(No Model.)

3 Sheets—Sheet 1.

S. H. SHORT.

METHOD OF AND MEANS FOR CONTROLLING ELECTRIC MOTORS.

No. 599,805. Patented Mar. 1, 1898.

Fig. 7.

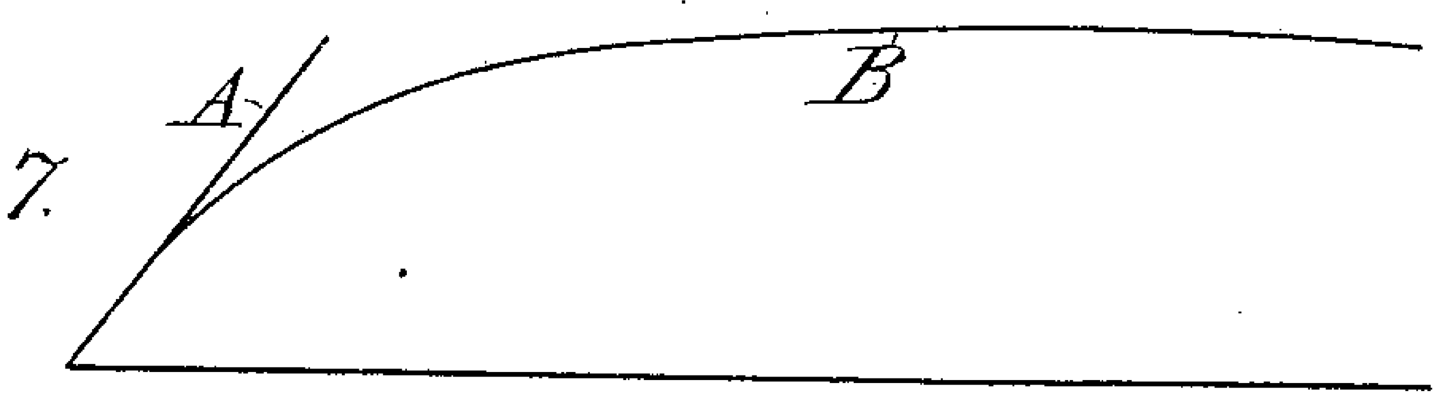
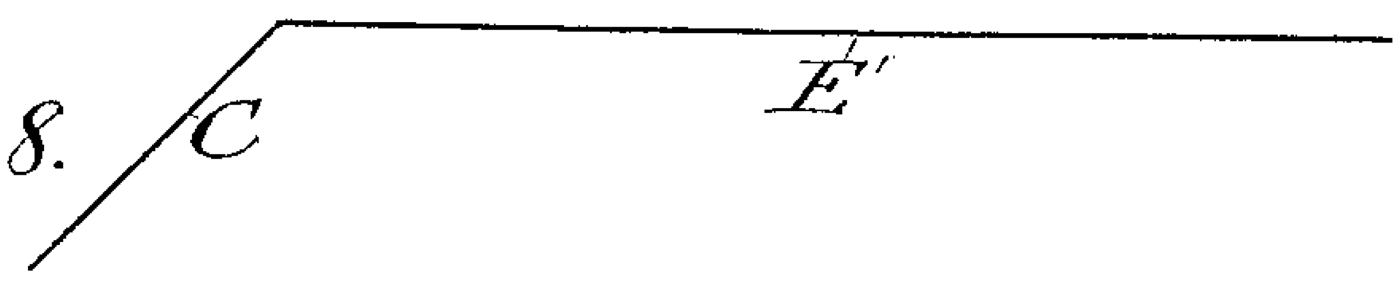


Fig. 8.



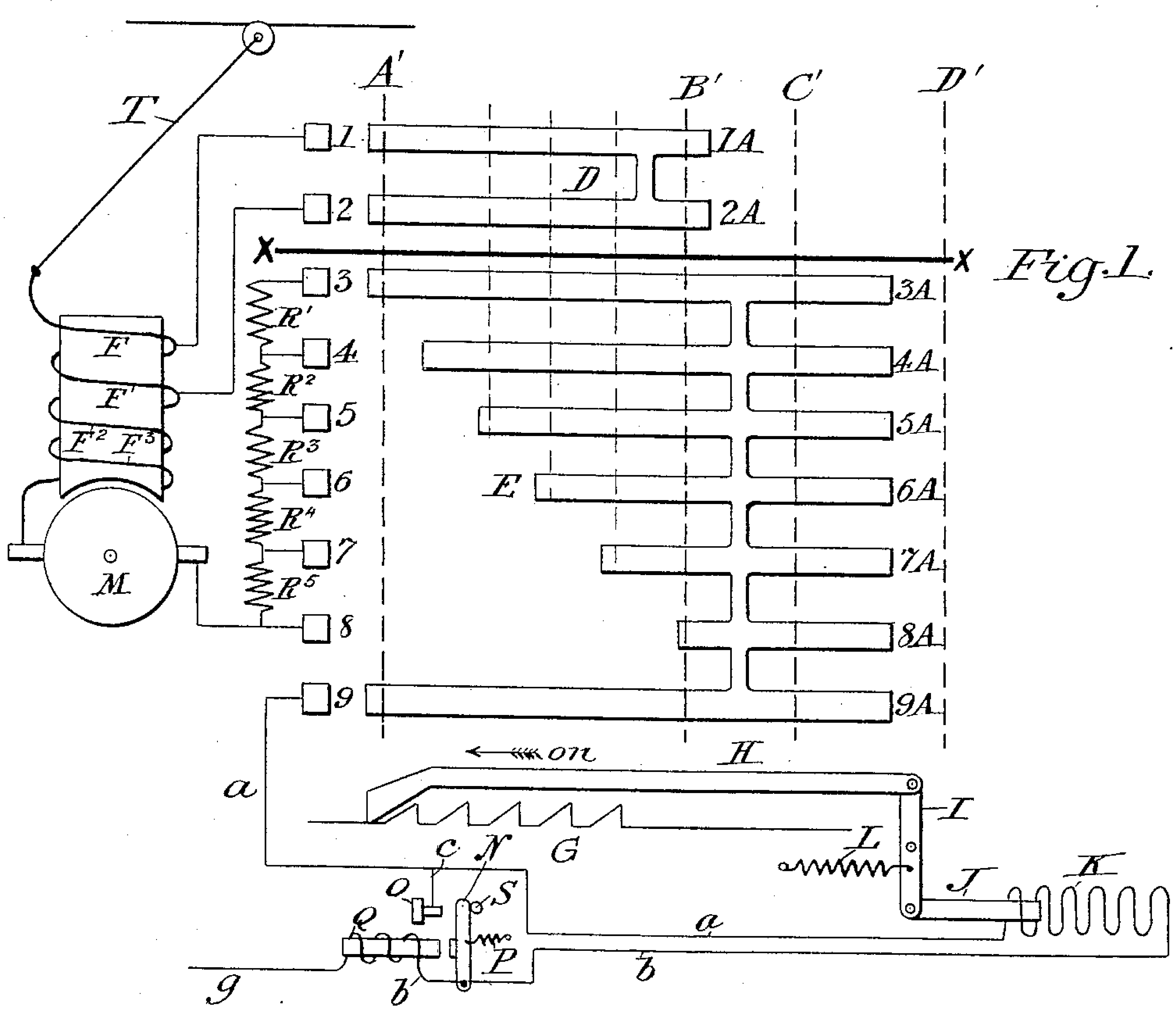
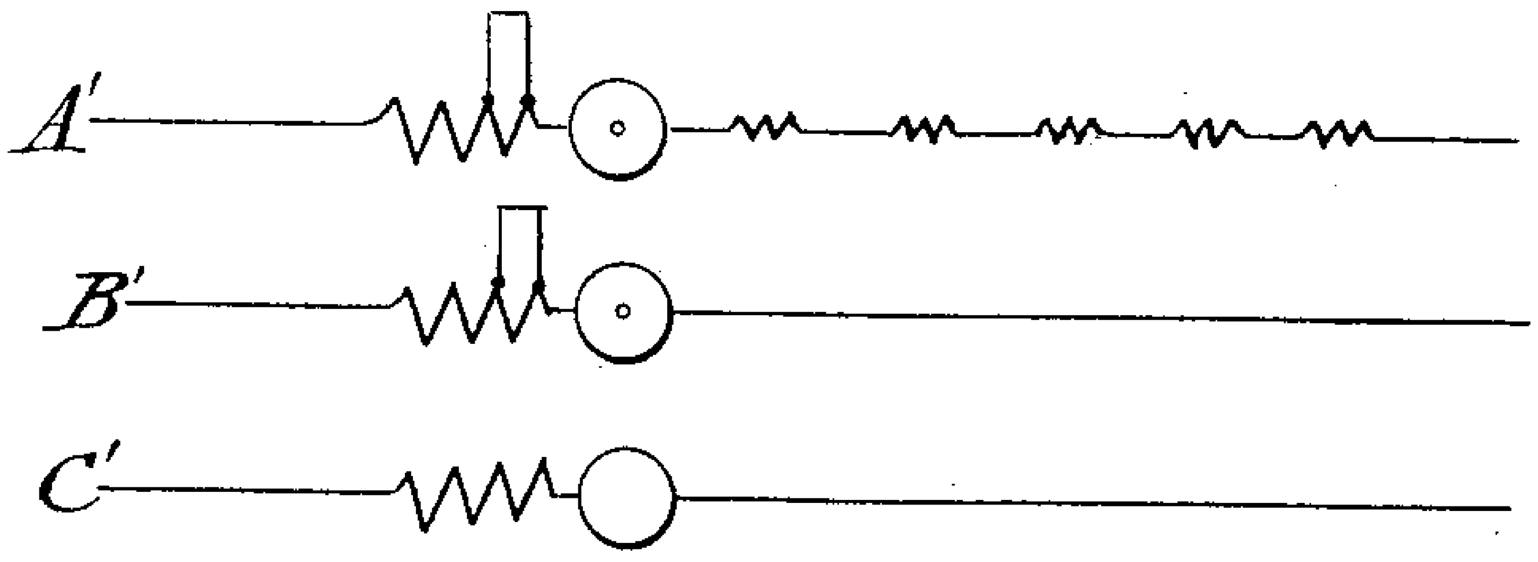
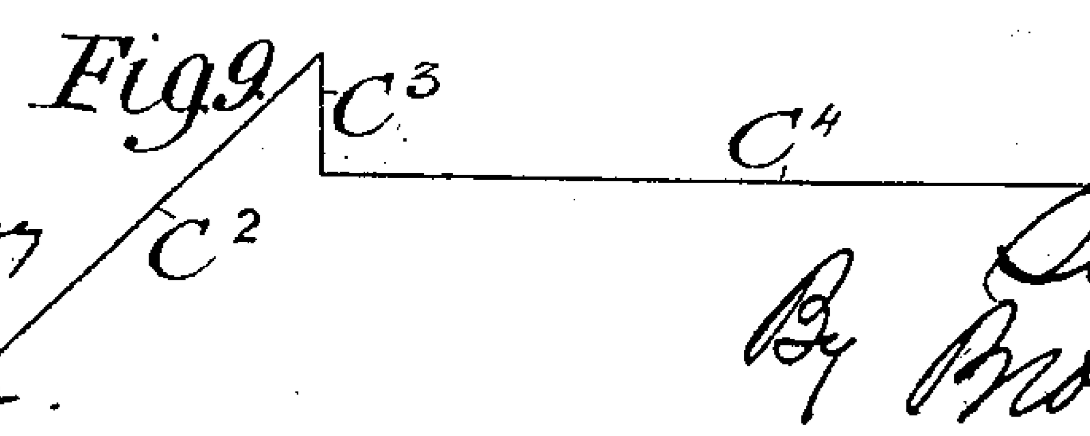


Fig. 1.

Fig. 2.



Witnesses: Fig. 9



H. H. Humphrey

W. Q. Olden.

Inventor:

Sidney H. Short

By Brown & Darby Attys

(No Model.) 3 Sheets—Sheet 2.

S. H. SHORT.

METHOD OF AND MEANS FOR CONTROLLING ELECTRIC MOTORS.

No. 599,805. Patented Mar. 1, 1898.

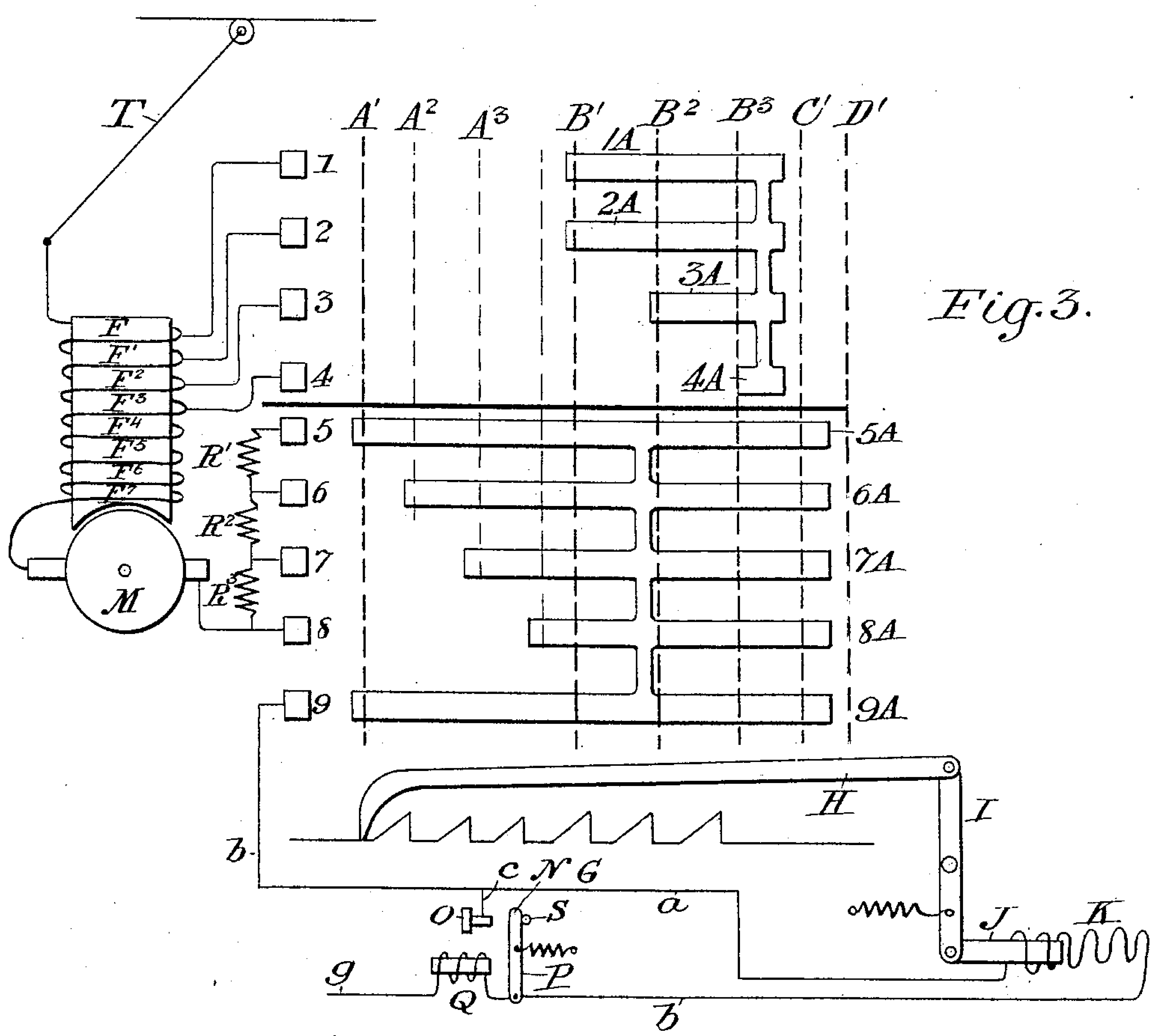
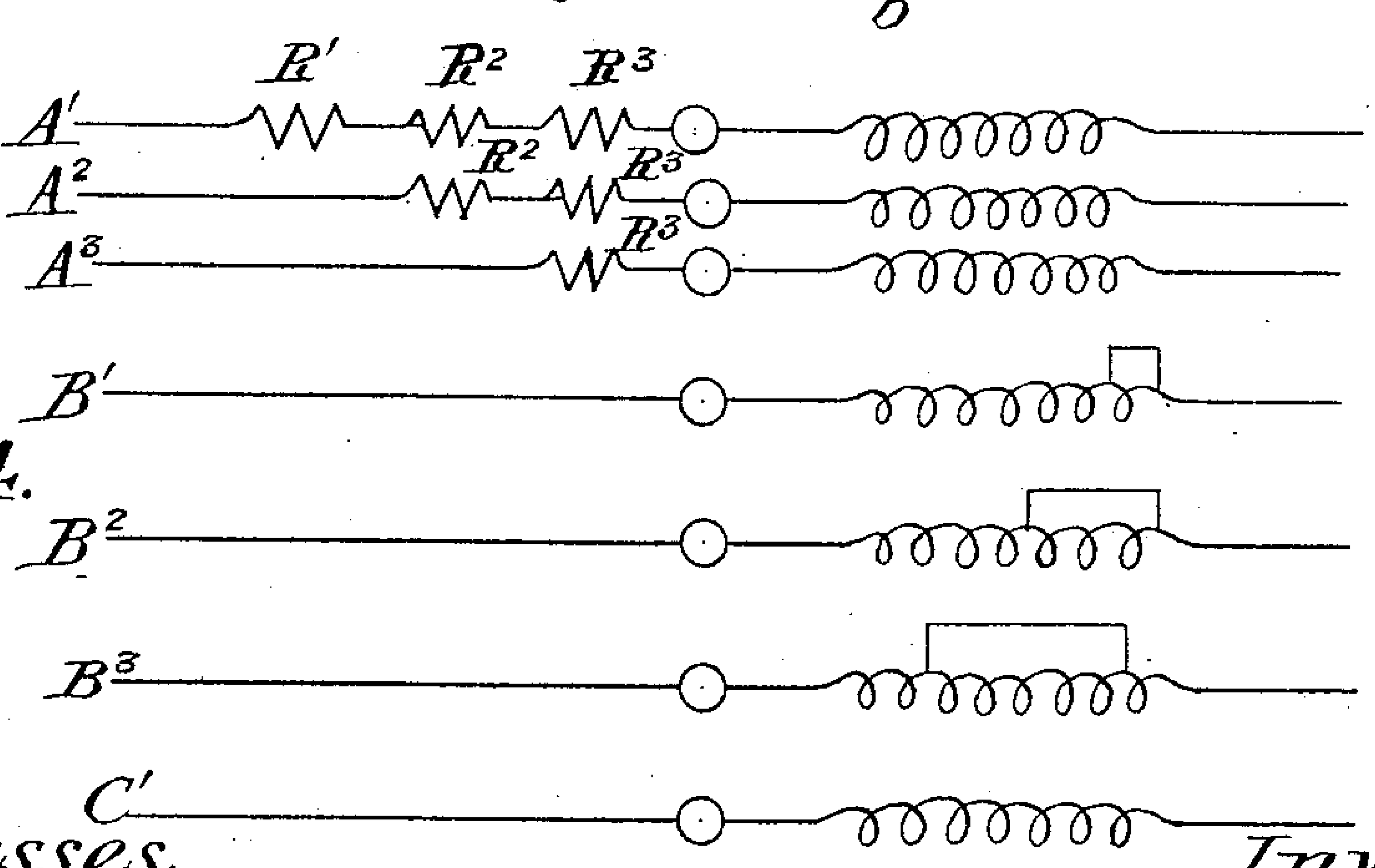


Fig. 3.

Fig. 4.



Witnesses:
H. H. Humphrey
W. Q. Olden.

Inventor:
Sidney H. Short
By. Brown & Darby
Attys

(No Model.) 3 Sheets—Sheet 3.

S. H. SHORT.

METHOD OF AND MEANS FOR CONTROLLING ELECTRIC MOTORS.

No. 599,805. Patented Mar. 1, 1898.

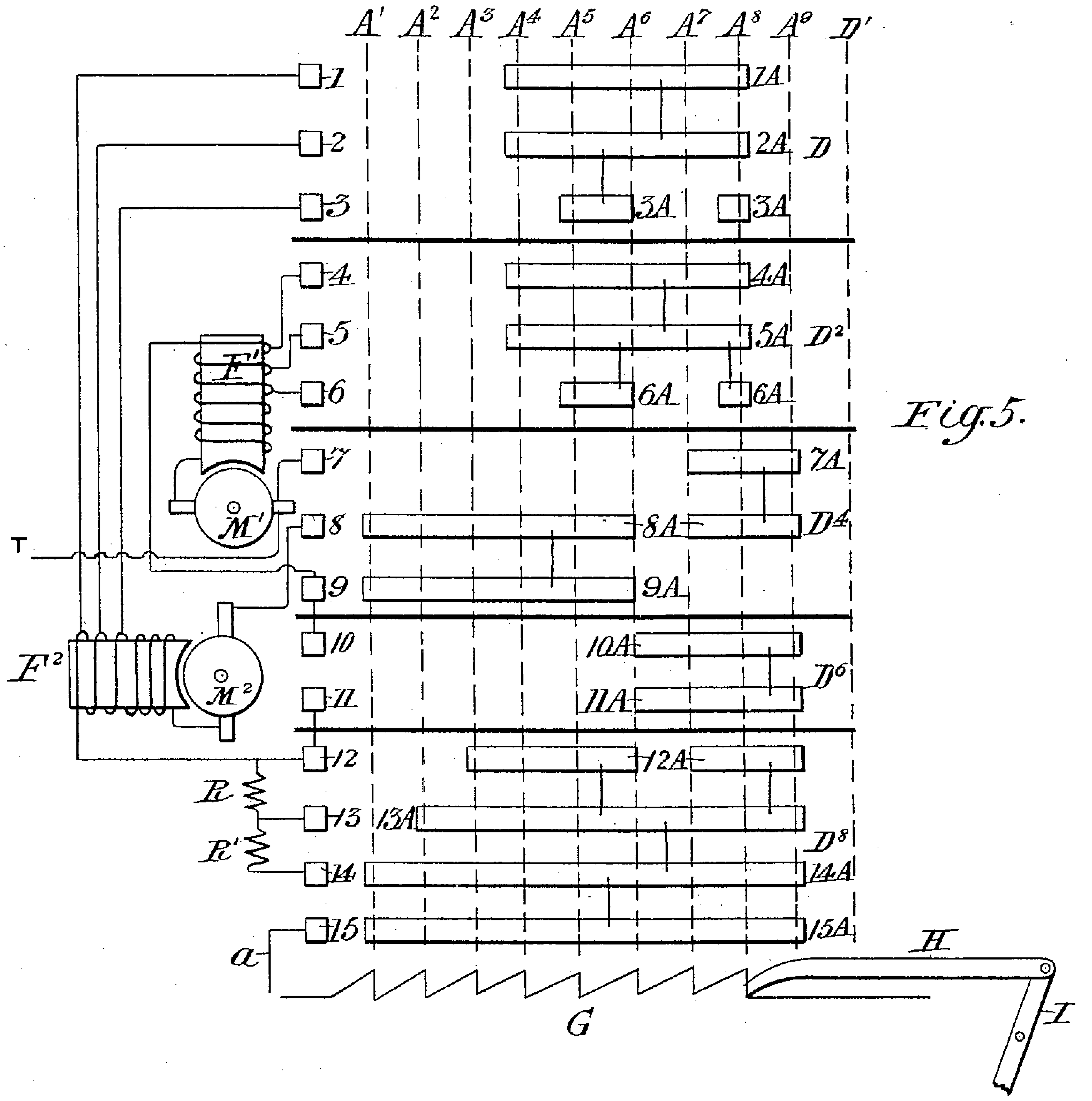
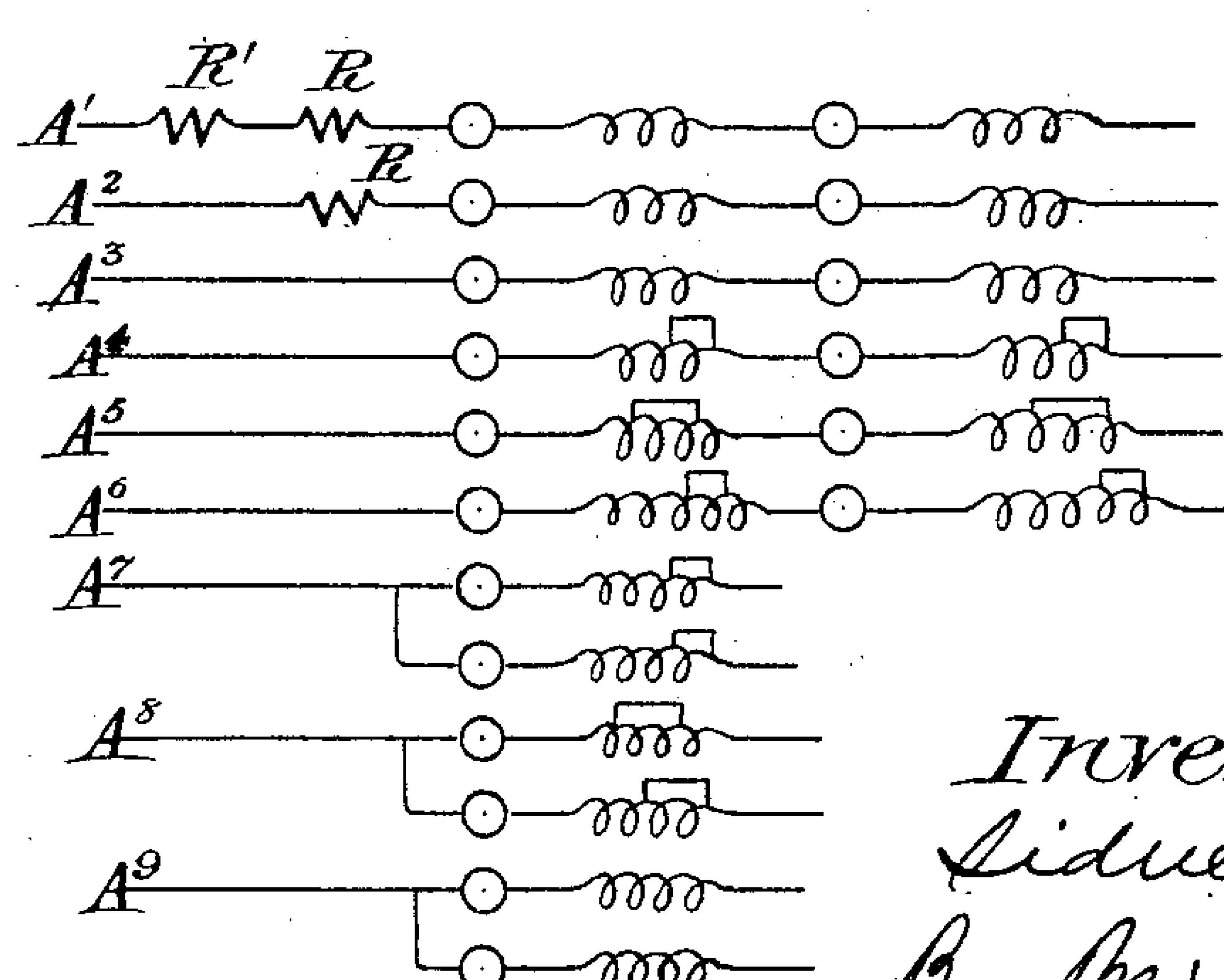


Fig. 5.

Fig. 6.



Witnesses:
H. H. Humphrey
W. Q. Olden.

Inventor:
Sidney H. Short
By Moxon & Darby
Attys.

UNITED STATES PATENT OFFICE.

SIDNEY HOWE SHORT, OF CLEVELAND, OHIO.

METHOD OF AND MEANS FOR CONTROLLING ELECTRIC MOTORS.

SPECIFICATION forming part of Letters Patent No. 599,805, dated March 1, 1898.

Original application filed May 19, 1897, Serial No. 637,212. Divided and this application filed October 21, 1897. Serial No. 655,911. (No model.)

To all whom it may concern:

Be it known that I, SIDNEY HOWE SHORT, a citizen of the United States, residing at Cleveland, in the county of Cuyahoga and State of Ohio, have invented a new and useful Improvement in Methods of and Means for Controlling Electric Motors, of which the following is a specification.

This invention relates to a method of and means for controlling electric motors, and is a division of my application, Serial No. 637,212, filed May 19, 1897.

The object of the invention is to provide an apparatus and mode of operation for controlling electric motors for traction purposes in a manner to secure a rapid acceleration of the car or train and with a much less consumption of power in starting the train and in maintaining the proper speed.

A further object of the invention is to provide an arrangement and method of control for motors particularly adapted for use on trains which are started and stopped often—as, for instance, in elevated-railway service and in interurban or suburban trains.

Further objects of the invention will appear more fully hereinafter.

The invention consists, substantially, in the construction, combination, arrangement, location, and mode of procedure, all as will be more fully hereinafter set forth, as shown in the accompanying drawings, and finally specifically pointed out in the appended claims.

Referring to the drawings and to the various views and reference signs appearing thereon, Figure 1 is a view in diagram illustrating an arrangement of circuits and circuit-controlling contacts for carrying the principles of my invention into operation. Fig. 2 is a diagram illustrating the leads of the circuits from the varying positions of the controller. Fig. 3 is a view similar to Fig. 1 wherein a less amount of resistance is employed. Fig. 4 illustrates in diagram the various circuits and changes thereof under the several steps in the operation of the controller shown in Fig. 3. Fig. 5 is a view similar to Figs. 1 and 2 of an arrangement employing two or more motors and embodying the principles of my invention and the method of coupling up the motors in accordance with my invention in series or in parallel to produce the effect of a uniform acceleration. Fig. 6 illustrates diagrammatically various changes in the circuits resulting from the various positions of the apparatus shown in Fig. 5. Fig. 7 is a diagram illustrating the acceleration-curve of the ordinary series motor. Fig. 8 is a diagram illustrating the acceleration-curve of a motor operated in accordance with the principles of control embodied in my invention. Fig. 9 is a diagram illustrating a theoretical power-curve.

In the practical operation of motors for traction purposes it is exceedingly desirable to maintain a constant acceleration of the train while getting under way until the desired speed is attained and thereafter for the train to proceed at a uniform speed. Such a desirable result cannot be satisfactorily obtained under prior methods of control for reasons which I shall endeavor now to explain. In the case of an ordinary series motor—for instance, such as is usually employed for traction purposes—in order to start the train from rest a large current is turned into the motor to start it, thereby developing in the motor a very large horizontal effort. For the first few seconds the acceleration of the motor, and hence the train, is rapid and satisfactory. If this acceleration could be continued uniform, the theoretically-ideal condition would be attained and the acceleration-curve of the motor would be indicated by a straight line A, Fig. 7, and such uniform acceleration in speed would accomplish the starting of the train from rest in a satisfactorily quick and speedy manner, and would therefore effect a large saving of time in getting under way; but in the case of an ordinary series motor, however, as the armature of the motor gets under headway a counter electromotive force is set up therein which reduces the current flowing through the motor. This reduction of the current flowing through the motor results in a falling off of the horizontal effort, with a corresponding falling off for each second of the increase in speed per second, so that instead of the ideal acceleration-curve A, Fig. 7, such curve takes the form of that shown at B, Fig. 7, until finally the current falls to a point where it will develop only the power necessary to move the train at a uniform speed. This variation of the curve B from the straight or theoretically-ideal acceleration-curve A illustrates the fall in acceleration of the motor and train, and hence a departure from the most satisfactory and economical operation of the motor. It is the purpose of my invention to provide a method of control wherein the acceleration in speed is uniform or practically so until the required speed is attained, and from that point onward the acceleration is arrested and a uniform speed is maintained, thus resulting in an acceleration-curve C, Fig. 8, substantially the same as the theoretically-perfect curve A, Fig. 7, such uniform acceleration resulting in the train increasing its speed a given number of feet per second for each second it is in operation. If this uniform acceleration were to continue as above described, the train would reach a rate of speed far beyond the safety limit, and therefore my method of control contemplates arresting the acceleration when the desired speed is attained and thereafter permitting the train to continue to run at a uniform speed. Thus it will be seen that in the method of control embodying these principles the train will rapidly and quickly attain its desired speed in a shorter space of time than heretofore and with a much less consumption of power, and hence effecting a saving of time in driving the train from one station to another, the train getting under headway rapidly and quickly under the substantially uniform acceleration of speed until the desired or running speed is attained, when the acceleration is arrested and a uniform speed is thereafter maintained until it is again desired to stop the train.

In my before-mentioned application, of which the present application is a division, I have disclosed the generic conception of the invention embodying these principles, and I have also shown and described therein various forms and arrangements for the purpose of carrying the principles of the invention into practical operation, and in said prior application is shown and described, but not specifically claimed, the species of the invention embodying the subject-matter of the claims of the present case.

Referring to Fig. 1, illustrating an embodiment of the principles above outlined, reference sign M designates a motor; T, the trolley-circuit therefor; F F′ F^2 F^3, the field-magnet coils; R′, R^2, R^3, R^4, and R^5, resistances; 1, 2, 3, 4, 5, 6, 7, 8, and 9, suitable contacts; D and E, portions of coöperating contacts, which may comprise contacting segments 1^A, 2^A, 3^A, 4^A, 5^A, 6^A, 7^A, 8^A, and 9^A, the several points 1 2 3 4, &c., and the corresponding contact-strips 1^A 2^A 3^A, &c., being relatively movable, so as to be moved into contact with each other. In the particular form shown the strips 1^A 2^A 3^A, &c., are mounted upon the surface of the controller-cylinder, Fig. 1 illustrating, diagrammatically, such surface developed. The portion D of the controller-cylinder is insulated from the portion E, as illustrated at X X. The motor M is provided with a very large field-magnet in which the iron is not thoroughly saturated with the lines of magnetic force under ordinary conditions under which it is expected to operate, so that any variation of the number of ampere-turns on the magnet-core will greatly affect and influence the speed of the armature. It is therefore necessary, in accordance with my improved method of control, that the reluctance of the magnetic circuit of the motors employed in connection therewith should be moderately low and that the windings of the field-magnets be varied considerably without resulting in undue sparking at the commutators under great variations of load. In other words, the motor should be of larger capacity than is ordinarily used at the present time for the same class of work.

The first operation of the controller embodying my invention is for the motorman to move the controller-cylinder D E into the position indicated by dotted lines at A′, Fig. 1. The motor-circuit will thereupon be made as follows: from trolley T through the windings of the motor-field magnet, the motor M, resistances R^5 R^4 R^3 R^2 R′, strips 3^A 4^A 5^A 6^A 7^A 8^A 9^A, these several strips being in electrical connection with each other, thence to contact 9, and thence through the arrangement for automatically actuating the controller-cylinder. This automatic arrangement may comprise a ratchet G, suitably mounted on the controller-cylinder, in the teeth of which is arranged to engage a lever H. A suitably automatically-operated auxiliary motor, preferably included in the circuit above described, is arranged to operate pawl arm or lever H. Many different arrangements of auxiliary motor and specific constructions thereof may be employed for this purpose. While I have shown and will now describe a particular form and arrangement of apparatus for accomplishing the desired result, I desire it to be understood that I do not limit or confine myself thereto, as the principles thereof may be embodied in a wide variety of specific forms and arrangements of apparatus and still fall within the spirit and scope of my invention. In the particular form shown the pawl-lever H is pivotally connected to one end of rock-lever I, to the other end of which lever is connected a magnetic core J, arranged to form the core of the solenoid K, the coils of which solenoid are included in circuit connection *a* from contact 9. Suitable means for cutting the coils of solenoid K into and out of live circuit with contact 9 automatically may be provided. This may be accomplished in any suitable or convenient manner, and while I have shown and will now describe a suitable and convenient arrangement for accomplishing the desired result I do not wish to be understood to limit or restrict myself thereto, the arrangement shown being merely illustrative of an operative apparatus for accomplishing the desired object. In the form shown the circuit connection *a*, after passing through the coils of the solenoid K, includes a connection *b* and the coils of the magnet Q, and thence through connection *g* to ground. The lever N makes contact with a stop O, included in the branch connection *c* from connection *a*, thereby completing the circuit from contact 9 through the connections *a* and *c*, contact O, lever N, connection *b*, coils of magnet Q, and connection *g* to ground. The spring P is arranged to normally maintain lever N against the stop S and out of contact with contact O. From this arrangement it will be seen that when the controller is turned by the motorman into position indicated by the dotted line A′, Fig. 1, a circuit through the motor and all the resistances is completed, as above described, to contact 9, thence through connection *a*, auxiliary motor K, connection *b*, the coils Q, and connection *g* to ground. As soon as current begins to flow through the windings of the auxiliary motor K core J is drawn into said coils, thereby rocking lever I against the action of the retractile spring L and in a direction to move the pawl-lever H in the direction indicated by the arrow in Fig. 1 and marked "On." This movement of pawl-lever H, however, does not effect a movement of the controller-cylinder, because there are no teeth on ratchet G in advance of the arm or pawl-lever H. The current passing from motor K through magnet Q effects an attraction of the armature-lever N, thereby establishing contact between said armature-lever and contact O, thereupon completing the short circuit through connection *c*, contact O, armature-lever N, connection *b*, the windings of Q and connection *g* to ground, thus short-circuiting the auxiliary motor K, and hence allowing spring L to rock lever I in the opposite direction to that above described and causing the end of the pawl-lever H to engage behind the first tooth of ratchet G. Under this condition the main motor begins to accelerate. As the motor starts up the counter electromotive force begins to develop in said main motor, which, if permitted to continue, would cause a falling off of the acceleration, and hence the production of acceleration-curve B, as indicated in diagram in Fig. 7. The development of this counter electromotive force in the main motor causes a reduction in the current-traversing relay Q. The tension of spring P is so regulated that when the current traversing the short circuit which includes armature-lever N, as above described, falls below a certain point retractile spring P comes into operation and withdraws said armature-lever N from contact O into contact with stop S, thereby breaking the short circuit above described and reëstablishing the circuit through auxiliary motor K. The reëstablishment of this circuit through the auxiliary motor effects a forward projection of pawl-lever H, which, through the engagement of the front end thereof with the first tooth of ratchet G, effects a movement of the controller-cylinder in a direction to cause contact-strip 4^A to make contact with point 4. The current through the motor now passes through resistance $R^5 R^4 R^3 R^2$, the resistance R′ being short-circuited by the contact established between point 4 and strip 4^A. The cutting out of this resistance R′ has the effect of again increasing the current through the motor, so as to maintain a substantially constant acceleration. At the same time the increase in current due to cutting out resistance R′ again causes relay Q to operate to again short-circuit auxiliary motor K automatically until the current through the main motor again falls below the desired point by reason of the continued development of the counter electromotive force therein until the relay is again opened by such fall of current and the auxiliary motor K is again cut into live circuit, thereby advancing ratchet G another step, thus bringing contact 5 and strip 5^A into electrical connection, and hence short-circuiting or cutting out resistance R^2, thus again increasing the current through the motor-circuit, again actuating auxiliary motor K and advancing the controller another step in the manner above described, and so on, thus maintaining a constant or practically constant acceleration of the main motor until finally, strip 8^A and contact-point 8 are brought into electrical connection, at which point in the operation all resistances are cut out of the motor-circuit. In the meantime and when the controller is moved to its first position A′, as above explained, contact-strips 1^A and 2^A are brought into electrical connection with points 1 and 2, respectively, the strips 1^A and 2^A being in electrical connection with each other. The points 1 and 2, respectively, form the terminals of the coils F F′ of the main motor-field magnets, and hence so long as strips 1^A and 2^A remain in contact with points 1 and 2 the coils F F′ are short-circuited out of the field-magnet circuit, and hence during the conditions above described, wherein the resistances R′ R^2 R^3, &c., are successively cut out of the main-motor circuit, said coils F F′ of the main-motor field-magnet windings remain short-circuited, leaving only the coils F^2 F^3, &c., to produce the lines of magnetic force in the armature of the main motor. When finally the controller-cylinder arrives, under the automatic action thereof, as above described, in the position indicated by dotted line B′, Fig. 1, the current during the several steps mentioned remaining substantially constant, slightly rising above the normal accelerating-current as the resistances are successively cut out and slightly dropping below the normal accelerating-current as the counter electromotive force in the main motor develops. If left in this position, the main motor would thereafter rapidly develop a speed greater than that required. The parts are so constructed and arranged, however, that when the point indicated by dotted line B′ is reached the desired speed has been attained, and therefore by suitably constructing and arranging the teeth of the ratchet G the automatic action of the controller ceases at this point; but during all the preceding operations and up to this position of the parts a large portion of the field of the main motor has been short-circuited and out of use, as above described. Now in order to arrest the acceleration of the motor, the desired speed having been attained, so as to permit the motor to continue to operate at a constant speed, the motorman now turns, by means of the controller-handle or otherwise, the controller-cylinder from the position indicated by dotted line B′ to that indicated by line C′. This movement of the controller, effected by the motorman manually or otherwise, but under the control of the motorman, breaks the short circuit of the coils F F′ of the motor-field by bringing into contact strips 1^A and 2^A and their coöperating contacts 1 and 2, thus causing the motor-current from trolley T to traverse all the windings of the motor-field, and hence more magnetic lines are forced through the armature of motor M, thus cutting down the motor-current by building up the counter electromotive force of the armature to a point which is just sufficient to maintain the motor, and hence the train, at a uniform speed thereafter. This movement by the motorman of the controller to the position indicated by the line C′ does not effect the resistance-circuits, the motor continuing to operate with an increased number of ampere-turns around the core of the field-magnet, a circuit leading from trolley T through all the ampere-turns of the motor-field through the motor, this being a path of no resistance, thence to strip 8^A, strip 9^A, contact 9, and thus on, as described, through the short circuit *c* O N *b* Q *g* to ground, or else through connection *a*, K, *b*, Q, and *g* to ground, it being understood that at this point the automatic action of the controller-cylinder has ceased, and hence it is immaterial which of the above-described circuits from contact 9 on the circuit may take. Under this condition the motor has attained through the constant acceleration described its desired speed, and then the acceleration has been arrested and the motor continues to operate at a uniform speed thereafter.

From the foregoing description it will be readily seen that the acceleration-curve will be somewhat jagged by reason of the slight rising of the current above the normal accelerating-current and then gradually falling to a point below the normal accelerating-current; but by introducing a sufficient number of resistances with a corresponding increase in the number of coöperating contacts and contact-strips this acceleration may be made practically constant, thereby substantially developing a straight acceleration-curve C, Fig. 8, until the position indicated by the line B′ is attained, when the movement effected by the motorman of the controller to the position indicated by line C′ effects a cutting in of the whole coils into the main-motor-field circuit, thereby arresting the acceleration, and hence producing the straight horizontal line E, Fig. 8, in the acceleration-curve, which indicates the subsequent uniform speed.

When it is desired to stop the train, the controller-lever is moved by the motorman, thereby moving the controller-cylinder to the position indicated by the dotted line D′, Fig. 1, which is "off" position, thereby breaking all the motor-circuits, and thereafter the application of the brakes brings the train to a stop. In Fig. 2 is shown, diagrammatically, the circuits corresponding to the several positions A′ B′ C′ of the controller-cylinder. From this diagram it will be seen that in the position A′ the main motor operates with a portion of the field-coils cut out of circuit or short-circuited and with all the resistances included in circuit. In position B′ all the resistances are cut out of circuit and the motor operates with a portion of the field-coils short-circuited, and in the position C′, which is the last position before the "off" position is attained and which position corresponds to the uniform speed which is maintained after the desired degree of acceleration has been developed, the motor operates with all its field-coils in circuit and with no resistance.

From the foregoing description it will be seen that the acceleration of the motor in starting may be effected in two ways—namely, by varying the resistance included in the circuit, and, secondly, by varying the coils or ampere-turns in the motor-field, the cutting out of resistance in the motor-field serving to increase the current through the motor, and hence to counteract the development of counter electromotive force in the motor-armature. In the other case the cutting in of the coils in the motor-field increases the number of lines of force cut by the motor-armature, and hence builds up the counter electromotive force of the armature, thereby reducing its acceleration, and hence, conversely, the successive cutting out of circuit of the coils or ampere-turns in the main motor-field effects a reduction in the counter electromotive force developed in the armature, and hence secures the same effects as the successive cutting out of resistances from the motor-circuit. It is evident that the method of motor-control embodied in the principles of my invention may employ either one or both of these ways or manners of controlling the motor.

In my prior application I have claimed the generic idea of controlling a motor whether by varying the motor-field windings or the resistance in the motor-circuit, and in said application I have claimed specifically the method of motor-control consisting in varying the resistance in the motor-circuit. It is the purpose of the present case to cover specifically the method of control, which consists in varying the motor-field windings to maintain a substantially uniform accelerating-current. In Fig. 3 I have shown diagrammatically an arrangement wherein both of these methods for controlling the acceleration are employed together. In this arrangement I employ a comparatively small amount of resistance, all the field-magnet coils being included in the main-motor circuit at the time of starting, and hence a large number of lines of force are urged through the magnetic circuit of the motor, and in this arrangement I use a portion of the counter electromotive force of the motor to maintain a uniform current during acceleration instead of some of the resistance, as described in connection with Fig. 1. In this arrangement and method when the controller is first moved to position A′, which is the initial movement of the controller, by the motorman the current traverses the following path: from trolley T through all the windings of the motor-field coils, through motor M, resistances R^3 R^2 R′, contact 5, strip 5^A to strip 9^A, contact 9, connection *a*, auxiliary motor K, connection *b*, relay Q, and connection *g* to ground. The motor thereupon starts up and begins to accelerate rapidly, as indicated in diagram in Fig. 4 in position A′, all the resistances being in circuit and all the coils of the motor-field magnet being also included in circuit. Through the automatic action of relay Q and auxiliary motor K, as above explained, the controller-cylinder is advanced to the position indicated at A^2, Fig. 3, thereby bringing strip 6^A into contact with contact 6, thus cutting out resistance R′, and thereupon the motor operates, as indicated at A^2, Fig. 4, with only resistances R^2 R^3 in circuit and with the same condition of the field-coils above described, until the current again falls below the normal accelerating-point, thereby again effecting an action of the automatic mechanism to advance the controller-cylinder to the position indicated by line A^3, Fig. 3, thereby cutting out resistance R^2, as indicated at line A^3, Fig. 4, the circuit condition being that the motor operates with only resistance R^3 in circuit and with the same condition of the field-windings as before. Thus finally the controller arrives at the position B′, at which point all the resistances are cut out, as indicated at line B′, Fig. 4, and simultaneously therewith strips 1^A 2^A make electrical contact with points 1 and 2, thereby short-circuiting the first or one of the coils of the motor-field. This increases the accelerating-current of the motor by reducing the number of lines of force which had theretofore been forced through the armature, and hence serves to maintain a constant acceleration of the motor until the counter electromotive force developed in the armature reduces the current to a point slightly below the normal or desired accelerating-current, whereupon the automatic mechanism above described again comes into play and moves the controller-cylinder to the position marked B^2, Fig. 4, and consequently again increasing the accelerating-current to a point slightly above the normal until such current again falls by the development of counter electromotive force, thereby effecting another actuation of the automatic auxiliary motor K and relay Q, and hence advancing the controller-cylinder to the position B^3, hence bringing strip 4^A into electrical connection with point 4, thereby cutting out another or other coils of the motor-field, and hence a repetition of the above action. I have shown this as the last step in the operation necessary to bring the controller to a position where if the parts are left without further movement a too great speed would be developed. It is evident, however, that more strips may be provided on the controller-cylinder and more or any desired number of ampere turns or windings of the main-motor field may be thus successively cut out. When the desired speed of the motor and train has been attained, the motorman effects a further movement of the controller to uniform-speed position, as indicated by dotted line C′, thereby breaking contact between strips 1^A 2^A 3^A 4^A, &c., and their corresponding contacts 1 2 3 4, &c., and hence again cutting into the motor-circuit all of the field-coils, thus increasing the lines of force in the magnetic circuit of the motor, and hence building up the counter electromotive force of the motor and reducing its speed to a uniform point, thereafter operating the motor with all its field-coils in circuit and with no resistance. The several positions A′ A^2 A^3 and B′ B^2 B^3 represent the several steps in the operation for effecting a constant acceleration, and when the desired speed has been attained position C′ indicates the condition of the motor-circuit during the time when the motor is operating at a constant speed, with the acceleration arrested, and when it is desired to stop the car the motorman moves the controller to position D′ or "off" position, thereby breaking the circuits of the motor, whereupon an application of the brakes effects a stopping of the car.

In the foregoing description I have described the invention designed to be specifically covered in the present application, and which consists in securing a uniform acceleration of current by varying the motor-field windings, in association and connection with a variation of the resistance in the motor-circuit, as applied to a single-motor equipment; but it is obvious that the principles thereof are equally well adapted for use in connection with two or more motors placed on each axle of the car.

In Fig. 5 I have shown an adaptation of my invention for producing a constant acceleration of current until the desired degree of speed is attained and thereafter a constant speed by varying the motor-field windings either alone or in connection or association with a variation in resistance in the motor-circuit in connection with two or more motors, and wherein the idea of securing a constant acceleration is still further carried out by changing the motor connections so as to couple the motors from series to series parallel or to parallel relation. In this embodiment of the invention I divide the controller-cylinder into five parts $D' D^2 D^4 D^6 D^8$, insulated from each other and each part containing electrically-connected contact-strips, and I provide coöperating contacts 1 2 3, &c., forming the terminals of the field-windings of the several motors employed and also the terminals of the circuits which include resistances R R'. When it is desired to start the motor from rest, the motorman turns the controller to the position indicated by line A', thereby completing circuit through points 8 9 14 15 and their coöperating strips 8^A 9^A 14^A 15^A. Thereupon the circuit is completed from trolley T' through motor M', the field-windings F' of the field-magnet of motor M', the contact 9, strip 9^A, strip 8^A, contact 8, motor M^2, all the windings F^2 of the field of motor M^2, resistances R R', the contact 14, strip 14^A 15^A, contact 15, and connection *a*, and thus on through the automatic arrangement above described in connection with Figs. 1 and 3. Thus, as indicated at A', Fig. 6, the motors are started, the relative connection and arrangement of the motors being such as to include said motors in series with each other in a circuit which also includes all the resistances R R' and all the coils of the field-magnets of all the motors, and thus the acceleration of the motors begins. When the accelerating-current falls by reason of the counter electromotive force developed to a point slightly below the normal, the controller is advanced a step by the action of the automatic auxiliary motor, as above explained, to position A^2, thereby bringing strip 13^A into contact with point 13, and hence cutting out resistance R', as indicated in the diagram at A^2, Fig. 6. This restores the accelerating-current to a point slightly above the normal until further development of counter electromotive force in the motors again reduces the accelerating-current to a point such as to bring into action the automatic mechanism above explained, which advances the controller-cylinder another step and to position A^3, causing strip 12^A to contact with point 12, and so on until all the resistances are cut out, as indicated at A^3, Fig. 6, the successive cutting out of resistances serving to successively restore the accelerating-current which had successively fallen by reason of the development of counter electromotive force, and hence maintaining a substantially constant acceleration of the motors. After all the resistances have been cut out of circuit further reduction of the current again causes the controller-cylinder to be advanced another step to the position A^4. Without altering the electrical position last above described this advancement of the controller-cylinder brings contact 1^A, 2^A, 4^A, and 5^A into contact with their corresponding points 1, 2, 4, and 5, thereby short-circuiting a portion of the field-windings of both motors, as indicated in diagram at A^4, Fig. 6. This reduction of the ampere-turns of the motor-field windings serves, as above explained, to restore the accelerating-current by reducing the lines of force in the magnetic circuit of the motors. This condition is maintained until the accelerating-current again falls slightly below the normal, whereupon the controller-cylinder is advanced automatically to the position A^5, thereby bringing strips 3^A and 6^A, respectively, in contact with points 3 and 6, thus again cutting out additional coils in the field-windings of the motors, and hence correspondingly increasing the accelerating-current and restoring the same to a point slightly above the normal by still further reducing the lines of force in the magnetic circuit of the motors. This operation is continued until the desired number of field-windings of the motors have been successively cut out of circuit, until finally when all the field-coils of the motors have been cut out which it is desired should be cut out a further fall of the accelerating-current to a point slightly below the normal causes the controller-cylinder to be again advanced automatically to the position A^6, which is a step necessary preparatory to a change of relation or circuit connection of the motors from series to series parallel or parallel, thereby cutting in more turns of the motor-field windings. At this point it is necessary to operate the controller by hand, inasmuch as the accelerating-current has not been increased by the last automatic action, but rather has been still further decreased. Therefore at this point the motorman actuates the controller to advance it to a point A^7. This movement brings contacts 10^A 11^A in contact with points 10 and 11, respectively, and hence changes the connections of the motors in the particular arrangement illustrated from series relation to parallel relation, as indicated at A^7, Fig. 6. During this step or transition from series to parallel it is desirable to again introduce resistance, and I therefore provide a gap in strip 12^A. If desired, only one of the motors may be employed during this transition step, and hence a similar gap may be provided in strip 8^A. In a similar manner, if desired, gaps may be also provided in strips 3^A and 6^A. However, whatever the changes may be during this movement or change in the end thereof the motors operate, as indicated at A^7, in parallel with only a portion of the field-windings of each short-circuited. This transition serves to increase the accelerating-current to a point slightly above the normal, and hence the automatic mechanism is again brought into play, when such current falls below the normal, thereby advancing the controller to the point A^8 and also cutting out more coils of the field-windings of one or both motors, but leaving the motors in parallel, and hence again increasing or restoring the accelerating-current, and so on until finally the desired acceleration has been attained. When in the position A^9, all the field-windings are again cut into live circuit, thereby arresting the acceleration and reducing the current to a point necessary to maintain a constant speed. Whenever it is desired to stop the car, the motorman turns the controller to position D' or "off" position, thereby breaking all circuits, when on application of the brakes the car will stop, if desired.

I do not desire to limit myself to the use of only two motors, as it is evident that any number of motors may be employed in association with the method of control embodied in the principles above explained. If four or more motors are used, each may be placed, respectively, in series, series parallel, and finally in parallel. In making the changes from one to the other the contact-springs and coöperating contact-points of the controller may be so relatively adjusted and arranged as to cut out more or less of the windings of the field of one or several of the motors and to cut into circuit a desirable resistance to produce and maintain a constant or substantially constant and uniform acceleration and a substantially uniform current in each motor until the desired speed has been attained, and thereupon the windings of the field-magnets of all the motors may again be placed in circuit in order to reduce the current to a point where it will operate the motors to propel the train at a uniform speed.

In the operation of the controlling method embodied in my invention it will be obvious from the foregoing description that the power developed increases constantly and uniformly coincident with the constant acceleration of speed up to a point where the acceleration is arrested. At this point, however, a greater power is being developed than is required to continue to operate the motor at a uniform speed. Therefore the action of reducing same to a point such as to maintain a uniform speed after the desired speed has been attained also causes the power to drop to a point just necessary to carry the train at a required and uniform speed. In the specific embodiment forming the subject-matter of the present application the constant acceleration is secured by varying the windings of the motor-field—that is, by successively cutting out from the motor-circuit the ampere turns or windings of the motor-field, each step of the operation which effects a cutting out of a motor-field coil resulting in a restoration of the accelerating-current to a point slightly above the normal, the position of the parts being thereafter maintained until the development of counter electromotive force reduces the current to a point slightly below the normal, whereupon through the automatically-actuating auxiliary motor the controller-cylinder is advanced another step, thereby cutting out another or other coils from the motor-field with a corresponding restoration of the accelerating-current until finally the desired speed has been attained, when all the windings of the motor-field are reëstablished in the motor-circuit, thereby maintaining thereafter a constant speed. In the diagram Fig. 9 I have shown the power-curve illustrating this operation, C^2 designating the development of power during the constant acceleration, and C^3 indicating the fall of power when the desired speed has been attained, and C^4 indicating the constant power applied thereafter to maintain a uniform speed.

It is evident that the uniform accelerating-current may be secured by varying the motor-field windings of one or of all of the motors either alone or in connection and association with the variation in the circuit-resistance or in connection and association with changes in the relative connections of the motors themselves when two or more motors are employed or in connection or association with both.

It is evident that the principles of my invention may be embodied in a wide variety of specific forms and apparatus. I do not desire to be limited or restricted to the specific details and arrangement shown and described; but,

Having now set forth the object and nature of my invention and a form of apparatus embodying the principles and mode of operation thereof, what I claim as new and useful and of my own invention, and desire to secure by Letters Patent of the United States, is—

1. The method of controlling motors which consists in varying the windings in the motor-field to maintain a substantially uniform accelerating-current and, thereafter, reducing the motor-current to a point such as to maintain a uniform speed, as and for the purpose set forth.

2. The method of motor-controlling which consists in gradually reducing the number of field-windings of the motor-field, as the motor attains its speed, in order to secure a substantially uniform accelerating-current and finally reducing the current to a point such as to operate the motor at a uniform speed, as and for the purpose set forth.

3. The method of controlling motors which consists in varying the windings in the motor-field and also the relative connections of two or more motors to maintain a substantially uniform accelerating-current and, thereafter reducing the current to a point such as to maintain a uniform speed, as and for the purpose set forth.

4. The method of controlling motors which consists in varying the windings in the motor-field to maintain a substantially uniform accelerating-current and, finally, restoring all the field-windings to the working circuit to maintain a uniform speed, as and for the purpose set forth.

5. In a motor-controller, a motor-circuit

initially including therein all the motor-field windings, relatively movable and stationary contacts arranged to control said field-windings, an auxiliary circuit actuated by the fall of current due to the development of counter electromotive force for moving said movable contacts, whereby a substantially constant accelerating-current is maintained by successively cutting out of circuit coils of the motor-field, as and for the purpose set forth.

6. In a motor-controller, a motor-circuit initially including therein all the motor-field windings, insulated contacts electrically connected to the successive coils of the motor-field windings, coöperating contacts arranged to contact with said first-mentioned contacts, said sets of contacts being relatively movable, an auxiliary motor arranged in said circuit and actuated by the fall of current due to the development therein of counter electromotive force, for moving said movable set of contacts, whereby as the motor accelerates the motor-field windings are successively cut out of the motor-circuit, thereby maintaining a substantially uniform accelerating-current, as and for the purpose set forth.

7. In a motor-controller, a motor-circuit initially including all the windings of the motor-field, a series of stationary insulated contacts respectively connected to the motor-field coils, a controller-cylinder having electrically-connected contact-segments of varying lengths adapted to coöperate with said stationary contacts, an auxiliary motor, means actuated thereby for rotating said controller-cylinder, said auxiliary motor arranged in the main-motor circuit and actuated by the fall of current due to the development of counter electromotive force, whereby a substantially constant accelerating-current is maintained, as and for the purpose set forth.

8. In a motor-controller, a motor-circuit initially including all the coils of the motor-field magnet, a controller-cylinder, an auxiliary motor for actuating the same, said motor arranged in the main-motor circuit and actuated by the fall of current due to the development of counter electromotive force in the main motor, contacts arranged to be closed by the successive movements of said controller-cylinder for successively cutting out of the motor-circuit the field-coils thereof until the desired speed has been attained, and a contact actuated by the further movement of said controller-cylinder for reëstablishing all the field-coils in the motor-circuit, thereby reducing the acceleration to maintain thereafter a constant speed, as and for the purpose set forth.

9. In a motor-controller, two or more motors, a circuit for said motors, said circuit initially including all the field-windings of both of said motors, a controller-cylinder, an auxiliary motor for actuating same, said auxiliary motor arranged in the main-motor circuit and actuated by the fall of current due to the development of counter electromotive force in the main motors, and contacts controlled by the movements of said cylinder for successively cutting out of circuit the field-windings of said motors and for changing the relative connections of said motors, and finally reëstablishing the field-windings in said circuit, as and for the purpose set forth.

In witness whereof I have hereunto set my hand, this 18th day of October, 1897, in the presence of the subscribing witnesses.

SIDNEY HOWE SHORT.

Witnesses:
M. A. KENSINGER,
JOHN J. BEVER.