No. 767,351. PATENTED AUG. 9, 1904.

J. G. V. LANG.

METHOD OF REGULATING ELECTRIC MOTORS.

APPLICATION FILED APR. 30, 1904.

NO MODEL. 4 SHEETS—SHEET 1.

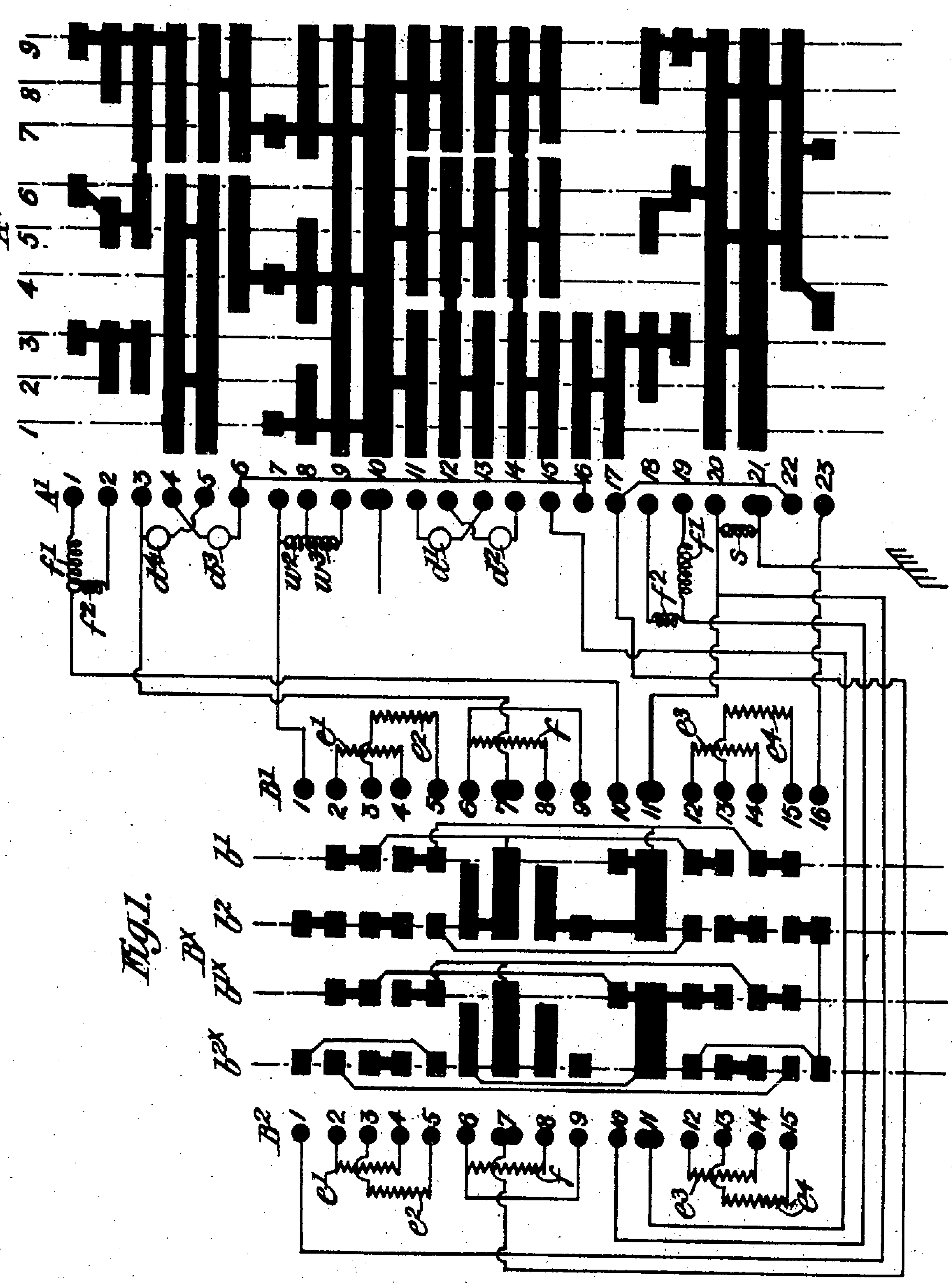

Fig. 1.

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NO MODEL. 4 SHEETS—SHEET 2.

Fig. 2.

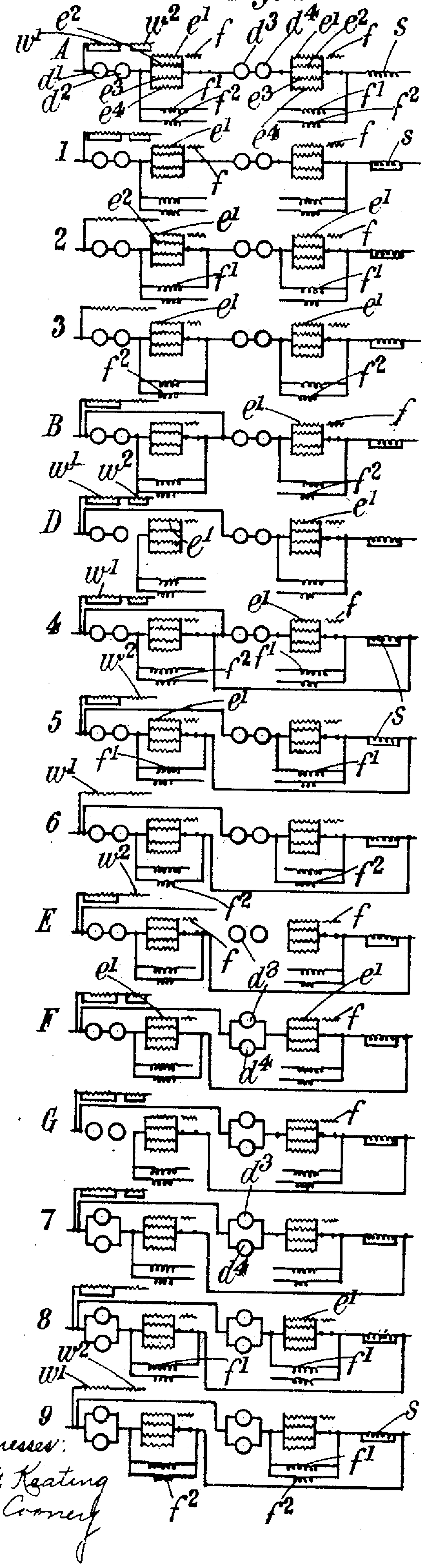
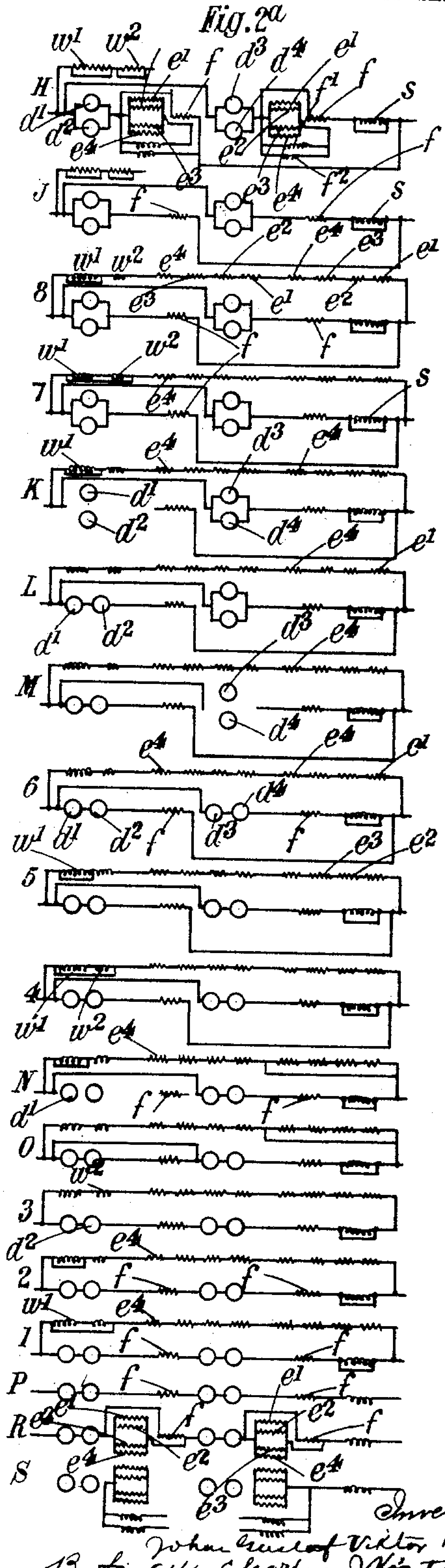


Fig. 2a



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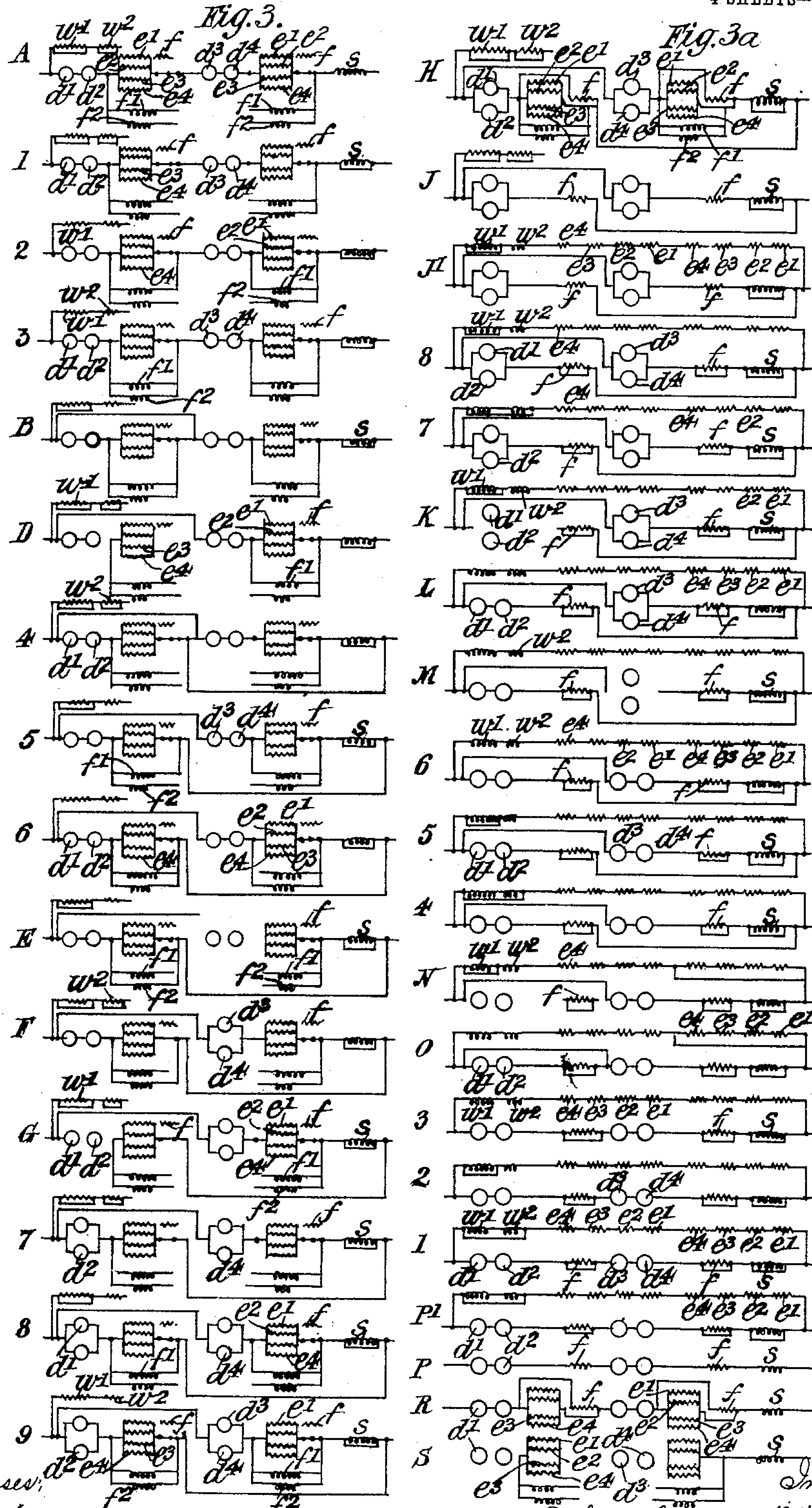

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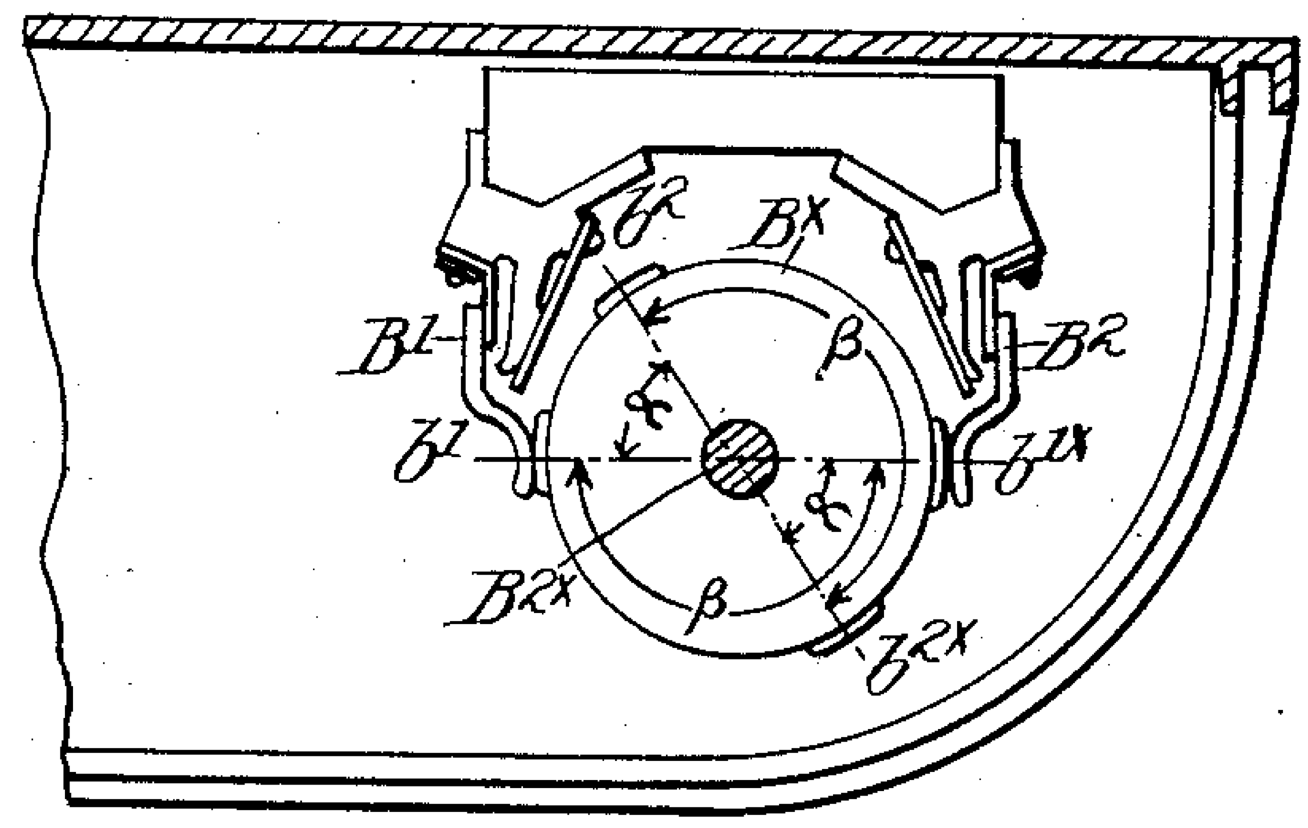
NO MODEL. 4 SHEETS—SHEET 4.

Fig. 4



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UNITED STATES PATENT OFFICE.

JOHAN GUSTAF VIKTOR LANG, OF LONDON, ENGLAND, ASSIGNOR OF ONE-HALF TO EDWARD HIBBERD JOHNSON, OF LONDON, ENGLAND.

METHOD OF REGULATING ELECTRIC MOTORS.

SPECIFICATION forming part of Letters Patent No. 767,351, dated August 9, 1904.

Original application filed February 1, 1904, Serial No. 191,620. Divided and this application filed April 30, 1904. Serial No. 205,717. (No model.)

To all whom it may concern:

Be it known that I, JOHAN GUSTAF VIKTOR LANG, electrician, a subject of the King of Sweden and Norway, residing at 16[a] Soho Square, London, England, have invented an Improved Method of Regulating Electric Motors, of which the following is a specification.

This invention relates to a method of and means for regulating electric motors, particularly those of the kind that are employed for propelling vehicles and that work on a regenerative system, in which the motors act as such while propelling and accelerating the vehicle and act as generators for returning electric energy to the source of supply while braking or retarding the vehicle.

In the specification of a previous application for United States Patent, Serial No. 203,838, filed April 19, 1904, there was described a method whereby the series windings of two or more double-wound motors were so constructed and subdivided for the purpose of saving space occupied by the motors and copper used for the windings that said subdivisions could be connected in various parallel relationship and then be used as part of the shunt-winding. For effecting this change from series to shunt, or vice versa, a special field-change cylinder was set forth in said prior specification. It has been found that the aforesaid change when effected by said change-cylinder causes a considerable shock in the motors, which shock is sometimes sufficient to operate the overload-switch of the vehicle, thus causing inconvenience. This shock may be explained by the fact that the strength of the magnetic field of the motors decreases to practically zero at the moment of breaking the field-circuit to change from the series to the shunt condition, or vice versa. As some time is required to enable the field to resume its original strength, it follows that the motor-armatures momentarily revolve in a very weak magnetic field, with the result that the counter electromotive force falls almost to zero, while the voltage remains unchanged, so that in order to balance the difference in voltage between the line-pressure or power-circuit and the counter electromotive force a rush of current through the motors takes place. According to the present invention this rush of current is avoided by retaining in the circuit of the series field-windings or introducing into such circuit a certain amount of series turns when the series field-winding is broken in changing from the series to the shunt condition (said series turns being, if desired, employed partly or wholly to form the series windings for the compound excitation) and when the shunt field-winding is broken in changing from the shunt to the series condition still retaining in the said circuit or introducing thereinto a certain amount of series turns, which when the said change has been completely effected—*i. e.*, the full series excitation established—are either totally or partially cut out of circuit or are kept in circuit as part of the complete series field-windings. By this arrangement also not only is the aforesaid rush of current avoided, but the sparking at the contacts of the controller is minimized when the portion of the series field-winding which is formed by the paralleling of the shunt-windings is broken. This reduction of the sparking results from not completely breaking the field-circuit, and therefore not rendering the motors electrically inactive, but, on the contrary, leaving the motor-armatures in circuit and with a magnetic field of considerable intensity for them to revolve in, thereby making this part of the motor control conform with the principle of what is known as "closed-circuit control." Instead of applying this closed-circuit-control principle only at the times when the field-windings are being changed from series to shunt, or vice versa, it will be found preferable to apply the principle throughout all the changes that are made in the series, series-parallel, and parallel relationship of the armatures, as will be hereinafter explained. It should here be stated that for series-wound motors regulated in the usual way by means of resistances in the armature-circuit and simple series paralleling of the field-windings the closed-circuit principle of control is not novel.

Neither is it novel to employ the said closed-circuit principle of control with compound-wound motors in which there are two separate shunt fields and in which the various combinations of armatures, fields, and resistances are alike for a particular speed-notch of the controller, whether such notch is reached by a forward movement of the controller-cylinder—*i. e.*, from zero toward the highest-speed notch—or by a backward movement of the controller-cylinder—*i. e.*, from the highest-speed notch toward zero. In the present case, however, where the regulation of the speed of the motors is effected by means of changes in the strength of the magnetic field of the motors and where by a backward movement of the controller-cylinder the constitution of the field-windings is radically changed, the application of the closed-circuit principle of control is believed to be novel and for the first time employed in such connection.

In order that the said invention may be clearly understood and readily carried into effect, the same will be described more fully with reference to the accompanying drawings, in which—

Figure 1 is a diagrammatic development of the various stationary and movable contacts of the improved controller. Figs. 2 and 2^a are diagrammatic representations of the various combinations established by the movements of the cylinders of said controller when the machines are of the compound-wound type, Fig. 2 representing the various combinations when the controller-handle is turned in a forward direction, and Fig. 2^a representing the various combinations when the controller-handle is turned in a backward direction. Figs. 3 and 3^a are diagrammatic views similar to Figs. 2 and 2^a, showing the various combinations that are established by the movements of the cylinders of the controller when the machines are of the shunt-wound type. Fig. 4 is a horizontal section of the reversing and field-change cylinder and its stationary contacts used with this method of control.

$A^{\times}$ represents the main controller-cylinder, and A′ the stationary row of contacts with which it coöperates, said stationary contacts being numbered from "1" to "23."

$B^{\times}$ represents the combined reversing and field-change cylinder, and B′ B^2 are the rows of stationary contacts with which it coöperates, the row B′ being numbered from "1" to "16" and the row B^2 from "1" to "15." The four vertical rows of black squares b' b^2 $b'^{\times}$ $b^{2\times}$ represent the various movable contacts with which the said reversing and field-change cylinder $B^{\times}$ is provided. The stationary contacts B′ B^2 are situated on opposite sides of the cylinder $B^{\times}$, those on one side being connected with the field-windings of one of the two double-wound motors and those on the other side being connected with the field-windings of the other of the two motors. There are nine notches of the controller, (represented by the numerals 1 to 9,) arranged in three groups, as set forth in the specification of the aforesaid prior application for patent. In the example illustrated there are supposed to be two double-wound electric motors, of which the circles d' d^2 d^3 d^4 represent the armatures.

e' e^2 e^3 e^4 represent groups or subdivisions of the series windings, which are so dimensioned as to enable them to serve as series windings when connected in parallel and as shunt-windings when connected in series. f f represent other groups or subdivisions of the series windings, which are introduced only during the period of regeneration, it being understood that the windings e' to e^4 when paralleled enable the motors to work like series-wound motors and that when said windings e' to e^4 are thrown from their paralleled condition to their series condition they enable the motors to work as compound-wound machines.

s is the starting resistance, and f' f^2 are field resistances, the former of which is ohmically higher than the latter.

In Figs. 2 and 2^a the letters and numerals on the left-hand side of the diagrams represent the various speed changes and transition steps between such changes, the numerals indicating the speed changes and the letters the transition steps, said transition steps taking place between notches 3 and 4 and notches 6 and 7 when the controller-handle is being turned in a forward direction and between notches 9 and 8, 7 and 6, and 4 and 3 when the controller-handle is being turned in a backward direction. It is to be observed that the same transitions as between notches 9 and 8 are repeated whenever a change from motor to generator characteristic takes place and similarly that the same transition as between notches and "off" are repeated whenever a change from generator to motor characteristic takes place.

Referring more particularly to Figs. 2 and 2^a, diagram A shows the two double-wound motors in series connection, the field resistances f' f^2 and the windings f being disconnected. In this condition of the parts the whole current passes through the windings e' to e^4 in parallel and the starting resistance s and the field excitation is at its maximum and the motors are operating to start the vehicle into motion. At diagram 1, Fig. 2, which represents the condition of the motors when the controller-handle is turned to the first or lowest-speed notch for increasing the speed of propulsion of the vehicle, the connections are the same as in diagram A, with the exception that the starting resistance s has been short-circuited. At diagram 2, Fig. 2, which represents the condition of the motors when the controller-handle is turned to the second-speed notch, the connections differ from diagram 1 only to the extent that the high resistances f' are put in circuit, thus diverting part of the current from the field-windings e' to e^4 and weakening the field. At diagram 3, Fig. 2, (the next-succeeding speed-notch,) more of the current is diverted from the field-windings e' to e^4 than in diagram 2 by the introduction into the circuit of the other resistances f^2, thus still further weakening the field excitation. In effecting the change of speed from notch 3 to notch 4 the motors are changed from their series connection to their series-parallel connection by two transition steps, (diagrams B and D)—that is to say, the field of one motor is first strengthened, as at diagram B, by cutting out the resistance f^2 and then the other motor, with its two armatures and field-windings, is short-circuited, as is generally done, and almost simultaneously the circuit through the armature and field-windings of the short-circuited motor is broken, as at diagram D, thus leaving one motor to do all the work. At diagram 4, Fig. 2, (the next-succeeding speed-notch,) the short-circuited motor in diagram D is reintroduced, with maximum field strength in parallel with the other motor, the field of which latter is simultaneously strengthened to its maximum by breaking its field resistances f' f^2. At diagram 5, Fig. 2, (the next-succeeding speed-notch,) the maximum field strength of the motors in diagram 4 is weakened by the introduction of the high resistances f', as in diagram 2. At diagram 6, Fig. 2, (the next-succeeding speed-notch,) the field strength of the motors is slightly increased by substituting for the high resistances f' in diagram 5 the low resistances f^2. In effecting the change of speed from notch 6 to notch 7 the motors are changed from their series-parallel connection (in which they existed in diagrams 4, 5, and 6) to full-parallel connection by three transition steps, (diagrams E, F, and G)—that is to say, the circuit connections of one motor and its field are first broken, as at diagram E, leaving the other motor undisturbed. The disconnected motor, with its armatures in parallel and with maximum field strength, is then reintroduced, as at diagram F, and afterward the other motor is disconnected, as at diagram G, and rearranged and reintroduced with its armatures in parallel and with maximum field strength, thus bringing about the arrangement indicated at diagram 7, Fig. 2. At diagram 8, Fig. 2, (the next-succeeding speed-notch,) the field strength of both motors is weakened by the introduction of the high resistances f', and at diagram 9, Fig. 2, (the next and last succeeding speed-notch), the field strength of both motors is further weakened by the introduction of the low resistances f^2 in addition to the said resistances f'. When the controller-handle is turned backward, the reversing and field-change cylinder $B^\times$ is shifted angularly through the angle—sixty degrees, thus moving its contacts b' and $b'^\times$ away from the rows of stationary contacts B' B^2 and bringing its contacts b^2 $b^{2\times}$ into engagement therewith. This movement of the cylinder $B^\times$ causes the contacts 6 and 8 of the rows of stationary contacts B' B^2, Fig. 1, to engage with the contacts of the cylinder $B^\times$, this engagement taking place before the other stationary contacts of the rows B' B^2 break connection with the rotary contacts b' and $b'^\times$. By the aforesaid change of contacts effected by the angular movement of the cylinder $B^\times$ through the sixty degrees a certain amount of series turns f, Figs. 1, 2, and 2^a, are introduced, with the result that the connections are as represented in diagram H, Fig. 2^a. By the continued backward movement of the controller-handle a moment later the field-windings, consisting of the paralleled groups e' to e^4, are broken and only the field-windings f remain in circuit, as shown in diagram J. As soon as the rotary contacts b^2 $b^{2\times}$ of the cylinder $B^\times$ have made contact with the stationary rows of contacts B' B^2 the groups of field-windings e' to e^4 are connected together in series and, together with the windings f, convert the machines into their compound condition, as represented at diagram 8, Fig. 2^a, without interrupting the circuit through the armatures, the shunt resistance w' being short-circuited and the shunt resistance w^2 retained in circuit. At diagram 7, Fig. 2^a, the field strength is increased by short-circuiting both the shunt resistances w' w^2. In changing back from the full-parallel to the series-parallel condition of the motors the armature-circuit of one motor is broken, as at diagram K, leaving the shunt field of the same in circuit and the resistance w' is short-circuited. Then the armatures of the disconnected motor are rearranged and reintroduced into the circuit, as at diagram L, both of the shunt resistances w' w^2 being then in circuit. The same operation of breaking and reintroducing the other motor is repeated as shown in diagram M and diagram 6, Fig. 2^a, thus bringing about the series-paralleling condition of the motor. At diagram 5, Fig. 2^a, (where the controller-handle has been turned back another speed-notch) the shunt resistance w' is cut out of circuit to strengthen the shunt-winding and at diagram 4, Fig. 2^a, (where the controller-handle has been turned back another speed-notch,) the other shunt resistance, w^2, is also cut out of circuit to still further strengthen the shunt-winding. In passing from the series parallel to the series condition it is necessary to short circuit one motor at the moment it is being introduced in series with the other. To effect this without developing a dangerous short-circuiting current, the field must be reduced as much as possible. Therefore, at the moment of breaking the circuit of one motor in leaving the series-parallel condition its shunt field is short-circuited, as at diagrams N and O, a suitable resistance being at the same time introduced in the field of the other motor, as shown in these diagrams, to prevent an excessive development of its field strength. Thus the speed-notch represented by diagram 3, Fig. 2^a, is reached, the continued backward movement of the controller-handle bringing about the cutting out of the circuit of first one and then the other of the shunt resistances w' w^2 as speed-notches 2 and 1 are reached, as represented in diagrams 2 and 1, Fig. 2^a. The continued backward movement of the controller-handle causes the shunt-windings to be broken, as at diagram P, and to be reintroduced in their series condition, as at diagram R, and eventually breaks the connections when the said controller-handle reaches the off position, as represented in the diagram S. It is to be remarked that in passing through the various speed steps during the backward movement of the controller-handle, Fig. 2^a, no change takes place in the series field. In the shunt field the resistances are short-circuited until the armature combination has been changed, (see diagrams 7 and 4,) whereupon the said shunt resistances w' w^2 are successively reinserted, thus weakening the field—that is to say, at speed-notches 8, 5, and 2, Fig. 2^a, one resistance—viz., w^2—is in series with the shunt field, the other resistance—viz., w'—being short-circuited. At speed-notches 7, 4, and 1, Fig. 2^a, both of the shunt resistances w' w^2 are short-circuited and at speed-notches 6 and 3, Fig. 2^a, both of the said resistances w' w^2 are in series with the field-windings. The transition steps (shown by diagrams P and R) are typical transitions for changing the field from the shunt to the series condition. The shunt field is first broken, leaving the series turns in circuit, diagram P. The shunt-windings e' to e^4 are then rearranged—*i. e.*, converted into the parallel condition and reintroduced as series windings in parallel with the other series windings f, diagram R. Then these series windings f are entirely removed from the circuit, diagram S, and at the same time the armature and field connections are broken by the controller-handle reaching the off position.

The flow of the current through the various connections will now be traced in connection with Fig. 1. For this purpose let it be assumed that the controller-handle occupies the speed-notch 3, where the motors will be in the condition represented by diagram 3 of Fig. 2 and operating to propel the vehicle. The row of rotary contacts b' of the cylinder $B^{\times}$ will then be in contact with the row of stationary contacts B', and the row of rotary contacts $b'^{\times}$ of said cylinder $B^{\times}$ will be in contact with the row of stationary contacts B^2, as represented in Fig. 4, it being understood that the main controller-cylinder $A^{\times}$ will be occupying a position in which its row of contacts 3 will be in contact with the stationary row of contacts A', Fig. 1. Then the current will flow from the trolley-contact 10 through the main-cylinder contacts to contact 11, through armature d', contact 13, and main-cylinder contacts to contact 12, armature d^2, contact 14, then through the main-cylinder contacts to contact 15 and contact 11 of the row of stationary contacts B^2. Here the current divides, part of it passing to contact 10 (row B^2) and thence through the resistances f' f^2 to contacts 18 and 19 of row A', whence it passes through the main-cylinder contacts to contact 17 of row A'. The other part of the current passes through the row of contacts $b'^{\times}$ of cylinder $B^{\times}$ to the stationary contacts 2, 3, 12, and 13 of row B^2 and passes simultaneously through the field-windings e' e^2 e^3 e^4 belonging to the armatures d' d^2 and returns to the contacts 4, 5, 14, and 15 of the row B^2 and unites again at contact 7 of said row B^2. From this contact 7 the current returns to the main cylinder $A^{\times}$ through contact 17 of row A', where it unites with the part from contacts 18 and 19 and passing over the main-cylinder contacts reaches contact 16 and thence flows to contact 6 of row A'. The current then flows through armature d^3 to contact 4 of row A', and from this contact it flows through the contacts of the main cylinder $A^{\times}$ to the contact 5 of row A', and thence through armature d^4 and contact 3 of row A', which is electrically connected with contact 7 of the stationary row of contacts B'. Here the current again divides, part of it passing through the row of contacts b' of the cylinder $B^{\times}$ and reaching the contacts 2, 3, 12, and 13 of row B', the other part passing through the field-windings e' e^2 e^3 e^4 belonging to the armatures d^3 d^4 of the motors and returning through contacts 4, 5, 14, and 15 of row B' and uniting again at contact 11 of row B'. Thence the current flows to contact 20 of row A' and through the contacts of main cylinder $A^{\times}$ reaches contact 21 and flows to earth. The current also passes through the resistance f' f^2 of the other motor and reaches the contact 10 of row B'. It then flows through the contacts b' of cylinder $B^{\times}$ to contact 11 of row B' and unites with the other part of the current at contact 20 of row A' and also reaches earth through contact 21. Let it now be assumed that the controller-handle is turned in a backward direction from the speed-notch 3 to speed-notch 2 in order to bring about the retarding or braking of the vehicle, or, in other words, to change the series condition of the motors to their compounding condition, so that they will act as generators and return current to the main supply. Their condition will then be as shown at diagram 2 of Fig. 2^a and the flow of the current will be as follows, it being understood that the cylinder $B^{\times}$ is then in the position in which its contacts b^2 and $b^{2\times}$ are respectively in contact with the rows of stationary contacts B' B^2 and the main cylinder $A^{\times}$ is in the position in which its contacts 2 are in contact with the row of contacts A′: The current passes through contact 10 of row A′ to contact 11 of said row, and thence flows through armature d', contact 13, (row A′,) contact 12, (row A′,) armature d^2, and contact 14, (row A′,) to contact 15, (row A′.) Thence the current flows to contact 11 of row B^2, and here it finds only one path of contacts on cylinder $B^\times$ to follow. Hence it flows to contact 6 of row B^2. Thence the current flows through the series windings f of one of the motors to contact 8 of row B^2, and thence it passes through the contacts of cylinder $B^\times$ to contact 7 of row B^2. From this contact the current returns to contact 17 of row A′ and reaches contact 16 of said row. Thence the current flows to contact 6, (row A′,) through armature d^3, contacts 4 and 5, (row A′,) and armature d^4 to contact 3, (row A′.) The current then passes to contact 7 of row B′ and reaches contact 6, (row B′.) It then passes through the series windings f of the other motor and reaches the contact 8 of row B′. Thence it flows to contact 11 of row B′ and passes to contacts 20 and 21 of row A′, and thus to earth. At the same time current flows from contact 10 of row A′ to contact 8 of said row and passes through the resistance w^2 to contact 7 of row A′. The current then flows to contact 1 of row B′, and thence passes to contact 2 of said row, through the field-winding e' to contacts 4 and 3, field-winding e^2, contacts 5 and 12, field-winding e^3, contacts 14 and 13, and field-winding e^4 to contact 15. Thence the current passes to contact 12 of row B^2 and through field-winding e^3 to contacts 14 and 13 of said row, thence passing through field-winding e^4 to contacts 15 and 2, (row B^2,) thence through field-winding e' to contacts 4 and 3, and thence through field-winding e^2 to contact 5. Then the current passes to contact 1, (row B^2,) whence it flows to contacts 20 and 21 of row A, and thus to earth. The direction of the flow of current is the opposite if the counter electromotive force of the motors is higher than the line voltage.

As explained in the specification of my application for United States Patent Serial No. 191,620, filed February 1, 1904, the four rows of contacts carried by the combined reversing and field-change cylinder $B^\times$ are arranged in pairs of vertical rows b' $b'^\times$ b^2 $b^{2\times}$, situated diametrically opposite each other. By the angular movement of the shaft $B^{2\times}$, carrying said cylinder, each of the two rows of these contacts can be in turn brought into simultaneous engagement with the two rows of stationary contacts B′ B^2. The group or pair of contacts b' $b'^\times$ serves to connect the separate field-windings of the motors in parallel, Fig. 2, so that the machines work as series motors, and the other group or pair of contacts b^2 $b^{2\times}$ serves to connect said windings in series, Fig. 2^a, so that the machines work as compound generators. The angular distance α between the two groups of contacts b' b^2 and $b'^\times$ $b^{2\times}$ is only that which is necessary to insure the breaking of the arc of one group of contacts before making contact with the other group, and the angular distance β between the groups of contacts b' and $b'^\times$ and b^2 and $b^{2\times}$ is one hundred and eighty degrees. The circuits controlled by these contacts are so arranged that when the cylinder B occupies the position represented in the drawings the motor will revolve in one direction and that when said cylinder is turned through the angle β—*i. e.*, one hundred and eighty degrees, or a half-revolution—to bring the cylinder-contacts that are represented on the left into the position occupied by those on the right the motors will revolve in the opposite direction. This angular displacement of the cylinder in no wise interferes with the capacity of the cylinder-contacts to bring about the change of the field-windings of the motors from the series to the compound condition, and vice versa, when said cylinder is oscillated through the angle α in whichever of the two extreme positions it may be placed by turning through the said angle β—that is to say, when one group of contacts—say b' $b'^\times$—engages with the stationary contacts B′ B^2 the windings of the motors will be in paralleled condition and form part of the series windings and when the other group of contacts—say b^2 $b^{2\times}$—engages with said stationary contacts the windings will be in the shunt or compounding condition, this function of the contacts being equally well fulfilled by the oscillation from one group of contacts to the other through the angle α irrespective of the one-hundred-and-eighty-degree position of the cylinder, and therefore independently of the direction of rotation of the motors. The oscillation through the angle α from one row or group of contacts to the other cannot effect a reversal of the current through the fields of the motors, since that requires the movement of the cylinder through the angle β—*i. e.*, one hundred and eighty degrees.

When the machines are shunt wound instead of compound wound, the different variations in their character and electrical relationship during working is illustrated in Figs. 3 and 3^a. In view of the full explanation given with respect to Figs. 2 and 2^a it is unnecessary to describe these Figs. 3 and 3^a in detail.

No claim is made hereinafter to the structural apparatus hereinbefore described and disclosed in the accompanying drawings and by the use of which the methods of operation hereinafter claimed are effected, as this feature constitutes the subject-matter of an original application bearing Serial No. 191,620, filed in the United States Patent Office on the 1st day of February, 1904, and of which the present application is a division.

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

1. A method of regulating a regenerative

electric motor, which consists in making the field-windings capable of acting alternatively as series windings when the motor is propelling and accelerating and as compound or shunt windings when the motor is performing its braking or retarding function, and in keeping the current from the power-circuit uninterrupted while the change in the character of the field-windings is being effected, for the purpose specified.

2. A method of regulating a plurality of regenerative electric motors, which consists in making the field-windings capable of acting alternatively as series windings when the motors are propelling and accelerating and as compound or shunt windings when the motors are performing their braking or retarding function, and in keeping the current from the power-circuit uninterrupted while the change in the character of the field-windings is being effected and also while the various changes are being made in the series, series-parallel and parallel relationship of the armatures for varying the speed of the motors, substantially as described.

In testimony whereof I have hereunto set my hand, in presence of two subscribing witnesses, this 26th day of March, 1904.

JOHAN GUSTAF VIKTOR LANG.

Witnesses:

EDWARD H. JOHNSON,

HENRY HASPER.