AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, November 18th, 1896.

The 110th meeting of the INSTITUTE was held this date, at 12 West 31st Street, and was called to order by Vice-President Steinmetz at 8 P. M.

The Secretary announced the election of the following associate members by the Executive Committee at its meeting in the afternoon.

Name.	Address.	Endorsed by
HAMMER, EDWIN W.	Electrical Engineer, 46 Second Avenue, Newark, N. J.	W. J. Jenks. Chas. A. Terry. A. E. Kennelly.
HILL, H. P.	Engineer, Wendell and MacDuffie, 813 Havemeyer Bldg, N. Y. City; residence, Washington, D. C.	Max Osterberg. Edw. Caldwell. W. D. Weaver.
KNOX, GEO. W.	Electrical Engineer, Chicago City Railway Co., 2020 State Street, Chicago, Ill.	D. C. Jackson. C. F. Burgess. S. B. Fortenbaugh. B. J. Arnold.
MCCARTHY, E. D.	Electrical Engineer, The F. P. Little Electric Construction and Supply Co., 135 Seneca St.; residence, 451 14th Street, Buffalo, N. Y.	C. R. Huntley. Henry G. Stott. C. W. Ricker.
SCHWAB, MARTIN C.	1729 Madison Avenue, Baltimore, Md.	Louis Duncan. H. S. Hering. H. A. Rowland.
STRAUS, THEODORE.	Tester, General Electric Co., Schenectady, N. Y.; residence, 1213 Linden Avenue, Baltimore, Md.	C. P. Steinmetz. H. S. Hering. Ernst J. Berg.
VOSMAER, ALEXANDER.	Mechanical, Chemical and Electrical Engineer, The General Ozone and Electric Supply Co., Suerkade 104, The Hague, Holland.	H. Doijer. H. F. R. Hubrecht. R. W. Pope.
WALLACE, CHAS. F.	Engineer, Stone and Webster, Boston, Mass.; residence, 62 Forest Street, Roxbury, Boston, Mass.	A. M. Schoen. Chas. R. Cross. Russell Robb.
WHITING, ALLEN H.	Electrical Engineer, Riker Electric Motor Co., Brooklyn, N. Y.; residence, Stamford, Conn.	A. L. Riker. T. L. Proctor. W. L. Bliss.

WOODWARD, W. C.	Electrical Engineer, Narragansett Electric Lighting Co.: residence, 21 Arlington Avenue, Providence, R. I.	C. H. Herrick. C. D. Haskins. F. V. Henshaw.
WRIGHT, LOUIS S.	Manager, The Carbondale Traction Company, Carbondale, Penn.	S. G. Flagg, Jr. A. E. Kennelly. E. J. Houston.
YSLAS, CARLOS.	Electrician of Railways in Jalapa, Jalapa, Vera Cruz, Mexico.	C. C. Chesney. H. L. Fridenberg. Wm. Stanley.

Total 12.

TRANSFERRED FROM ASSOCIATE TO FULL MEMBERSHIP.

Approved by Board of Examiners, Oct. 14th, 1896.

NICHOLS, GEORGE P.	Partner, Geo. P. Nichols & Bro., Electrical Engineers and Contractors, Chicago, Ill.
FOSTER, SAMUEL L.	Electrical Engineer, Market Street Railway Co., San Francisco, Cal.
CUSHING, HARRY C., JR.	Electrical Inspector, Fire Underwriters' Tariff Association of New York, 32 Nassau St., New York City.
BALDWIN, BERT L.	Mechanical and Electrical Engineer, The Cincinnati Street Railway Co., Cincinnati, O.

Total 4.

The Vice-President announced that the evening would be devoted to the reading and discussion of a paper by Mr. H. Ward Leonard, entitled "Volts *vs.* Ohms." The apparatus described, had been installed upon the platform, and was shown in operation by the author, with the following preliminary remarks.

MR. LEONARD:—It may be well for me to show the operation of the apparatus. I will say in explanation that the apparatus was not manufactured for this special purpose, and that the motor generator is not exactly of the best form for this use. The windings of the two armature ends are not identical, and the field strengths are not the same. The result, therefore, is not quite as good in many ways as it would be if they were very much more nearly identical. There is quite a difference; the voltage is 70 on one and 120 on the other; but I would say that it was loaned by the Crocker-Wheeler Electric Company, and will answer the purpose sufficiently well to illustrate the performance, so I will show it as well as I can under the existing conditions.

If you will turn to Fig. 4 of the paper "Volts vs. Ohms," I will point out what we have here. I have marked upon the board of the machine here the letter S, which is the shunt-wound end of the transformer; and that marked R is the reversible end of the transformer; and the motor M is connected, as you see. This is the reversing rheostat in the field of the reversible machine, which you will notice is quite large relatively to the size of this particular machine. This apparatus would be no larger, however, if it were to handle 100 kilowatts instead of one: the dimensions being due to the number of contact buttons more than anything else.

I have here a voltmeter, which is connected across the terminals of M, the motor to be driven. I will first start up the shunt-wound motor, and when running at full speed I will now adjust the rheostat in such a way that the line volts of 125 will be opposed by the 125 volts of the armature of M.

When I close the armature circuit you will see there will be no change in the current flowing, and that by the adjustment of this rheostat I will be able to make the motor armature go from rest to full speed; and not only that, but I can make it go slowly in a backward direction, for the reason that the speed of these two machines must be always equal, and as soon as the voltage of R is higher than that of S, the current will be reversed in this loop 1, 2, 3, 4; and the voltage of R being higher than the voltage of the line, M must run in a reverse direction. You will notice that there will be no change in the current when I close the armature circuit, and there will be no effect upon the armature of the motor.

By manipulating this rheostat you can make it go in either direction. By turning in this direction (illustrating), the motor will run in the direction which is the reverse from its full speed direction. In this case the E. M. F. produced by the reversible machine is higher than that of the line. By this device I can run it backward, but if the motion is to be reversed so as to run backward at full speed, it is better to have a reversing switch upon the motor armature terminals which would be thrown at a time when there is no voltage at the terminals, and then you could go backward at full speed as the current through the armature would be reversed.

Now, there has been considerable talk as to whether or not any practical amount of energy could be restored to the line by this system, and I wish to show that this is done. This ampere meter showing the current from the line, reads both ways from zero. Now while running the motor at full speed in that direction, I instantly reverse the rheostat, thus. You noticed that when I did that, current was restored to the line. The armature reversed, and its retardation and acceleration in the opposite direction was accomplished by making the armature of M generate useful energy which is restored to the line.

A Paper presented at the 110th Meeting of the American Institute of Electrical Engineers, New York, Nov. 18th, 1896. Vice-President Steinmetz in the Chair.

VOLTS VS. OHMS.

SPEED REGULATION OF ELECTRIC MOTORS.

BY H. WARD LEONARD.

The control of the speed of an electric motor from a state of rest to that of full speed is a problem of rapidly growing importance to the electrical engineer. The operation by means of electric motors, of elevators, locomotives, printing presses, traveling cranes, turrets on men-of-war, pumps, ventilating fans, air compressors, horseless vehicles, and many other electric motor applications too numerous to mention in detail, all involve the desirability of operating an electric motor under perfect and economical control at any desired rate from rest to full speed.

The most commonly practiced method of controlling the speed of an electric motor for such applications at present, involves the use of ohmic resistance in the circuit of the motor armature, which resistance is varied to control the speed of the motor.

The use of an ohmic resistance for controlling the speed of an electric motor results necessarily in a waste of energy, and in an unstable control of the speed. The object of this paper is to endeavor to show the advantages arising from the use of a system of motor control having several modifications, but all of which involve the idea of controlling the speed of an electric motor by controlling the E.M.F. generated in its armature circuit, and without using any regulating resistances in that circuit.

I shall consider only the control of a single motor, that is, I shall not refer to the control of several mutually dependent motors by grouping in series and series parallel. I shall also limit the consideration to that of a continuous current motor.

Fig. 1 shows the first and simplest form of the E. M. F. system of motor speed control.

S is an engine or other source of power operating at a practically constant speed.

G is a generator.

M is the motor.

E is a circuit of constant E. M. F. which supplies current for exciting the fields of G and M.

It will be noticed that the fields of both G and M are independent of the E. M. F. and current of their armatures. The field of M is practically constant. The field of G is variable from full strength to zero strength by manipulation of the controlling rheostat C in the field circuit of G. It will also be noticed that there is no rheostat in either the field or armature circuit of the motor M which is to be controlled.

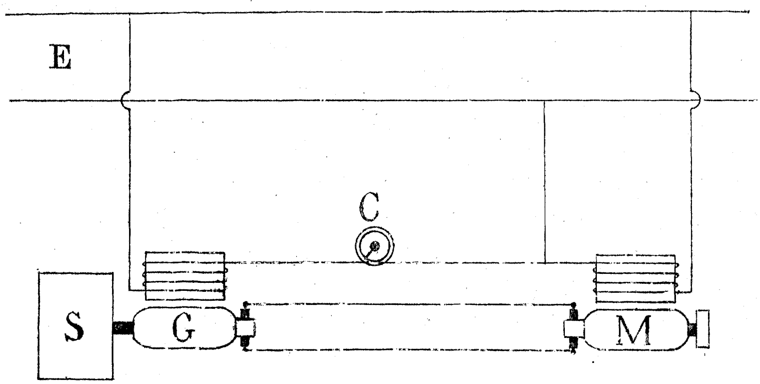

Fig. 1.

It will be evident that by varying the field strength of G we can vary the E. M. F. generated in the armature circuit from zero to the full working E. M. F.

In order to make definite comparisons, let us assume certain figures for the full E. M. F. and current of G. Suppose its full E. M. F. to be 250 volts, and its full working current to be 100 amperes. Also let us assume that the resistance of the armature of M is .05 ohms, giving a C^2R loss in that armature of 2 per cent. of its rated capacity, when the full working current is flowing. Let us assume that the full speed under full torque is 500 revolutions per minute. For the sake of simplicity and because it does not affect the practical accuracy of the deductions, let us neglect the slight losses due to Foucault currents, hysteresis, friction and the slight ohmic resistance of the rest of the armature circuit.

Suppose that our motor is to drive a large printing press, such, for example, as is used for printing calico, and that it is required of us that we shall drive the press at any desired rate from rest to full speed, and that we shall maintain any such intermediate speed practically constant even though the torque should vary from mere friction torque to the maximum torque of operation.

Let us suppose that the friction torque is represented by 10 amperes through the armature of M, and that the maximum torque of operation is represented by 100 amperes through the armature of M. We have now fixed all the conditions necessary, in order that we may determine the exact performance of the motor.

If, by manipulation of the controller C, we allow a slight and gradually increasing current to flow through the field of G, the E. M. F. at its brushes will gradually rise from zero upward, since the armature of G is being constantly driven at its full speed. When it is generating one volt at its brushes, a current will flow through the armature of G, due to one volt acting through .05 ohms, causing 20 amperes to flow through M. If the press be under full torque it will not start with this current. When we have five volts at brushes of G, we have 100 amperes through M, and the armature is just about to start; but since any motion of M would cause the development of a counter E. M. F. which would reduce the current below 100 amperes, it does not start as yet.

As soon as we raise the E. M. F. at brushes of G above five volts, the armature of M moves at a rate of speed sufficient to develop a counter E. M. F. of five volts less than at G.

Thus if we have six volts at G, the armature of M will move at a rate of speed sufficient to develop one volt counter E. M. F. and permitting the flow of the proper current for the necessary torque, that is 100 amperes.

I call attention to the fact that since the field of the motor is constant, the counter E. M. F. is directly proportional to its speed.

At full torque and full speed, the counter E. M. F. would be 245 volts, five volts being dropped by the passage of the 100 amperes through the ohmic resistance of .05 ohm.

Similarly if G has 125 volts at its brushes, that is one-half of its full voltage, and the full torque current of 100 amperes be in use, the counter E. M. F. of M would be 120 volts and its speed would be 120÷245 of its full speed, that is M would run at 245 revolutions per minute or practically speaking at one-half of its full speed.

Similarly, with one-tenth of the full E. M. F., that is with 25 volts at the brushes of G, the speed of M under full torque current would be 20÷245 of its full speed, that is 41 revolutions per minute or approximately one-tenth of its full speed.

Suppose now while M is running thus at 41 revolutions per minute under full torque, the entire load be thrown off, except merely the friction the torque current of which we have assumed as 10 amperes.

Instead of five volts drop, due to the 100 amperes through the .05 ohm, we now have only 10 amperes through .05 ohm, or .5 volt drop, and the resulting momentary increase of current through M causes slight acceleration of its armature until its counter E. M. F. is 24.5 volts instead of 20 volts, which it was under full torque. That is, its speed is now under friction load $\frac{24.5}{245} \times 500$, or 50 revolutions per minute.

Hence we see that when operating the motor at one-tenth of its full speed of 500 revolutions per minute, and while under full torque, we can throw off the entire load and experience a change in the speed of only 9 revolutions per minute.

Now let us consider the same motor under same conditions excepting that it is connected as usual to a constant E. M. F. circuit of 250 volts, and that the speed is controlled by an ohmic resistance in the armature circuit, the field being in shunt directly across the line.

If we are to operate the motor under full torque, we must have the full 100 amperes flowing through its armature, and if it is to be operated at one-tenth of its full speed its counter E. M. F. must be 245÷10 or 24.5 volts. This means that we must drop in the rheostat 220.5 volts out of the 250 volts constantly impressed. By having 220.5÷100 = 2.2 ohms in the rheostat we can secure this condition of affairs. But now we are wasting 100 × 220.5 = 22,050 watts in the rheostat and only utilizing in the motor 2,450 watts.

Perhaps the worst feature, however, about the conditions now prevailing, is that we have practically no control over the speed under change of torque. For example, suppose as before that we now throw off the entire load, leaving only the friction load. Under the reduced torque the motor speeds up until its counter E. M. F. plus the drop of E. M. F. in the rheostat again equals the line E. M. F. When this condition is realized, we have the friction torque current of 10 amperes flowing through the resistance of 2.2 ohms in the rheostat, and causing a drop of only 22. volts, and consequently the counter E. M. F. of M must be 250—22. = 228 volts and its speed must be $\frac{228}{250} \times 500 = 456$ revolutions per minute.

That is, by throwing off the full load, our motor has jumped from 41 revolutions per minute to 456 revolutions per minute,

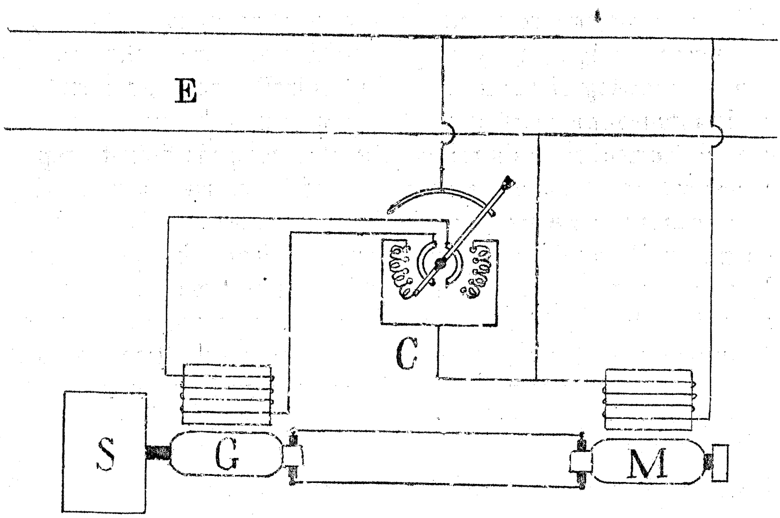

FIG. 2.

a change of 415 revolutions in this case as compared with 9 revolutions in the former case, the change in speed under the same conditions being nearly 50 times as great by the system of ohmic control as by the system of E. M. F. control.

Suppose we are again operating at one-tenth speed under full torque and therefore have 2.2 ohms in our rheostat. Now let the torque increase only 12 per cent. which must be expected in any kind of commercial practice. To keep the armature in rotation will require 112 amperes, but the ohms in circuit, 2.25, will only permit the passage of 111 amperes with 250 volts impressed, hence the increase of 12 per cent. in torque will cause the armature to come to rest. In the system of control by volts instead of ohms on the other hand, the speed would only be reduced from 41 revolutions per minute to 40 revolutions per minute which change would not be perceptible.

I have gone thus fully into the detailed figures of the cases considered, believing that the radical difference detween the systems of control can only be appreciated fully by such concrete examples as I have given.

I now desire to call attention to the fact that in the speed control by ohms, the operator can, by moving the lever of his rheostat, change the volts upon M as fast as he can move his hand. This is a frequent cause of burning out of armatures. In the case of a reversing rheostat, the instantaneous throwing of the rheostat lever while the motor is at full speed would mean that double the line E. M. F. would be acting to send a current through merely the ohmic resistance of the armature, for the reversal of the rheostat switch would cause the line and motor E. M. F.'s to act in the same instead of counter directions.

When, however, the change in E. M. F. at the motor is due, as in the case of Fig 1, to a change of field magnetism, the instantaneous throwing of the lever of the controller does not result in an instantaneous change of E. M. F. at M; for a change of current through the field of G results in a gradual although sufficiently rapid change of E. M. F. at the brushes of G, and hence the armature of M has a chance to accelerate and develop a counter E. M. F. which in practice will never be greatly different from that impressed. Even an instantaneous reversal of the connections of G can be made in ordinary practice without any detrimental result upon the generator or motor, because of this appreciable time required to reverse the magnetism of G. By various well known methods the time required for this reversal of magnetism can be varied over wide limits.

Fig. 2 shows the changes in connections of Fig 1 necessary for the operation of a motor whose motion is to be reversed.

Fig. 3 shows a modification of the general system in which the source of E. M. F. is composed of several different generators in series with each other and having a system of several conductors, upon each of which a different constant potential is maintained, so that by connecting the motor armature across different conductors, different E. M. F.'s are obtainable at the motor armature. With two generators and three conductors we can obtain three reversible, different automatic speeds. Similarly, with three generators and four conductors we can get six reversible, different automatic speeds. This modification of the system is especially suited to the distribution of power in an isolated plant such as a large manufacturing establishment.

I now come to the modification of the E. M. F. system of motor speed control in which the substitution of E. M. F. for ohms in the motor circuit for the purpose of controlling its speed, is most conspicuous.

We found, when considering the case of the rheostat control with the motor running at $1 \div 10$ speed and with 100 amperes

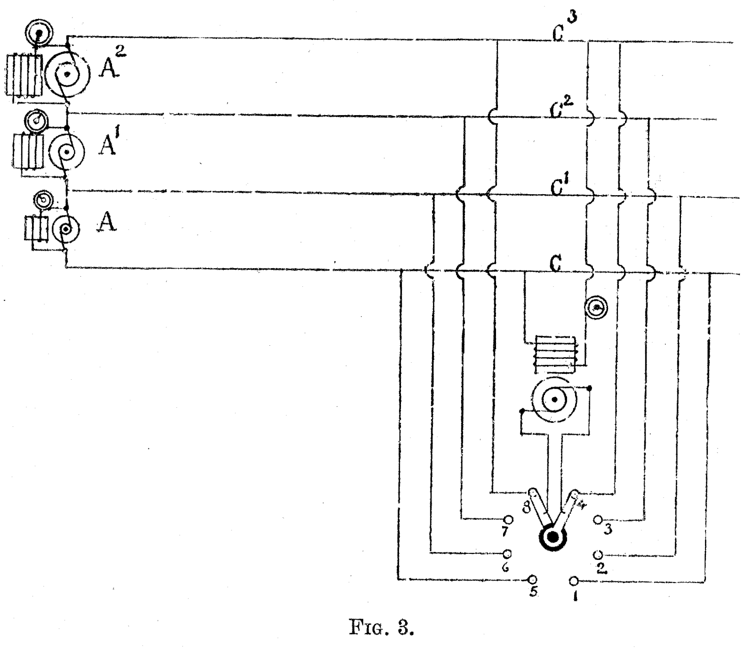

Fig. 3.

through it, that the rheostat had to absorb and dissipate 100 amperes $\times$ 220.5 = 22,050 watts while only 2,450 watts were utilized in the motor.

As has been shown, this loss in the rheostat is troublesome, not only because of the waste of energy, but especially because of its interference with all positive control.

Evidently what is needed is to substitute for the rheostat a device which will absorb the 220.5 volts and 100 amperes, and, instead of wasting them, convert them into useful work.

Fig. 4 shows how this is accomplished by one modification of the E. M. F. system of motor speed control.

G is a source of 125 volts constant E. M. F.

S is a shunt-wound dynamo connected across the constant E. M. F. and hence running at a constant speed.

R is a dynamo mechanically connected to drive or be driven by S, and running at a practically constant speed.

The field of R is excited by the main line E. M. F. and is independent of the E. M. F. of its armature and of the current through its armature. It has a variable and reversible field rheostat in

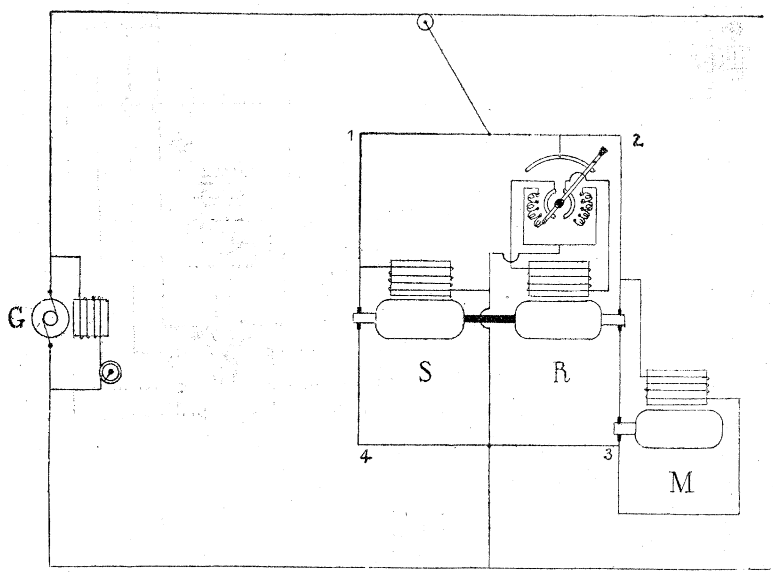

FIG. 4.

circuit by means of which the magnetism of the field of R may be varied and reversed at will.

M is the working motor. Its armature is in series with the armature of R across the line. Its field is excited by the main line E. M. F. and hence is independent of the E. M. F. or current of the armature M.

Let us suppose that the armature of S is wound for 125 volts and 100 amperes. The armature of R for 125 volts and 100 amperes, and the armature of M as in the former illustration for 250 volts and 100 amperes.

I will neglect the armature losses for the sake of simplicity, and because they do not materially affect the conclusion.

Suppose that as before we want to run M at one-tenth of full speed under full torque, full speed being 500 revolutions per minute and corresponding to 245 volts counter E. M. F. and full torque being that due to 100 amperes in the full field.

At first let us have the rotary transformer RS so adjusted that the fields of R and of S are both fully excited. Each end takes a slight current through its armature. Both ends are motors, and they divide between them the friction load.

Now let us weaken the field of R until its field strength is only nine-tenths of its full strength. In this weaker field, R tends to run faster; but in doing so it is obliged to drive faster the armature of S, whose counter E. M. F. has been almost equal to that of the line.

The dynamo S now acts as a generator and has two paths open for its current, the first being the circuit through the generator G and the other path being in the closed loop through R and M.

The E. M. F. of G balances that of S, but the E. M. F. of R which formerly was equal to that of G and also that of S, has been reduced by the weakening of its field, hence S sends a large current through the local circuits 1, 2, 3, 4, causing a large torque in the armature of M, in its constant field. M evidently will run at a speed such that its counter E. M. F. plus that of R equals the line E. M. F.

Expressing the conditions in figures under the assumption made, there will be upon the terminals of M, 25 volts and through its armature 100 amperes, that is, a total of 2500 watts in the armature of M. The armature of R will have 125—25 = 100 volts and 100 amperes or 10,000 watts, and the armature of S will have 125 volts and 80 amperes, that is 10,000 watts.

The generator G produces 20 amperes at 125 volts or 2,500 watts, which, by the method described, is transformed into 25 volts and 100 amperes at the working motor.

By continuing the weakening of the field of R, we finally have a field of no strength, and hence R becomes inert and we have the full line E. M. F. of 125 volts upon the 250-volt motor M, which, consequently, runs at half speed. Under these conditions no energy is transformed by the rotary transformer RS. If, now, we reverse the connections leading current to the field of R, and send a gradually increasing current around its field, its voltage is added to that of the line instead of being counter as heretofore, until finally its full voltage of 125 being added in series with the line E. M. F. of 125 volts we have upon M, 250 volts and it runs at its full speed. While R is thus adding to the line volts, it of course is acting as a generator instead of a motor, which it formerly was, and is now driven by S, which acts as a motor instead of a generator.

I call attention to the fact that the current capacity of all three armatures, R, S and M, is equal, but the full E. M. F. of R and S is only half that of M, which means that the K. W. capacity of R and S is each only half that of M.

The rotary transformer R can also be designed to run at much higher speed than is demanded for the working motor, since it can be perfectly balanced, and is free from any side or end thrusts and has a minimum friction.

There are other modifications of the E. M. F. system of motor speed control which I am not able to describe at present, but as in the case of those described above, the underlying feature is, to insert or cut out E. M. F. instead of ohms in the armature circuit of the motor when we wish to change its speed.

Since many have thought this system of motor speed control limited to a few peculiar cases, and also limited to peculiar kinds of generators and motors, I give in the table below, instances within my own knowledge, showing the kind of machinery operated and the size and make of the motor used:

Kind of Machinery Operated.	Size of Motor.	Maker of Motor.
Traveling Cranes.	1 K. W. to 50 K. W.	Crocker-Wheeler, Eddy, Edison, Waddell-Entz, Billberg, C. & C., Westinghouse.
Passenger Elevators.	5 K. W. to 40 K. W.	Edison, Eickemeyer.
Mining Hoists.	10 K. W. to 125 K. W.	C. & C., Crocker-Wheeler.
Turrets on Men-of-War.	25 K. W.	General Electric.
Billet Shifter in Rolling Mill.	30 K. W.	Crocker-Wheeler.
Heilmann Locomotive.	8 of 50 K. W. each.	Brown.
Cloth Printing Press.	25 K. W.	Edison, General Electric.
Newspaper Printing Press.	50 K. W.	Unknown.
Universal Boring Machine.	5 K. W.	Unknown.