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I. General.

In general, in comparing the electric with the gasolene car, the advantages of the electric car are:-

1) Very low cost of maintenance and repair.
2) Reliability and simplicity of operation
and with the present gasolene prices, usually,
3) Lower cost of operation.

The disadvantages of the electric car are:-

1) Dependence on a charging station or charging outfit.
2) Limited mileage of operation with a single charge, and usually also,
3) Lower speed.

In city use, the dependence on a charging station is jot material, as such stations are available. For much of city service, such as light and heavy delivery wagons, professional carriages, such as physicians' cars, etc., a daily mileage of 30 to 50 is ample and excessive speed undesirable.

Still more so, this applies to commercial trucks, such as light and heavy delivery wagons, and industrial trucks or moving platforms, such as are increasingly used in stores, factories, railway depots, docks, etc. In the latter, the gas engine is usually entirely excluded by fire danger and contamination of the air by the exhaust gases, in indoor use.

The electric vehicle would therefore be greatly preferable for these uses, if it were not for the further disadvantages incident to the present electric car.

1) Excessive slowing down on grades.

2) Sluggish get away in starting.

3) Great weight and high cost.

These disadvantages have been overcome in the car described in the following -

Its foremost features are:-

(1) The method of motor control, by a storage cell floating on the field circuit, which gives the motor compound characteristics.

The result thereof is:-

a) The speed is well maintained on heavy upgrades and with heavy loads.

b) A quicker and less sluggish get away in starting.

c) On level and slight down grades the maximum speed is limited, so that a careless driver cannot race the car.

d) On down grades and in slowing down, the motor automatically becomes generator, acts as brake and feeds electric current back into the battery.

Therefore:

The car is perfectly safe when on heavy down grades, without relying on the brakes, and indeed, the brakes are used only for completely stopping the car, but never for slowing down and on down grades, as the motor checks the speed on down grades, and holds it down to a safe value, Incidently, this saves wear of the brakes.

On down grades and in slowing down, the car recharges the battery, thus saving the power which other cars waste in grinding up the brakes. This results in a better maintenance of the car mileage especially in hilly territory.

e) Much of the power wasted in the motor field at large currents, is saved, thus increasing the mileage.

(2) The method of motor construction and gearing. The field and armature of the motor both revolve, each driving one of the car wheels.

The result thereof is:-

a) The elimination of the differential. The motor acts as differential, with corresponding saving of weight, and saving of the power losses in the differential, etc.

b) The motor gives twice as much power as the same motor in the customary arrangement with the field standing still. As the losses in the motor are very little increased, this results in a higher efficiency and much lesser weight, than the usual automobile motor, both resulting in a saving of power and corresponding increase of mileage, with a given size of battery.

(c) A simpler and more compact, thus more reliable power plant of the car.

(3) Lower weight of the car, due to:-

a) The saving of weight in the motor, resulting from its double rotation.

b) The saving of the weight of the differential.

c) The saving of weight (or increase of mileage) of the battery, due to the recovery of power on the down grades, and due to the lesser weight of motor, etc., which has to be carried.

d) The design of the entire structure in eliminating every unnecessary weight.

(4) Lower cost and correspondingly lower price, resulting from the above discussed features, and from the use of standard parts throughout as far as possible.

II. Motor and Control.

In its electrical, magnetic and mechanical construction, the motor essentially is a standard completely compensated series motor, except that the field also is mounted movably. That is, the motor comprises an armature with commutator, a laminated four polar field with series field exciting winding, and with a series connected compensating winding in the f field pole faces, for neutralizing the armature reaction. The commutator brushes, mounted on the field, revolve with the field and four collector rings lead the current into the field exciting winding and into the compensating winding in the field. Thus far, the motor would have the characteristics of all series motors, that is, excessive slowing down at heavy load, such as up grades, and speeding up on the level and on slight down grades, with the danger of running away, giving the speed curve as shown in dotted lines in Fig. 1, with the current, and in Fig, with the percentage grade as abscissae.

The essential and novel feature in the control of the motor consists in the use of a storage battery cell, permanently connected in shunt to the motor field. The resistance of the motor field is proportioned so that at average load the voltage drop across the field winding is equal to the voltage of the battery cell shunting the field winding, and at average load this cell thus neither receives nor give out current, but all the main battery current passes through the field winding. At heavier load and thus larger motor current, the voltage drop across the motor field would rise above the cell voltage, but as the cell maintains approximately constant voltage, the increased motor current passes through the cell, charging it; at light load and thus less than average motor current, the voltage drop across the motor field would drop below the cell voltage, and the cell thus discharges through the motor field, maintaining the field excitation and thereby checking the excessive increase of speed. If then the cell voltage would remain entirely constant during charge and discharge, the field current of the motor would remain perfectly constant, like in a shunt motor, and the only drop of motor speed under load would be that due to the increased voltage drop in the resistance of motor armature, commutator and compensating winding, and the drop of voltage, of the main battery under load. As however the cell voltage slightly rises under charge and drops under discharge, the field exciting current somewhat increases at heavy load - as is desirable to saturate the field and thus give maximum torque - and slightly decreases with decrease of load, giving the speed characteristics shown in drawn lines in Figs. 1 and 2. That is, electrically we may say that the motor has compound characteristics. Over the motor with compound field winding (that is, shunt and series field, such as used for elevator motors, etc.) it has however the advantage of greater simplicity, having only one field winding, and higher efficiency of the field, since the entire field winding is always used, while in the compound motor, at light load the series field carries little current and the series winding is practically wasted, while at heavy load the series winding carries most of the current, giving a greater loss than when using the entire field winding uniformly.

As this field cell charges whenever the load is above average, discharges whenever the load is below average, that is, we may say "floats on the field", it maintains itself charged, thus requires no charge or other attention, but may be forgotten.

This method of control, by battery cell floating on the field, thus has over the series motor the advantage of a greater uniformity of speed, and over the compound motor the advantage of greater simplicity and higher efficiency.

Unlike the series motor, in which with decreasing current the field excitation decreases and the speed therefore increases indefinitely, in this motor, no matter how much the motor current decreases on the level or slight down grades, the field excitation and therefore the speed are maintained, so that even with no current in the motor armature, a definite speed remains, (just as in a shunt motor), and if on a down grade the car speed and thus the motor speed increases beyond the free running speed, with the field excitation maintained by the battery cell the motor voltage increases beyond the battery voltage, that is, the current reverses and recharges the battery, the motor becoming generator. Thus, as seen on Fig. 1, at a car speed of 18.4 miles per hour - or 9.8 miles per hour in the low speed position, with the two halves of the main battery in multiple - regeneration begins, that is, the motor becomes generator and charges the battery, and thereby acts as a brake, the more so, the greater the excess of speed over the free running speed. It must be realized that no special operation or connection is required to bring about the braking action of the motor and the recharge of the battery, but by merely letting the car run at full speed or half speed position - whichever is desired - whenever a down grade is reached, the speed increases and the motor becomes generator and brake, without the driver even knowing it. Thus the brakes never have to be applied to check the speed - except to come to a dead stop - and a reckless driver cannot race the car, but it holds its own speed. The operation of the car thus is the most simple imaginable; the power is put on and kept on, regardless of up grade or down grade; no manipulation of brakes is needed to check the speed on down grades, but the only change of operation is that, when on a steep down grade and poor road or sharp curves the full speed appears too high, to turn the controller back into half speed position.

The amount of power, which thus is saved by feeding back into the battery on down grades, is quite considerable. It results in a greater mileage or permits the use of a lighter battery, thus saving weight and cost.

A further saving in power results from this ability of the motor of returning energy when stopping. With the ordinary series motor, as exclusively used heretofore, whenever a stop is made, the total energy of motion of the car has to be destroyed by the brakes. This results in a rapid decrease of mileage with increasing number of stops. In stopping when throwing off the controller, it goes from full speed position over half speed position, and in the latter position, regeneration takes place down to 9.8 miles per hour. Thus with a running speed of 17.8 miles per hour of the car, all the energy down to 9.8 miles, or $\frac{17.8^2 - 9.8^2}{17.8^2} = 70\%$, is regenerated when stopping and that at a good efficiency - 70 to 80%, as seen from Fig. 1, - that is, the energy wasted by a stop is reduced to less than half. As the energy of motion of the car, at 17.8 miles per hour, which is destroyed in stopping, is sufficient to carry the car about 800 ft. on the level, a saving of half of this energy at every stop, by feeding back, is quite considerable, if any appreciable number of stops are made.

it is usually claimed as the advantage of the series motor for traction work, that on heavy grades the increase of current consumed by the motor increases the field magnetism and thereby the torque per amperes. This is true, but to a limited extent only. Magnetic densities in traction motors, for reasons of space and weight economy, necessarily must be already so high at average load, that a further increase of the field current of 50 to 75 percent gives as high a magnetic saturation as can economically be reached, and this is about the increase of field current, resulting in the control of the motor by the battery cell floating on the field, due to the rise of the cell voltage under charge. Quite commonly however, the motor current on heavy grades is four to six times the average current, and this excessive current passing through the field means not only heat -- 16 to 36 times normal -- and wasting of power, but what is still more serious, a voltage drop in the field, and corresponding decrease of speed under load, without comprnsating advantages. Thus, if normally the field consumes 5% of the power and thus voltage, at five times the current it consumes 25% of the voltage, giving an increased drop of speed of 20%, most of which is saved by shunting the current through the battery cell. Thus, the greatly decreased drop of speed under overload, in this method of control, is not due to lower magnetic saturation, and thus lower torque, but is mainly due to the saving of the voltage otherwise consumed in the field resistance by the heavy currents. And also due to a second important feature. The series motor speed up with decrease of current, and thus on a level or slight (up or down) grade, would run at higher speeds than the motor controlled by a battery cell floating on the field. To give the same average car speed, the series motor therefore has to be geared at a higher ratio than the controlled motor. Thus the dotted curves in Figs. 1) and 2) are the speed characteristics of the same motor as series motor, which are given for it as controlled motor by the drawn lines, but in the series motor a gear ratio 10 to 1 had to be used, to limit the light load speed, while in the controlled motor an 8 ÷ 1 gear ratio is used to be comparable with the former. Both motors as geared in Figs. 1 and 2, would carry the same car over the same average 10 mile road in the same time, within a few seconds of each other as seen from the performance curves in 3) and 4), so that their curves in Figs. 1 and 2 are directly comparable.

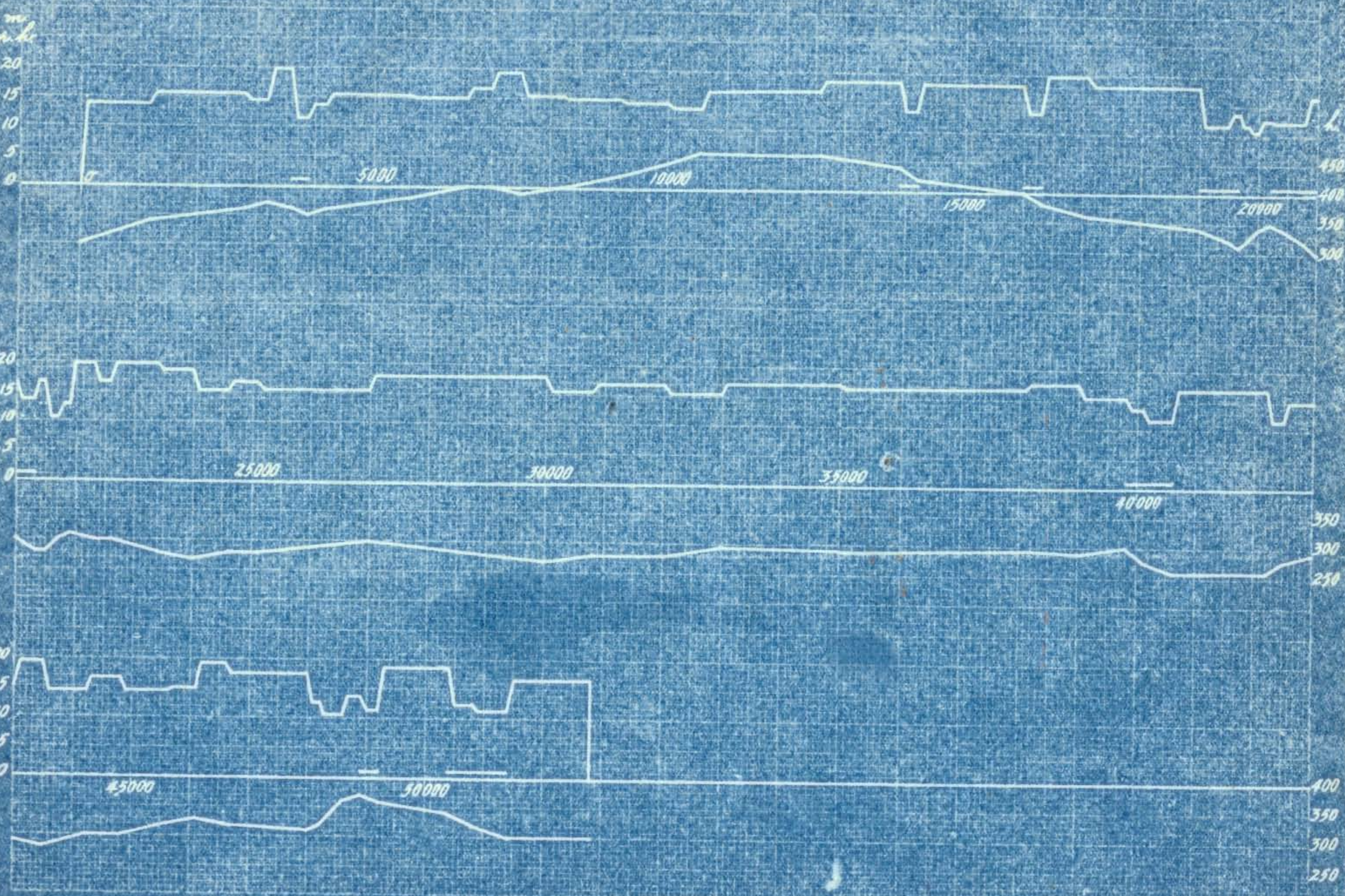
The series motor thus is slower at heavy load, due to the greater voltage drop in the field, and faster at light load, thereby requires a higher gear ratio, which makes the car still slower at heavy load or grade.

For comparison of the performance of the two motors, a typical run over 10 miles of an average road - neither perfectly level, nor abnormally hilly - is given in Fig. 3, for the controlled motor, in Fig. 4, for the same motor as series motor (but with 25% higher gear ratio). (The profile of the road is that from Schenectady to Watervliet.)

The average speed and the time consumed by the 10 mile run, are almost identically the same. 15.9 miles per hour and 37 m. 40 sec. for the controlled motor against 15.7 miles per hour and 38 m. 8 sec. for the series motor. However the maximum variation of speed of the controlled motor is between 19.3 and 10.6 miles per hour, while that of the series motor is between 25.6 and 6._6miles per hour, or more than twice as great. In the controlled motor power is put on the motor and kept on continusously, and the motor left to take care of itself, the brakes never used, but merely on the steepest down grades the controlled motor pulled back to low speed position. In the series motor, the brake has frequently to be used to hold the car on down grades - for 22.3% of the distance. The series motor consumes about 20% more power than the controlled motor. That is, about 20% of the battery power are saved by this method of control. With the same mileage, this means a saving of 20% of the battery weights, and as the battery is a considerable part of the car weight, a further saving of power due to the lesser weight which has to be carried.

The motor drives by ~~spool~~ spur and bevel gear mounted in a gear case at the hind axle adjoining the motor; the motor armature drives the one, the motor field the other hind wheel, so that the motor acts as its own differential, and the weight and complication of a differential are saved.

For the lowest speed, the two halves of the battery are connected in multiple, and in series with a resistance; for half speed running, the resistance is cut out; for the third speed position of the controller, the two halves of the battery are in series with each other and in series with the resistance, and in the full speed position this resistance is again cut out.



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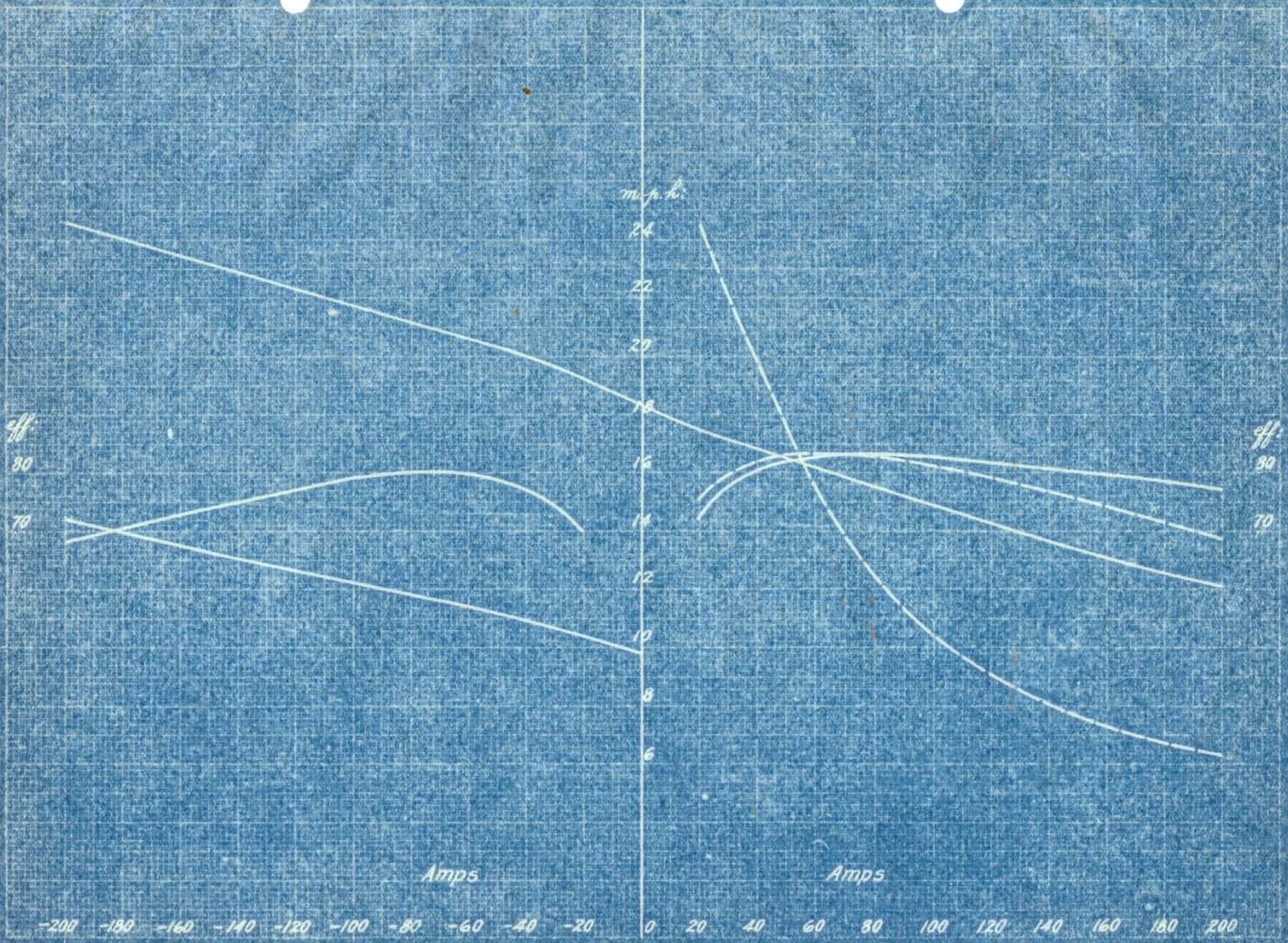
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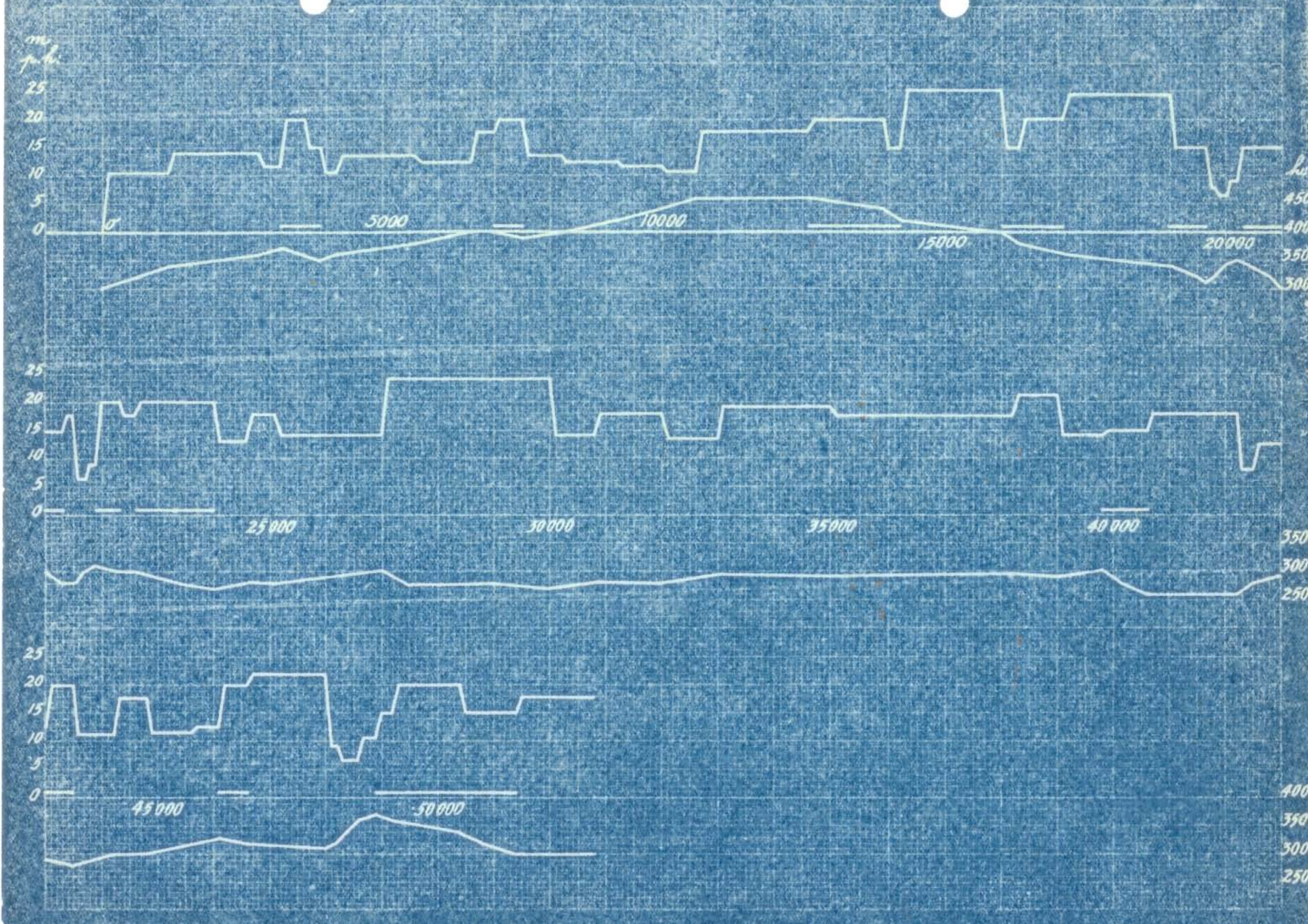
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Car weight: 3000 lbs.

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	1716	685	2716	5117
Δ %	0.8	64.1	13.6	16.1
	18.8			

Speed var: +21, -33 %

+59, -58 %

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