(No Model.)

3 Sheets—Sheet 1.

S. H. SHORT.

METHOD OF AND MEANS FOR CONTROLLING ELECTRIC MOTORS.

No. 599,806.

Patented Mar. 1, 1898.

Fig. 7.

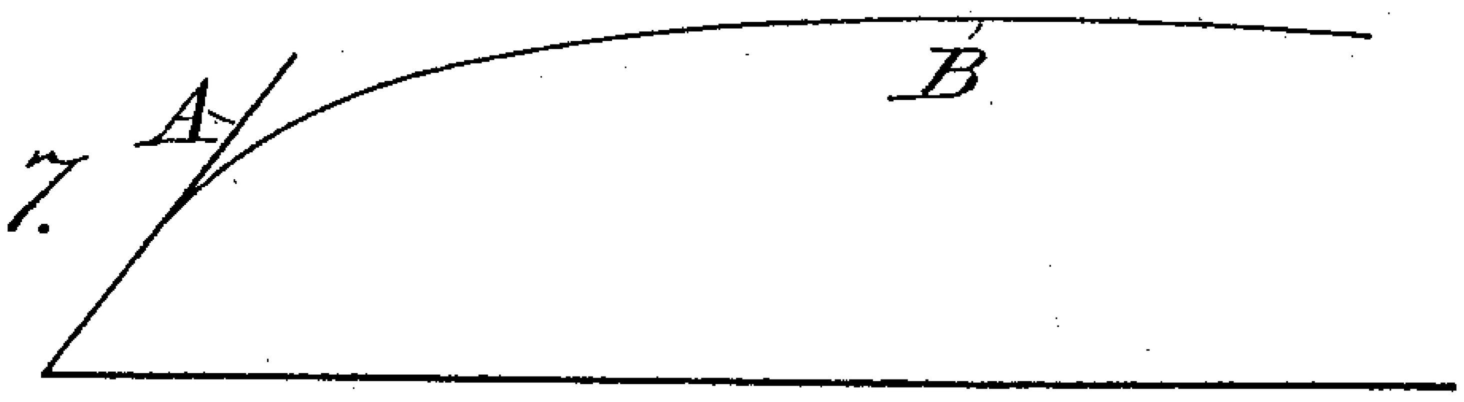


Fig. 8.

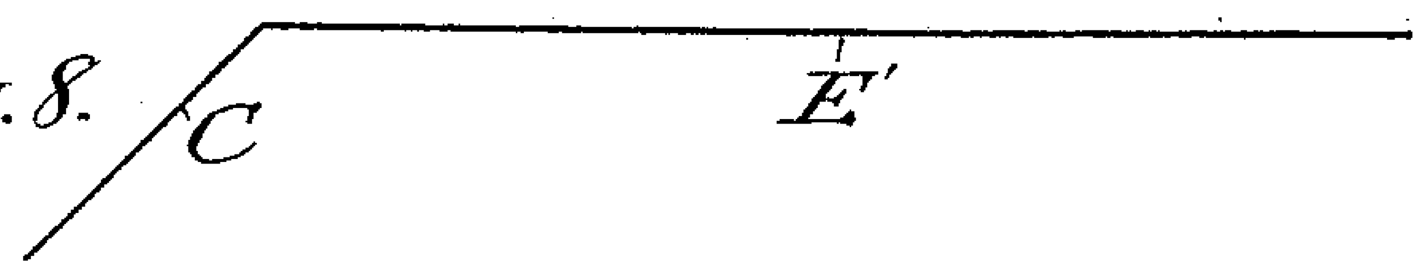


Fig. 1.

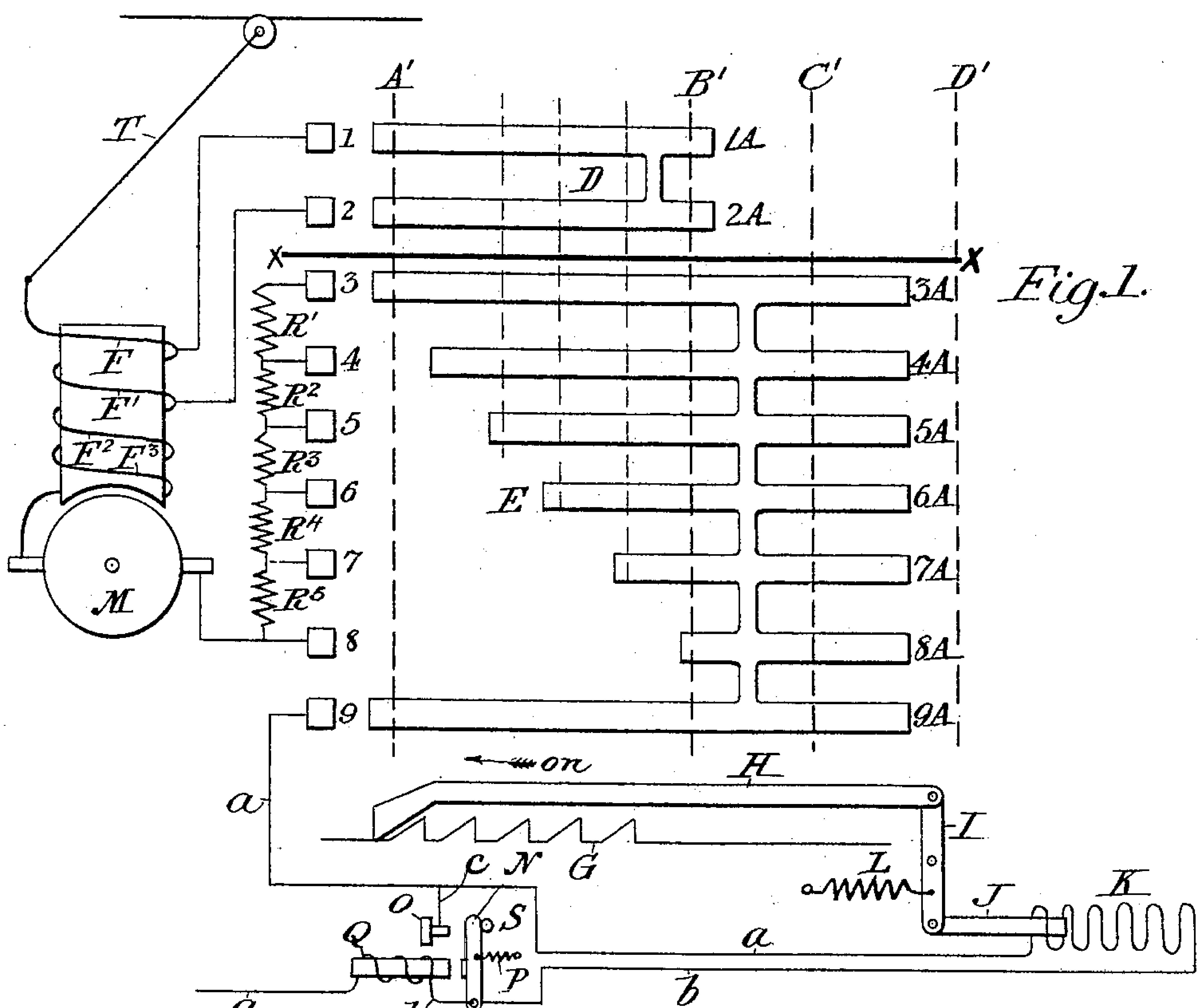


Fig. 2.

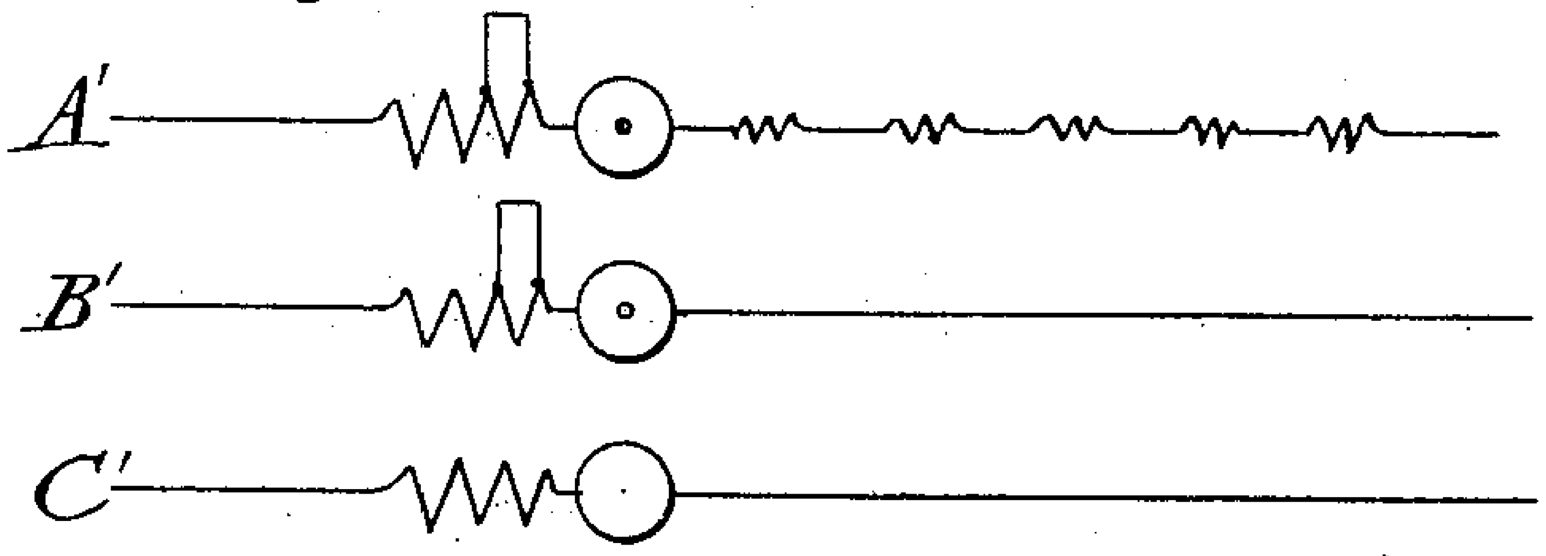
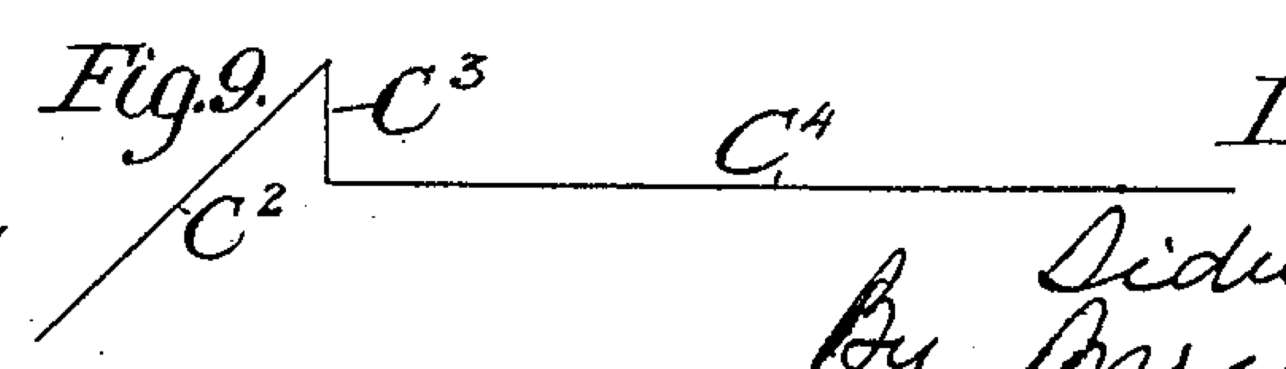


Fig. 9.



Witnesses:
H. H. Humphrey
W. Q. Olsen

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. 599,806.

Patented Mar. 1, 1898.

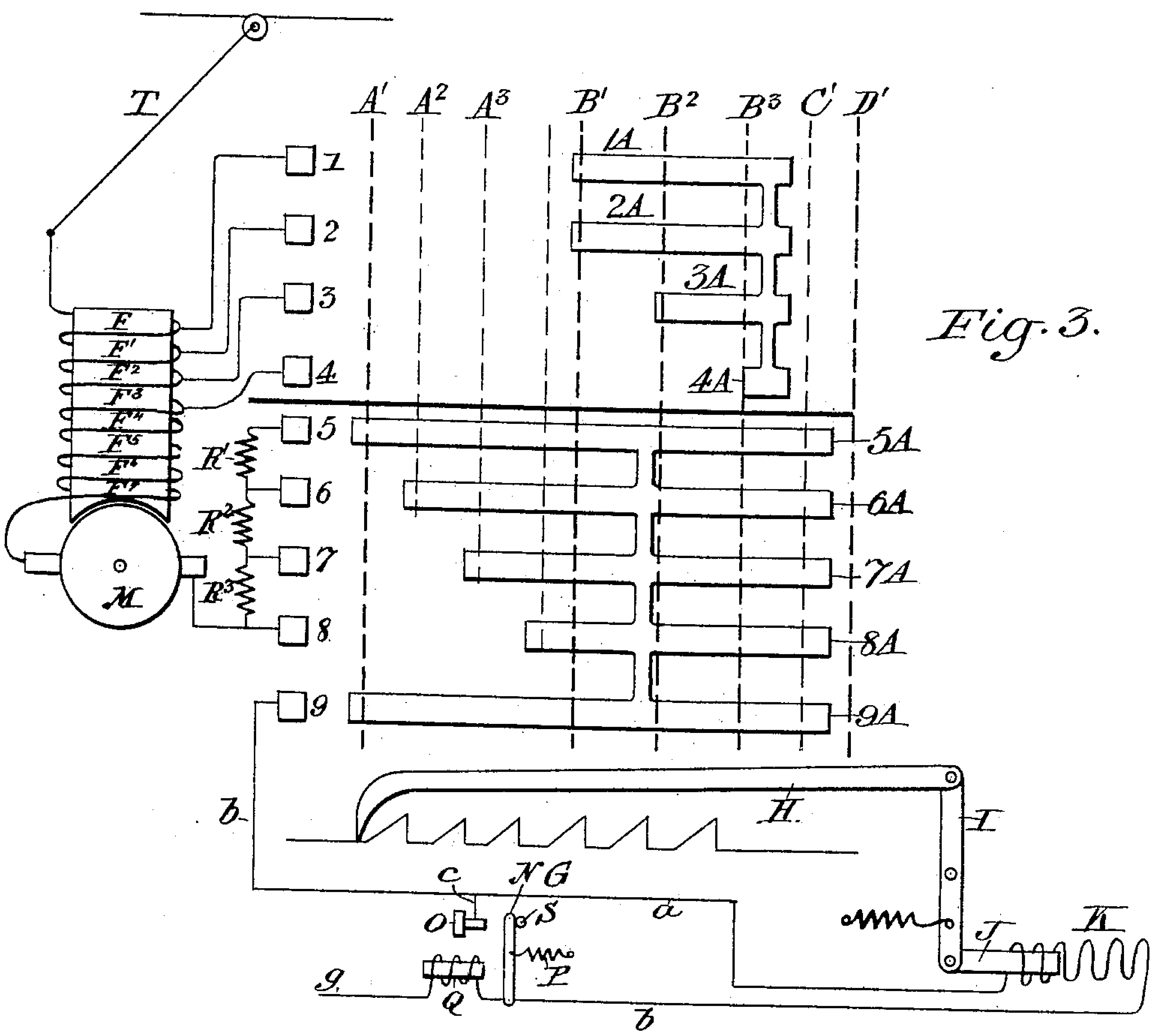


Fig. 3.

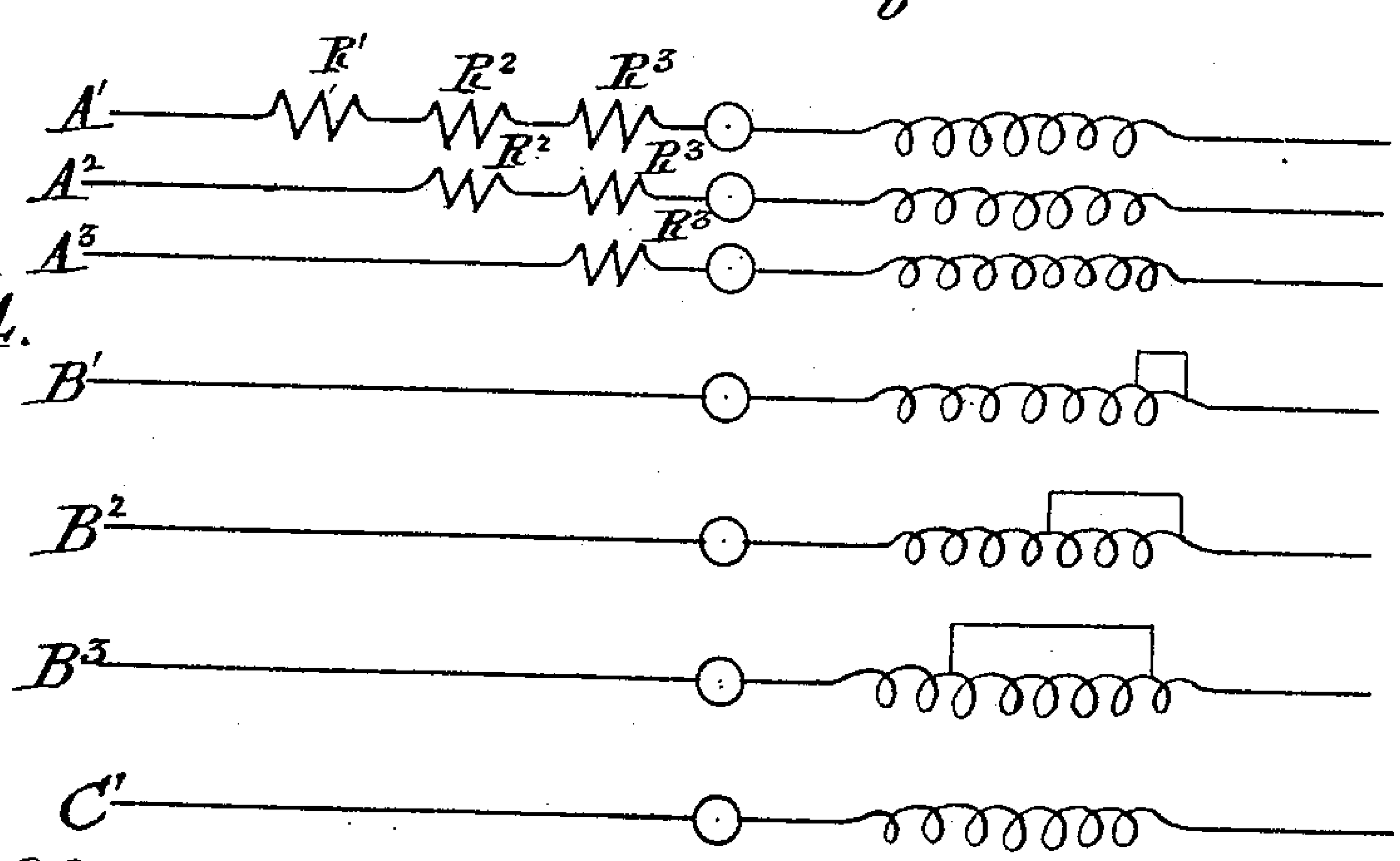


Fig. 4.

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

Inventor.
Sidney H. Short
By Brown & Darby Attys

THE NORRIS PETERS CO., PHOTO-LITHO., WASHINGTON, D. C.

(No Model.)

3 Sheets—Sheet 3.

S. H. SHORT.

METHOD OF AND MEANS FOR CONTROLLING ELECTRIC MOTORS.

No. 599,806. Patented Mar. 1, 1898.

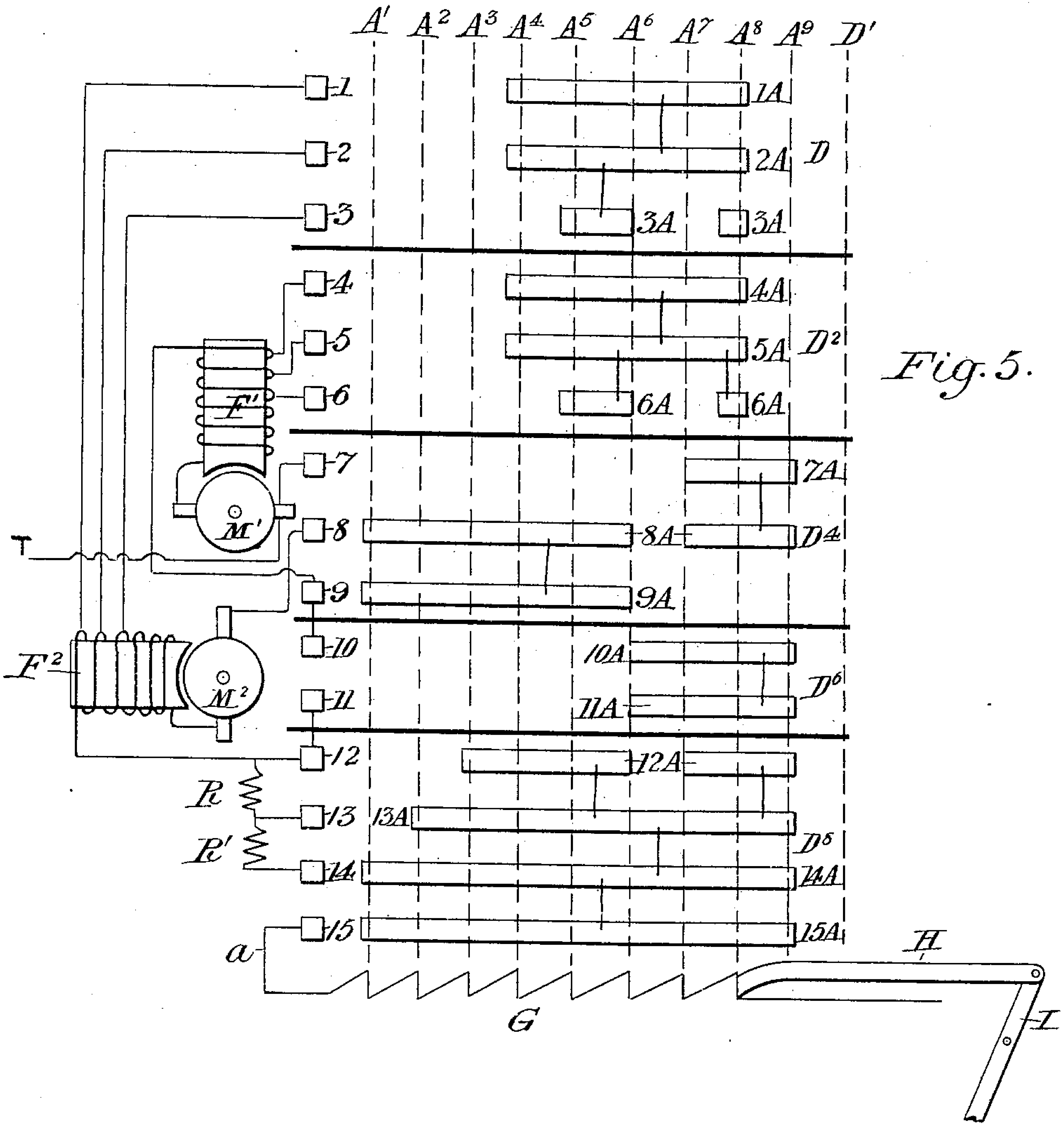


Fig. 5.

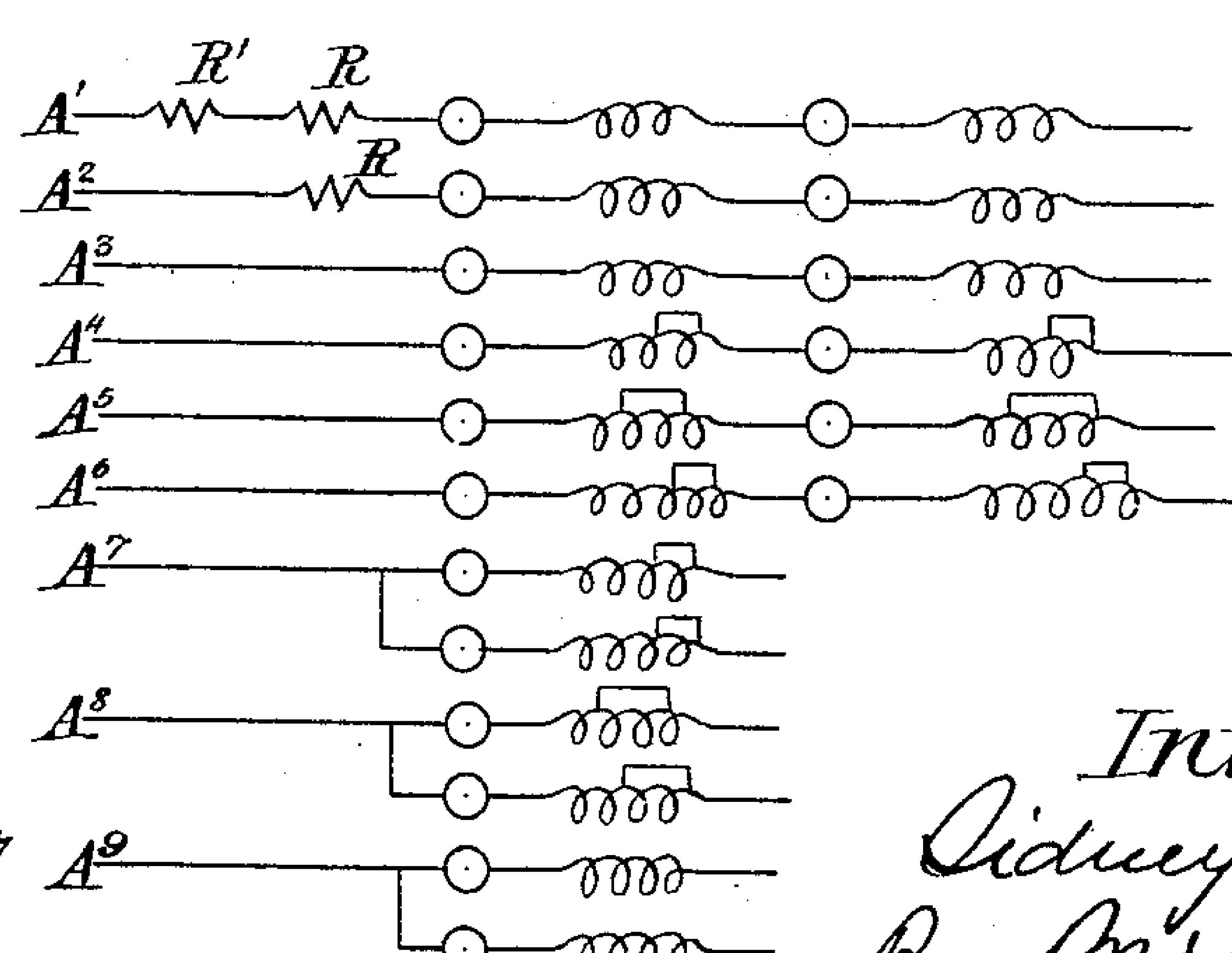


Fig. 6.

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

Inventor.
Sidney H. Short
By Morton & 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. 599,806, dated March 1, 1898.

Original application filed May 19, 1897, Serial No. 637,212. Divided and this application filed October 21, 1897. Serial No. 655,912. (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 methods of and means for controlling 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 much less consumption of power in starting the train from rest and in maintaining a 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 and suburban trains.

Further objects of the invention will appear more fully hereinafter.

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

Referring to the accompanying drawings and to the various views and reference signs appearing thereon, Figure 1 is a view in diagram illustrating an arrangement of the circuits and circuit-controlling contacts embodying in part the principles of my invention. Fig. 2 is a diagram illustrating the leads of the circuits under various positions of the controller. Fig. 3 is a view similar to Fig. 1, wherein a less amount of resistance is employed. Fig. 4 is a view illustrating in diagram the various circuits and changes therein resulting from the several steps in the operation of the controller shown in Fig. 3. Fig. 5 is a view similar to Figs. 1 and 3, illustrating diagrammatically two or more motors and circuits therefor embodying the principles of my invention and a method of coupling up said motors in series or in parallel to produce the effect of a uniform acceleration. Fig. 6 is a diagram illustrating the various changes in the motor-circuits resulting from the various positions of the apparatus shown in Fig. 5. Fig. 7 is a diagram illustrating the acceleration-curve of an ordinary series motor. Fig. 8 is a diagram illustrating the acceleration-curve of motors operated in accordance with the principles of control embodying 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 in 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 obtained under prior methods of control for reasons which I shall now endeavor 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 of the train, would be rapid and satisfactory. If this rapid and satisfactory acceleration could be continued uniform, a theoretically ideal condition would be attained and the acceleration-curve of the motor would be indicated by a straight line A, Fig. 7, and said uniform acceleration would accomplish a starting of the train from rest in a satisfactory, quick, and speedy manner, and hence would effect a large saving of time in starting the train from rest. If this uniform acceleration were to continue, however, the train would soon reach a rate of speed far beyond the safety limit. In the case of an ordinary series motor, however, as the armature of the motor gets under headway a counter electromotive force is developed therein which reduces the current flowing through the motor. This reduction of current flowing through the motor results in a falling off of the horizontal effort with a corresponding falling off of the increase each second of 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 a fall in the acceleration of the motor, and hence of the train, and therefore 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 practically uniform until the required speed is attained, and from that point onward the acceleration is arrested and a uniform speed is maintained, thus resulting in the acceleration-curve C, Fig. 8, substantially the same as the theoretical 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, a speed of the train or car would soon be attained which would be 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. Therefore in the method of control embodying these principles of my invention a train starting from rest will rapidly and quickly attain its desired speed and in a shorter space of time than heretofore and with a much smaller consumption of power, and hence resulting in a saving of time in driving the train from one station to another, the train getting under headway rapidly and quickly under a uniform acceleration of speed until the desired speed is attained, when the acceleration is arrested and a uniform speed thereafter is maintained until it is desired to stop the train. These generic principles may be embodied in a wide variety of apparatus.

In my above-mentioned application, from which the present case is divided, I have disclosed the generic idea involved and have shown therein several arrangements for accomplishing the desired object. For instance, a constant acceleration may be attained by successively cutting out resistances from the motor-circuit during the accelerating period, or the same result may be obtained by varying the windings of the motor-field, or the same result may be obtained where two or more motors are employed by varying the relative connections of the motors so as to connect said motors in series, in series parallel, or in parallel relation, or the desired object may be attained by combining in two or more motors these several methods, and while all of these several methods are disclosed and generically covered in my above-mentioned application only the case where the desired objects are obtained by varying the resistance is specifically claimed, and it is the purpose of the present invention to specifically cover that arrangement wherein the object sought to be secured is attained by varying the relative connections and relations of the several motors. In a companion application executed and filed of even date herewith, respectively, I have covered specifically the case where the desired object is attained by varying the motor-field windings. However, in order to enable a person skilled in the art to understand and comprehend the principles involved I have deemed it expedient to illustrate herein the several embodiments referred to in order that their relation and coöperative arrangement may be fully comprehended.

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 R^5, resistances; 1 2 3 4 5 6 7 8 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 9^A, the several points 1 2 3, &c., and corresponding strips 1^A 2^A 3^A, &c., being relatively movable, so as to be moved into or out of contact with each other. In the particular form shown the strips 1^A 2^A 3^A, &c., are mounted on the surface of a cylinder, the diagram Fig. 1 illustrating such surface developed. The portion D of the controller-cylinder is insulated from the portion E, as indicated at X X, Fig. 1.

The motor M is provided with a very large field-magnet, in which the iron is not thoroughly saturated with the lines of force under ordinary conditions under which it is designed to operate, so that any variation in the number of ampere-turns of the magnet-core will greatly influence the speed of the main motor. It is therefore necessary in accordance with the principles of 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 larger in capacity than is ordinarily used at present for the same class of work.

The first operation of the controller embodied in the principles of my invention is for the motorman to move the controller-cylinder D E into the position indicated by the 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′, contact 3, strip 3^A, and thence to strip 9^A, the several strips 3^A to 9^A being electrically connected together, from strip 9^A to contact 9, thence through the automatic arrangement for automatically actuating the controller-cylinder. This automatic arrangement may comprise the ratchet G, suitably mounted on the controller-cylinder. The pawl arm or lever H is arranged to engage the teeth of ratchet G. A suitable auxiliary and automatically-operated motor, preferably included in the circuit above described, is arranged to project said pawl arm or lever H. Many different arrangements of motor and specific constructions thereof may be employed for this purpose. Therefore while I have shown and will now describe a particular form of arrangement and apparatus for accomplishing the desired object I desire it to be understood that I do not limit or confine myself thereto, as the principles therein 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 pawl-lever H is pivotally connected to one end of a rock-lever I, to the other end of which lever is connected the magnetic core J, arranged to form the core of the solenoid K, the coils of which solenoid are included in the 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 object I do not desire to be limited or restricted thereto, the arrangement shown being merely illustrative of an operative apparatus for accomplishing the desired result. 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 a magnet Q, and thence through connection *g* to ground. A lever N, carrying or forming the armature of magnet Q, is arranged to be attracted when said magnet is energized and thereby moved into position to make contact with stop O, included in a branch connection *c*, from connection *a*, thereby completing the circuit from contact 9 through connections *a* and *c*, contact O, armature-lever N, connection *b*, the coils of magnet Q, connection *g*, to ground. A spring P is arranged as a retractile for lever N and normally exerts its tension to maintain lever N against stop S and out of contact with stop O. From this arrangement it will be seen that when the controller-cylinder is turned by the motorman into the position indicated by dotted line A′, Fig. 1, a circuit through the motor-field windings and all the resistances is completed, as above described, to contact 9, thence through connection *a*, auxiliary motor K, connection *b*, coils Q, and connection *g*, to ground. As soon as current begins to flow through the windings of motor K the core J is drawn into said coils, thereby rocking rock-lever I against the action of its retractile spring L and in a direction to move pawl-lever H in the direction indicated by the arrow, Fig. 1, and marked "On." This movement of lever H, however, does not effect a movement of the controller-cylinder, because at this stage in the operation there is no tooth on ratchet G in advance of the end of the pawl-lever H. The magnet Q becomes energized by the passage of current therethrough, upon completing the circuit above described, and hence effects an attraction of armature-lever N, thereby establishing contact between said lever and contact O, thereby completing the circuit through connection *c*, contact O, armature-lever N, connection *b*, the windings of Q, and connection *g* to ground, thus short-circuiting 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 pawl-lever H to engage behind the first tooth of ratchet G. Under this condition the motor starts up and begins to accelerate. As the motor starts up a counter electromotive force, as above explained, begins to develop in the motor, which if permitted to continue would cause a falling off of the acceleration, and hence the production of acceleration-curve B. (Indicated in diagram in Fig. 7.) The development of this counter electromotive force in the motor acts to cause a reduction in the current traversing relay Q. The tension of spring P is so regulated that when the current falls below a certain point said retractile P comes into action and effects a separation of the armature-lever N from contact O, thereby breaking the short circuit described above, and reëstablishing circuit through auxiliary motor K. The reëstablishing of this circuit effects the 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 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 only the resistances R^5 R^4 R^3 R^2, resistance R' being short-circuited or cut out by the contact established between point 4 and strip 4^A. The removal of this resistance R' from the motor-circuit results in again increasing the current through the motor to a point slightly above the desired point. At the same time the increase in current due to cutting out resistance R' again causes relay Q to attract armature-lever N, thereby again short-circuiting the auxiliary motor K automatically, until the current flowing through the motor again falls below the desired point by the continued development of counter electromotive force therein, until the relay is again opened by such fall of current and the auxiliary motor K is cut into live circuit, thereby advancing ratchet G another step, thus bringing contact 5 and strip 5^A into electrical contact. This connection results in cutting out resistance R^2 from the motor-circuit, thus again increasing the current through the motor-circuit and again actuating auxiliary motor K and advancing the controller-cylinder another step, in the manner above described, and so on, thus maintaining substantially a constant or practically constant acceleration of the motor. When the controller-cylinder has been moved to a position such as to cause strip 8^A to come into contact with point 8, all the resistances are out of the motor-circuit. In the meantime, and when the controller-cylinder is moved to its first position A′, as above explained, the contact-strips 1^A and 2^A are brought into connection with points 1 and 2, respectively. The points 1 and 2 respectively form the terminals of the coils F F′ of the motor-field magnet, and so long as strips 1^A and 2^A, which are electrically connected together, remain in contact with points 1 and 2 coils F F′ are short-circuited out of the field-magnet circuit, and hence during the conditions above described, wherein resistances R′ R^2 R^3, &c., are successively cut out of the motor-circuit, said field-coils F F′ remain short-circuited, leaving only the coils F^2 F^3, &c., to produce the necessary lines of force to be cut by the armature of the motor. When, finally, the controller-cylinder arrives, under the automatic action above described, in position indicated by dotted line B′, Fig. 1, the current during the several steps mentioned remaining fairly constant, slightly rising above the normal accelerating-current desired as the resistances are successively cut out of circuit, and slightly dropping below the desired normal accelerating-current as the counter electromotive force develops. If left in this position, the motor would thereafter rapidly develop a speed greater than that required, as has been above explained. Therefore the parts are so constructed and arranged that when this point is reached the desired speed has been attained, and hence by suitably constructing and arranging the teeth of ratchet G the automatic action of the controller-cylinder ceases at this point; but, as above explained, during all the preceding operations and up to this position of the parts a large portion of the field of the motor has been short-circuited and out of use. 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, manually or otherwise, the controller-cylinder from the position indicated by dotted line B′ to that indicated by line C′, Fig. 1. This movement breaks the short circuit of coils F F′ of the motor-field by breaking contact between 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, thereby increasing the number of magnetic lines of force cut by the armature of motor M. This results in 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 line C′ does not affect the resistance-circuits, the motor continuing to operate with the increased number of ampere-turns around the core of its field-magnet, current passing to point 8 without any resistance, thence to strip 8^A, strip 9^A, contact 9, and thence on, as above explained, either 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. Hence it is immaterial which of the above-described circuits from point 9 on the current 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 thereafter at a uniform speed.

From the foregoing description it will be readily seen that the acceleration-curve will be somewhat jagged by reason of the slight rising and falling of the current above and below the desired or normal accelerating-current; but by introducing a sufficient number of resistances, with an increase in the number of the coöperating contacts and contact-strips, this acceleration may be made practically constant, thereby developing a substantially straight acceleration-curve C 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 more coils of the motor-field circuit, thereby arresting the acceleration and hence producing the straight line E′, Fig. 8, in the acceleration-curve, which indicates the uniform speed thereafter.

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 the "off" position, thereby breaking all the motor-circuits, whereupon an application of the brakes brings the train to rest.

In Fig. 2 is shown diagrammatically the circuit conditions corresponding to the several positions A′ B′ C′ of the controller-cylinder and from which it will be seen that in the position A′ the motor operates with a portion of the field-coils cut out of circuit and with all the resistances included in circuit. In the position B′ all the resistances are 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 "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 circuit, and, secondly, by varying the coils of the motor-field—the cutting out of resistances in the motor-circuit serving to increase the current flowing 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 coils in the motor-field increases the number of lines of force cut by the motor-armature and hence serves to build up the counter electromotive force of the armature, thereby reducing its acceleration.

In Fig. 3 I have shown diagrammatically an arrangement of both of these methods for varying the acceleration employed together. In this arrangement I employ a comparatively small amount of resistance, and all of the field-magnet coils are initially included in the 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. In this arrangement I use a portion of the counter electromotive force of the motor to maintain a substantially 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 current travels 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, the circuit condition being illustrated in diagram in the position A′, Fig. 4. All of the resistances and also all the field-magnet coils are now 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 connection with contact 6, thus cutting out resistance R′. The line-circuit condition by reason of this movement is indicated diagrammatically at A^2, Fig. 4, only resistances R^2 R^3 being in circuit with all the field-coils. This condition is maintained until the current again falls below the normal or desired accelerating-point, thereby again effecting an action of the automatic mechanism and advancing the controller-cylinder another step and to the position indicated by line A^3, Fig. 3, thereby cutting out resistance R^2, the circuit condition resulting therefrom being indicated in diagram at A^3, Fig. 4, all the field-coils and only resistance R^3 being included in circuit. Finally, the controller arrives at the position B′, Fig. 4, and simultaneously therewith strips 1^A and 2^A make electrical connection with points 1 and 2, thereby short-circuiting one of the coils of the field-winding. This increases the accelerating-current of the motor by reducing the number of lines of force cut by the armature, and hence serves to restore the accelerating-current to a point slightly above the normal or desired stage. This condition is maintained until the continued development of counter electromotive force in the armature causes the current to fall to a point where the automatic auxiliary motor above described again moves the controller-cylinder another step to the position marked B^2. This movement brings strip 3^A into contact with point 3, thereby cutting out another coil or coils of the motor-field, as indicated at line B^2, Fig. 4, thereby again increasing the auxiliary current to a point slightly above the normal. This condition is maintained until the current again falls by reason of the development of counter electromotive force in the armature, thereby effecting another actuation of the automatic auxiliary motor and relay, and hence advancing the controller another step to the position B^3, and so on, thus successively cutting out the coils of the motor-field and automatically maintaining a substantially constant accelerating-current, until finally strip 4^A is brought into contact with point 4. At this point in the operation the controller is brought to a position where if the parts were left without further movement too great a speed would be developed. Therefore a further movement of the controller-cylinder to uniform-speed position is necessary, as indicated by dotted line C′. This is effected by the motorman and results in breaking contact between strips 1^A 2^A 3^A 4^A, &c., and their corresponding contacts 1 2 3 4, &c., thus again cutting into the motor-circuit all of the field-coils. This results in increasing the lines of force in the magnetic circuit of the motor and consequently builds up the counter electromotive force of the motor and reduces its speed to a uniform point, thereafter operating the motor with all of its field-coils in circuit and with no resistance, the position C′ (indicated in diagram, Fig. 4) indicating the continuation of the motor to operate at its constant speed, and when it is desired to stop the car the motorman moves the controller-cylinder to position D′ or off position, thereby breaking the circuit of the motor, whereupon on application of the brakes the car comes to rest. It will be readily seen that by suitably regulating the number of resistances and also the number of ampere-turns in the motor-field, which are successively short-circuited or cut out of the working circuit, a substantially uniform accelerating-current is secured, and the greater the number of these resistances and coils which are successively cut out the less jagged will be the accelerating-curve.

In the foregoing description my invention is described as applied to a single-motor equipment; but it is obvious that the principles thereof are equally well adapted for use with two or more motors placed on each car or on each axle of a car. I have found that the principles of my invention may be attained in such an equipment by varying the relative connections of the motors themselves—that is, by changing the relation of the motors from series to series parallel or parallel, such change or variation in the motor connections being utilized to secure the advantages noted—namely, a substantially uniform acceleration. This method of control is also and preferably employed in conjunction and coöperation with the methods above described.

In Fig. 5 I have shown an adaptation of my invention for producing a substantially uniform acceleration of current until the desired speed has been attained and thereafter maintaining a constant speed in connection with two or more motors, wherein the relative connections of the motors from series or series parallel or to parallel is employed in connection with the variations of resistance in the motor-circuit and also variations in the motor-field windings. In this arrangement 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, also the terminals of the circuits, which include resistances R R′, &c., and also the terminals of the motor-circuits. When it is desired to start the motors from rest, the motorman turns the controller-cylinder to the position indicated by dotted line A′, thereby completing the circuit from trolley T through motor M′, the windings F′ of the field of said motor M′, to contact 9, controller-cylinder strip 9^A, strip 8^A, contact 8, motor M^2, all the coils F^2 of the field of said motor M^2, all the resistances R′ R^2, to contact 14, cylinder contact-strip 14^A, strip 15^A, contact 15, and connection *a*, and thus on through the automatic auxiliary motor above described in connection with Figs. 1 and 2. Thus the motors are started, the circuit condition being indicated at A′, Fig. 6, the motors being in series and all the resistances R R^8 and all the coils of the field-magnets of all the motors being included in the motor-circuit, and the acceleration of the motors begins. When the accelerating-current falls by reason of the development of counter electromotive force in the motor-armatures to a point slightly below the desired normal point, the controller-cylinder is advanced automatically one step by the action of the auxiliary motor, as above described, to position A^2, thereby bringing contact-strip 13^A into connection with point 13 and hence cutting resistance R′ out of the motor-circuit, as indicated in diagram at A^2, Fig. 6. The removal of the resistance R′ from the motor-circuit again restores the accelerating-current to a point slightly above the normal. This condition of the line-circuit is maintained until further development of the counter electromotive force in the motors again reduces the accelerating-current to a point such as to again bring into action the automatic mechanism above explained, thereby again advancing the controller-cylinder another step and to position A^3. This movement brings strip 12^A into contact with point 12, thereby cutting out resistance R^2, thus again restoring the accelerating-current. The foregoing action continues until finally all the resistances are cut out, only two of such resistances being shown as illustrative of the principles involved. Thereafter further development of counter electromotive force results in a further reduction of the accelerating-current and a consequent actuation of the auxiliary motor, whereby the controller-cylinder is caused to be advanced another step to the position A^4. Without altering the electrical connections above described this last-mentioned step or advancement of the controller-cylinder brings contact-strips 1^A 2^A into contact with points 1 and 2 and also strips 4^A 5^A into contact with points 4 and 5, respectively, 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 to restore the accelerating-current by reducing the lines of force in the magnetic circuits of the motors, thereby again restoring the accelerating-current to a point slightly above the normal. This condition is maintained until the accelerating-current again falls slightly below the normal by reason of the development of counter electromotive force, whereupon the controller-cylinder is again advanced automatically and to position A^5, thereby bringing strips 3^A and 6^A, respectively, into contact with points 3 and 6, thus again cutting out additional coils in the field-windings of the motors and hence correspondingly increasing or restoring the accelerating-current to a point slightly above the normal by further reducing the lines of force in the magnetic circuits of the motors. This action is continued until finally all the coils of the fields of all the motors which it is desired to remove have been cut out, and upon the fall of the accelerating-current to a point slightly below the normal after the last coil which it is desired to be cut out of the motor-circuit has been removed the controller-cylinder is advanced again automatically to the position A^6, which is a step necessary preparatory to a change of the circuit connections of the motors from series to series parallel or to parallel. This movement of the controller-cylinder causes the following circuit condition to result, as indicated at A^6, Fig. 6, wherein the resistance R^2 and also some of the coils of the field-magnets of the motors which had been previously cut out are again restored to the working circuit. Inasmuch as the accelerating-current has not been increased by this last-mentioned change, but rather has been still further decreased by cutting in more turns of the motor-field windings, it is necessary to now operate the controller-cylinder by hand to advance it to the next position or to the point A^7. This movement brings contacts 10^A and 11^A into electrical contact with points 10 and 11, respectively, and hence changes the relation of or connections of the motors in the particular arrangement illustrated from series to parallel, as indicated at A^7, Fig. 6. If desired, only one of the motors may be employed during this transition, and hence a gap may be provided in strip 8^A. Similarly, if desired, gaps may also be provided in strips 3^A and 6^A and in strip 12^A, thereby cutting in some of the field-coils which had previously been cut out of circuit and also cutting in some of the resistance which had been previously cut out. However, whatever the changes may be during this movement at the end thereof the motors operate, as indicated at A^7, in parallel, with only a portion of the field-windings of each motor short-circuited. This transition results in increasing the accelerating-current to a point slightly above the normal, and hence when such current again falls below the normal by the development of counter electromotive force the auxiliary motor is again brought into play, thereby again advancing the controller-cylinder and to the point A^8, thus passing the gaps of the strips 3^A and 6^A and hence cutting out more coils from the motor-fields, but leaving the motors in parallel and hence again restoring the accelerating-current to a point slightly above the normal, and so on, until finally the desired acceleration has been attained, until the controller-cylinder arrives at the position indicated at A^9, when all the field-windings are again cut into live circuit in order to arrest the acceleration and reduce the current to the point necessary to maintain a constant speed. Finally, when it is desired to stop the car the motorman turns the controller-cylinder to the position D' or off position, thereby breaking all the circuits, whereupon on application of the brakes the train comes to rest.

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 carrying into practical effect the method of control embodying the principles above set forth. If four or more motors are used, they may be placed, respectively, in series, in series parallel, and finally in parallel, and in making the changes from one to the other the contacting strips and the coöperating contact-points may be so regulated and relatively adjusted as to cut out more or less of the windings of the field of one or of several of the motors and to cut into circuit a desirable resistance, thereby producing a substantially uniform acceleration and a uniform current in each motor in which the desired speed has been attained, and thereafter the windings of the field-magnets of all the motors are again replaced in circuit in order to reduce the current where it will operate the motors to propel the train at a uniform speed.

In the operation of the controlling method embodying my invention it will be obvious from the foregoing description that the power developed increases constantly and uniformly coincident with the constant or substantially constant acceleration of speed up to the point where it is desired to arrest the acceleration. 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 the current 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 uniform speed. I have shown in diagram, Fig. 9, the power-curve illustrating this operation, C^2 designating the development of power during constant acceleration, C^3 indicating the fall of power when the desired speed has been attained and the acceleration arrested, and C^4 indicating the constant power applied thereafter to maintain a uniform speed. Thus it will be seen that in the method of control embodying my invention I secure economy in current and also in power, at the same time attaining the advantages of a substantially uniform acceleration, by which the train rapidly attains its speed when started from rest.

While I have disclosed a method of control wherein the desired objects sought are attained by varying the resistance in the motor-circuit, I do not claim the same herein, as the specific subject-matter thereof is set forth and specifically claimed in my application, Serial No. 637,212, filed May 19, 1897, of which the present application is a division, and while I have disclosed herein a method of control wherein the results sought are secured by varying the field-windings I do not claim the same in this application, as such subject-matter is specifically covered in my companion application executed and filed of even date herewith.

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

Having now set forth the object and nature of my invention and a form of apparatus embodying the principles thereof and the mode of operating the same, 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 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.

2. In a motor-controller, two or more motors, initially connected in series, a controller-cylinder, an auxiliary motor arranged in the motor-circuit and actuated by the fall of current due to the development of counter electromotive force, for automatically actuating said cylinder, and contacts controlled by said cylinder for varying the relative connections of said motors, as and for the purpose set forth.

3. In a motor-controller, two or more motors, initially arranged in series, a controller-cylinder, an auxiliary motor arranged in the circuit of the motors and actuated by the fall of current due to the development of counter electromotive force, for actuating said controller-cylinder, circuits controlled by said controller-cylinder for varying the relative connection of said motors, whereby when the current falls by reason of the development of counter electromotive force such current is restored automatically, and means for finally arresting the acceleration and reducing the current, 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.