AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, April 19th, 1892.

The 66th meeting was held this date at No. 12 West Thirty-first Street. The meeting was called to order at 8 P. M. by Vice-President Lockwood.

THE SECRETARY:—Mr Chairman. At the meeting of the Council this afternoon, it was decided in accordance with the report of the Committee to have the dinner, that was mentioned in the notices, at "The Arena," No 41 West 31st Street. The business meeting of the Institute will be held on the 17th of May, in this room, at 4 P. M., and the adjournment will be at about 7 P. M. There will be no paper read, the meeting being devoted strictly to the reception of the annual reports, the election of officers, and matters of that kind.

The Council at its meeting this afternoon elected the following associate members:

Name.	Address.	Endorsed by
BADT, FRANCIS B.	Manager, Mining Dep't, T.-H. Electric Co., 6506 Lafayette Ave., Englewood, Ill.	George Cutter. W. A. Kreidler. Joseph Wetzler.
BLADES, HARRY H.	General Sup't, The Detroit Motor Co., 1343-55 Cass Ave., Detroit, Mich.	A. L. Rohrer. H. A. Kinney. J. C. Hatzel.
COOLIDGE, CHARLES A.	Sup't and Electrician, Northern Improvement Co., Centralia, Wash.	Leo Daft. Ralph W. Pope. T. C. Martin.
CORY, CLARENCE L.	Professor of Electrical Engineering, Highland Park College, Des Moines, Ia.	Edwd. L. Nichols. Harris J. Ryan Ernest Merritt.
EDWARDS, JAMES P.	Firm of W. A. & J P. Edwards, Electrical Contractors and Engineers, Graniteville, S. C.	G. H. Stockbridge. Ralph W. Pope. Alexander S. Brown.
FLATHER, JOHN J.	Professor of Mechanical Engineering, Purdue University, Lafayette, Ind	James E. Denton. Jas. A. Vandergrift. R. O. Heinrich.
HIGGINS, EUGENE	Assistant Electrical Engineer, with Frank B. Rae, 302 Hammond Building, Detroit, Mich.	Frank B. Rae. Wm. A. Anthony, Ralph W. Pope.
HILL, GEORGE	Chief Engineer and General Manager, Carrere and Hastings, 44 Broadway, New York City.	Montgomery Waddell. A. St. Clair Vance. J. T. Marshall.

HOOPES, ARTHUR	Experimenter, Edison Laboratory, Orange, N. J.	A. E. Kennelly. T. C Martin. Ralph W. Pope.
MARVIN, HARRY N.	Secretary and Expert, Marvin Electric Drill Co , Schenectady, N Y.	Frank J. Sprague. Nikola Tesla. Chas. L. Clarke.
METCALFE, GEORGE R.	Electrical Engineer, with C. O. Mailloux, 45 William and 404 West 22d Streets, New York City.	Wm. E. Geyer. C. J. Field. C. O. Mailloux.
PARKER, HERSCHEL C.	Assistant in Physics, Columbia College, 21 Fort Greene Place, Brooklyn, N. Y.	M. I. Pupin. Holbrook Cushman. F. B. Crocker.
SCOTT, CHARLES F.,	Assistant Electrician, Westinghouse Electric and Mfg. Co., Pittsburg, Pa.	Chas. A Terry. O. B. Shallenberger. W. J. Jenks.
SMITH, T. JARRARD	Manager Electrical Dep't., The E. S. Greeley & Co., 5 and 7 Dey St., New York City.	W. M. Miner. Ralph W. Pope. F. Jarvis Patten
SPERRY, ELMER A.	Electrical Engineer, Sperry Electric Mining Machine Co., Chicago, Ill.	T. C. Martin. Joseph Wetzler. Ralph W. Pope.
STILLWELL, LEWIS B.	Electrical Engineer, Westinghouse Electric and M'f'g Co., Pittsburg, Pa.	Chas. A. Terry. Ralph W. Pope. Joseph Wetzler.
TISCHENDOERFER, FRED. W.	Electrical Engineer, Eickemeyer & Osterheld M'f'g. Co , Yonkers, N. Y.	Chas. P. Steinmetz. Joseph Wetzler. T. C. Martin.
WATERHOUSE, LAWRENCE MAXWELL,	Consulting and Practical Electrical Engineer, 16 St. Michael's Place, Brighton Eng.	Geo. A. Hamilton. T. C. Martin. Ralph W. Pope.
WURTS, ALEXANDER JAY,	Electrical Expert, Westinghouse Electric & Mfg. Co., Pittsburg, Pa.	Chas. A. Terry. Wm E. Geyer. O. B. Shallenberger.

Total, 19.

THE FOLLOWING ASSOCIATE MEMBERS WERE TRANSFERRED TO FULL MEMBERSHIP.

AYER, JAMES I.	General Manager. Municipal Electric Light and Power Co , 322 Pine St., St Louis, Mo
EMERY, CHARLES EDWARD	Consulting Engineer, Bennett Building, New York City.

Total, 2.

THE CHAIRMAN :—[Vice-President Lockwood.] The Institute is to be congratulated upon these accessions and especially upon the fact that, as you will have observed. they are not confined to New York alone, and the tendency to centralize is in this case at least departed from, so many of the new associate members hailing from different parts of the United States and some from foreign countries.

The subject for our consideration this evening, as you will see by the papers before you, is "Methods of Electrically Controlling Street Car Motors." Unfortunately the author of the paper is not with us this evening.

[The following paper was then read by Mr. R. W. Ryan.]

A paper read at the sixty-sixth meeting of the American Institute of Electrical Engineers, New York, April 19th, 1892. Vice-President Lockwood in the Chair.

METHODS OF ELECTRICALLY CONTROLLING STREET CAR MOTORS.

BY H. F. PARSHALL

While in many respects the controlling apparatus for street car motors and the general requirements of the same do not differ greatly from some other cases, there are some features that demand the closest attention if the car is to be handled either efficiently or comfortably so far as the passengers are concerned. While the number of methods proposed and tried in times past has been great, at the present time there seems to be sufficient agreement between the principal designers and sufficient data at hand to warrant the writing of a fairly comprehensive paper on the subject.

The problem of controlling the motors is probably the most difficult one in the whole range of street car work, and in no small degree determines the electrical design of the motors, or to be more specific, to start a car under any given conditions of track a certain torque is required. Beyond a certain limit, fixed largely by the convenience of passengers, this torque cannot be exceeded. The smaller the current with which the motor is able to develop this torque, the smaller the rheostat or other starting devices may be and the more efficient the car equipment. Should the motor, therefore, be incapable of developing a comparatively powerful torque per ampere, the amount of energy dissipated either in the magnetic windings, armature windings, or rheostat becomes excessive, the results being the more or less rapid deterioration of these parts.

It may not be out of order just here to discuss the design of the motor with reference to getting this torque most efficiently. The average H. P. exerted by a street car motor at the car wheel probably does not exceed 20 per cent. of the maximum it is expected to do in starting the car under the various conditions encountered. Now to get the highest efficiency from a motor run under these conditions, it is necessary to get the highest possible efficiency at that H. P. at which the greatest amount of work is to be done, and inasmuch as the loss in the conductors for this average H. P. is necessarily low, (otherwise the motors would burn out in doing the maximum work to which they are subjected), the question does not resolve itself into how to get the least possible motor resistance of armature and magnets, but rather, how to minimize the constant loss of hysteresis, eddy currents and friction. While all of these losses vary somewhat with the speed in series wound motors, the variation of these losses is not great, since for an increased speed there is in general a diminished intensity of magnetization and pressure. To render these losses a minimum, and at the same time to get the requisite torque to handle the car efficiently, there is but one solution, that is, to put the maximum number of turns on the armature compatible with good running as to heating and sparking.

While the truth of these statements may be more or less apparent to all when stated in plain terms, but little attention was paid to this matter in the earlier motors designed. The numerous measurements made, however, have so uniformly been in favor of motors with a comparatively large number of conductors on the armatures, that the importance of this matter is now pretty generally understood. This agreement as to the general design of motors has in no small way been influential in bringing electricians into agreement as to how the motor should be controlled, since with an armature of a comparatively large number of turns, less turns are required in the field magnets to produce a given torque with a given number of amperes. The function of the magnets, therefore, has become of less importance. It is always, however, to be borne in mind, that other things being equal, the motor with the greatest number of turns in the magnets will develop the greatest torque for small currents. With a given electromotive force acting on the armature circuit, and a given torque developed by the armature per ampere, it does not matter, so far as efficiency is concerned, whether the difference in electromotive force at the armature terminals and the line is due to drop in external resistance, or to drop in the magnets. This point determines once for all, that motors with commutated fields are not necessarily more efficient than other motors.

The particular advantages of the commutated field method are, that with a limited number of pounds of copper, or in the case of street car motors, with the limited space available for field magnet windings, it is possible to adjust the magnetizing force of the field coils so that the rate of doing work of the motors may be made to correspond with the rate this work is required by the car for the various speeds and conditions of track. This adjustment may be made for any size of motor, with any required degree of precision by varying the number of magnet coils. To increase the range or precision it is only necessary to increase the number of coils. In practice it has been found that this number could not be very great, otherwise the car wiring becomes too complicated and too expensive. This same holds true of the controlling switch. Three magnet coils or sets of magnet coils seem to be the practical limit, since there is a general agreement between street railway managers that the present number of magnet connections (6) should not be increased, and even with this number there is occasional trouble with broken wires or terminals. With a 15 H. P. motor it is possible with three sets of coils to run under most conditions met with in practice without employing external resistance. It is occasionally necessary, however, when the car is to be run at two or three miles an hour, to make use of the resistance coil that is ordinarily used only when starting. With 25 H. P. motors it is necessary, with three sets of magnet windings, to make use of this resistance coil very considerably in ordinary practice, since without this it is not possible to get a speed of less than one-third the maximum speed of the car, which is generally taken to be about 18 miles an hour.

The range of speeds without the use of a rheostat is determined by the limit to which it is safe to heat the magnets. The temperature of the magnets should not in any case exceed 65°C. This would put the increase of temperature at about 30°C. This increase corresponds to an average loss in the magnets of about 0.3 of a watt per square inch of radiating surface. For the few seconds generally taken to start the car the loss may be as high as two watts per square inch without dangerous heating. Experience, however, has demonstrated that to exceed this limit, even for very short periods, there is considerable risk. Having the maximum number of watts that may be dissipated in the magnets, the series resistance of same may be calculated from the properties of the motor on the supposition that each ampere taken by the motor produces a certain number of pounds pull at the periphery of the car wheel. In a well designed motor with commutated fields, it is easy to get from 35 to 40 pounds pull at the periphery of a 30″ car wheel with the coils in the series position. These coils are either wound side by side, or one on top of the other, according to the necessities of the case as determined by the general design of the motor. Experience has shown the advisability of winding these coils in independent spools whenever the general design will permit, since in case of trouble it is cheaper and easier to replace the damaged coil, and there is less liability of crosses between the coils. As an example of a design, that has been found to give general satisfaction in practice, I give the following figures from a series of tests made on a Sprague No. 6, S. C. Motor, the magnetic data of which has already been published by myself:[1]

EFFICIENCY OF STREET CAR MOTOR NO. 6.

[Reduction 11.7 to 1,—30″ Wheels.]

Brake H. P.	Efficiency.	Speed.	Remarks.	Res.
14.3	87 Per Cent.	1110	3 coils in parallel	0.8
11.8	87 "	1174	3 " "	.8
11.4	86 "	1184	2 " "	1.4
9	84 "	1309	2 " "	1.4
8.25	82 "	955	2 in parallel, 1 in series......	3.24
6.35	79 "	1040	2 " 1 "	3.24
4.9	72 "	1070	2 coils in series.........	4.86
3.9	70 "	1014	3 " "	7.42

It is to be noted especially that it is possible to get an approximately constant speed with a wide range of loads, and yet have the energy dissipated in the magnets remain approximately constant, and that it is possible to get a torque corresponding very approximately over a wide range, to that required to propel a car under conditions met with. This is the solution of the question, how to get the highest efficiency. For instance, suppose a car is to be run between two points in a given space of time, and this is not an infrequent requirement, and that the magnet windings of the motor are such that either the car runs the distance in too short a time or in too long a time, it will be necessary then to

1. TRANSACTIONS, vol vii, p. 218.

accelerate the car for a time beyond the limit required, then to allow it to slow down, then to accelerate it again, or go through some such cycle of operations to get the required results. More power will be required with such windings than when such a torque can be had at the motor, that will produce the required speed by an approximately uniform acceleration. To get the same results given above for the No. 6 motor, with the magnet coils arranged in loops instead of separate coils would require upwards of three times as many pounds of copper as was used in the present case (110 lbs.) This motor was designed to give a maximum car speed under ordinary conditions of from 12 to 15 miles an hour. At present it is thought advisable to have a maximum car speed of from 18 to 20 miles an hour,[1] since numerous measurements have shown the economy of running street cars at as high a speed as the conditions of track, etc., will permit. In a series of measurements made by myself, it was found that the watt hours per car mile decreased very considerably with the speed of the car up to 30 miles an hour. To get this high speed, (20 miles per hour) it has been found necessary to vary the proportions of the magnet coils from that given in the above for the No. 6 motor. Thus for a single reduction 15 H. P motor the resistance of the last coil to be turned from series to parallel is only 15 per cent. of the total resistance of the magnets, and the turns of this coil only 20 per cent. of the turns in the other two coils. The reason for putting this low resistance coil inside, is to get the greatest number of turns when the coils are all in series and the least resistance when the coils are all in parallel. Further, under ordinary conditions this coil has the least expenditure of energy in it. and the least radiating surface. With a winding of this proportion, it is necessary with 15 H. P. motors to use an external resistance of 6 or 8 ohms. With 25 H. P. motors an external resistance of from 10 to 12 ohms is required. This resistance should be so sub-divided that there is not more then 20 volts E. M. F. between adjacent contact pieces, and so proportioned that the increase of temperature is not in any case above 150°C.

A method that is receiving a great deal of attention now is that known as the "Series Parallel Method." While it has not

1. All car speeds are quoted for straight and level tracks. These when calculated for a new motor are determined from the speed and H. P. curve of the motor, assuming the resistance to be 30 lbs. per ton. The methods of measuring these speeds are in general such, that the probable error is too great to determine the percentage slip of the wheels.

yet been introduced very largely in practice, numerous experiments have indicated the desirability of doing this as soon as some of the troublesome features of the switch have been overcome. The method of operating is as follows :

In starting, a rheostat of from 8 to 20 ohms is used, according to circumstances, in series with the motors, which are in series with each other. After this resistance is thrown out of circuit the magnet coils of one of the motors are short-circuited, a section at a time. To make the start smooth, 3 or 4 coils at least are required. The magnet coils being short-circuited, the armature is then short-circuited, and the magnet coils thrown in circuit simultaneously with the armatures being thrown in parallel. It is just at this point where the difficulty with the switch has been encountered, since either the switch has to be operated with great rapidity, or the contacts act in perfect unison, otherwise unpleasant results as to short-circuiting occur.

The advantages of the method are that a very wide range of speeds is obtainable at a comparatively high efficiency, and that the energy required to be dissipated by the rheostat is small for the low speeds frequently required in city practice. This lessening the duty of the rheostat is a very important point, since as yet it has been found exceedingly difficult to construct a cheap rheostat that could be placed under the car in the small space available and dissipate so large an amount of energy as is required when the car is to be run for a considerable time at a speed as low as 2 or 3 miles an hour. Any method of control that has lessened the energy to be dissipated in the rheostat has in general been considered with favor, since there has been a corresponding diminution of trouble in each case that the energy to be dissipated has been lessened.[1]

Having now given a general discussion of the problem a brief description of some of the apparatus recently devised may prove of interest.

Figure 1, shows the general design and arrangement of an improved form of platform switch, which combines both the "field commutation" and the "series resistance" methods of starting

1. Since writing the above concerning the series parallel method of control, some months ago, I have had an opportunity of inspecting the apparatus very recently put in operation by the Thomson-Houston Electric Company. The trouble from arcing at the switch has been overcome by a novel and ingenious construction. It is gratifying to learn that the results of a practical trial recently made on the West End road. show that the expectation in regard to better efficiency is fully realized, a gain of 39 per cent. having been obtained in actual practice.

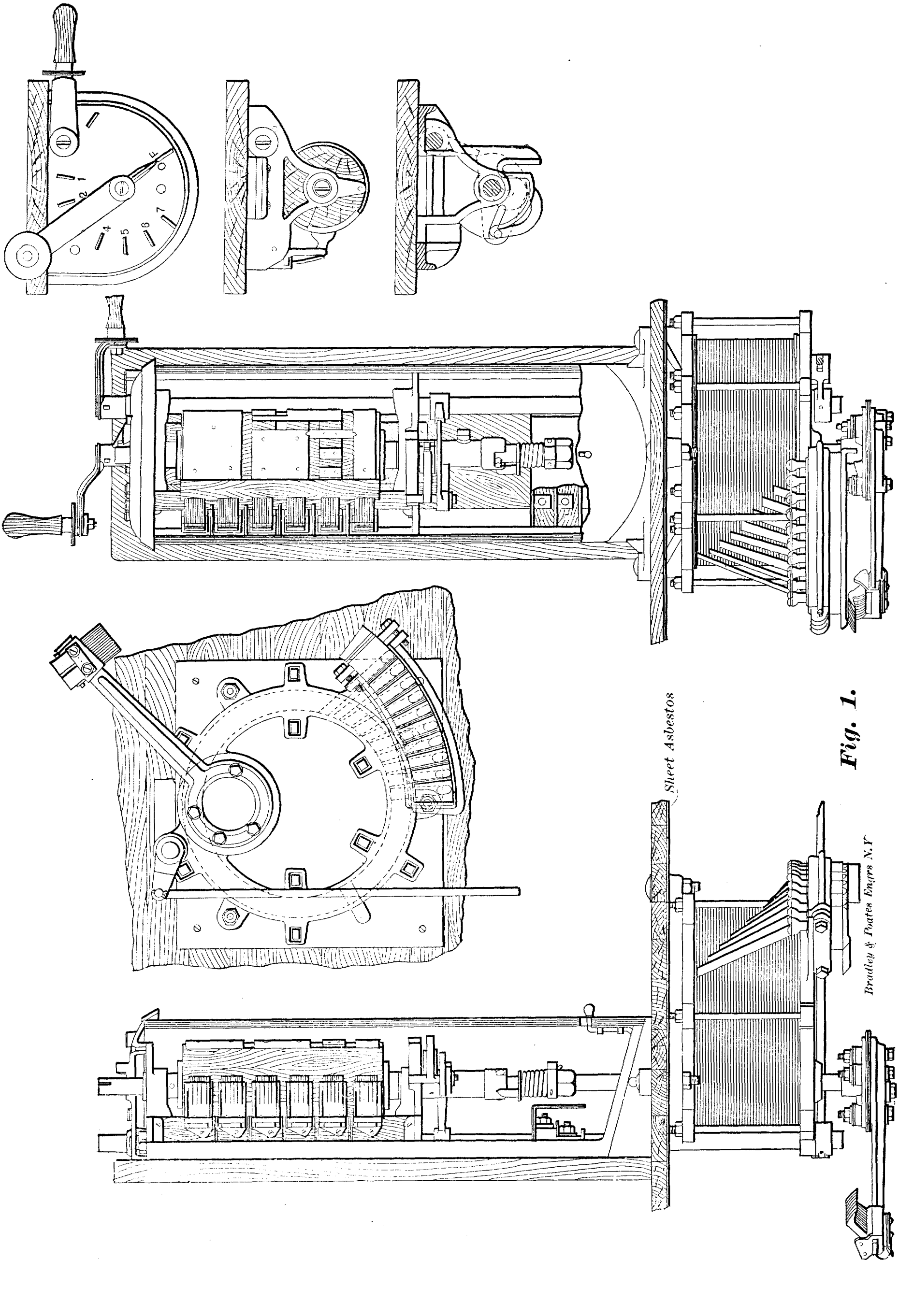

Fig. 1.

COMBINED REHOSTAT AND PLATFORM SWITCH.

cars. To start the car, the switch handle is turned from the position marked "off" with a counter clockwise movement; this movement carries the arm of the rheostat, which is placed under the switch, around and over the contact segments, so that the resistance is gradually cut out of circuit. After the contact arm has been carried around to 135 degrees and all the resistance has been cut out, it is released from the cylinder shaft and left locked in this position. A further movement of the switch handle then affects only the cylinder, and commutates the sectional windings of the field magnets of the motor from series to parallel in the usual way. In stopping the car the field coils are turned from parallel to series, the resistance coil is then again put into circuit and the circuit broken when the contact lever leaves the last segment of the resistance coil, and not, as hitherto, upon the cylinder contacts The only caution to be observed in stopping is to see that the switch handle shall be turned to the position marked "off," for the motors are reversed by means of a separate reversing switch placed under the car and operated by a lever connecting with a separate shaft in the controlling switch case. The shaft of the platform switch interlocks with this reversing shaft in such a manner that it is impossible to reverse the motors until the cylinder is in the "off" position. The use of this separate controlling switch has been objected to, but to combine both the advantages of the rheostat and commutated fields the switch mechanism becomes too complicated and the switch too large to have the reversing performed by a reverse movement of the controlling switch handle.

The cylinder plates and contacts are made of thick iron stampings, as experience has shown that iron is more durable than brass for this purpose. The burning, due to the formation of arcs, does not have so much effect upon iron as it does upon brass, and there is more certainty of good contact. The contacts on the cylinder consists of a number of stampings arranged in a brass frame, each stamping making an independent spring contact with the switch cylinder. The rheostat employed is built up in a circular form from a large number of flat rings stamped from thin iron sheets. The rings are built up in the form of a cylinder, each ring of iron being separated from the adjacent rings by a ring of mica, except at point where it makes contact with the ring on other side of it. Instead, however, of being arranged in a continuous spiral circuit, the coil is divided into a

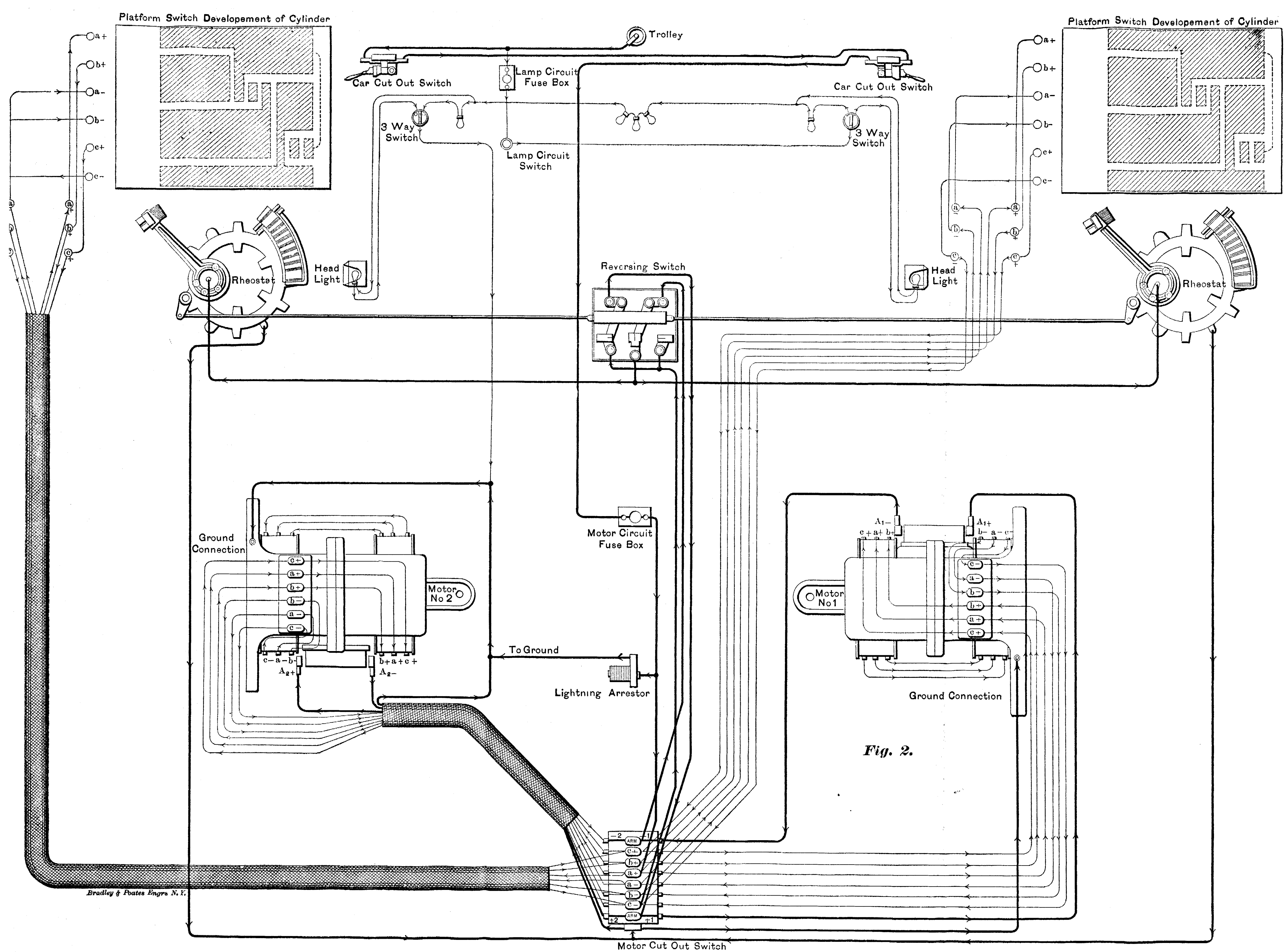

Diagram of Connections for Two Motors in Parallel.

number of parts so arranged that the direction of rotation of the adjacent spirals is reversed, this being done to make the inductance of the coil as small as possible. A coil wound up in a continuous spiral having a mean diameter of 12″ and a radial depth of 1″, 6″ long, and composed of 400 plates, was found to have an inductance of 40 milli-henrys. The coil was then wound up in 12 sections, the direction of each section being reversed, and the inductance in this case was found to be 8.5 milli-henrys. These sections are stamped from different thicknesses of metal, so that those coils which are in circuit the shortest time and have

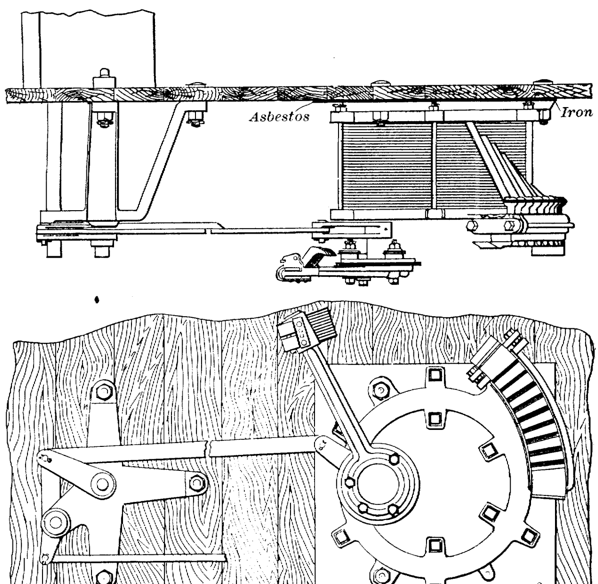

Fig. 3.

DETACHABLE RHEOSTAT FOR COMBINED RHEOSTAT AND PLATFORM SWITCH.

the least current to carry are of highest resistance and least ampere capacity, and those that are liable to be in circuit for some time are thicker and have less resistance and greater ampere capacity. Copper connections are made at different points in the coil, all these connections being brought to a number of small iron contact pieces fitted in a spiral form and arranged so that the switch contact lever can slide over them. The contact pieces are insulated from the frame with sheet mica and from one another with small slate slabs. The rheostat is entirely fireproof and can expel with safety the heat evolved within it under all ordinary conditions. As a point of practical importance it is, however, advisable to place a sheet of metal and a layer of asbestos paper between the rheostat frame and the car floor. This will prevent any danger from fire, either from heating or sparking, should such occur. It is to be noted that the general design of this rheostat is such that those parts having mechanical functions and energy dissipating functions have been separated as much as possible. Of course the mechanical functions of a rheostat are more or less limited; it is evident, however, this effort is in the right direction. It is with respect to this particular point that the rheostat has a decided advantage over any form

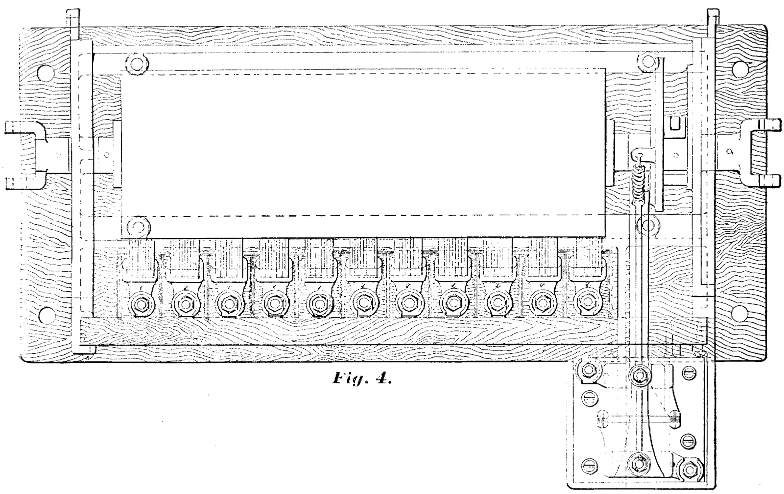

Fig. 4.

CYLINDER CAR SWITCH, GENERAL ARRANGEMENT

of mechanical clutch in starting a car. The clutch, of course, has its advantage in starting quickly bodies that have a great amount of inertia. In ordinary practice, however, the amount of energy dissipated in a clutch is approximately equal to that necessary to dissipate in a rheostat, but the clutch has in addition to its energy dissipating function, a very exact mechanical function, and these two functions are interdependent on the same wearing parts. For this reason, if no other, clutches have not yet been made to compete favorably with rheostats.

Figure 2 gives a diagram of the car connections for this switch. It will be seen that the current from the trolley wire first goes through the field coils and switch cylinder for commutation, then through the armature and reversing switch, and thence through the switch contact lever and resistance coil (in starting) to ground. It will be noticed that by use of the separate reversing switch the armature wires and field wires are each kept separate and distinct from one another. Formerly there was considerable trouble from the breaking of these wires, especially where the wire entered the brass terminals at the various terminal boards. This has been almost entirely obviated by using 49 strand cable wherever wire was subjected to bending.

In some cases the construction at the platform ends is such as to make it inconvenient to place the rheostat used with this form of switch immediately underneath the cylinder. This is the case when certain kinds of draw bar or step constructions are used. In these cases a modification of the switch arrangements is made that is shown in Fig. 3. Instead of the rheostat a light frame is placed directly under the cylinder. This frame serves to support the switch shaft, upon which is placed a crank connecting with a bar, which is carried off to the rheostat contact lever. With this arrangement the rheostat can be placed under any convenient part of the car flooring and operated as well as when directly under the platform.

Figures 4, 4A and 4B show general plans of a car switch designed to be placed under the car and about half way between the motors, when the car construction permits. This design, while open to the criticism that the switch is somewhat inaccessible for inspection, meets the demand that has sometimes been made when it has been thought the space ordinarily occupied by the platform switch could not be sacrificed. The principle is the same as the platform switch already described, but it is modified in form and shape to suit the particular condition under which it is to work, and it is to be noted that the mechanical adjustments required are much more exact, otherwise there would be considerable burning of the contacts, since the motorman would be unable to tell whether or not the switch contacts were on proper positions.

The rheostat is arranged in sections and connections brought from them directly to cylinder contacts. A cylinder is used to commutate both resistance and field magnet coils.

An important point that has been attended to in this switch is the breaking of the circuit on a separate switch instead of on the cylinder. A snap switch, of the knife blade pattern, is employed to break the circuit at four points. It operates in connection with the cylinder shaft, to which it is connected with a special locking and releasing gear of similar design to that shown in Figure 1. The first movement of the cylinder shaft closes the snap switch and completes the circuit through the coil. Further movement then disengages the snap switch from the shaft

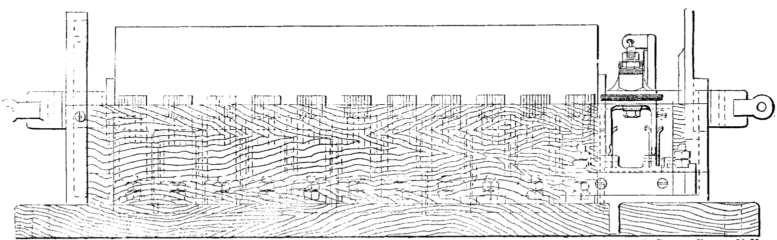

Fig. 4. A   *Bradley & Poates Engrs N.Y*

(leaving it closed) and the different commutations are affected. joints makes connection between the platform lever and the When breaking the circuit the snap switch is again brought into action.

When this form of car controlling switch is used, the platform lever is fitted at its lower end with a bevel gear wheel meshing into another gear wheel placed on the cylinder shaft. When necessary an extension shaft fitted with one or more universal

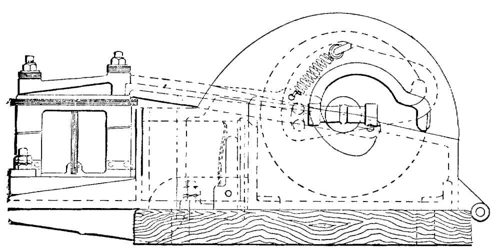

Fig. 4. B

cylinder shaft. When this switch is placed in the middle of the car, the amount of car wiring is materially lessened and the car inspection made more easy.

With reference to controlling switches in general, it is evident that a great number of designs may be prepared that will give approximately the same electrical results in point of efficiency. In deciding then upon the merits of a new design of switch, the commercial factor relating to repairs has therefore to be very largely considered, and had designers been able to guide their work more closely from the balance sheets of railroad companies, when such had been properly kept, instead of conforming to popular notions, very much more progress would have been made in this line during the last few years.

In closing this paper it might be well that I should remark that my experience has been largely confined to what is known as the commutated field method of control, and that I have naturally expressed many of the qualities of other methods in terms of this method. If these expressions are not judged satisfactory, I leave it for those who have had a similar experience with other systems to express in their criticisms the qualities of the commutated field system in their own terms.

Discussion.

The Chairman [Vice-President Lockwood]:—It is to be regretted that the author of the paper is not present this evening, as he might very likely have been able to add very largely to the interest which its perusal no doubt inspires. This paper, as you will have observed, is of the most intensely practical type, and I may say also rather paradoxically perhaps, that its brevity is something of an improvement in length on some of the best which have been before us—even those of the most classic and able character which we have had. From experience I can myself say that it is much easier to write a long paper than a short one, and it seems to me that Mr. Parshall is greatly to be commended for the terseness and shortness of his paper and especially in that he has left a reasonable time for a fair discussion of the points he has enumerated. When we recollect that it is hardly four years since our first paper on electric street railways was brought out, and hardly five since the first papers on the electrical transmission of power were placed before us, I consider it most remarkable that this paper is as practical, as definite, and as positive as it is. These, indeed, are its most prominent characteristics. We should note especially, I think, the exact tone of every statement made and the sharp transition in this respect between it and some of the earlier papers which we had upon the subject, which necessarily dwelt upon the phenomena concerned from a general point of view, and as necessarily contained generalizations, some of which experience has proved to be without foundation in fact. The paper of itself merits a full and free discussion, and although we are, as I have intimated, deprived of the opportunity to put questions to the author, yet I conceive that every point which is necessary and useful will be fully elicited.

While the paper itself and the diagrams accompanying it modestly style themselves, virtually a "Parshall" paper and "Parshall diagrams," we cannot fail to observe that both the paper and the diagrams are very complete. The subject is now open for the discussion of the Institute.

While it is possible that street railroads may not be a subject with which many of us are conversant, yet I may suggest that the fullest and freest discussion is always in order, and that it is not perhaps necessary for us to confine ourselves to street railroads—that the matter deals with motors and that we should be glad to hear from any one who can instruct us, or even entertain us, upon the subject.

Mr. Chas. Hewitt: — In order to start the discussion, I would call attention to the statement on the last part of the second page and top of the third page, not so much with the idea of disputing what is said as because it seems to me slightly misleading. It says: "With a given electromotive force acting on the armature circuit and a given torque developed by the armature per ampere, it does not matter,so far as efficiency is concerned, whether the difference in electromotive force at the armature terminals and the line is due to drop in external resistance, or to drop in the magnets." When I first read that, it certainly gave me the impression that Mr. Parshall was saying that there was no difference in efficiency whether we regulated our motors by commutated fields or whether we used an external resistance. But in reading it more closely, I notice that he does not say that exactly, but that seems to me to be a question which is certainly open to debate and a very interesting point to discuss. Is it possible to operate two cars, say in the same city or under the same conditions—I mean to get the same results from the car as far as the railway company is concerned—in one case by commutating the fields and in the other case by using a rheostat or any external resistance. My experience has been mostly with the commutated fields, but at the same time I have had the privilege of examining a good many cars using the external rheostat, and in every case, whether a double reduction motor or a single reduction motor or a gearless motor is used it takes more watts to accomplish the same result with a car using an external resistance than with a car which uses simply the commutated fields. Whether that is inherent in the method, I am not prepared to say, but I merely state that as a fact, and I would like to throw that out as a matter for discussion—as to whether in the opinion of the members here it is possible to build motors —no matter what the ratio of reduction is—that they may be operated with a rheostat with the same efficiency as with the commutated fields. Mechanically there is much to be said in favor of the rheostat, but electrically there is much to be said against it, so far as we have seen.

Another point that I would also like to draw out in discussion is the apparent loss of efficiency in the departure from the old double reduction motors. Every departure which has been made from the high efficiency double reduction motors—for instance, from the No. 6 motor which Mr. Parshall refers to—if we start with that, every type of motor which has been made since then has been a step backward, so far as efficiency is concerned, until we get to the gearless motor, which I believe takes the most energy of all to accomplish the same result. The single reduction motor comes in between, and the high speed motors are the most efficient of all. Now is this lack of efficiency inherent in the motors or not? Will it be possible in the future to build single reduction or gearless motors which will be as efficient as the double reduction motors? I think these two points might make an interesting discussion.

MR. TOWNSEND WOLCOTT:—In regard to Mr. Parshall's statement here, it seems to me very plain that he means simply you can design a motor so that the resistance will be in the coils themselves. A certain number of volts has got to be wasted, whether inside the magnet or outside. It is possible to design a motor so that you would not use any outside resistance at all, but it does not follow that it will be any more efficient. There are plenty of stationary motors on the market running on incandescent circuits—small sizes—that have such high armature resistance that you can turn on the current without any rheostat whatever. But the efficiency of motors of course is low when it gets up to its normal speed. It is not possible to run a motor from the constant potential circuit and put the current with full voltage right on to the armature when the armature is standing still. Of course you get burn-outs, unless the resistance is enormously high. But even if the armature was made with such resistance that is would start without burning out, the efficiency would be the same, as though that was an external resistance while it was running at that speed, which would require such resistance in the rheostat.

In regard to the efficiency of double, single reduction and gearless motors, as I understand it, the efficiency measured at the car wheel does not show the discrepancy the gentleman spoke of. Of course the power delivering at the end of the motor shaft would be greater and the efficiency would be greater on a high speed motor, but when we consider all the gear friction, as far as I have been able to ascertain, the efficiency is not so greatly different. In fact the gearless motor people claim that they run with the highest efficiency in some cases, which they do not claim for all work, but under certain conditions they claim to run with as good an efficiency as with double reduction motors.

MR. CHAS. P. STEINMETZ:—If we wish to speak about the efficiency of motors, we should decide first what we mean by this term, for although electrical engineering has very exact methods of determination, there are so many meanings for efficiency that the term usually means nothing. The one measures the resistance of the motor, and finds say one ohm. With 15 amperes current this means a loss of 15 volts, or three per cent. at 500 volts line potential. Then he begins to say what a beautiful motor he has of 97 per cent. efficiency. But he does not take into account that he loses perhaps 20 per cent. by hysteresis and Foucault current, loses 10 per cent. by friction in the bearings, and wastes 30 per cent. besides by grinding the gears to dust, and gets then only a mere nothing to the wheel axle. Another one desires to proceed more correctly, and measures the "mechanical efficiency" of the motor. That is, he applies a brake to the armature shaft, measures the electric power sent into the motor, and the mechanical power taken off from the motor shaft, and finds 87 per cent. "a very good motor." Whether in practical service under the strain of the gear thrust, the friction is the same, and how much he loses in the high speed gearing; nobody knows.

I have no exact data of the losses in the high speed gears of the street car motors used here; I remember only one data on an English system of geared street car motors, very carefully cut zig-zag gears, which certainly do not waste much more power than the usual spur gears; there the loss amounted to about 40 per cent. In the data given on the efficiency of street car motors this loss is generally *not* included. And especially street car gears must be very wasteful, not only because of the rough usage they are exposed to when going through rain and dirt or over dusty roads, but from the fact, that the transmission of power by gearing is at its best only when the height of the gear teeth is negligibly small compared with the radius of the gear. But in this high speed gearing the pinion must necessarily be small, and then the height of the teeth is very perceptible compared with the radius of the pinion.

In this case the gearing does not transmit with a fixed, but with a varying ratio; the teeth touch each other first with their heads, slide over each other and come out of impact when touching each other with their feet. That means, that the ratio of transmission for each tooth which passes another, varies between the ratio of the maximum, and the ratio of minimum radii of impact.

Suppose the pinion has 16 teeth, the motor revolves with 1,200 revolutions. Then 19,200 times per minute the leverage of the transmission goes up and down. Either the speed must vary, fluctuate as often—which is out of the question because of the momentum—or as many times per minute the gears come out of impact and in again, alternately the one or the other leading. Every time they come in impact again—19,200 times per minute—it gives a blow against the teeth. This is what causes the rattling and hissing noise of high speed gearings, and their rapid destruction.

That the loss of energy in the gearing is considerable, we can see without any tests, if we consider in what very quick time steel and phosphor-bronze pinions are ground to dust and raw-hide gears torn to fibres. For the law of conservation of energy teaches us that where a display of energy takes place, a corresponding consumption of energy exists, and if such a tremendous energy is set free as to grind steel and bronze to dust, and to chop raw-hide pinions rapidly to fibres, the consumption of energy must be correspondingly large, and the only source of energy is the motor. With regard to gearless motors, I have seen a number of test curves of such a motor, which showed an efficiency of 80 per cent., and considering the absence of the loss of energy in the gearing, I really cannot see, how the double geared motor can possibly be more efficient.

MR. THORBURN REID :—The practical street car man has an exceedingly simple method of getting the efficiency of the street car motor. He does not bother his head very much about the resistance of either the armature or the field. He does not know how much friction there is in the gear, but he runs his car and he sees how much current it takes to drive and how many volts E. M. F. there are on the terminals. He multiplies the two together and gets the number of watts to drive his car on the road. He gets another car and tries that and sees that the one that takes the smallest number of watts has the best efficiency. That is all that is necessary for his purpose, and I think that for our purposes that is all that is necessary. If a motor draws a car with the least amount of energy, that is the best motor we can get for the work. Mr. Hewitt told us that the double reduction motor appeared to be the most efficient, the single reduction the next, and the gearless motor the least efficient. I suppose that he means by that just what the practical street car man would mean—that it takes the most current to drive a gearless motor, less for a single reduction and less for a double reduction. If I remember Mr. Short's paper, read, I have forgotten where now, he gave three curves, as I remember it, for efficiency of street car motors in which he put the gearless motor as using the smallest amount of energy of the three, the single reduction motor next and the double reduction motor as using the most. That is my recollection of it and I won't be certain that I am right. I would like to know really which motor is the most efficient of the three as a practical street car man looks at it.

THE CHAIRMAN :—In justice to Mr. Parshall, I perhaps should show this plate and read a note which he has sent about it which has only recently been received. I do not know whether you can see it, but at all events it will be printed in the proceedings :

"The three curves in Figure 5, are for single reduction motors with commutated fields. No. 1 is for a 25 H. P., No. 2 for a 15 H. P., and No. 3 for a 20 H. P. motor. The pull at the car wheel for the more important points is given, since without this such curves of efficiency and horse power of street car motors are of but very little value. It may be well to state that it has been found possible to increase the limits of the high efficiency part of the curve by modifying the construction of the armature core so as to diminish the losses by hysteresis and Foucault currents."

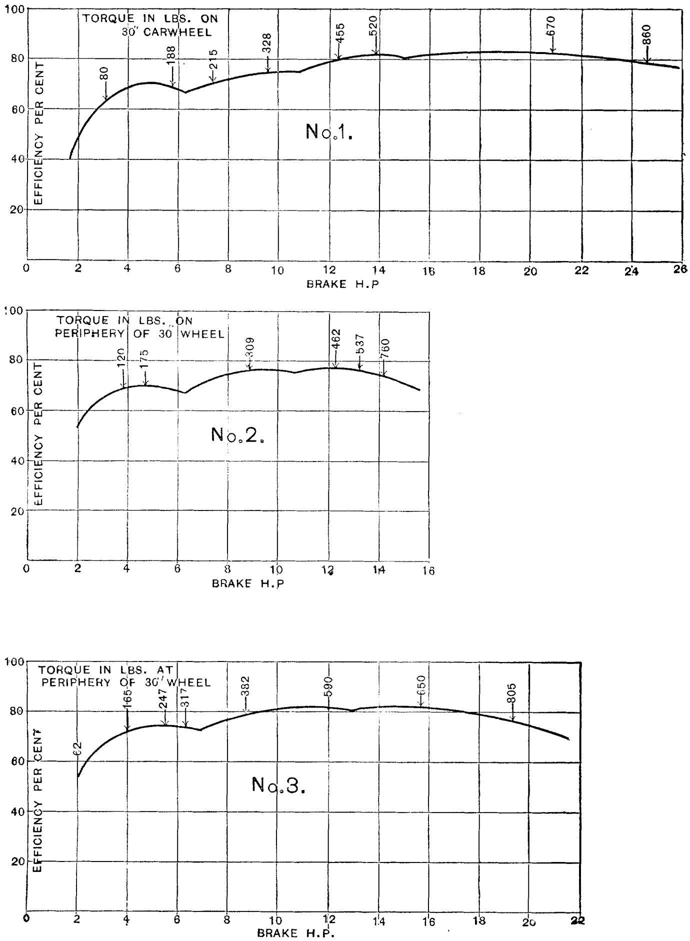

Fig. 5.

MR. HEWITT:—I think the paper Mr. Reid referred to was read by Mr. Short before the Chicago Electric Club and the portion of the paper that misled Mr. Reid and perhaps others is the fact that Mr. Short started with his double reduction motor, whose maximum efficiency is no higher than the maximum efficiency of his gearless, viz.: 70 per cent. He first tested the motor without gears. He then put on a single reduction of gears and tested again. Of course he got a lower efficiency.

Then he put on another reduction and tested again and of course he got a lower efficiency still. Now we all know that every reduction in gears gives a loss in power. The misleading portion is that he uses a motor of very low maximum efficiency. A well designed double reduction motor with commutated fields starts off with an average efficiency of 85 per cent. and a maximum efficiency of 88 per cent. to 90 per cent. Allowing 15 per cent. loss in gears as shown by Mr. Short we get an *average* efficiency at the car axle of 70 per cent, which is as high as the *maximum* efficiency of Mr. Short's gearless motor. We can discuss here theoretical efficiencies of motors, but so far as the street railway is concerned, the commercial efficiency is the only one to be considered. Any road which is worthy of the name of an electric road has definite routes and puts cars on those routes to run on schedule time. It will not let its motormen race or run ahead of time or behind time. So that no matter what system a car belongs to, it has given to it a certain service and it is the car which does that service with the least expenditure of energy (repairs being equal) which is the most efficient to the railroad company. Crosby and Bell in their recent book show that the coal consumption is comparatively a small part of the operating expenses of a road, but there is another point which is not stated, I believe, in connection with this extra energy required to drive the single reduction and the gearless motor, and that is the vastly larger power plant required to be operated. I know very well that with the No. 6 motor on an average road we could easily run twelve cars with a 100 kilo-watt dynamo, whereas with single reduction motors we can run only 8 and with some motors only 5 or 6 cars Now it makes a great difference whether you have got to install two 100 kilo-dynamos to do a certain duty or one. It is not only the actual cost of the coal pile and the actual cost of attendance but it is the increased cost of the plant. Power plants have got to be built of almost double the size now, that they were two years ago with the No. 6 motor. That, I think is a serious item and one which designers of apparatus ought to consider and one which I think the railway companies will consider seriously before very long A prominent engineer of a railroad syndicate told me, after testing thirty-five roads, that they actually could not afford to build the stations to provide current for the motors now made.

MR. WOLCOTT:—In regard to the power consumed by gear, Mr. Hewitt correctly stated Mr. Short's method But, as I remember, the Franklin Institute made some tests some years ago with refereence to the efficiency of gearing The best possible spur gear gave 90 per cent —this is a laboratory test. With two reductions, that is 81 per cent. Now if the motor has 85 per cent. efficiency as Mr. Hewitt mentions, that gives us 68.85 per cent.—call it 69 per cent. efficiency, and the gearless motor started with about the same—about 70 per cent.

Mr. Hewitt:—That was the highest efficiency, not the average. The double reduction motor will average about 85 per cent.

Mr. Wolcott:—Now the chief difficulty with the gearless motor, to my mind, is a mechanical one. I have not seen any gearless motor that suits me all around for mechanical reasons. The Short motor drives cars with a sort of a lathe dog arrangement. It always seemed to me that there would be considerable loss on that. Some of the motors drive with side-rods like a locomotive. Of course one difficulty in putting an armature right on the shaft is the trouble of getting it out in case anything is the matter with it. With side-rods you have got to have a truck much more rigid. One of the greatest improvements of street cars of late years is what is called flexible gearing. Four wheels are always resting on the track. If you connect up with side-rods, it is all right on the straight track; but when you come to curves I think you will find there is a great deal of the power wasted in that way. It does not seem to me so much an electrical problem as a mechanical problem.

Mr. Hewitt:—I beg to differ from the gentleman on that very last statement. If you will notice the curve published by Mr. Short, you will see that it falls off very gradually, so that the average efficiency in the gearless motor is very low—somewhere about 45 per cent. We can get with the double reduction an efficiency of 60 to 70 per cent. for the whole car equipment. With the gearless we go down to 45 or 50 per cent.

Mr. Steinmetz:—I have not read Mr. Short's paper, but I am of the feeling that the gearless motor which gives an average efficiency of 35 per cent as stated must be a very poor motor. I know that the average efficiency of a well-designed gearless motor can be brought to as high as 75 per cent. Tests made by an independent railroad company on such a gearless motor showed that the highest efficiency reached is a little over 80 per cent., and compared with other single reduction motors what struck me as most remarkable was that the efficiency curve was just very flat and over a wide range beyond 70 per cent.[1] But I think that this falling off of the efficiency curve in the geared motor is due more to some defect in the design of the motor and is not essential in the principle of double reduction or single reduction or gearless motor. But 35 per cent. efficiency—that is a very poor motor, no question about that, and entirely drops out of consideration. Then there was another point. What was the objection against the transmission of the power by connecting rods?

Mr. Wolcott:—Requiring the truck to be less flexible. In the modern street car gear the two axles can move.

Mr. Steinmetz:—Yes, but in the gearless motor with connecting rods they can move just as well, or even more freely.

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1. See correspondence, p. 166, for diagram showing these curves.

MR WOLCOTT:—The best street car gears have several improvements. They will move to and from each other. That certainly cannot take place with side-bars and they can be twisted.

MR. STEINMETZ: —Locomotives have been built in that manner so that there is no mechanical hindrance to be provided for, and it has not been found necessary in practice.

MR. WOLCOTT: —It seems to me that even that would interfere somewhat with the flexibility of the arrangement. You certainly would require the dissipation of some energy there.

MR. STEINMETZ: —I cannot see that. Suppose the motor to be rigidly connected with the car body, but resting together with the car body on springs. Then the motor shaft can go up and down and oscillate freely with the car body, while the wheel axles can twist and come out of parallelism with each other and with the motor shaft just as they like, or rather as the condition of track and car causes it, without interfering with the action of the connecting rods, hence without dissipation of energy, all three axles moving in parallel vertical planes.

MR. WOLCOTT: —If the motor shaft and the car axle are in parallel plane how can they move out of parallel?

MR. STEINMETZ:—Motor shaft and car axle can take any inclined position against each other, and nevertheless remain in parallel vertical planes, moving up and down and twisting with regard to each other. The fact is, there is no dissipation of energy, because there is no wearing out, for after a year's continuous and daily running I found a pair of such connecting rods not worn at all. Besides, it is exactly the same method of transmitting the power, to which steam railroading has been led by 70 years practical experience.

MR. HEWITT:—I would like to ask Mr. Steinmetz if the test he refers to was made on a car in actual service and whether that car was operated by a rheostat. I feel confident in saying that if we can furnish gearless motors that will operate with an *average* efficiency of 75 per cent. in actual practice, there never will be another geared motor sold. I think there is another point in Mr. Parshall's paper here which gives an inkling of the cause of this low efficiency. At the top of the second page he says: "The average H. P. exerted by a street car motor at the car wheel probably does not exceed 20 per cent. of the maximum it is expected to do in starting the car under the various conditions encountered." I am prepared to say that that is rather overstating than understating the fact If we examine the dynamo curve, a good dynamo will give a high efficiency from half load to full load, but when it gets below half load it drops very suddenly. The trouble in street car work is to get a high efficiency under average conditions.

MR. STEINMETZ:—The tests were made by the West End Street Railway company in Boston and the motor was working with a commutated field—not with a rheostat—the gearless motor that I referred to.

Mr. Chas. G. Curtis :—I am rather surprised to hear those who have evidently had a good deal of experience with railway motors express themselves so strongly against gearless motors. There seems to be an idea that it is impossible even by the use of enough copper and iron, without reference to the weight of the machine, to accomplish the same result at a slow speed that is accomplished at a high speed. Now why should not a gearless motor, which revolves at one-tenth of the speed of the old style double reduction machine, be made to give the same power as the double reduction machine, provided enough copper and iron is put into it, provided the cross-section of the iron is increased and provided the number of turns of the armature is sufficiently increased? Now I know of a gearless motor which was operated for several months, and tested by some experts who were not interested in any way and who found by comparison that it took 16 amperes to make 18 miles an hour, while one of the regular Thomson-Houston cars required 28 amperes to make 17 miles an hour. The Thomson-Houston car was one that had been in use about six weeks without any renewal of the gear and therefore the gears were probably more than half worn out. Then the test was made with another car where the gears had been used about two weeks and it was found that the car required about 25 amperes. Some Stevens Institute young men made some tests on the same road—a long series of tests—and they found that the cars required about 26 amperes on an average, while this car that I speak of that was operated by a gearless motor ran along invariably with as low as 16 or 17 amperes and the average of a long series of tests made it 16 amperes as against 28; which is a saving of about 40 per cent I do not see any reason why it should not be so, and when the characteristics of the machine are known, it is perfectly evident that it must be so. It is simply a question of having enough iron and enough turns on the armature. Now the increased turns on the armature would result in an increased resistance were it not for the fact that a larger wire is used. The same is true of the field. But it must be remembered that with the old double reduction machine the field required a good many ampere turns to bring it up to saturation, and in the new machines such as those made by the Thomson-Houston company to-day the ampere turns are less. The resistance of this machine was about $2\frac{1}{10}$ ohms and my impression is that the resistance of the Thomson-Houston double reduction machine is about two ohms. I know that the armature is half an ohm. I think there are about 40 lbs. of No. 12 wire on each of the field spools and that I figure is about two ohms. The weight of this machine was 2.400 pounds, and the armature had no objectionable heating at 22 H. P. We never ran it 22 H. P. running a car alone, but we dragged trailers with it and tried it up grades and it would stand 22 H. P. easily enough. Probably 300 or 400 pounds could be knocked off that weight by a judicious re-arrangement of the metal. As I say the diminution in efficiency is purely a question of increasing resistance. All the other factors must be better in the gearless motor than in the geared motor. Hysteresis and Foucault currents, which are the only other losses that amount to anything are reduced by the diminution of the speed and in direction proportion to the reduced speed, except for the fact that the number of poles is increased. In regard to the difficulty of communicating the rotation of the armature to the wheels which Mr. Wolcott speaks of, we did not notice any difficulty of that kind at all. On the other hand we rather smiled at the perfection with which the mechanical part of it worked. The power was transmitted by a face plate carrying flat pins and those pins stood between rubber cushions and the torque of the motor operated to compress one set of cushions, or the other set, according to which way it was going. Of course when the two pins were in a vertical position, if you should pass over a rut in the track the motor would descend and the face plate with its pins of course would slide down between the cushions—probably never exceeding half an inch. The cushions had cast-iron caps which protected their ends and after their motor had been in use several weeks there appeared some wear on those caps Of course any question as to loss of efficiency was disposed of by the speed and by the amperes and volts. As Prof. Short was saying in his last paper, the efficiency of gearing seems to increase enormously with the speed. That is shown in the peculiar phenomenon which takes place in the Thomson-Houston double geared cars. They operate their cars on what they call a loop. In order to get the maximum speed they throw out some of the field winding. Now when they do that, it is done with one throw, that is to say there is only one section of the field that is thrown out. The power comes on suddenly and the car jumps ahead, but there seems to be very little difference in the speed whether there are trailers on or not. In other words the gearing seems to be the limited element. Beyond a certain limit the gearing consumes an enormous amount of power. Below that speed it consumes about 30 per cent. My experience is that those gears, with the usual amount of dirt will consume 30 to 40 per cent. at a speed not over 15 miles an hour I have seen two 15 H. P. Thomson-Houston motors with passengers hanging on to the steps and making within two miles an hour of the same speed that it would make with no trailing cars on and no passengers in. I should think there was a difference of two miles an hour out of 17. My experience is that the main difficulty with the whole problem is to get a mode of running at a slow speed or a half speed which is reasonably efficient and at the same time be enabled to run at full speed. The only method which has been devised which is at all practical is that pursued by the Thomson-Houston company which I have referred to which consists in cutting out some of the field winding and diminishing the strength of the field. But that is open to the objection that you cannot carry it beyond a certain point, because you get self-induction in the armature. I should like to ask some gentleman here whether the new Thomson-Houston waterproof motor, as it is called which has a slotted armature, is operated in that way with a divided field coil or "loop," as they call it. If it is, I should think that the comparative strength of the loop must be very little because otherwise they would have sparking at the commutator.

MR. HEWITT:—The last gentleman seemed to infer that I was arguing against the gearless motor *per se*, which is not the case. I merely tried to bring out facts as they actually exist on roads as they are running. I spoke of the gearless motor as shown in Mr. Short's paper because it is to be inferred that he has choson a fair example to illustrate that paper, and he shows an average consumption of 24.5 amperes including zero readings. It is very misleading for us to compare the consumption of amperes alone, because of the variation in electromotive force. The last gentleman said he tested one motor with something like 16 amperes, another one 25 amperes; but the difference in electromotive force may be very great. With 16 amperes you may have 500 volts; with the 28 amperes you may have 320 volts. The watts are the same in each case. The only safe comparison we can make is the actual watts which the car consumes in doing its work. Mr. Short's paper shows that the motor he refers to gives an average consumption of 13.8 electrical horse power. That is an actual test and I know of no other gearless motors in actual street railroad practice that have done any better. I do not think anybody is prepared to say that the Westinghouse motors have exceeded that in economy. In fact, at Pittsburg I am told that they have shown a much larger consumption of power. I do not know what motor the gentlemen are referring to; therefore I cannot speak intelligently about the test he refers to, but certainly no published tests show the efficiency he speaks of. If he has a motor that will show that efficiency in actual operation it is as good as any single reduction motor on the market. But even at that figure, it cannot compare with the efficiency of the double reduction motor.

MR. C. G. CURTIS:—I only meant to speak of this motor as a matter of general interest, not as a result that has been accomplished, which is remarkable, or anything of that kind. When I spoke of the amperes required, a comparison of 16 to 28, I of course took into consideration the volts. I mean that there was not enough difference in the volts to affect that One was 480 and the other 465 or nearly 470, so that it made a difference of about $2\frac{1}{2}$ per cent., whereas the total difference in the amperes was 43 per cent., I think, so that the net result was about 40 per cent. gain.

As regards Prof. Short's gearless motor I was not speaking of it in comparison with that, nor do I see why the question should be judged scientifically by a consideration of any particular motor. From the theoretical point of view there is no reason why the gearless motor should not be just as efficient as any other kind of motor provided you can get on enough copper to make the resistance as low. Now if Prof. Short's motor is as inefficient as he says, it may be due to bad construction of the armature which results in very high Foucault currents. But it is more likely due to too high resistance. He has got a large amount of wire on the field and a large amount of wire on the armature and those two things combined make a considerable loss. But even then I do not see why he should get such a loss as he states. It takes an immense resistance there to make a very much greater resistance than they have in the old style machines. It must be borne in mind that in this new machine the field which consumes more energy than the armature due to its resistance is very much reduced. The field in the new Thomson-Houston machine is operated with one coil. This coil has a cross-section which is about square, and the machine weighs 2,300 pounds. I saw one the other day in operation in Pittsburg. The superintendent told me he had it operating a snow-plow with over 100 amperes on the two motors steadily and there was no injurious heating, and he was under the impression that he had had it operating as high as 130 amperes for over an hour. That of course is an enormous current for the 25 H. P. machines. But as I say, by adopting the slotted form of armature which reduces the resistance of the magnetic circuit, they have succeeded in reducing the amount of ampere turns on the field, so that they can get along with much less resistance. If there is any other cause of efficiency in a motor, I should like to hear it mentioned. Certainly the loss from friction on the bearing is not worth speaking of. A gearless motor has an advantage in that respect over any other form of motor for the simple reason that the torque is transmitted to the wheels symmetrically with respect to the axle. There is no thrust tending to throw the armature shaft out of its position Whereas in the ordinary geared motor there is a tremendous thrust. But even with that thrust the friction is so little with the oil bearing that it is hardly worth speaking of.

Another point, where you have a hollow shaft which necessitates a shaft probably from 5 to 6 inches in diameter, it makes a very large bearing and the distance that the bearing surface travels is very great compared with the ordinary bearing. But when you come to compare it you find the ratio is about two to one in diameter. Now your speed has come down to one-tenth, so you are five times as well off as you were before. It is only a question of keeping the bearing oiled. That can no doubt be accomplished by using a saddle bearing brass such as that in an ordinary car-box. I do not suppose the loss due to friction on the bearings is 1 per cent. There is no reason why that the resistance should not be reduced to a sufficiently low point. It is simply a question of copper. In this machine No. 10 wire was used instead of No. 12. No. 10 is pretty nearly twice the cross-section of No. 12, and the turns were about $2\frac{1}{2}$ times as many. The consequence was that the resistance of this armature was about $1\frac{1}{2}$ times that of the old Thomson-Houston machine. But the Thomson-Houston is very low indeed; it is one-half an ohm, and that is one reason why the Thomson-Houston machine has been so successful. It has got a margin there. I have seen two of those 15 H P. Thomson-Houston machines drag 3 trail cars and do it hour in and hour out in summer with the thermometer up to 90, at a speed of 16 miles an hour, and that is half again as good as any other kind of motor I have seen working on a car.

MR. CHARLES P. STEINMETZ:—I cannot see that the resistance of a gearless motor must be any larger than that of a high speed motor. For a slight increase in the size of the armature wire easily brings the armature resistance down. For instance the gearless motor I referred to, had an armature resistance of $\frac{3}{4}$ ohm, using wire No. 9 B & S gauge. The field was commutated, and, when in parallel, had a little less than $\frac{1}{2}$ ohm resistance, giving a total motor resistance of somewhat less than $1\frac{1}{4}$ ohms. The Foucault currents in the armature amounted to some 20 watts. Hysteresis was considerably larger because of the high magnetization used, and reached a maximum of 124 watts. The loss by the resistance of the motor depends upon the current and can easily be calculated by the figures given above.

The system I referred to was the Eickemeyer-Field system, as used in Toledo, Lynchburg, Yonkers, etc.

In Toledo they had these gearless motors, and double reduction motors running at the same time, on the Consolidated Electric Railway Company, and there the station superintendent found that if he ran only gearless motors he consumed less coal under the boiler of the steam engine than when he ran double reduction motors.

THE CHAIRMAN:—Were not the motors that you referred to that were tried at Toledo, those in which it is said that the inside helix excites the armature direct instead of being excited by the field magnet polarity?

MR STEINMETZ:—Yes, sir. The magnetizing helix directly and closely surrounds the armature and consequently there is not only no magnetic leakage, but the length of the magnetic circuit the least possible. In consequence thereof with a given weight of material, the cross-section of the magnetic circuit and therefore the magnetization can be as much higher. For instance the motor I referred to, with the field fully excited, drives 24 million lines of magnetic force through the armature. Besides, if the field coil surrounds the armature, the height of the whole motor is very little more than the diameter of the armature.

This has the advantage again, that the lowest part of the motor is still $4\frac{1}{2}$ inches above the ground, and nevertheless only 26 inch car wheels—the ordinary horse car wheel size—is used.

MR. C. G. CURTIS :—What speed do you run at?

MR. STEINMETZ :—Well, the lowest speed is about six to seven miles; that is with commutated fields.

MR. CURTIS :—What speed was this loss of a hundred and some odd watts?

MR. STEINMETZ :—I did not measure it for a certain speed, but I followed it over the whole range of speeds; this loss by Foucault currents and by hysteresis depends upon the speed, decreasing for slow speed because of the smaller number of reversals, and decreasing for high speed also, because of the decreasing magnetization. The figures I gave correspond to that speed, where the loss is maximum. Indeed, it can never be $24+124=148$ watts, because the maximum of Foucault current does not take place at the same speed as that of the hysteresis loss, the one varying directly proportional to speed and to the 1.6th power of the magnetization, the other following the square law.

MR. HEWITT :—What Mr. Steinmetz said and what the Chairman said about the magnetization of the armature on the Eickemeyer motor is true also in large measure of the Edison motor and the Thomson-Houston motor. The field coils overlap the armature and form the pole piece, but still they are not as efficient as the double reduction motors. I do not pretend to deny that the gearless motor can be made as efficient as any other motor, provided we have unlimited space and can put unlimited iron and unlimited copper in it. On a street car we have got a limited space and we have to conform to that space and that is the reason why perhaps more iron and more copper are not used. Another thing if we use more iron and more copper we would have a more expensive machine. That is another very serious point Mr. Short's motor I believe runs about three inches from the ground, two or three inches; I am speaking from memory and am not positive. But we certainly should not run a motor nearer than three inches to the ground because we are liable to strike something—a loose paving stone or piece of iron. Three inches is complained of by railway companies. And when we start with 30 inch wheels or even 36 inch wheels we have very little space, but when we come to locomotives for high speed, 100 or 120 miles an hour and can use 40 inch wheels and larger, we have all the space needed. It seems to me that so far as street railways are concerned we have reached our limit with the single reduction motor and with them I would like to see a better efficiency than we are now getting.

PROF. F. B. CROCKER :—This question of the relative efficiency of single and double reduction gear motors is really a question of the relative efficiency of motors at different speeds, and is an old problem. Take a given motor; of course the lower the speed the less the losses are. I have made a list of them—Foucault currents, hysteresis, friction and air resistance are all reduced at lower speeds. The only losses that are increased are the C^2 R effects; that is the heat due to the electrical resistance. There seems to be a great confusion as to whether we can run a motor at slow speed and get a reasonable efficiency. Now as I say the only losses that are increased at low speeds, other things being equal, are the resistance losses and as Mr. Curtis says it does not require any great increase in the size of the wire to make up for this. For instance, No. 12 wire increased to No. 10. A machine wound with a No. 10 wire does not occupy much more space than one wound with No. 12 and that yet makes enough difference to materially reduce the resistance, and in the case Mr. Curtis spoke of it almost made up for the increased length of wire. The facts that the Foucault currents and hysteresis are materially reduced at low speed is quite a saving. Another point Mr. Curtis spoke of—the reduction in the thrust on the bearings in gearless motors—is also quite important. Unfortunately, as Mr. Hewitt says, we have to have some means of allowing the car to go at slow speed. We are supplied with 500 volts whether we are running at fast or slow speed. Therefore we have to introduce external resistance or resort to some peculiar method of overcoming this difficulty. But the single reduction gear or double reduction gear motors when standing still or running at low speed, require practically the same resistance in series as gearless motors. It would be simply a question whether the rheostat had 20 ohms or 22 ohms. In other words the rheostat would actually require a little more resistance in the case of high speed motors on account of these motors having a little less resistance than low speed ones. Any motor running at less than its *normal* speed whether that be high or low requires regulation which probably reduces its efficiency. But a motor can be designed to run at 200 revolutions almost as well as at a thousand. I agree with the remark of Mr. Steinmetz that the man who cannot design a motor of better than 35 per cent. efficiency had better not try to apply it to street car work. Any one can design a motor to run with better efficiency than that—at any reasonable speed.

The Chairman:—We have a very good illustration of the solution of the question: What will happen when an irresistible force meets an immovable body? I have not any doubt that the irresistible force would keep on backing and obtaining new and fresh headway and that the immovable body would remain immovable. I think therefore that as the evening is far advanced we should let Professor Crocker's remarks stand as the last word of science this evening, and unless there is a strongly evidenced desire for a debate a motion to adjourn will be in order.

[Adjourned.]

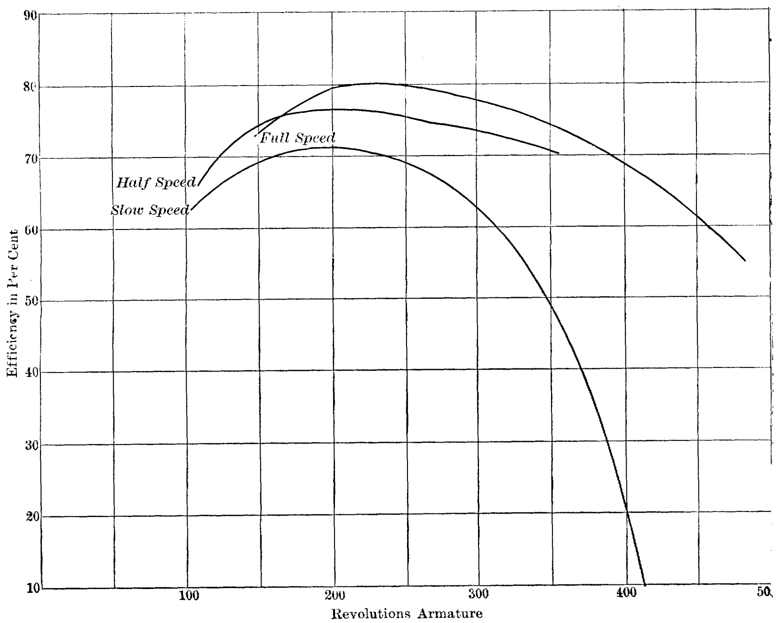
Prof. Dugald C. Jackson:—[Communicated.] The able paper by Mr. Parshall on controlling street car motors is sufficient in itself to demand attention. Moreover, the whole subject of electric railway motors has been given too little careful attention, except by a small number of manufacturers and street railway managers. It is therefore to be hoped Mr. Parshall's lead will be followed by others equally competent. There is much in Mr. Parshall's paper that has been felt by careful designers and users of street car motors but that has not before been reduced to words, and Mr. Parshall deserves the thanks of all interested for laying views resulting from his wide experience before the Institute.

One side of the subject that is an eminently practical one to the street railway manager has not been touched by Mr. Parshall. As it often determines the receipts of the electric car, its demands upon methods of motor control are worthy of full discussion. In the smaller cities and towns and in suburban places it is possible to run street railway cars at a high rate of speed and with a considerable interval between them. These cars can be placed on wheels of large diameter (33 in. and 36 in.) without detriment to the traffic. The motors can, therefore, occupy considerable vertical space, armatures of large diameter can be used, and the magnets can have four poles. The development of this type of machine has apparently led to the controlling device described by Mr. Parshall. Such motors admit of placing a large number of turns of wire on the armature and of using each turn to its greatest advantage.

In some of our large cities quite different conditions exist. Speed is limited to a maximum not exceeding 10 to 15 miles per hour, and much of the traffic is carried for short distances; in other words, it is shopping or pleasure traffic. This demands cars on close headway and *easy of access*. The floors must not be raised far above the street level, and the motors must therefore take up little vertical space, hence requiring armatures of small diameter. This limits the number of turns of wire on the armature, makes the utility of four pole magnets doubtful, and requires the field turns to be increased. To do their work properly, such motors when mounted on 26 in. wheels should give satisfaction equal to that given by 15 H. P. or 20 H. P. motors of the latest types placed on 33 in. wheels. I think nearly all who have studied the matter will agree that the conditions here defined must be met in New York City and Chicago before the electric car can compete with the grip car. In many of the smaller cities now operating electric cars the same conditions are felt with greater or less force, and meeting the requirements means considerably increased traffic (receipts per car).

It is questionable whether it is not best to permanently connect the motor armatures in series with each other and with their fields for such work. The starting and speed regulation can be very satisfactorily effected by a rheostat, while it is possible to put the fields of the two motors in parallel for fastest speeds. Practically this method of connecting has been used with excellent success. It retains the principal advantages maintained for two motors on each car, *i. e.*, added traction and decreased chances of trouble due to lack of harmony between the motors, and introduces no unnecessary complications.

While the magnetic and parasitic armature losses should be reduced with special care in street railway motors, at the same time the electrical resistances of armatures and field should with equal care be made the least that is consistent with meeting other requirements. Reducing the energy used in the rheostat by increasing the losses in the fields is not likely to meet universal favor, as it merely transfers the seat of trouble to a point



more expensive to repair. Hence *rheostat* regulation, with or without auxiliary commutation of fields seems likely to prevail with the majority. With proper design, such as Mr. Parshall would give us, the auxiliary commutation of the fields may serve an excellent purpose in economizing weight of copper.

Mr. Chas. P Steinmetz [Communicated]:—To prove the statement I made in the discussion, with regard to the efficiency of the Eickemeyer-Field gearless street car motor, I give herewith a reproduction of the efficiency curves found in the tests made by the West End Street Railway Company in Boston.

In this 20-H. P. motor, the car wheels are 24 inches in diameter, and the distance from lowest part of the motor to the ground is 4 inches. The motor is one of the first of its class ever built.