DISCUSSION ON "PROBLEMS OF HEAVY ELECTRIC TRACTION,"
AT PITTSBURG, PA., DECEMBER 5, 1904.

N. W. STORER: It is not the purpose of this discussion to give an exhaustive treatise on the subject announced, but merely to bring forward one or two points that have come up in working over electric railway projects.

The question of an efficient means for regulating the speed of electric motor-driven cars has always been a serious one. The direct-current motor is limited to two running points on the controller—full series and full multiple. On these two points the cars are obliged to meet all the contingencies that arise. The motors must always be geared so as to meet the maximum speed conditions required to maintain the schedule. This necessitates in most equipments used for interurban service, as well as for locomotives, very inefficient operation at the low speeds in the cities and wherever frequent stops are made. There have been various schemes proposed to remedy this, the first being used in the original Sprague motor, where the field was wound with several coils which were successively connected in different combinations which varied the field strength and consequently the speed at which certain torques were developed. This worked successfully on the small motor and was attempted to a certain degree in other double-reduction motors designed by the Thomson-Houston and the Westinghouse Companies. It was followed later by the General Electric motors which were provided with a resistance for shunting the field coils to obtain high speeds. It was found to be unsatisfactory, however, and as far as we know is not now used to any extent on modern motors. The problem still remains, and how great a one it is can hardly be appreciated by one who has not studied it by means of the speed-time-current curves.

It is well known that gearing a motor for 20 miles per hour with a certain tractive effort will take 25 per cent. more power to accelerate at a given rate than if it were geared for 16 miles per hour, and that the motors may easily be overloaded and burned out in performing a certain work, and that the consumption of power is much too great if the gear reduction is too small. This is an evidence of the necessity for a more efficient speed control which should be grasped at once by everybody.

The steam locomotive, it is claimed, has the advantage of the electric railway motor in that it can develop its maximum output over a wide range of speed while the electric motor operating at a certain pressure develops its maximum output at only one speed, and the output decreases rapidly as the speed increases. This renders it practically impossible for the electric motor to make up lost time unless it is geared for a higher speed than is ordinarily required. This again points to the necessity of an efficient means for speed regulation.

Unfortunately there seems to be no means for avoiding the difficulty with 2-motor equipments. With 4-motor equipments,

which are now used a great deal for interurban service, the inefficient starting may be overcome to a certain extent by throwing all motors in series at start. This gives one more running point. It, however, complicates the control apparatus so much that it is seldom used.

The following plan is submitted as one which, while involving some complications, avoids others and will result in a much more efficient and flexible speed control than any at present in

FIG. 1.

Total weight of car loaded—tons.....	39.5
Length of run—miles.....	2.2
Schedule speed—miles per hr.....	28.6
Length of stop—seconds.....	20
Acceleration—miles per hr. per sec.....	0.7
Braking rate—miles per hr. per sec.....	1.5
EQUIPMENT.	
Motors.....	4-75h.p.
Sq. root mean sq. amperes per motor.....	41
Sq. root mean sq. kilowatts per car.....	81
Average kilowatts per car.....	62
Pressure at car.....	550

use. It is adapted for use only on cars having at least four axles on which motors may be placed. Briefly, it consists in having two large motors wound for the line pressure and two smaller motors wound for some lower pressure, say 25 per cent. of the line pressure. The smaller motors will be used only in series with the larger ones and will develop a torque in proportion to the pressure for which they are wound. They will be controlled simply as so much resistance and will complicate

the control very little. With these two small motors operated only as motors, the car speeds obtained without resistance in series will correspond to pressures applied to the large motors of 200, 225, 250, 400, and 500, the last being the line pressure. If it is desired to go still further and add some small complication, the small motors may be used part of the time as boosters; that is, they could be reversed and driven by the other motors as generators for raising the pressure applied to the large motors. This method would add to the other equivalent speeds, the pressures of approximately of 280, 320, and 640. The whole range of speed could thus be covered by pressure control. The use of the small motors as boosters is mentioned merely to show the possibilities of the case but is not recommended for ordinary service.

Now, the question arises as to what is to be gained by this method of control and what equipment would be recommended. Take, for example, the case of a car ordinarily requiring an equipment of four 50-h.p. motors. In place of that equipment there would be two 75-h.p. and two 25-h.p. motors, the former being standard railway motors and the latter being standard type but wound for 125 volts. The advantages gained would be in accelerating with about 20 per cent. less current, in reducing the peaks on power-house load, in having five efficient speeds instead of two, and in substituting two 125-volt motors for two 500-volt motors which would decrease the cost of maintenance.

Another example would be found in the elevated railways where two-motor equipments are used. It would pay to add two small motors to each motor-car to reduce the load on the power-house or to increase the rate of acceleration or loads carried.

The disadvantages are few. It means two sizes of motors instead of one; but, as stated above, the small motors are wound for low pressure and will have a very low cost of maintenance, as the windings will in all cases be of comparatively heavy copper which is susceptible of the highest insulation. The commutators will take care of themselves.

Another disadvantage might be that if the wheels driven by the small motor should slip, the motor might have several times its normal pressure applied to it and would be injured thereby. Such a contingency is extremely remote, however, because the wheels have nearly as much weight on them as those driven by the large motors and only one-fourth of the torque applied to them.

One more objection is that the car is carrying motors around that are used only a part of the time. This is true, but they are used practically all the time except when the car is running with light loads; and the capacities of the motors can be arranged so that there will be no excess capacity carried.

Before leaving the question of speed regulation, it is well to

point out the fact that the foregoing applies only to direct-current motors and is entirely unnecessary with the single-phase motors where any pressure within the capacity of the motor may be easily and efficiently applied to it by means of the induction regulator or by the auto-transformer with a number of loops brought out. This system thus possesses the advantage which it is impossible to attain entirely with the direct-current system.

FIG. 2.

Total weight of car loaded—tons.....	39.5
Length of run—miles.....	2.2
Schedule speed—miles per hr.....	28.6
Length of stop—seconds.....	20
Acceleration—miles per hr. per sec.....	1.3
Braking rate—miles per hr. per sec.....	1.5
EQUIPMENT.	
Motors.....	4-75h.p.
Sq. root mean sq. amperes per motor.....	41
Sq. root mean sq. kilowatts per car.....	79
Average kilowatts per car.....	60.5
Pressure at car.....	550

Besides the lack of efficient speed regulation, the interurban railways are great sufferers from the tremendous fluctuations of load on their power stations and sub-stations. Since most of such roads operate with a small number of cars, frequently only one on a sub-station at one time, the capacity of the station is fixed entirely by the *maximum* load on it and not at all by the average load. It is thus of the greatest importance to limit the fluctuations of load to the minimum allowable to meet

the conditions of schedule. With the ordinary hand-control it is impossible to keep down the fluctuations except by putting resistance in the line, which is not particularly efficient. Automatic acceleration is therefore desirable, which will take the matter out of the hands of the motorman.

In most places the acceleration is made at a constant rate until full pressure is reached. This means that the same average current per motor is used in series and in multiple, which gives twice as much current per car in multiple as in series. We now recommend accelerating with a constant average current *per car* until full pressure is reached. To get the same average acceleration this necessitates accelerating much faster in series and slower in multiple. This is easily possible where 4-motor equipments are used, since they will always have plenty of weight on the drivers. In case the slipping point is reached, however, the current in series should be the maximum allowable, and in multiple just enough more to give the required average. Where the same line current is used for both series and multiple, the maximum current is 20 to 25 per cent. less than where a constant current per motor is used. The power consumption and the heating effect on the motors will be practically the same. The effect on the motors will be good because the motor has ample capacity to commutate heavy currents at low pressures, and reducing the current at high pressures will be a distinct improvement.

Such an acceleration can be easily and automatically obtained by the multiple-unit system. Mr. W. Cooper in developing this control system for the speaker found that it was perfectly feasible by the addition of suitable limit-switches and arrangement of resistances, to control the current so as to keep it at any desired amount in series and at any amount in multiple.

The use of a different line current in series from that in multiple renders the scheme applicable to any class of service with good results, though of course its advantages are greatest in interurban service where a reduction of 25 per cent. in the maximum current required per car means not only a reduction of the same amount in capacity of the sub-station but a substantial decrease in the amount of copper in the line.

A similar scheme may be applied to the single phase where the insertion of a single limit-switch in the trolley circuit will keep a constant apparent kilowatt on the line and a variable rate of acceleration having its maximum at the start and gradually diminishing until full pressure is reached.

Figs. 1 and 2 show respectively the standard method of accelerating with a constant current per motor and the proposed method for accelerating with a constant current per car. It will be noted that the schedule speed is the same in both cases. The average power consumption and the equivalent heating current per motor are practically the same, while the acceleration in the first case is at the rate of 0.7 miles per hr. per sec. at the maxi-

mum, and in the second case is 1.3 miles per hr. per sec. The important point is that the maximum kilowatt in the one case is 176 while in the second case it is only 132, a reduction of just 25 per cent.

It is probable that the before-mentioned system of speed regulation combined with this scheme of acceleration will give the best operation of which the direct-current system is capable, It will give the greatest economy in power consumption, station capacity, and line copper, and with practically no additional complication or expense.