No. 608,309. Patented Aug. 2, 1898.

C. P. STEINMETZ.

REGULATING DYNAMO ELECTRIC MACHINES.

(Application filed Apr. 23, 1898.)

(No Model.) 2 Sheets—Sheet I.

FIG. 1.

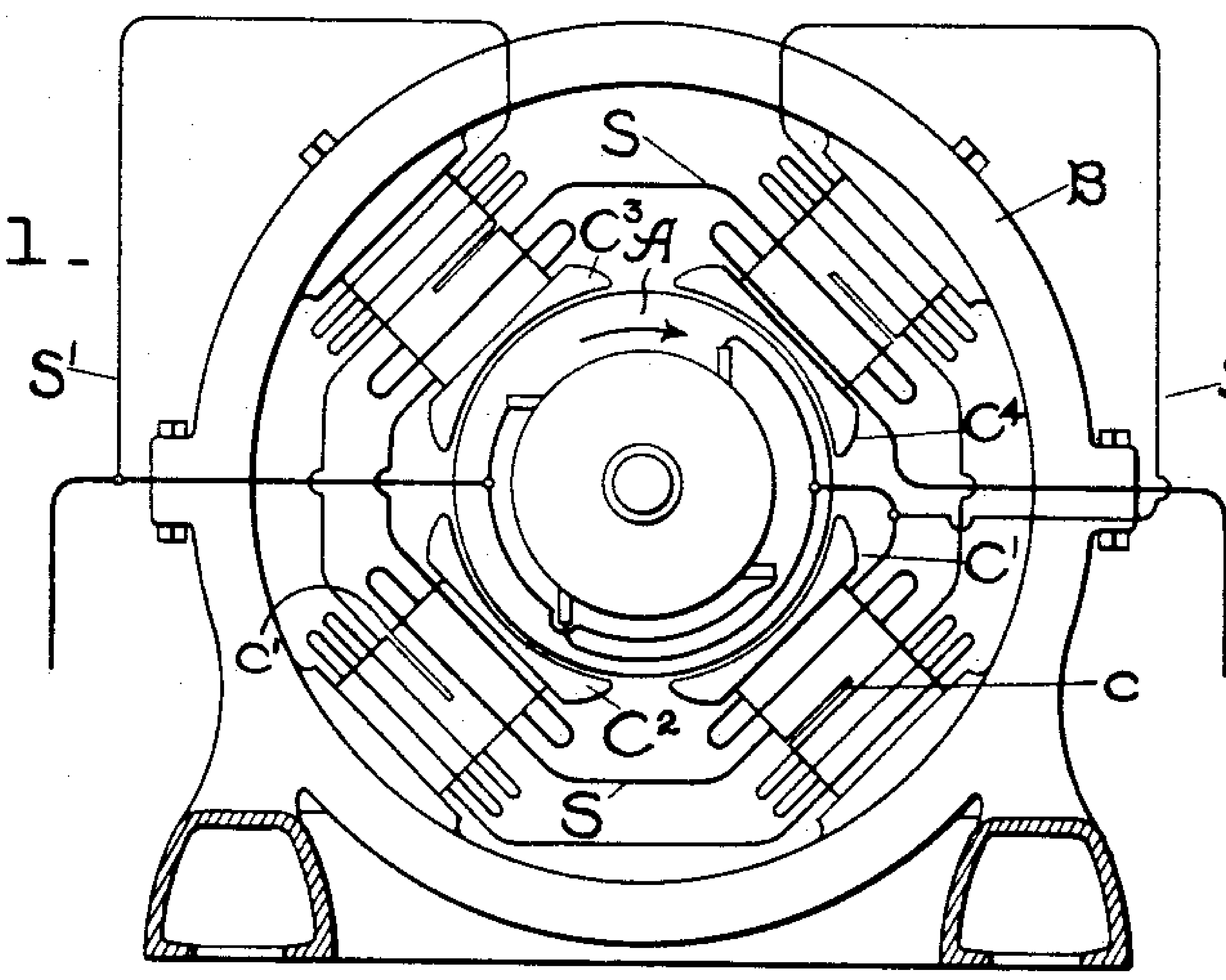


FIG. 2.

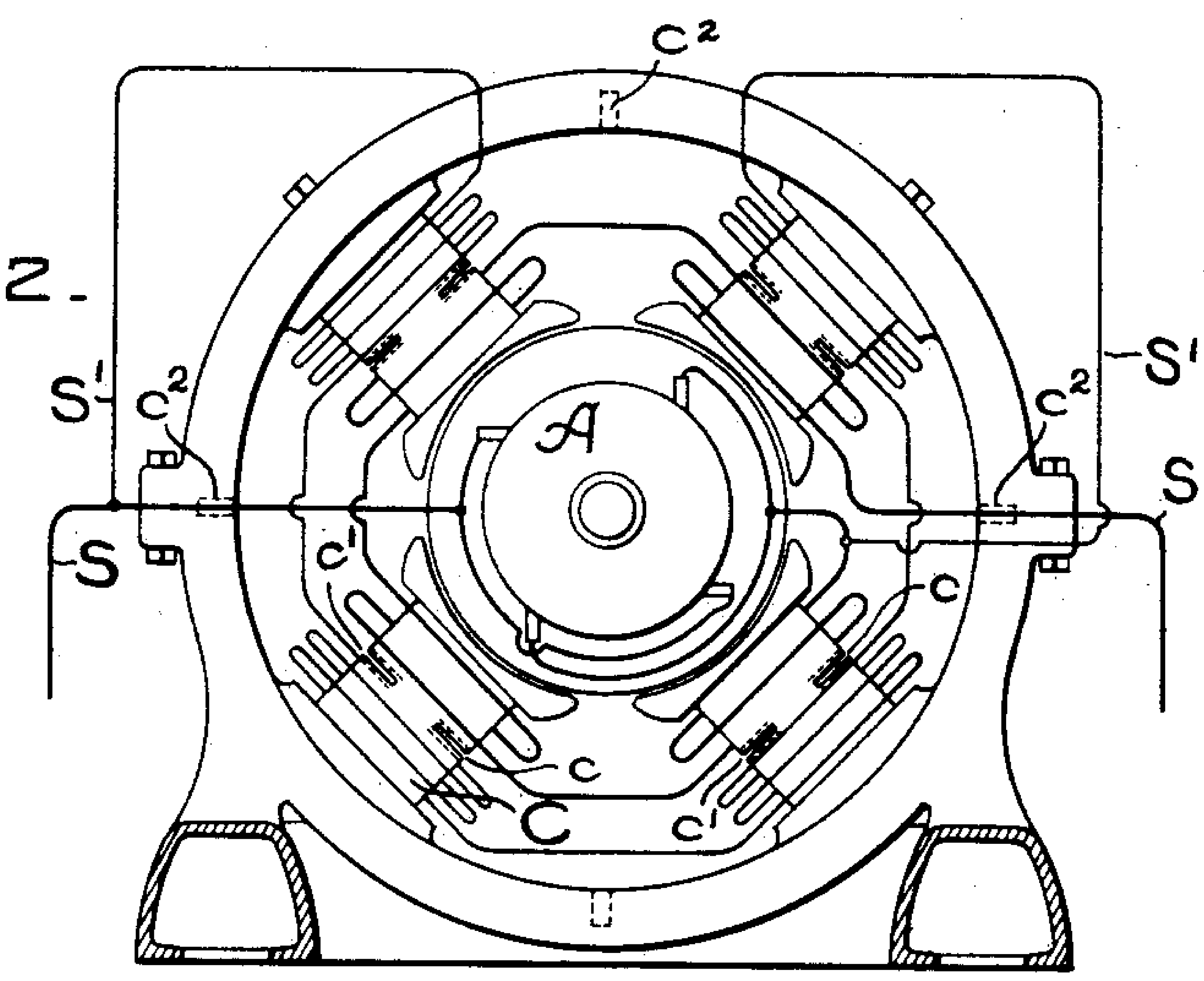
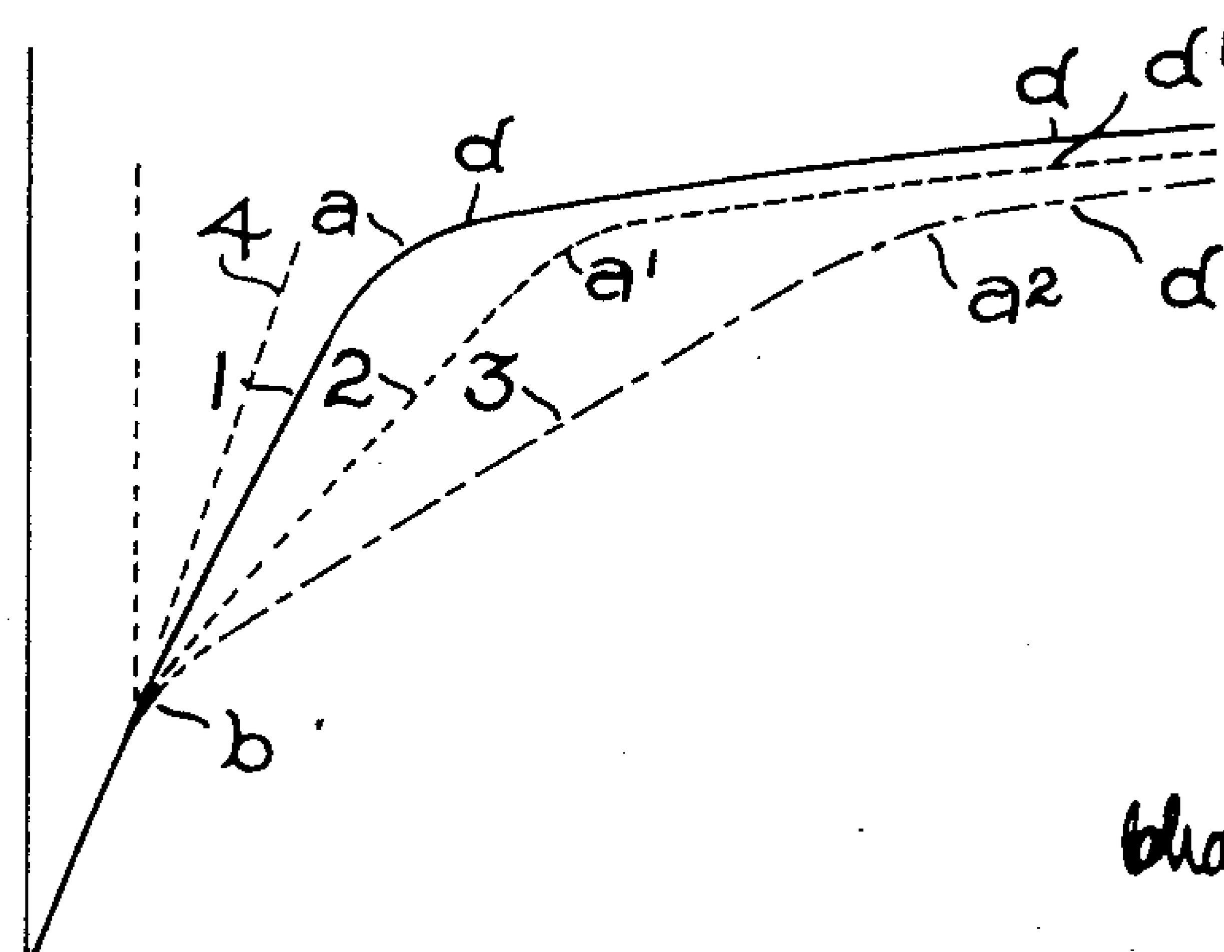


FIG. 3.



WITNESSES.

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FIG. 4.

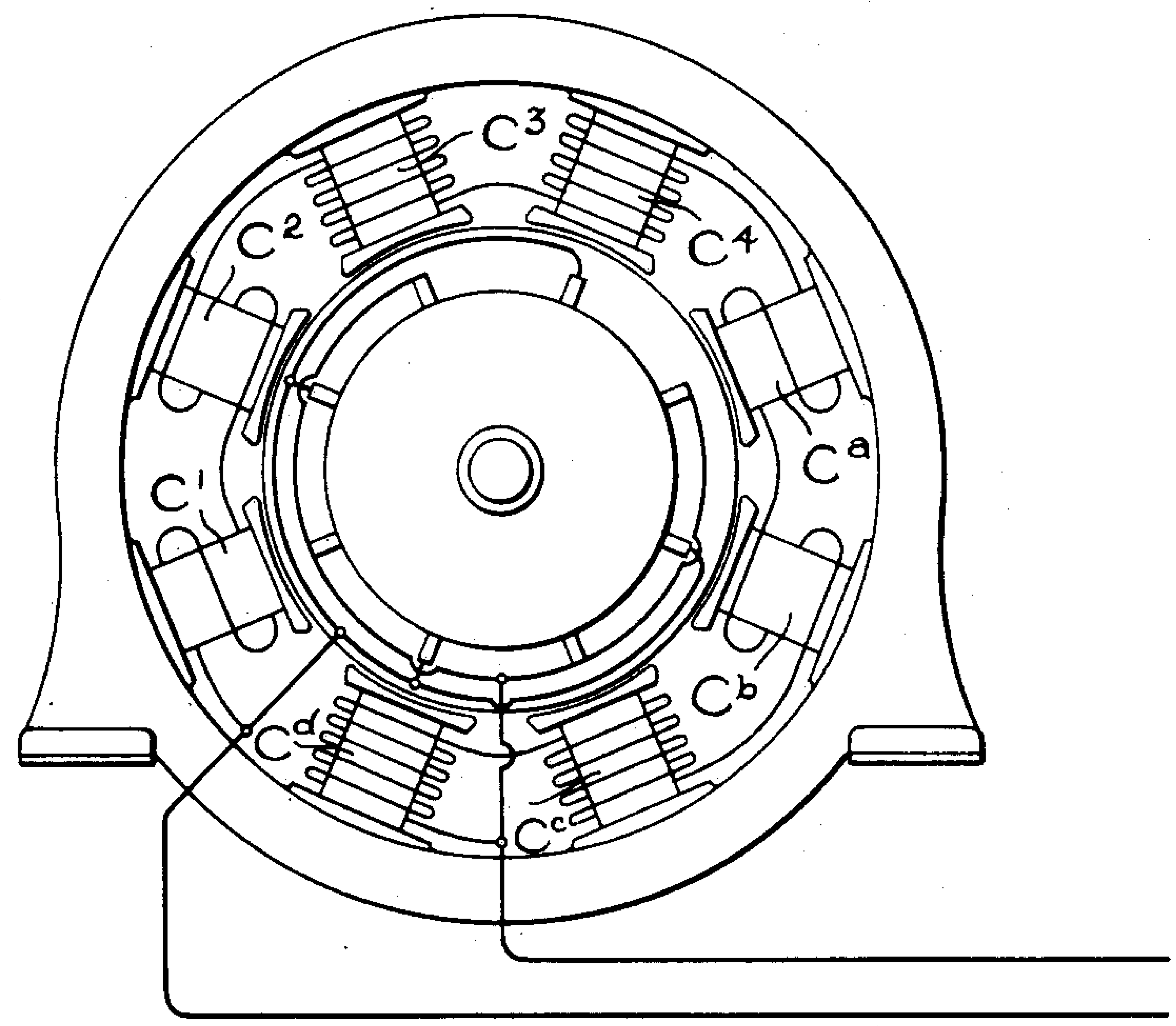


FIG. 6.

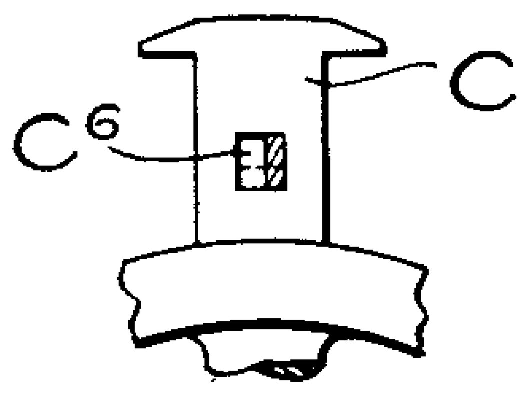
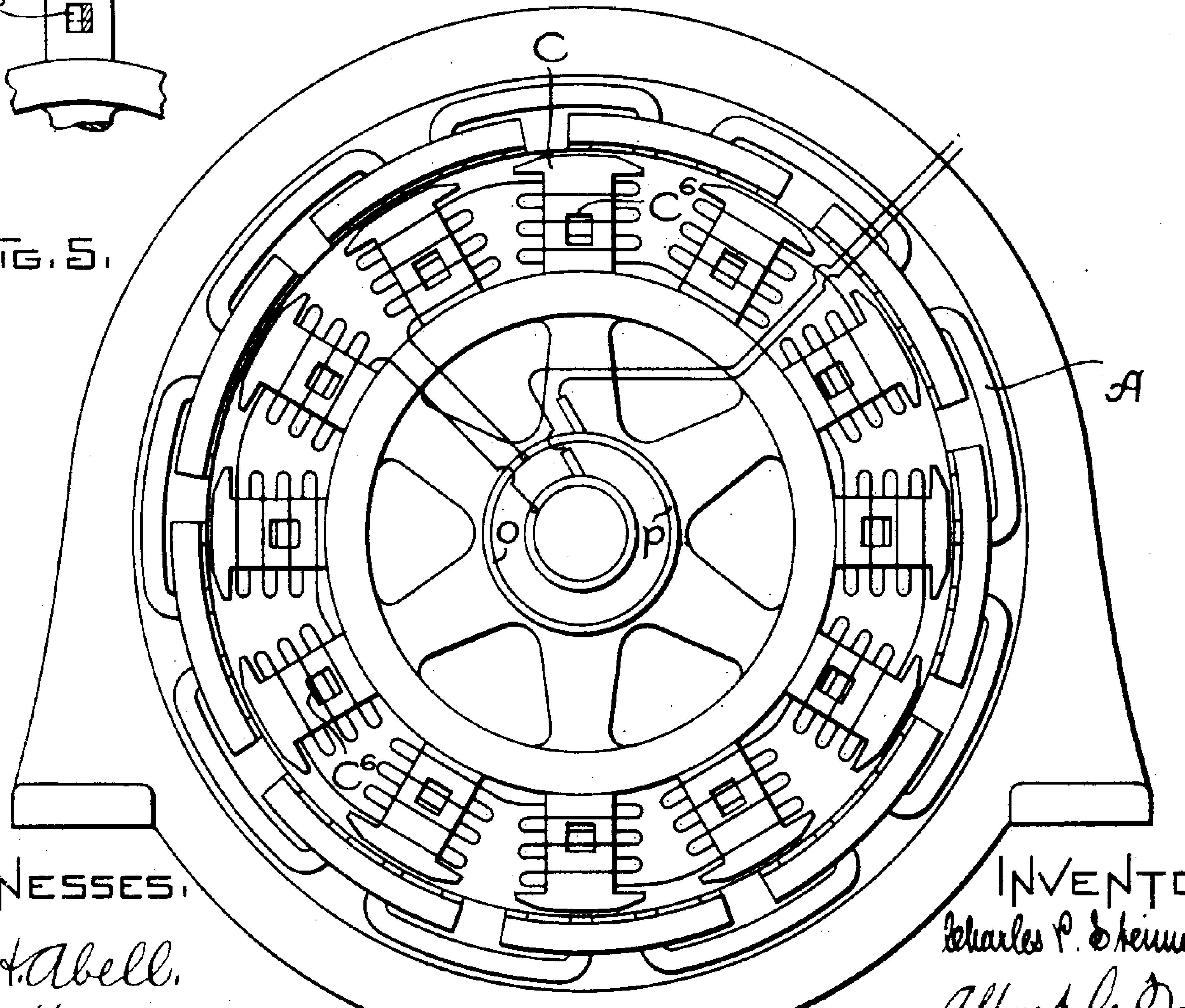


FIG. 5.



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UNITED STATES PATENT OFFICE.

CHARLES P. STEINMETZ, OF SCHENECTADY, NEW YORK, ASSIGNOR TO THE GENERAL ELECTRIC COMPANY, OF NEW YORK.

REGULATING DYNAMO-ELECTRIC MACHINES.

SPECIFICATION forming part of Letters Patent No. 608,309, dated August 2, 1898.

Application filed April 23, 1898. Serial No. 678,554. (No model.)

To all whom it may concern:

Be it known that I, CHARLES P. STEINMETZ, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Regulating Dynamo-Electric Machines, (Case No. 593,) of which the following is a specification.

My invention has reference to the regulation of dynamo-electric machines, and has for one of its objects to increase the range of stable working of such machines. By "stability of working," as applied to a self-exciting generator, for example, is meant that condition of operation under which slight changes of speed do not produce corresponding changes in the field-magnet strength. Hitherto in order to obtain stable working it has been necessary to maintain the field excitation on that part of the magnetic characteristic of the machine which is above the knee. On this part of the curve the field ampere-turns may vary considerably without changing the field strength appreciably. Under these conditions practically the only change of voltage of the machine is that directly due to the changes in speed of the armature-conductors relatively to the field. If, however, the machine were to work on that part of the magnetic characteristic below the knee, a small change of voltage due to change of speed would produce a considerable variation in the field strength, which, acting in its turn, would make the difference in voltage still greater. This instability of working is, as has been said, largely avoided by maintaining the field excitation above the knee of the magnetic characteristic. Some disadvantages are, however, involved in this arrangement. Thus, owing to the small change in field strength attainable between the limits of that portion of the magnetic characteristic above the knee along which it is practicable to work, it is possible to operate the machine under stable conditions only within a small change of voltage. My invention makes it possible to operate the machine within wide limits of voltage and at the same time under stable conditions at all voltages within the limits.

Another object of my invention is to perfect the regulation of dynamo-electric machines under varying conditions of operation within their load limits, that object being in the case of a generator to secure constant potential at some selected point on the system and in the case of a motor to secure constant speed.

Obviously to secure a straight compounding or overcompounding curve a saturation curve or magnetic characteristic of the machine is required, which is straight in the range of stability—that is, above the first bend. In machines as ordinarily constructed the magnetic characteristic of the machine within the range of stability is always to a certain extent curved, and thus when compounding the machine for constant potential by means of a series field the voltage at half-load is always higher than at no load and full load, as is well known. If the machine be overcompounded by a series field the ampere-turns of which are proportional to the load, the voltage does not rise proportionally to the load, but rises more from no load to half-load and less from half-load to full load.

In a differentially-compounded or constant-speed motor it is obvious that a magnetic characteristic which is straight in the range of stability will give constancy of speed at constant voltage independent of the load. The reverse is true in the case of a generator in which constancy of speed gives constant voltage.

To effect the ends pointed out, I aim to so proportion the magnetic circuit of the machine that the magnetic characteristic or saturation curve will make a bend or "knee" at a lower flux than that at which the same would occur in a similar machine as ordinarily designed, the curve, however, extending to substantially the same height as in the latter case. That portion of the magnetic characteristic beyond the first knee according to my invention is practically a straight line.

One way in which the object of my invention may be accomplished is by arranging the field-magnet winding of a multipolar machine so that some of the poles are brought to saturation before the others. This method of obtaining the result desired is entirely feasible, but is practically limited in its application to multipolar machines with series-wound armatures. It depends, nevertheless, upon the same principles for its operation as those constructions now to be described.

Another means of effecting the results at which I aim is a magnetic circuit having an auxiliary air-gap which acts as an air-gap only above a certain flux, being ineffective below it. The auxiliary air-gap is produced by suitably reducing the cross-section of the magnetic circuit at a convenient point. Various means may be employed for this purpose, as by forming a cut or cuts in the magnetic circuit, either in the field-poles or in the yoke. The cuts may extend into the iron from one side only or from opposite sides, as may be desired. The same purpose may be accomplished by cutting a slot in the iron of the magnetic circuit.

The effect of locally reducing the cross-section of the magnetic circuit is to cause a part of the iron to become saturated at a predetermined flux, the remainder of the circuit being left unsaturated. When the flux rises above the predetermined point, lines of force pass across the auxiliary air-gap, which thus has the effect of introducing an additional resistance into the magnetic circuit at this point in the saturation curve. It is obvious that the values of magnetization which would correspond to certain magnetizing forces were the auxiliary air-gap not present occur at higher magnetizing forces when the auxiliary air-gap is present. The result is that a bend or knee is produced in the saturation curve at that voltage at which the air-gap becomes effective. By proper proportioning of the reduced part of the magnetic circuit this bending may be made to occur at any desired voltage below that at which saturation would normally take place. The desired inclination in the curve above the bend so produced is effected by suitably proportioning the auxiliary air-gap. It will thus be seen that my invention renders possible the production of dynamo-electric machines with close regulation through any desired range of stable working.

The method of and the apparatus embodying my invention will be better understood from the accompanying drawings, in which—

Figures 1 and 2 are diagrammatic views of dynamo-electric machines embodying my invention. Fig. 3 is an explanatory diagram of saturation curves. Fig. 4 illustrates the first method of carrying out the invention. Fig. 5 is a modification, and Fig. 6 is a detail.

Referring to the drawings more in detail, Fig. 1 is a diagram showing the magnetic circuit and field-windings of a dynamo-electric machine embodying my invention. The machine belongs to the usual type of compound-wound machines, A representing the armature of the machine, B the yoke, and C′ to C⁴ the pole-pieces, which are magnetized by the series winding S and shunt-winding S′. In the pole-pieces slots *c c′* are made. Preferably these extend in from that side of the field-pole which is strengthened by the armature reaction, thus helping to reduce the effect of the same. In Fig. 2 I have shown the same parts with the same reference-letters, but here the slots *c c′* extend in from both sides of the field-magnet, and, as shown in dotted lines, they may be of various widths and lengths. At c^2 c^2 I have shown in dotted lines that the slots or cuts may be in the yoke of the field-magnet and need not necessarily be in the field-magnet poles themselves.

If the field-poles be cut in any of the ways shown, the slot will have no effect on the saturation curve at low voltage—that is, at a voltage where the total flux of the machine can pass through the magnetic material which is not cut. As soon, however, as saturation is reached at this point, the magnetic flux has to pass through the additional air-gap in the cut, which increases the reluctance of the magnetic circuit. At this point the bend occurs in the saturation curve. These actions are best understood from the diagrams in Fig. 3. In this diagram the solid line 1 is the ordinary saturation curve of a dynamo-electric machine without cuts or slots in the magnetic circuit. As will be seen, this curve bends at the point *a* and the working range of the machine which it represents is between the points *d d*, the available range of voltage of the machine being thus much restricted.

If now the field-poles of the machine have side cuts formed therein, as shown in Figs. 1 and 2, these cuts will have no effect in the saturation curve at very low voltage—that is, at a voltage where the total flux of the machine can pass through the reduced section of the magnetic circuit of the machine without saturating the same. As soon, however, as saturation is reached at this place the magnetic flux has to pass through the additional air-gap introduced by the cut. Under these conditions, in order to produce a certain flux, an increased field excitation is needed over that which would produce the same flux if no cuts in the magnetic circuit were present. The dotted curve 4, having the point *b* for its origin, represents the increased field excitation necessary for any given flux in the case where the cut takes away two-thirds of the magnetic cross-section of the field-pole and is about half the width of the air-gap of the machine.

Combining curves 1 and 4 by adding abscissæ gives curve 2. The result is a saturation curve which bends at a point corresponding to a low voltage of the machine and then continues in a straight line up to the same voltage at which curve 1 reaches its bend, and at this voltage a second and final bend is reached. The working range of the machine would thus be from about the bend *b* to the point *d′*. If, however, the thickness of the cut *c* be made twice as great, the curve of the machine would take the form shown in curve 3—that is, have a greater inclination on its stable range. The second and final bend would come at a^2 at about the same voltage as in the other cases considered, so that the stable working range would be between the points b and d^2. Thus a machine embodying my invention operates under stable conditions a little above a predetermined point b, Fig. 3, while without the cut it would reach stability only at the point a, corresponding to a much greater voltage of the machine. The position of the point b at which the curve makes its first bend is determined by the cross-section of the magnetic circuit at the cut, while the inclination of the curve above this point is determined by the width of the auxiliary air-gap introduced by the cut into the magnetic circuit.

It will be noticed that the saturation curves 2 and 3 are practically straight between the point b and the second bend. If the machine works at any voltage within this range, the compounding curve will be straight instead of curved, as would be the case if the machine were working at a point on the ordinary saturation curve beyond the bend—as, for example, between d and d, curve 1. The machine, moreover, would work with stability under these conditions, because the magnetic flux would vary slowly compared to the field ampere-turns, as has been explained.

I have described my invention as applied to continuous-current machines; but it is equally applicable to alternators, where close regulation—that is, a small rise of voltage when the load is thrown off—is desired. In these machines a high saturation is often employed in the whole magnetic circuit as well as the field-poles. This has the disadvantage of limiting the range of voltage, which tends to make such machines, while very satisfactory under proper running conditions, unsuitable to give their full voltage at a lowered speed or to give a higher than the rated voltage, as is frequently necessary to cover unforeseen losses in transmission. By the application of my invention to such machines the same increased slope of the saturation curve may be obtained as in the case of continuous-current machines, thus obtaining the same advantages of improved regulation and increased working range.

In Fig. 5 I have illustrated a modified form of my invention which is well adapted to alternators. The machine shown is of the revolving field type, to the field-magnet windings of which current is passed by the collectors o p from any suitable source of excitation. In the pole-pieces holes C^6 are cut, the effect being to reduce the magnetic cross-section of the poles and so accomplish the desired modification of the saturation curve.

Fig. 6 shows how by inserting a piece of iron in the holes illustrated in Fig. 5 the regulation may be readily altered to suit particular conditions. If the cross-section of the hole be diminished, as when the iron is placed as shown in solid section, the voltage at which the primary bend in the curve takes place will be raised, while if it be placed as shown in dotted section the air-gap will be diminished and the inclination of the curve above its primary bend made correspondingly less.

The first arrangement for carrying out my invention outlined in my statement of invention is illustrated in Fig. 4. Here the poles C' C^2 C^a C^b have but few turns of winding as compared to the other poles. In consequence they are free to change as the regulation may require, while the poles C^3 C^4 C^c C^d being wound with many turns are nearly or quite saturated. The consequence is that the magnetic circuits passing through the poles c^3, c^4, c^c, and c^d reach saturation before the others. The curve of saturation of the machine as a whole thus has a bend occurring at the voltage, at which the circuits through the poles c^3, c^4, c^c, and c^d reach saturation. Owing to the difference in the value of the electromotive forces produced in the armature by the several differing magnetic fields it is necessary to employ a series-wound armature with this embodiment of my invention. Although, as already stated, there are undesirable features about this form of my invention it is operative and beneficial, though not so desirable as the other forms shown.

Owing to the straight compounding curve resulting from the application of my invention a constant speed independent of the load is obtained in the case of a motor at constant voltage. The reverse is true in the case of a generator where constancy of speed gives constant voltage or a voltage gradually rising as the load comes on, as preferred. Slight variations of speed in the case of the generator and like variations of voltage in the case of a motor have but little effect, as heretofore explained.

My invention is particularly applicable in the case of generators used as exciters, in which stable working through a wide range of voltage is desired, and in all other cases where stable working and close regulation over a wide range is desirable my invention will be found of great value.

By using the term "dynamo-electric machine" in the claims it is manifest that I include motors as well as generators, for the constructions indicated are equally as applicable to the one as to the other.

What I claim as new, and desire to secure by Letters Patent of the United States, is—

1. The method of operating a dynamo-electric machine which consists in causing the saturation curve of the machine to bend at a flux value lower than that at which the bend would normally occur, and operating the machine on that part of the curve above the bend.

2. The method of adjusting the stable working range of dynamo-electric machines which

consists in varying the reluctance of the magnetic circuit by a definite amount and at a predetermined flux.

3. The method of securing a straight compounding curve in a dynamo-electric machine which consists in operatively introducing an air-gap into the magnetic circuit at a predetermined flux.

4. The method of compounding dynamo-electric machines, which consists in creating a magnetic flux by the action of two magnetomotive forces one of which is substantially constant and the other of which varies with the load, and artificially causing a bend in the saturation curve of the magnetic circuit in which said magnetomotive forces operate, at a point below that of normal operation.

5. The method of extending the stable working range of dynamo-electric machines which consists in artificially increasing the reluctance of the magnetic circuit at a predetermined flux.

6. In a dynamo-electric machine, a magnetic circuit having an auxiliary air-gap effective only above a predetermined flux.

7. In a dynamo-electric machine, a magnetic circuit having an auxiliary air-gap effective only above a predetermined flux, and means for adjusting the length of said air-gap.

8. In a dynamo-electric machine, a magnetic circuit having an auxiliary air-gap effective only above a predetermined flux, and means for simultaneously adjusting the length of said air-gap and determining the flux at which it becomes effective.

9. A dynamo-electric machine or motor, having an armature and field-poles, one or more of the field-poles having a hole cut through them acting as an additional air-gap, with a block of magnetic material filling part of the hole, and serving by its position and size to adjust the shape of the characteristic curve of the machine.

In witness whereof I have hereunto set my hand this 21st day of April, 1898.

CHARLES P. STEINMETZ.

Witnesses:
B. B. HULL,
M. H. EMERSON.