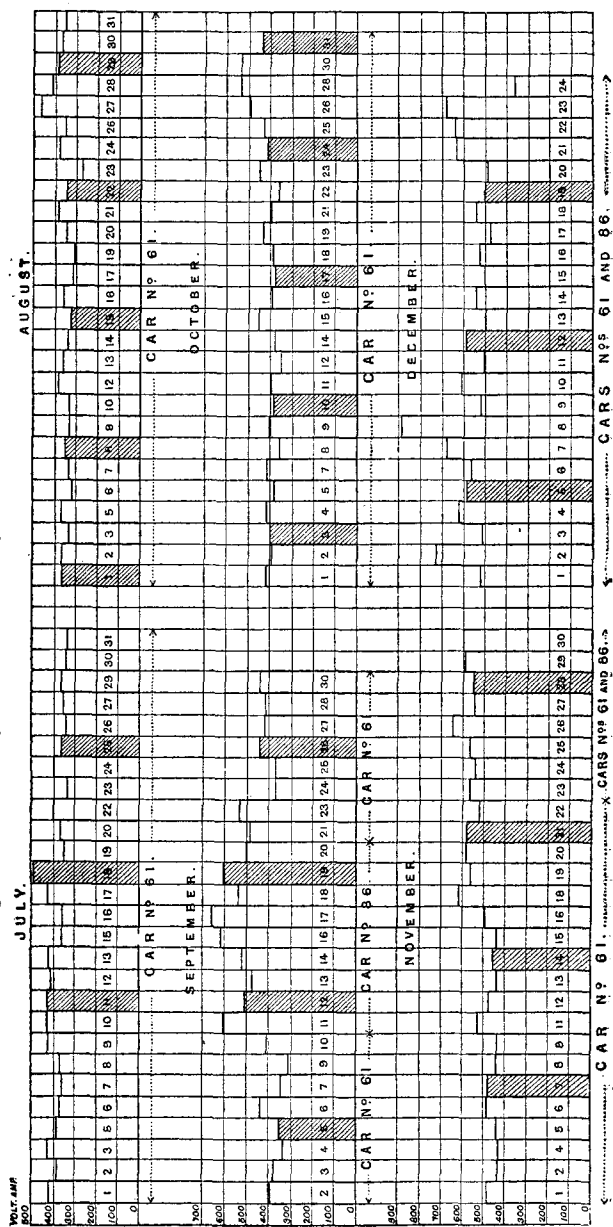
$$\frac{54 \times 630}{362} = 94 \text{ amperes on the inclines; and it is probable that,}$$

under bad conditions of the road on the inclines, the amount of power will be still higher than under good conditions, and that a current of over 100 amperes will pass the motor.

An electric current of 94 amperes \times 192 volts is equal to an expenditure of $24\frac{1}{2}$ HP., which had been taken out of the accumulators; but this had not been used only as tractive power, for it had heated the motor and had been wasted, and this is the weak point of all electric tramways. Every locomotive and every self-propelling car is made to do a certain amount of work on a

HAMBURG ELECTRICAL TRAMWAY.

Expenditure of Energy for 1 kilometre, July 1 to December 24, 1886.



certain line, to propel at a certain speed a limited weight on a maximum of incline, that is, at a maximum of resistance of the road; if the weight is constant, and the resistance on the road increased, the speed diminishes, and at last the motor must stand still. In a steam-engine the amount of steam, or energy, that might be taken out of the boiler (the accumulator) depends upon the volume of the cylinders and the number of revolutions. If the engines stand still no revolutions are made, and no steam is taken out of the boilers; and if the safety-valves do not blow off steam, no energy is wasted. Quite different are the conditions of the electric motor; the amount of current that flows through the coils of the motor (for tramcars series-wound motors are to be considered) depends upon the number of revolutions of the armature; and, at the same tension of the current, the greater the number of revolutions the less is the amount of current. Thus, when by increased resistance on the road the speed of the vehicle, and consequently of the motor (armature) diminishes, the amount of current increases and comes to its maximum, which depends upon the internal resistance of the motor when the motor stands still. Every motor is constructed to run at a certain tension of the current, at a certain speed, and will then take a certain amount of current. If, by overloading the car, or overcharging the motor, the speed diminishes, the amount of current will increase; yet the increase of current will perform very little useful work, but heat the motor. The heat partly disappears by radiation, but is, at all events, a waste of energy, and must be avoided.

The appearance of heat or light, where only power is needed, is a waste of energy, and consequently a waste of money. Still, this occurs in a great number of electrical installations, and principally electrical tramways; in these installations a series of artificial resistances are employed, and are more or less thrown into the circuit, according to the amount of current that has to pass the motor to attain a certain speed, or to start. Then, as in those installations the tension of the current is constant, the amount of current that flows through the motor depends only upon the resistance in the leads to be overcome. Then resistances do not act only like a throttle-valve, but they get heated, and this heat must be absorbed by radiation by the surrounding air, otherwise they will melt. In experiments made for this purpose, the Author has melted glass tubes 15 millimetres (0.59 inch) in diameter and 500 millimetres (19.68 inches) long, which he had surrounded with a spiral of German-silver wire 1.2 millimetre (0.05 inch) in

diameter, and imbedded in infusorial earth in a porcelain pipe of the same length, and of 25 millimetres (0·98 inch) outside diameter. The spiral was melted and stopped the experiment, which he repeated several times, varying the tension of the current, and therefore the amount of amperes passing, and consequently the time in which the wire melted. These experiments show what amount of heat or energy is wasted by resistances placed in the current, and that it is wasteful to adopt such means to use up less energy in the motor; it would be like employing a brake to regulate a steam-engine, instead of cutting off and expanding the steam; the resistances in an electric current will do there, because they are simple, where a small amount of current passes them, or where the loss of energy is negligible. To avoid the resistances, Mr. Julien has grouped the accumulators in parallel or in series, as most convenient, and this constitutes one of the great advantages of using accumulators instead of direct current; then by direct current the tension is always constant, and must be so high as to do the maximum of work required on the line, to ascend inclines, or to run with full load at a certain speed. Where this maximum of work is not required, resistances must be introduced. Since, as shown above, the use of the common resistance-spirals is wasteful, the Author recommends, instead of them, accumulators, which, when charged by the necessary surplus of energy in the line, will serve to light the train or otherwise, and so avoid the useless waste of energy. Finally, the amount of power required on different parts of the line may vary very much; but, as it is not necessary to ascend steep inclines at the maximum of speed, the motor or motors may be arranged in such a way that they can do, at a limited speed, the required maximum of work without getting hot, and to effect this the Author proposes the use of two motors instead of one, combined in such a way that one may suffice for the level, or for small inclines, but that the two may be placed in parallel on steep inclines; using, then, the current at half tension, the motors will turn at the lower speed, corresponding at this lower tension, and thus the car will run at lower speed and require less power to ascend the inclines. The simplest way to arrive at this "relay" for common tramcars would be to place two armatures on the same shaft in the same, or in two different magnetic fields. But the two motors should not be placed on two different bogies, as in that case a car would always be liable to run off the rails on sharp curves; the forward motor would, on entering a curve, be relatively the weaker one, as it has to overcome more resistance

than the one behind, and would be easily thrown by the latter off the rails. This is so well known to railway engineers, that he would not have mentioned it had he not seen an electric car arranged in this way, and consequently derailed.

After the first car, No. 61, had been in use some time, the Author arranged a second car, No. 86, for electrical traction (Plate 5, Figs. 4, 5, 6). This car was fitted in a similar way, but the motor was placed between the two axles, and the car had seats for twenty passengers inside; its weight was, ready for service, 6 metric tons, and when loaded with thirty passengers, one driver, and one guard, 8.24 tons; the weight of the accumulators was 1.94 ton, and of the motor 1,188 lbs. The motor was by Messrs. Elwell and Parker, and similarly to those used on the Blackpool electric tramway. A great advantage of these motors is that, instead of using two pairs of brushes, only one pair of contacts is employed to bring the current to the collector of the armature; it is thus possible, in running down-hill, to use the motor as a dynamo, driven by the mechanical energy developed, and charge the accumulators; but further, the motor itself serves as a powerful brake, and he has so employed it many times, when it is necessary suddenly to bring the car nearly to a standstill, to avert damage or accident. The final result of his trials is that to drive a tramcar on a line, for every 220 lbs. of weight and 1,000 metres (1,093 yards) of way, 7.8 watt-hours are required.

This communication is accompanied by several illustrations, from which Plate 5 and the Fig. in the text have been prepared.

Fig : 1.

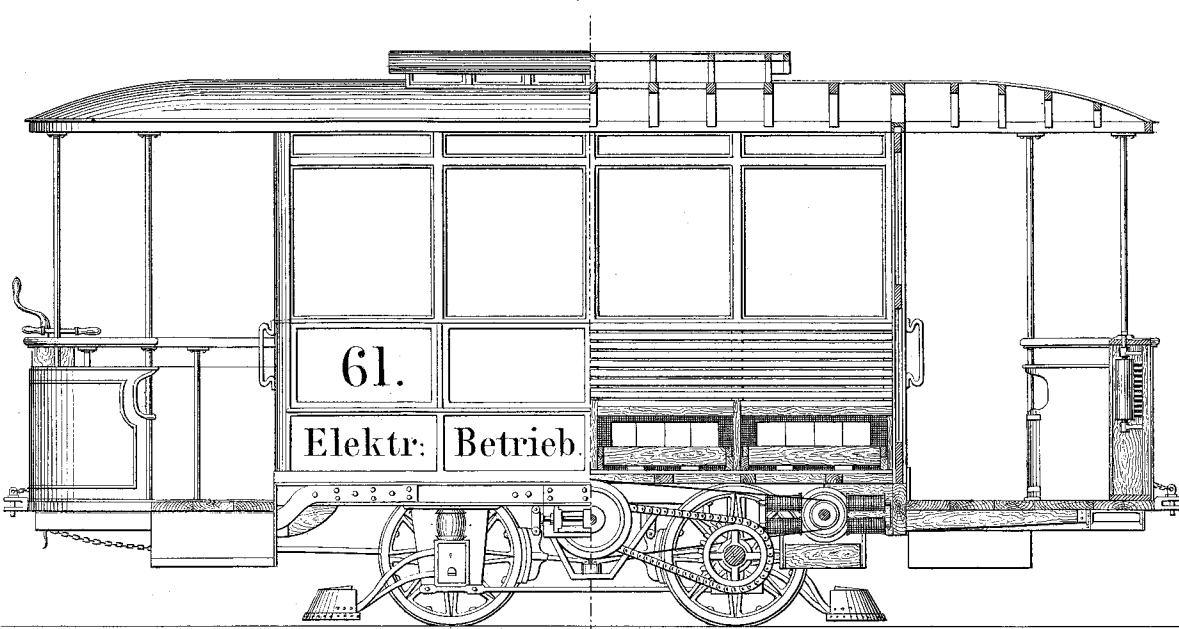


Fig : 3.

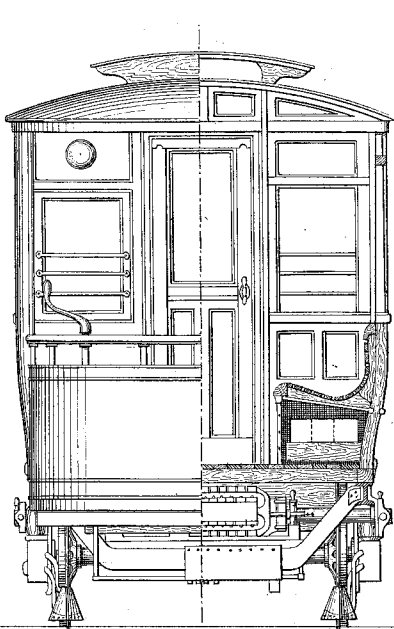


Fig : 4.

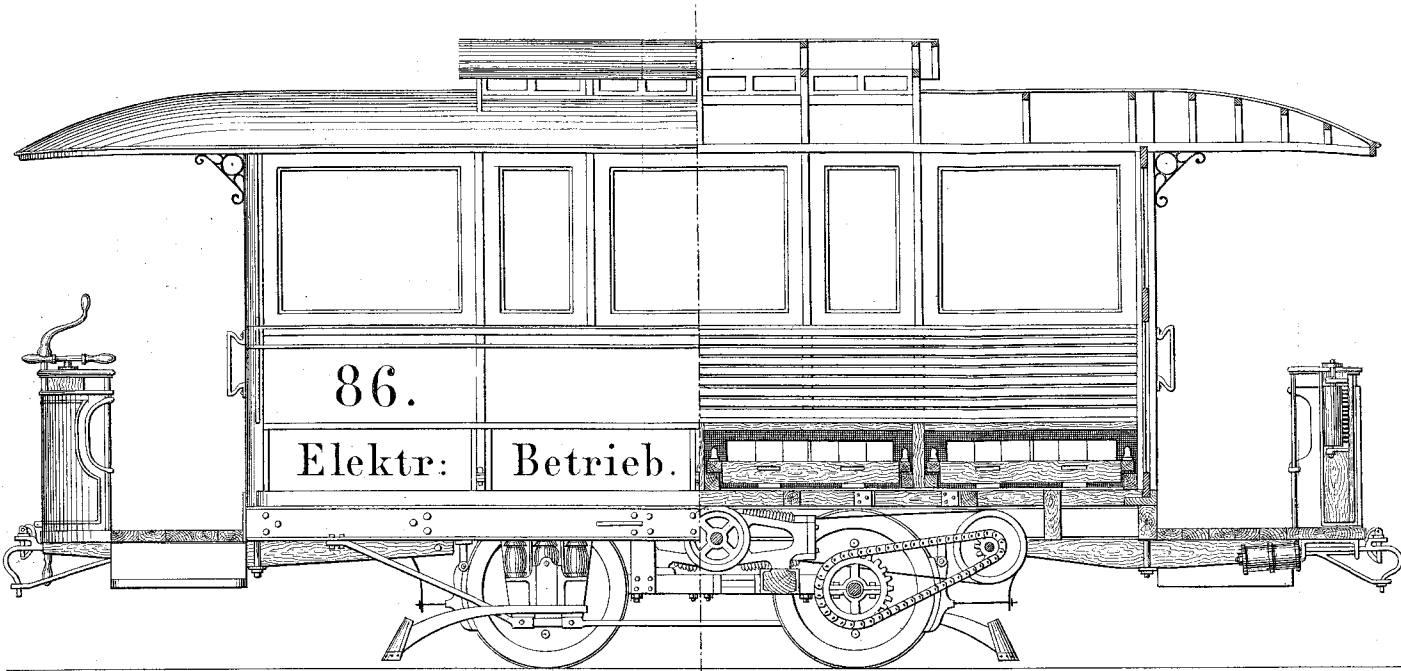


Fig : 6.

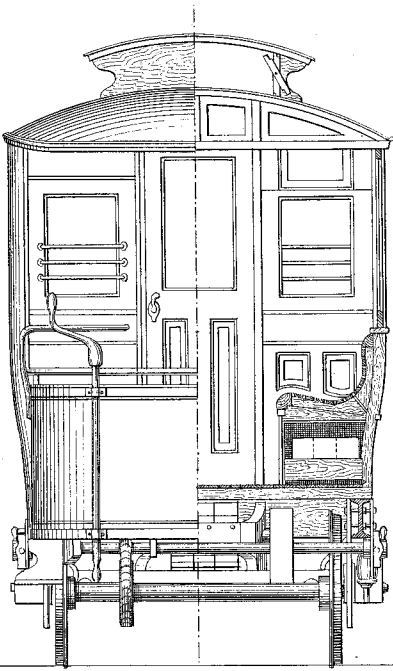


Fig : 2.

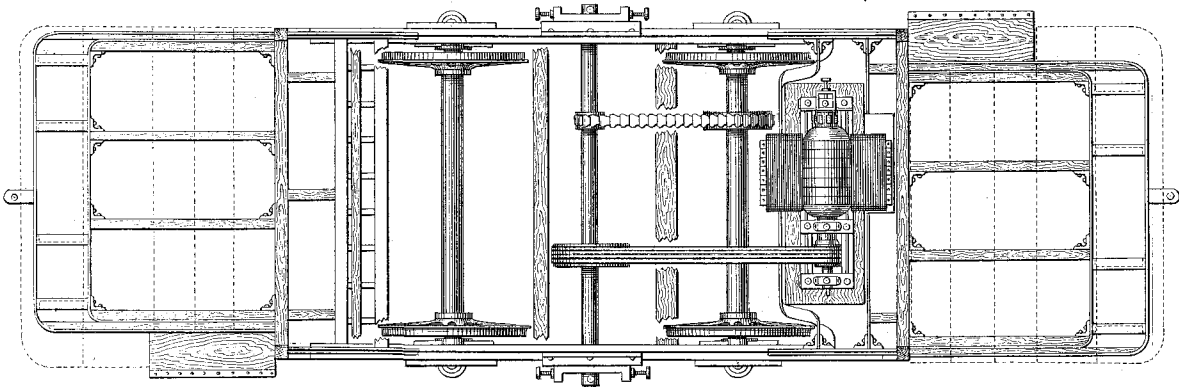


Fig : 5.

