

April 7, 1942.

A. S. NORCROSS

2,278,621

VOLTAGE REGULATOR

Original Filed Aug. 30, 1937

5 Sheets-Sheet 2

FIG. 8.

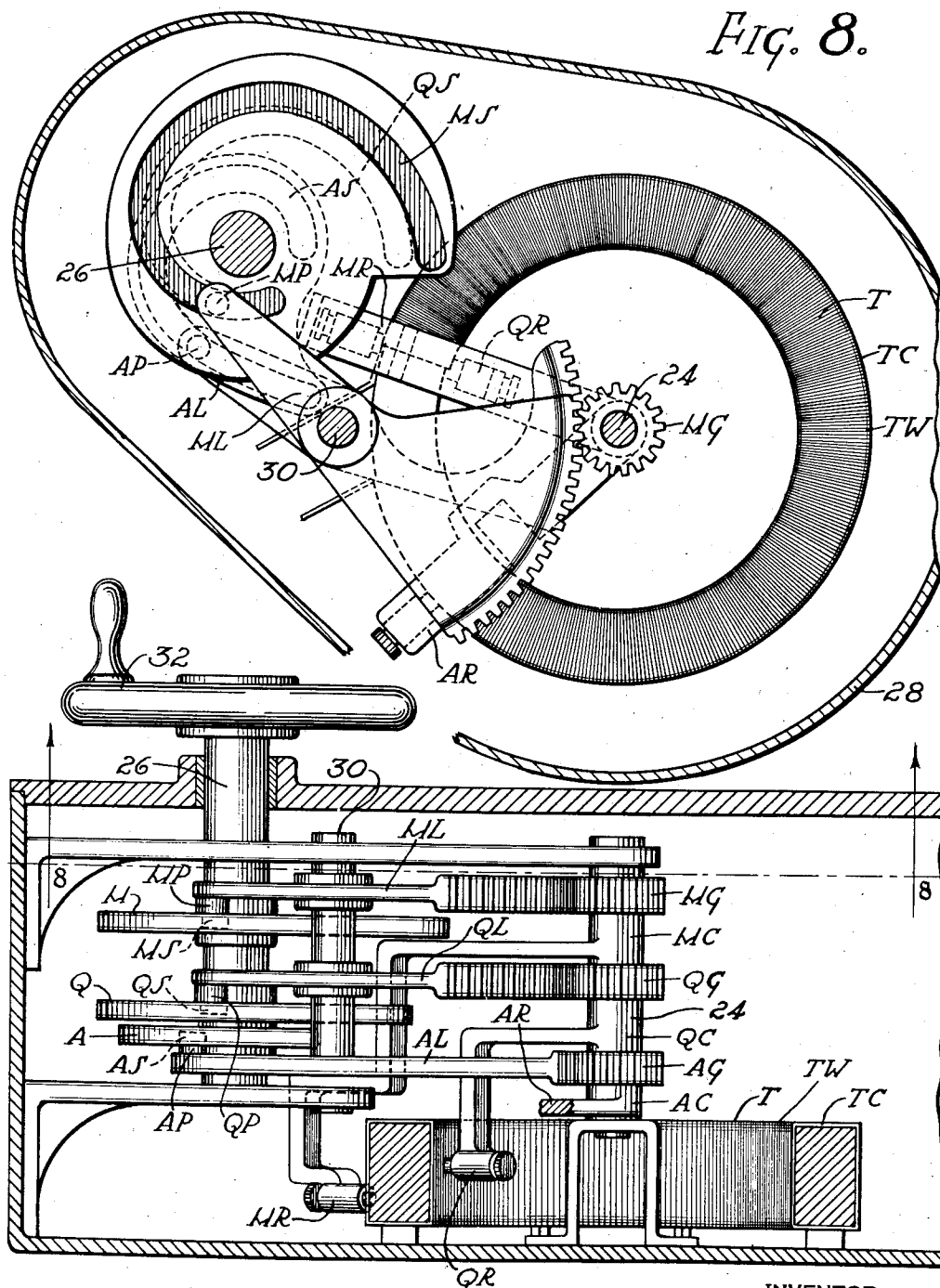


FIG. 7.

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5 Sheets-Sheet 3

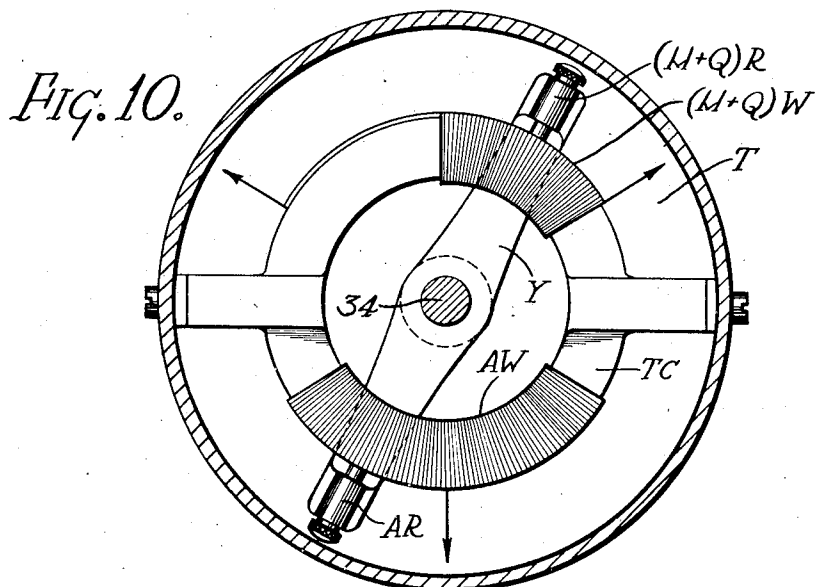
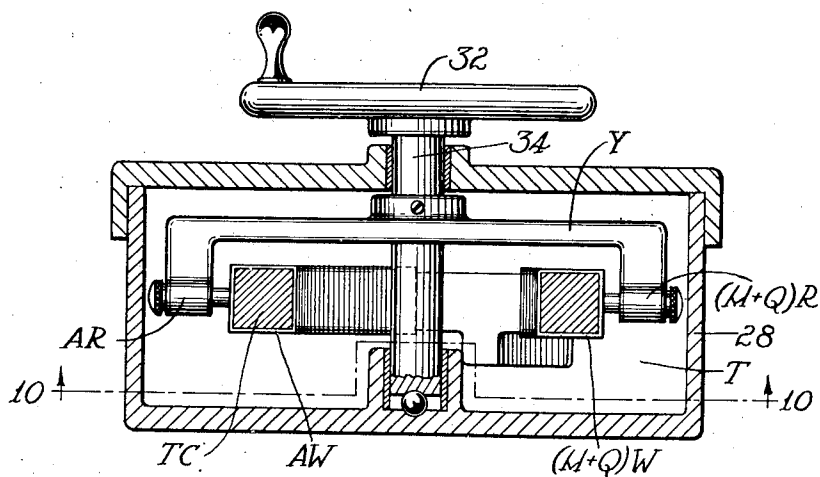


Fig. 9.

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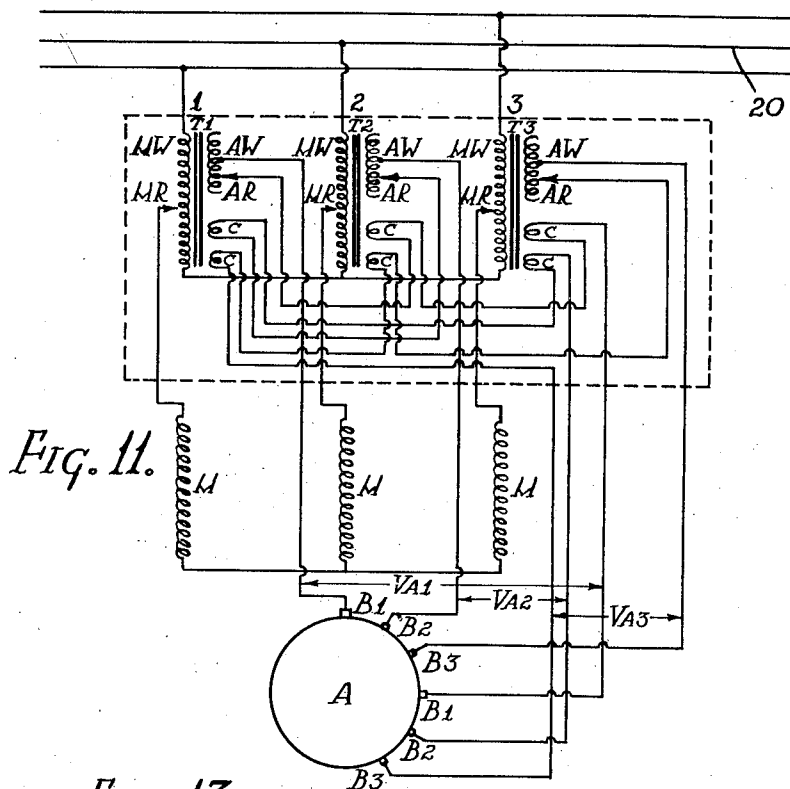
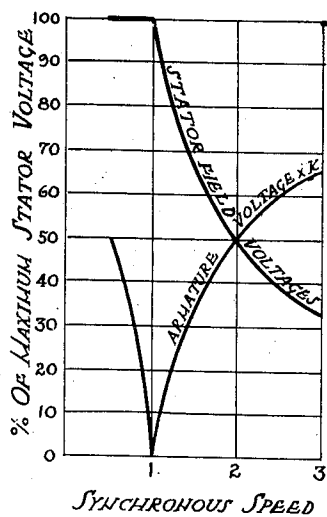
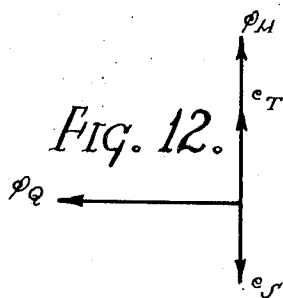
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VOLTAGE REGULATOR

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5 Sheets-Sheet 4



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VOLTAGE REGULATOR

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5 Sheets-Sheet 5

FIG. 15.

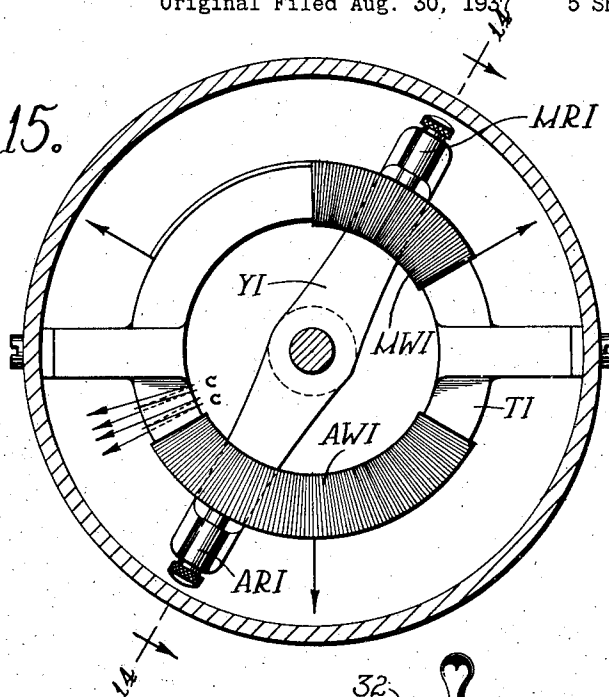
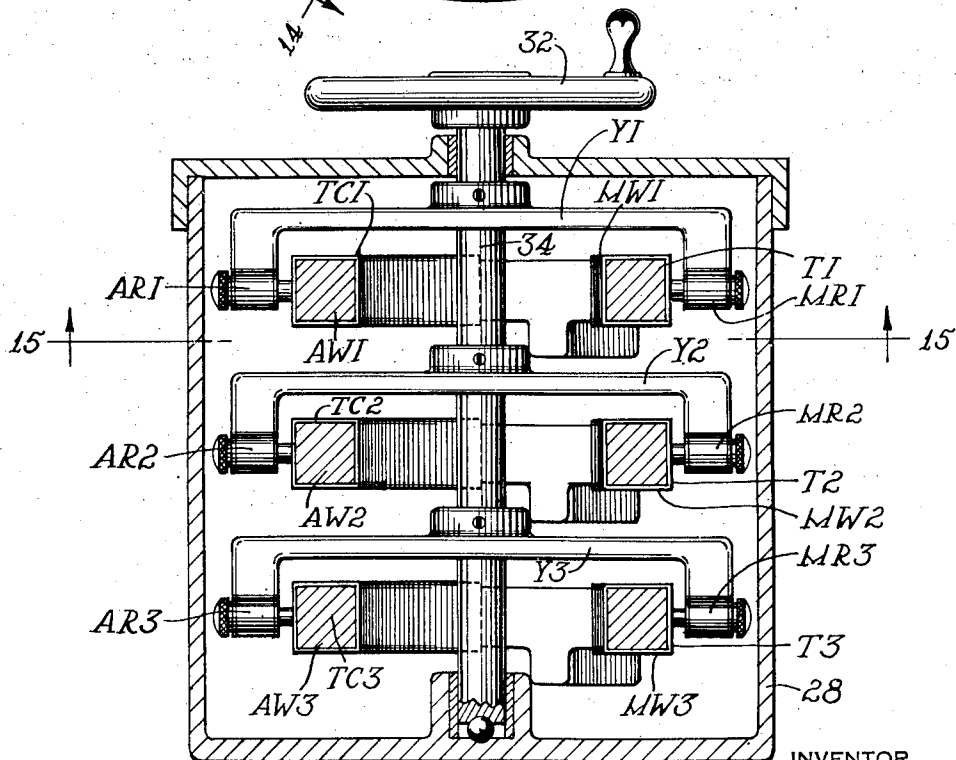


FIG. 14

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UNITED STATES PATENT OFFICE

2,278,621

VOLTAGE REGULATOR

Austin S. Norcross, Waban, Mass.

Original application August 30, 1937, Serial No. 161,614. Divided and this application May 10, 1939, Serial No. 272,779

10 Claims. (Cl. 171-119)

My invention relates to improvements in voltage regulators. My improved voltage regulator is specifically designed to provide a unitary control means for simultaneously relatively adjusting a plurality of simultaneously produced voltages in a predetermined manner. While my improved voltage regulator may be employed wherever it may be desired to adjust a plurality of voltages, it is particularly adapted for use in adjusting the voltages in the novel type of alternating current motor shown in my copending application for patent, Ser. No. 161,614, filed August 30, 1937, for Alternating current commutator motor, patented Feb. 27, 1940, No. 2,192,050, of which this application is a division.

A further object of my invention is to provide a voltage regulator which may adjust voltages, either through the medium of adjusting the rate of movement or displacement of a rider relative to a winding, or by varying the windings around a magnetic core in proportion to the desired variation in voltages to be produced.

Further features of my invention relate to the structural features of the various types of voltage regulators shown herein.

These and such other objects of my invention as may hereinafter appear will be best understood from a description of the accompanying drawings which illustrate various embodiments thereof.

In the drawings, Fig. 1 is a circuit diagram of an embodiment of my improved voltage regulator employed with a single-phase adjustable speed motor of the type described in my former Patent No. 2,060,106, modified in accordance with my invention so that the armature may be adjustably connected to the auto-transformer in order that the voltage impressed upon the armature circuit may be adjusted instead of having the armature short-circuited as shown in said patent with the voltages impressed upon the main winding and the quadrature winding each being independently adjustable.

Fig. 2 is a circuit diagram of another embodiment of my improved voltage regulator employed with the single-phase adjustable speed motor shown in Fig. 1 modified so as to have the same voltage adjustably impressed upon both the main and quadrature windings.

Fig. 4 is a vector diagram showing approximately the phase relations of the speed and transformer voltages induced into the coils undergoing commutation in all types of single-phase motors shown in Figs. 1 and 2.

Fig. 5 is a graph showing a particular manner

in which the voltages impressed upon the main, quadrature and armature windings of the single-phase motor shown in Fig. 1 may be adjusted in accordance with the curves shown therein to improve the commutation over a large speed range, the curves being determined on the basis of a constant torque below synchronous speed, as shown therein, and on the basis of a constant horse power above synchronous speed.

Fig. 6 is a graph showing a particular manner in which the voltages impressed upon the stator windings, including both the main and quadrature windings of the single-phase motor shown in Fig. 2 and the armature winding thereof may be adjusted to improve the commutation over a large speed range, the curves being determined on the basis of a constant torque below synchronous speed, as shown therein, and on the basis of a constant horse power above synchronous speed.

Fig. 7 is a vertical sectional view taken through a suitable voltage regulator for supplying separate voltages to the main winding, quadrature winding and armature winding of the embodiment of my invention shown in Fig. 1, adjustable to vary said impressed voltages in accordance with the graph shown in Fig. 5.

Fig. 8 is a cross sectional view taken along the line 8-8 of Fig. 7.

Fig. 9 is a vertical sectional view taken through a suitable voltage regulator for supplying voltages to the stator windings, including the main and quadrature windings of the embodiment of my invention shown in Fig. 2 and the armature winding thereof, adjustable to vary said impressed voltages in accordance with the graph shown in Fig. 6.

Fig. 10 is a cross sectional view taken along the line 10-10 of Fig. 9.

Fig. 11 is a circuit diagram of another embodiment of my improved voltage regulator employed with a three-phase adjustable speed motor constructed in accordance with my invention employing, however, power factor coils as the specific embodiment of means to provide in the rotor a power factor improving component of voltage.

Fig. 12 is a vector diagram showing approximately the phase relations of the speed and transformer voltages induced into the coils undergoing commutation in the polyphase motor shown in Fig. 11, being substantially similar to the vector diagram shown in Fig. 4 for the various types of single-phase motors shown herein.

Fig. 13 is a graph showing a particular manner in which the voltages impressed upon the stator

windings and armature windings of the poly-phase motor shown in Fig. 11 may be adjusted to improve the commutation over a large speed range, and being generally similar to the graph shown in Fig. 6 for the types of single-phase motors shown herein, the curves being determined on the basis of a constant torque below synchronous speed, as shown therein, and on the basis of a constant horse power above synchronous speed.

Fig. 14 is a vertical sectional view taken through a suitable voltage regulator, comprising three superimposed rings of the type shown in Figs. 9 and 10, one for each phase, rigidly mounted on a single shaft to be controlled by a single handle, for supplying voltages to the stator and armature windings of the embodiment of my invention shown in Fig. 11, adjustable to vary said impressed voltages for each phase in accordance with the graph shown in Fig. 13.

Fig. 15 is a cross sectional view taken along the line 15—15 of Fig. 14 and also showing the power factor improving coils.

In the drawings, wherein like characters of reference generally indicate like parts throughout, Figs. 1-10 illustrate various embodiments of my improved voltage regulator employed in a single-phase motor constructed in accordance with the principles of my invention, whereas Figs. 11-15 illustrate an embodiment of a voltage regulator constructed in accordance with my invention applied to a three-phase motor. The different embodiments of single-phase alternating current motors shown in Figs. 1-10 are in most respects modifications of the single-phase motor described and claimed in my former Patent No. 2,060,106. In general the embodiments of my invention shown in Figs. 1-10 are constructed and operate in similar fashion to the embodiments of my invention shown in said patent. If a fuller description of the theory of such a motor be desired than set forth herein, including the equations and symbols involved, reference is hereby made to said patent.

In the structure shown in Fig. 2 of said patent, I have provided adjustable means to supply voltage to the main stator winding and adjustable means to supply voltage to the quadrature winding. In the structure shown in said patent, however, the armature is permanently short-circuited. In order to improve the commutation throughout and to provide a greater speed range, I so modify the structure shown in my former patent as to adjustably vary the voltage also supplied to the armature winding. Instead of short-circuiting the armature A, I adjustably connect the armature to the auto-transformer T shown in Fig. 1 or to the transformer T shown in Fig. 2 to receive an adjustable voltage therefrom. In the type of single-phase alternating current motor shown in Figs. 1-2, I have employed and shown diagrammatically a motor with a main stator winding embodying a main coil M, which for convenience may be denominated the main coil or winding. A second or quadrature winding Q is located in quadrature or at ninety electrical degrees apart from said main winding. In other words, the coils M and Q are in space quadrature. For convenience, I will refer to the winding Q as the quadrature winding and to the windings M and Q together, namely, the main and quadrature, as the stator windings.

In the particular embodiment shown in Fig. 1, voltage is impressed from the main line 20 or

source of supply onto the auto-transformer T, where in turn it is impressed upon the main winding M and the quadrature winding Q as shown in said patent. By adjusting the positions of the riders MR and QR for the main winding and the quadrature winding on the auto-transformer shown in Fig. 1 or the single rider (M+Q)R on the transformer shown in Fig. 2, the voltages impressed upon the main and quadrature windings may be varied as shown in said patent. As also shown in said patent, I provide means to provide in the rotor a power factor improving component of voltage comprising the capacitor C connected in the quadrature field circuit. As stated in said patent, the capacitor C, in addition to improving the power factor, improves the torque, commutation and other desirable characteristics of the motor.

The armature A rotates within the stator and is provided with a commutator having brushes B. Instead, however, of short-circuiting the armature as shown in said patent, I adjustably impress voltage upon the armature winding from the transformer or auto-transformer T by means of adjustably moving the supplemental rider AR relative to said transformer or auto-transformer. I have found in practice that by supplementally adjustably impressing or varying the voltage impressed upon the armature winding, I am enabled to increase the speed range and in general improve the operating characteristics of the motor.

The speed of this motor may be adjusted by controlling ϕ_M and ϕ_Q as described in the above-mentioned patent, or by controlling the voltage V_A impressed upon the brushes. The voltage V_A is substantially in phase with E_{MT} above synchronous speed and in phase opposition to it below synchronous speed. It will be observed by referring to Fig. 3 of the above-mentioned patent that adding a voltage V_A in phase with E_{MT} will result in an increase in E_{qs} and a corresponding increase in speed. Similarly adding a voltage V_A in phase opposition to E_{MT} will decrease E_{qs} and the speed. Inasmuch as V_M and V_Q vary in proportion to ϕ_M and ϕ_Q , the speed of this motor may therefore be adjusted by controlling any one or all three of the variables V_M , V_Q and V_A , and may be approximately expressed by the following algebraic equation:

$$N = \frac{-I_a Z + K \phi_M f \pm V_A}{K \phi_Q} \quad (1)$$

where Z is the impedance of the armature circuit and I_a equals the armature current. This expression assumes that E_{qs} is in phase opposition to E_{MT} which is substantially the case as E_{qs} is only slightly displaced from this position to improve the performance of the motor.

The resultant voltage induced into the coil undergoing commutation must be small to prevent brush sparking and excessive losses due to circulating currents. This resultant voltage is made up of a transformer voltage e_t which is produced by the quadrature field flux and a speed voltage e_s which is produced by the main field flux. In the case of the single-phase motor referred to, these two component voltages are substantially in phase opposition to each other as shown by Fig. 4 so that the best commutation is obtained when

$$e_t = e_s \quad (2)$$

where $e_t = K \phi_Q f$ and $e_s = K \phi_M n$.

Therefore, in adjusting the speed of the above-mentioned single-phase motor in accordance with

Equation 1, it is advisable to adjust the controlling factors ϕ_m , ϕ_q and V_a in such a manner as to approximately satisfy Equation 2. Furthermore, it is possible to adjust the quantities ϕ_m , ϕ_q and V_a in such a way as to satisfy Equations 1 and 2 and at the same time maintain particular horsepower or torque characteristics. For instance, by adjusting ϕ_q inversely proportional to the speed, the motor will be inherently a constant horsepower motor, while if ϕ_q is maintained constant the motor will be inherently a constant torque motor.

In some cases it may not be practical to keep e_t and e_s exactly equal throughout the entire speed range. For example in Fig. 5, V_m , V_q and V_a are adjusted to satisfy Equation 2 and maintain constant horsepower characteristics only above synchronous speed. To maintain the same horsepower characteristics and keep e_s equal to e_t below synchronous speed, excessive main and quadrature field fluxes would be required if the field fluxes were normal at synchronous speed. Under this condition it might be advisable to obtain the speeds below synchronism by keeping V_m and V_q constant and adjusting V_a as indicated in Fig. 5. While e_s is not exactly equal to e_t when this is done, the resultant voltage induced into the coil undergoing commutation is small for speeds from synchronous to one-half synchronous speed. Constant torque characteristics will then be obtained below synchronous speed.

There are other cases where it may not be practical to maintain e_s exactly equal to e_t throughout the speed range. For example, if V_m is kept equal to V_q as indicated in Fig. 6, the auto-transformer is obviously simplified and the small difference between e_s and e_t in this case will not produce appreciable brush sparking throughout a large speed range.

The two component voltages e_t and e_s will be exactly in phase opposition when the two fields ϕ_m and ϕ_q are in exact time quadrature. In this case the two oscillating fields are in both space and time quadrature and when they are equal a circular revolving field results which is identical with that obtained from a polyphase machine. It therefore should be evident that commutation in a polyphase motor is equivalent to that of a single-phase motor when the main and quadrature fields are equal and in time quadrature.

The conditions of Fig. 6 therefore are applicable to a polyphase motor where the voltages indicated are phase voltages as shown in Fig. 13. By means of a circuit arrangement, such as indicated in Fig. 11, the speed of a three-phase commutator motor may be adjusted by controlling the voltages impressed upon the stator and armature brushes in such a manner as to keep the difference between e_s and e_t small and thus maintain very good commutation over a large speed range.

Figs. 5 and 6 represent graphs of suitable ways to satisfy the Equations 1 and 2 in the manner hitherto explained. To obtain these curves from Equation 1 the term $I_a Z$ drop will obviously not be the same for different motors and those skilled in the art can modify these curves to take into consideration the voltage drop for any particular motor. As will be apparent from an inspection of Figs. 1 and 5 there are three variables, namely, V_m , V_q and V_a . I have shown in Fig. 1 riders MR, QR and AR to adjustably contact the auto-transformer T to provide independent variation of each of these three variables. It is apparent

that if a voltage regulator be provided which will supply voltages to each of the stator windings, including the main winding and quadrature winding and the armature winding, separately and independently, in such predetermined combinations varying for different speeds in accordance with these curves or other curves to satisfy the respective equations at different speeds, the speed and transformer voltages induced into the coils undergoing commutation will be substantially equal at all speeds.

I have shown in Figs. 7 and 8 a voltage regulator so constructed which I will describe in more detail later. To provide a simpler motor, as illustrated in Figs. 2 and 6, and keep V_m equal to V_q , the auto-transformer T shown in Fig. 1 may be simplified into the transformer T shown in Fig. 2 and the small difference between e_s and e_t in this case will not produce appreciable brush sparking throughout a large speed range.

It is also apparent that by impressing the same voltage on the main and quadrature windings a much simpler voltage regulator may be provided which may be designed to act only for two instead of three variables. I have shown in Figs. 9 and 10 such a simplified voltage regulator which I will also describe in more detail later.

As stated hitherto, my invention is also applicable to a polyphase motor and I have shown in Fig. 11 a three-phase motor constructed in accordance with my invention. In such a motor there is provided a rotor A having a commutator armature winding, a stator having a separate stator winding M for each phase and a pair of brushes in contact with said commutator for each phase. In a polyphase motor of this description a quadrature winding is not necessary in order to produce the desired amount of torque, the desired amount of torque being provided by the relationship and connections of the respective various phase windings. The motor shown in Fig. 11, therefore, may be constructed in accordance with the curve shown in Fig. 6 to satisfy the two equations as shown in Fig. 13, which is a duplicate of Fig. 6. Thus in this type of motor, I adjust the voltage supplied to the stator windings M of each phase by means of riders MR in contact with the respective transformer T of each phase and I adjust the voltage supplied in said armature winding of each phase by means of riders AR also in contact with each respective transformer. I have shown in Figs. 14 and 15 a suitable voltage regulator to conjointly supply voltages to said stator and armature windings simultaneously in such predetermined combinations varying for different speeds as to cause the speed and transformer voltages induced into the coils undergoing commutation to be substantially equal at all speeds and substantially to satisfy said two equations, which I will describe in more detail later.

I also provide means to provide in each rotor circuit a power factor improving component of voltage. In place of employing an expensive capacitor for this purpose, however, in the preferred embodiment shown I provide the power factor coils C in each rotor circuit which may be readily energized from other phases as shown. Furthermore, by displacing the brushes B1, B1; B2, B2 and B3, B3 for the respective phases from the axis of their respective stator windings, I may supplementally improve the power factor. The magnitude of the power factor improving component derived from said power factor improving coils and the power factor improving

component of voltage derived by displacing the brushes is dependent upon the design of the motor and the speeds desired. It is evident that in general high power factor and high torque per ampere are inseparable and it is understood that the said means for producing a high power factor will also produce high torque per ampere because of the favorable phase relation between the armature currents and the torque-producing fluxes. The upper portion of the diagram shown in Fig. 11 diagrammatically illustrates the control which may comprise a linear transformer as diagrammatically illustrated therein having the adjustable riders MR for regulating the voltage impressed through the main winding MW and adjustable riders AR for regulating the voltage impressed through the armature winding AW for each phase, or each respective transformer T may comprise a ring auto-transformer as shown in Figs. 14 and 15.

The revolving field set up by a polyphase motor is equivalent to a field produced by two oscillating fields ϕ_m and ϕ_q which are equal and in time and space quadrature and thus may be represented by a vector diagram, as shown in Fig. 12, which also includes e_1 and e_2 . This diagram is the same as that for a single-phase motor with the quadrature winding equal to and in time and space quadrature with the main winding.

Therefore, ϕ_m and ϕ_q may be considered to exist in the armature whether produced by the main and quadrature windings of the single-phase motor or by the combined effect of the stator phase windings of a polyphase motor. However, in a polyphase motor ϕ_m and ϕ_q are equal and in time and space quadrature, while in a single-phase motor ϕ_m and ϕ_q may be unequal and not in exact quadrature as explained herein. It is understood, therefore, that ϕ_m and ϕ_q used in Equation 1 are produced by the combined effect of the stator windings and that they are equal and in time and space quadrature in a polyphase motor.

Figs. 7-10 and 14-15 illustrate different voltage regulators which may be employed for adjusting the voltages impressed upon the various windings by a unitary control. Such regulators can be designed to supply adjustable voltages in any desired manner, such for example as are illustrated in Figs. 5 and 6. However, it may be practical for some applications to use a simpler controller using a system of links or gears which will approximate the voltage relations that may be obtained from the regulator. It is possible that linear voltage characteristics approximating voltage relations such as illustrated in Figs. 5 and 6 will in some cases be satisfactory and if such is the case, the controller is obviously simplified.

I have shown in Figs. 7 and 8 and diagrammatically illustrated in the upper portions of Figs. 1 and 2 a suitable type of voltage regulator to adjust the positions of the respective riders AR, MR and QR, separately and independently, relative to the transformer winding TW spirally wound around the transformer core TC to supply separate voltages to said main winding, quadrature winding and armature winding to satisfy said equations, or in such predetermined combinations varying for different speeds as to cause the speed and transformer voltages induced into the coils undergoing commutation to be substantially equal at all speeds in accordance with the respective armature voltage curve, main field

voltage curve, and quadrature field voltage curve shown in Fig. 5. For this purpose the transformer T, in place of being linear as diagrammatically illustrated in Figs. 1 and 2, is made in the form of a ring rigidly mounted in the bottom of a casing and I mount a shaft 24 concentric with the center of the ring having a plurality of independently rotatable collars AC, QC and MC loosely mounted in superimposed relationship thereon. Each collar is provided with a respective gear AG, QG and MG and has a respective arm depending therefrom adapted to carry the respective riders AR, QR and MR to respectively contact the transformer winding on the transformer core TC. In the embodiment shown, the quadrature winding rider QR is adapted to contact the interior of the transformer core TC and the main rider MR and armature rider AR are adapted to contact respectively the exterior of said ring. A separate shaft 26 is independently mounted within the regulator box 28 and has rigidly mounted thereon the respective cams provided with the respective cam slots MS, main slot, QS, quadrature slot and AS, armature slot in the same superimposed relationship as the respective main collar MC, quadrature collar QC and armature collar AC are mounted on the shaft 24. A supplemental shaft 30 is also mounted within said regulator box 28 intermediate the shafts 24 and 26, and has loosely mounted thereon in the same superimposed respective relationship the main lever ML, the quadrature lever QL and the armature lever AL. The power arm of each of said levers is provided with a pin MP, QP or AP respectively, adapted to ride in the respective cam slots MS, QS and AS and at the opposite end thereof with respective gear segments adapted to mesh with and actuate the respective gears MG, QG and AG on the respective collars MC, QC and AC to actuate the respective riders MR, QR and AR relative to the transformer winding TW. The upper end of the shaft 26 is provided with the turning handle 32. The cam slots MS, QS and AS are constructed exactly in accordance with the respective main voltage curve, quadrature voltage curve and armature voltage curve shown in Fig. 5. It is thus obvious that on rotation of the handle 32, the respective cams will be rotated so that the respective pins will ride in the respective cam slots to move the respective riders relative to the transformer winding separately and independently, substantially in accordance with the respective curves shown in Fig. 5, to supply voltages to said respective main, quadrature and armature windings substantially in accordance with the two equations and in such predetermined combinations varying for different speeds as to cause the speed and transformer voltages induced into the coils undergoing commutation to be substantially equal at all speeds.

I have shown in Figs. 9 and 10 a voltage regulator adapted to function substantially in accordance with the graph shown in Fig. 6 to simultaneously vary the voltages supplied to the stator windings and the armature winding substantially in accordance with the two equations and in such predetermined combinations varying for different speeds as to cause the speed and transformer voltages induced into the coils undergoing commutation to be substantially equal at all speeds. As hitherto explained, in accordance with the graph shown in Fig. 6, I supply at all speeds equal voltages to the main and quadra-

ture windings so that only one voltage curve is required for the different speeds. In place, therefore, of constructing different cams to regulate the movements of two different riders in accordance with different curves, I mount the respective riders $(M+Q)R$ and AR diametrically of the ring T , and I arrange the respective windings $(M+Q)W$ and AW on the transformer core TC , such as by varying the spacings and number of the turns or otherwise in accordance with their respective curves. Inasmuch as the percentage changes of movement desired in the respective rider $(M+Q)R$ and AR are substantially equal to satisfy the curves shown in Figs. 6 and 13, it is obvious that the respective riders may be moved equally respective amounts to satisfy said curves and equations as shown in Figs. 9 and 10, the transformer T again being rigidly mounted in the transformer box 28. I provide a shaft 34 extending through the cover of the box having a diametric yoke Y mounted thereon having arms depending therefrom adapted to carry the respective riders AR and $(M+Q)R$ to contact the respective windings AW and $(M+Q)W$ diametrically of said ring on rotation of the handle 32 mounted on the upper end of said shaft 34.

I have shown in Figs. 14 and 15 a suitable type of control means for the polyphase motor shown in Fig. 11. Inasmuch as the respective riders MR and AR on the respective transformers $T1$, $T2$ and $T3$ for the three different phases may be adjusted simultaneously in accordance with the curves shown in Fig. 13, which as stated are similar to the curves shown in Fig. 6, a plurality of the control means shown in Figs. 9 and 10, which operate in accordance with the curves shown in Fig. 6 may be superimposed one upon each other for each transformer $T1$, $T2$ and $T3$ for each respective phase. Thus the respective transformer cores $TC1$, $TC2$ and $TC3$ are superimposed one above the others and a plurality of yokes $Y1$, $Y2$ and $Y3$ are rigidly mounted in the desired superimposed spaced relationship on the shaft 34 rotated in similar fashion as in Figs. 9 and 10 by the handle 32 to carry respectively and operate the respective riders $MR1$ and $AR1$, $MR2$ and $AR2$ and $MR3$ and $AR3$ respectively in equal diametric relationship in contact with the respective armature and main windings $AW1$ and $MW1$, $AW2$ and $MW2$, and $AW3$ and $MW3$ on the respective transformer cores $TC1$, $TC2$ and $TC3$. The respective windings on each core are similar to the windings hitherto described in Figs. 9 and 10 to satisfy the curves shown in Figs. 6 and 13. The respective power factor coils c in each rotor circuit are shown in Fig. 15 mounted adjacent one end of each respective armature winding.

It will be also noted that the parts of my device enclosed in dotted rectangles in Figs. 1, 2 and 11, including the voltage regulators heretofore described, also comprise novel types of transformers. It will also be noted that in all embodiments shown I have provided means adapted to connect the other side of the respective loads, namely the armature winding, main winding, and/or quadrature winding, to fixed points on the winding turns T . In the embodiment shown in Fig. 1, "the other sides of each of these loads" are connected to a single fixed point on the winding turns T . It is apparent that they may be individually connected to separate fixed points if desired. In the embodiment shown in Fig. 2, the armature winding is connected to a separate fixed point from that at

which the main and quadrature windings, connected in this instance in parallel, are connected to said winding turns T . In the embodiment shown in Fig. 11, the other sides of the respective loads are connected at different fixed points on said winding turns T . While I employ the words "fixed points" in the claims, it is apparent that if desired, said loads may, as shown in Fig. 1, be connected to said winding turns through a single common fixed point. While I employ the clause in the claims "control means for simultaneously moving said power transmitting means with respect to said winding turns," or its equivalent, said means also controls the movement of the respective power transmitting means and it is apparent, particularly in the embodiment of my invention shown in Figs. 7 and 8, that if desired at certain stages of operation one or more of said power transmitting means may temporarily remain stationary.

It is thus obvious that I have provided various novel embodiments of voltage regulators all employing the principles of my invention with the advantages described above.

For convenience, I append a list of the symbols used in this specification in referring to the various electric forces considered.

ϕ_M = Main field flux
 ϕ_Q = Quadrature field flux
 V_A = Voltage impressed upon brushes
 E_{MT} = Transformer voltage induced into armature from main field flux
 E_{QS} = Speed voltage generated in armature from quadrature field flux
 V_Q = Quadrature field voltage
 V_M = Main field voltage
 N = Speed
 I_a = Armature current
 Z = Impedance of armature current
 f = Frequency
 e_t = Transformer voltage induced into coil undergoing commutation
 e_s = Speed voltage generated in coil undergoing commutation
 n = Speed multiplied by number of pairs of poles
 K = Constant

It is understood that my invention is not limited to the specific embodiments shown herein and that various deviations may be made therefrom without departing from the spirit and scope of the appended claims.

What I claim is:

1. A voltage regulator comprising an annular magnetic ring, winding means wound around said ring connectable to a supply, shaft means having an axis concentric with said ring, a plurality of collars loosely mounted on said shaft, a plurality of cooperating power transmitting riders, each connectable to the means to be regulated, and each mounted on a collar to rotate in respect to said ring in contact with said winding means, each collar having a gear mounted thereon, a lever for each rider mounted on said regulator having a quadrant gear on one end thereof in mesh with its respective collar gear and a pin on the opposite end thereof, a shaft also mounted on said regulator having an operating handle therefor and having individual cam means for each rider mounted thereon constructed in accordance with the desired predetermined movements for each rider contacting each respective pin.
2. A transformer for simultaneously obtain-

ing a plurality of variable output voltages for a plurality of loads from a single A. C. source comprising, a magnetic core, winding turns wound on said core, a plurality of power transmitting means cooperating with said winding turns, control means for simultaneously moving said power transmitting means with respect to said winding turns, said control means moving each power transmitting means over a different number of turns than each other transmitting means on said winding turns, during a given movement of said control means, means adapted to connect each power transmitting means to one side of a separate load respectively, means adapted to connect the other sides of said loads to fixed points on said winding turns, and means adapted to connect fixed points on said winding turns to a source of A. C.

3. A transformer for simultaneously obtaining a plurality of variable output voltages for a plurality of loads from a single A. C. source comprising, a magnetic core, a set of winding turns of uniform pitch wound on said core, a plurality of power transmitting means cooperating with said set of winding turns, means for simultaneously moving each of said power transmitting means relative to said set of winding turns and relative to each of the other power transmitting means, means adapted to connect fixed points of said winding means to a source of A. C., means adapted to connect each of said power transmitting means to one side of each load respectively, and means adapted to connect the other sides of said loads respectively to a common one of said fixed points on said set of winding turns.

4. A transformer for simultaneously obtaining a plurality of variable output voltages for a plurality of loads from a single A. C. source, comprising, a magnetic core, one set of winding turns of a given pitch wound on said core, a second set of winding turns of a different pitch than that of the first set also wound on said core, said sets of turns being spaced from one another, power transmitting means for cooperating with each set of windings, means for simultaneously moving said power transmitting means over said windings, means adapted to connect fixed points of the first set of windings to a source of A. C., means adapted to connect a fixed point of each of the sets of windings to one side of each load, respectively, and means to connect the power transmitting means for each set of windings to the other side of each load, respectively.

5. A transformer for simultaneously obtaining a plurality of variable output voltages for a plurality of loads from a single A. C. source comprising, a magnetic core, a set of winding turns of uniform pitch wound on said core, a plurality of power transmitting means cooperating with said set of winding turns, means for simultaneously moving each of said power transmitting means relative to said set of winding turns and relative to each of the other power transmitting means, means adapted to connect fixed points of said winding means to a source of A. C., means adapted to connect each of said power transmitting means to one side of each load respectively, and means adapted to connect the other side of said loads respectively to fixed points on said set of winding turns.

6. A transformer for simultaneously obtaining a plurality of variable output voltages for a plurality of loads from a single A. C. source, comprising, a plurality of magnetic cores, each core having one set of winding turns of a given pitch

wound on said core, and a second set of winding turns of a different pitch than that of the first set also wound on said core, said sets of turns being spaced from one another, power transmitting means for cooperating with each set of windings, means for simultaneously moving said power transmitting means over said windings, means adapted to connect fixed points of each of the first sets of windings to a source of A. C., means adapted to connect a fixed point of each of the sets of windings to one side of each load, respectively, and means to connect the power transmitting means for each set of windings to the other side of each load, respectively.

7. A transformer for simultaneously obtaining a plurality of variable output voltages for a plurality of loads from a single A. C. source comprising an annular magnetic ring, one set of winding turns of a given pitch wound on a portion of said ring, a second set of winding turns of a different pitch than that of said first set wound on a different portion of said ring, said sets of winding turns being spaced from one another, power transmitting means for cooperating with each set of windings, rotatable means having an axis concentric with said ring, and means for supporting each of said power transmitting means in continuous association with its respective set of windings mounted on said rotatable means to simultaneously move said power transmitting means over said windings on rotation of said rotatable means, means adapted to connect fixed points of the first set of windings to a source of A. C., means adapted to connect a fixed point of each of the sets of windings to one side of each load, respectively, and means to connect the power transmitting means for each set of windings to the other side of each load, respectively.

8. A transformer for simultaneously obtaining a plurality of variable output voltages for a plurality of loads from a single A. C. source comprising a plurality of superimposed annular magnetic rings, each of said rings having one set of winding turns of a given pitch wound on a portion of said ring, and a second set of winding turns of a different pitch than that of said first set wound on a different portion of said ring, said sets of winding turns being spaced from one another, power transmitting means for cooperating with each set of windings, rotatable means having an axis concentric with said rings, and means for supporting each of said power transmitting means in continuous association with its respective set of windings mounted on said rotatable means to simultaneously move said power transmitting means over said windings on rotation of said rotatable means, means adapted to connect fixed points of each said first sets of windings to a source of A. C., means adapted to connect a fixed point of each of the sets of windings to one side of each load, respectively, and means to connect the power transmitting means for each set of windings to the other side of each load, respectively.

9. A transformer for simultaneously obtaining a plurality of variable output voltages for a plurality of loads from a single A. C. source comprising, a magnetic core, a set of winding turns of uniform pitch wound on said core, a plurality of power transmitting means cooperating with said set of winding turns, means for simultaneously moving each of said power transmitting means relative to said set of winding turns and relative to each of the other power transmitting means, including individual cam means for each

power transmitting means each constructed to provide said relative movement for its respective power transmitting means, means adapted to connect fixed points of said winding means to a source of A. C., means adapted to connect each of said power transmitting means to one side of each load respectively, and means adapted to connect the other side of said loads respectively to a common one of said fixed points on said set of winding turns.

10. A transformer for simultaneously obtaining a plurality of output voltages for a plurality of loads from a single A. C. source comprising, an annular magnetic ring, a set of winding turns of uniform pitch wound on said ring, a plurality of power transmitting means cooperating with said set of windings turns, shaft means having an axis concentric with said ring, means for rotatably supporting each of said power transmitting

means on said shaft means in continuous association with said set of winding turns, means for moving each of said power transmitting means relative to said set of winding turns and relative to each of the other of said power transmitting means, including a movable handle and individual cam means for each power transmitting means, each constructed to provide said relative movement for its respective power transmitting means moved by said handle to so move its respective power transmitting means, means adapted to connect fixed points of said winding means to a source of A. C., means adapted to connect each of said power transmitting means to one side of each load respectively, and means adapted to connect the other side of said loads respectively to fixed points on said set of winding turns.

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