United States Patent [19]

Ozawa

[11] **3,757,186**

[45] **Sept. 4, 1973**

[54] **VERNIER CHOPPER CONTROLLING DEVICE**

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[22] Filed: **Dec. 16, 1971**

[21] Appl. No.: **208,821**

[30] **Foreign Application Priority Data**

Dec. 29, 1970 Japan 45/128558

[52] **U.S. Cl.** **318/514,** 318/349

[51] **Int. Cl.** **H02p 1/20**

[58] **Field of Search** 318/514, 515, 516, 318/519, 520, 349, 380

[56] **References Cited**

UNITED STATES PATENTS

3,581,172	5/1971	Tsuboi	318/259
1,895,924	1/1933	Hammond, Jr.	318/349 X
3,341,759	9/1967	Torii	318/422
3,067,372	12/1962	Blanchard et al.	318/393

Primary Examiner—B. Dobeck

Attorney—Thomas E. Beall, Jr.

[57] **ABSTRACT**

The armature current of a D.C. electric motor is controlled for power control by selectively shunting a plurality of series starting resistances, in order, which have resistance values such that the armature current, upon shunting, changes in value from a fixed starting current minimum to a permissible current maximum for each starting resistance, in combination with means for assuring that each of these current changes will be smooth and continuous over a substantial period of time by changing an effective series connected resistance an amount substantially equal to the starting resistance to be shunted, for each of the starting resistances in the order of their shunting. This means includes a current chopper in parallel electrical connection with a control resistance. The chopper may operate to pass current over a range identical for each shunting with variation of the control resistance to match the starting resistance to be shunted, or the control resistance may be identical for each shunting and the chopper current range may be matched to each of the resistances to be shunted.

9 Claims, 5 Drawing Figures

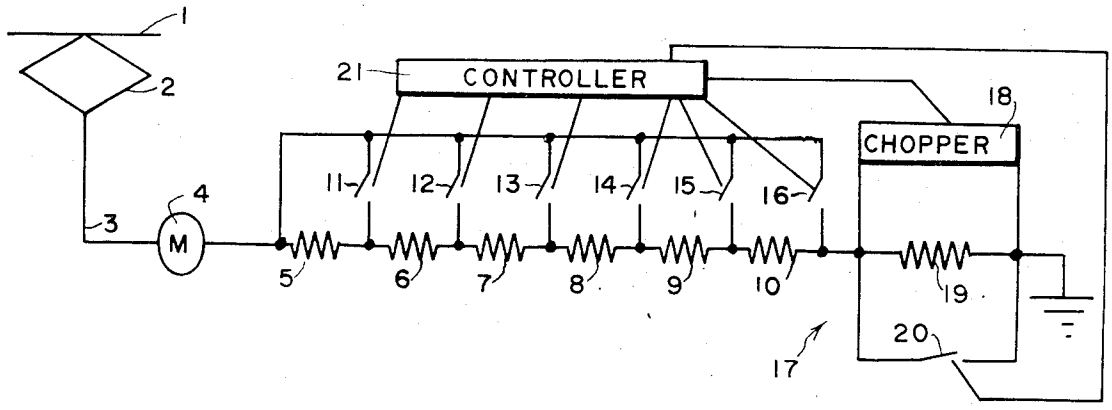


FIG. 1

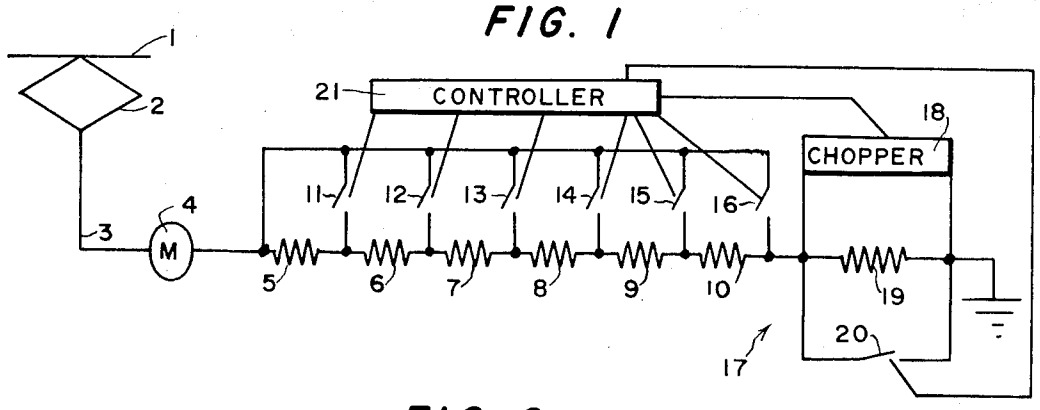


FIG. 2

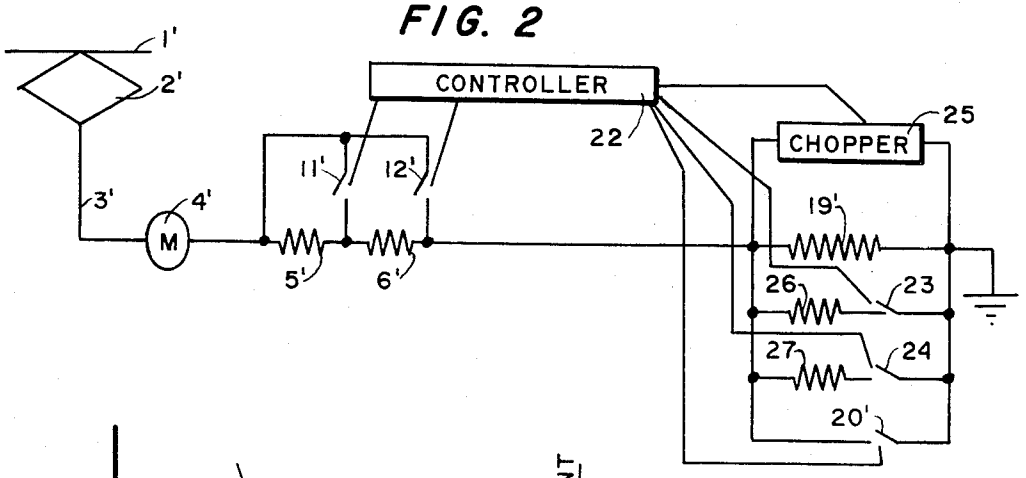
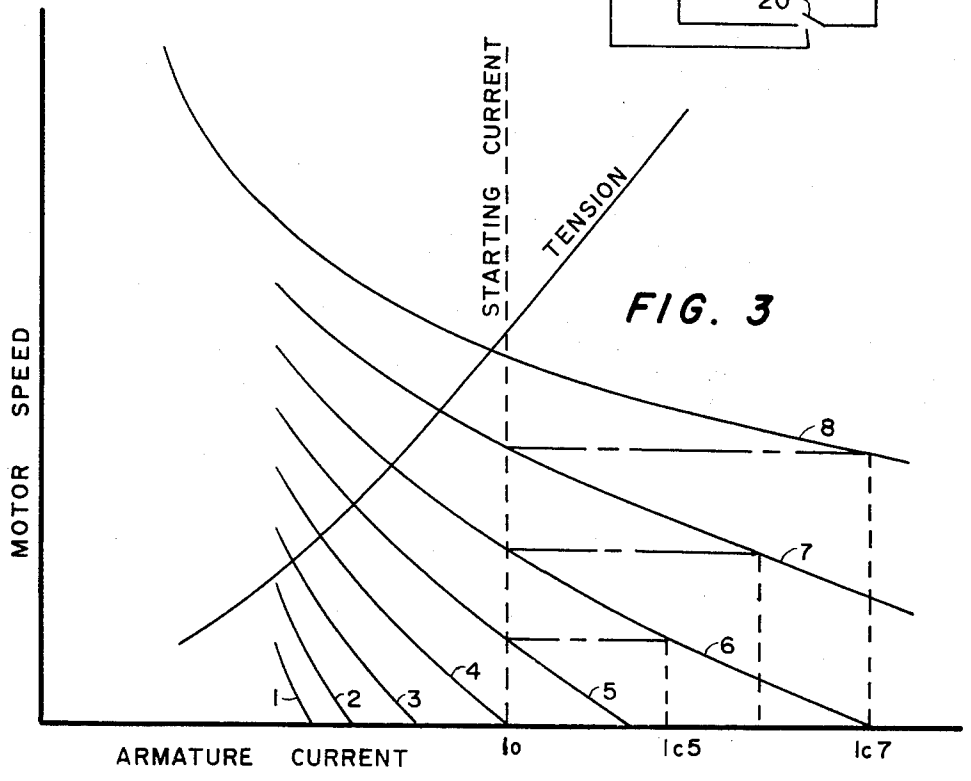


FIG. 3



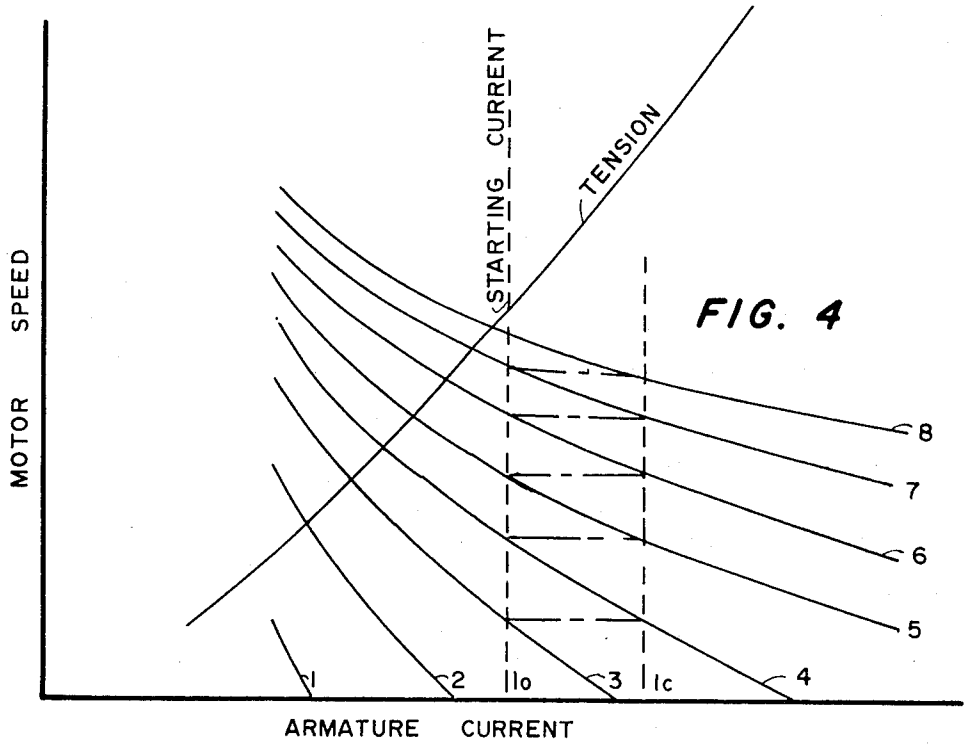

MOTOR SPEED
STARTING CURRENT
TENSION
8
7
6
5
4
1
2
Io
3
Ic
ARMATURE CURRENT

FIG. 4

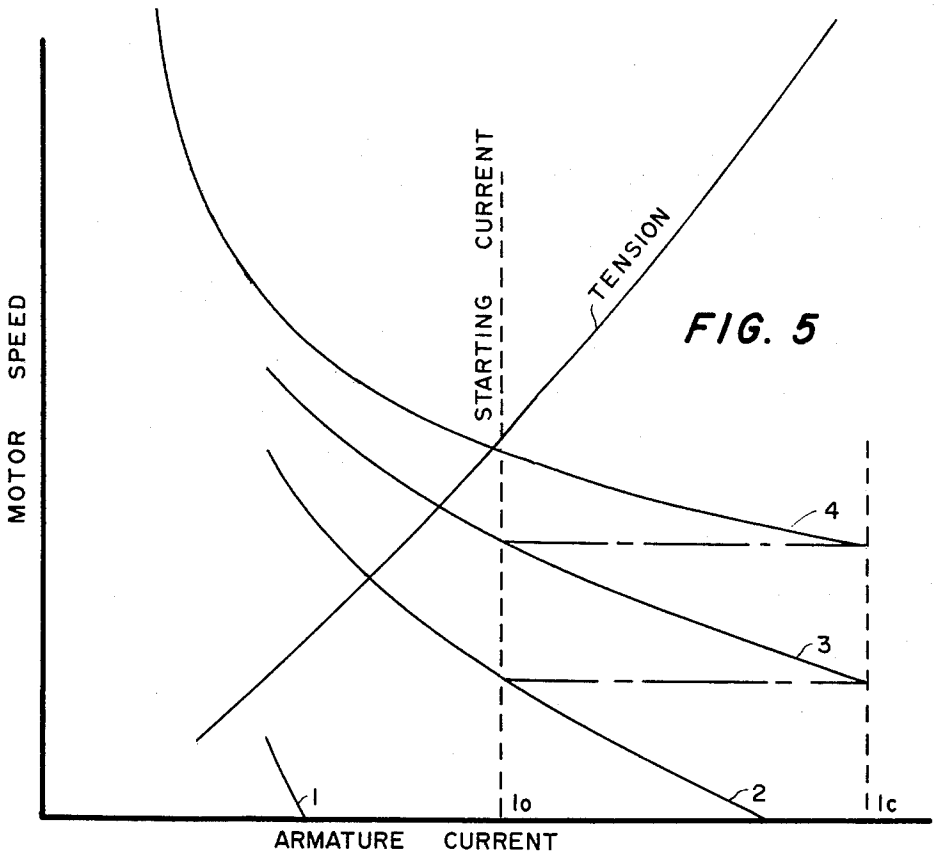

MOTOR SPEED
STARTING CURRENT
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4
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ARMATURE CURRENT

FIG. 5

VERNIER CHOPPER CONTROLLING DEVICE

BACKGROUND OF THE INVENTION

In the power control of rotary electric machinery, particularly D.C. rotary electric machinery for the purposes of controlling rolling stock prime movers, for either acceleration, deceleration by dynamic braking, or speed control in general, it has been the practice to change the power circuit resistance in steps, stages or notches. Particularly, it was accepted practice to provide a plurality of starting resistances in series with the armature of the main D.C. electric motor of rolling stock prime movers for successively shunting the starting resistances for in turn increasing armature current upon shunting.

The U.S. Pat. to Blanchard et al. No. 3,067,372, issued 1962, is an example of the prior art wherein the successive starting resistance shunting is conducted such that the armature current will vary between a constant maximum and a constant minimum for each shunting, but this type of device has the considerable disadvantage that there will be an instantaneous current surge in the motor armature for each shunting, which will produce wheel slipping upon occasion and considerable discomfort to the passengers of the rolling stock vehicle.

To overcome such current surge problems, it has been the practice to provide a switching circuit or current chopper in parallel with a control resistance serially connected with the starting resistances so that immediately prior to shunting the effective line resistance of the chopper and control resistance may be varied an amount equal to the starting resistance to be shunted to change the current from its minimum to its maximum over a considerable period of time and avoid the abovementioned surging. However, with such a device it has been necessary to construct each of the starting resistances and control resistance to have the same resistance value to completely eliminate current surging during shunting. This has the undesirable affect of having a different armature current range for each shunting. An example of such a circuit is shown in the U.S. Pat. to Tsuboi No. 3,581,172, issued May 25, 1971, to the assignee of the present invention.

Further, it is known to selectively connect a current chopper in parallel with each of the starting resistances, in order, immediately prior to their shunting, as shown by the U.S. Pat. to Torii No. 3,341,759, issued 1967.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide power control for the armature of an electric motor used as a prime mover for rolling stock so that with the successive shunting of series connected starting resistances, the armature current will vary between a constant minimum and a constant maximum, by using a single variable resistance means in series with the starting resistances at all times. This variable resistance means preferably employs a current chopper in parallel with at least one control resistance. The effective resistance provided in series by the resistance control means may be changed by providing a constant current range chopper in parallel with a plurality of control resistances, some of which may be switched into and out of circuit to match the resistance of the starting resistance to be shunted, or by providing a fixed single control resistance at least as great as the largest starting resistance in combination with a current chopper whose chopping range may be controlled to match the current effect of the starting resistance to be shunted. Preferably, the minimum armature current will be the motor starting current and the maximum armature current will be the maximum level permissible for the electric motor.

BRIEF DESCRIPTION OF THE DRAWING

Further objects, features and advantages of the present invention will become more clear from the following detailed description of the drawing, wherein:

FIG. 1 is a schematic electrical diagram of a control circuit employing the features of the present invention, for one preferred embodiment;

FIG. 2 is a schematic electrical diagram of a control circuit employing the features of the present invention, of a second preferred embodiment;

FIG. 3 is a motor speed-armature current plot for a control device similar to that shown in FIG. 1, but without the features of the present invention;

FIG. 4 is a motor speed-armature current plot for the control circuit of the present invention operating over a narrow armature current range as a small improvement over FIG. 3; and

FIG. 5 is a motor speed-armature current plot for the control circuit of the present invention operating over a wide armature current range between the starting current and the maximum permissible armature current.

DETAILED DESCRIPTION OF THE DRAWING

One preferred embodiment of the present invention is used for motor control for a rolling stock prime mover, either for power control of the motor or for dynamic braking with the motor operating as a generator. That portion of the embodiment of FIG. 1 corresponding with the prior art will first be described with respect to its operation and its circuit characteristics as shown in FIG. 3.

In FIG. 1, a power source is provided by the conventional string voltage line **1**, pantograph **2**, circuit breaker (not shown) and main disconnect switch (not shown) in series with line **3** leading to a D.C. electric motor **4**. For stepping control of the starting resistance, there are provided a plurality of separate serially connected starting resistances **5, 6, 7, 8, 9, 10** and a plurality of shunting switches **11, 12, 13, 14, 15, 16.** These shunting switches may be solenoid control switches or SCR switches. In a conventional manner, the closing of normally open switch **11** would shunt or short-circuit resistor **5**, the closing of switch **12** would short-circuit resistor **6**, etc.

In series with the motor **4**, there is additionally a resistance varying means **17** including a current chopper, current regulator or current divider **18** that may basically be of any conventional type, such as the "switching circuit" disclosed in the above-mentioned Tsuboi U.S. Pat. No. 3,581,172, whose disclosure is incorporated herein by reference in its entirety. The resistance varying means further includes a control resistance **19** and shunting switch **20**, in parallel with each other and in parallel with the chopper **18.**

In conventional operation of the device according to FIG. 1, the shunting switches **11–16** would normally be open at the starting of the main electric motor **4**, and the flow passage rate of the chopper **18** would, for ex-

ample, be effectively 0 percent so that the entire value of the resistance **19** would be in series with starting resistances **5–10**. Operation under these conditions would be denoted as the first stage or first notch. For moving from the first notch to the second notch, the flow passage rate of the chopper **18** would be gradually increased from **0** percent continuously to 100 percent, for example to effectively short-circuit the control resistance **19**, which control resistance **19** would conventionally be equal in value to each of the equal starting resistances **5–10**. Upon reaching the 100 percent rate for the chopper **18**, the control resistance **19** would effectively be short-circuited, and the switch **11** would be closed to simultaneously short-circuit starting resistance **5**; simultaneously the flow rate of the chopper **18** would be reduced substantially instantaneously to a 0 percent to again connect the full value of the resistance **19** in circuit. The same controlling pattern would be repeated to close the succeeding switches **12, 13, 14, 15, 16**, in order, to successively short-circuit the starting resistances **6, 7, 8, 9, 10**, respectively along with the appropriate operation of the chopper **18**. This procedure would be determined by the controller **21** having control communication as indicated with the switches **11–16** and chopper **18**.

The plot of FIG. **3** shows the notching curves obtained with the above-mentioned conventional portion of FIG. **1**. The maximum permissible range of variation of the main electric motor current when the chopper **18** is turned on for 100 percent passage of current or off for 0 percent passage of current depends on the allowable pulsation factor of the main electric motor **4**. In FIG. **3**, assuming that the fifth notch position has just been reached with switch **15** closed and the chopper **18** off, the electric current of the main electric motor **4** will be Io, and will be Ic5 when the chopper is on and switch **15** closed. The range of such motor electric current variation is enlarged in proportion as the resistivity of the starting resistance connected in series to the chopper **18** is decreased, and at the moment when the seventh notch position is reached, such range will span from *Io* to Ic **7**.

Noting the fact that the scope of variation of the starting current of the main electric motor is varied according to the resistivity of each starting resistance as mentioned above, the present invention has for its object to reduce the number of notches necessitated by making use of this fact.

According to the present invention, the values of the starting resistances **5–10** are all different and so chosen that when the chopper **18** is effectively in its off position immediately prior to each shunting operation, that is closing of switches **11–16** successively, the armature current will be the same, and when the chopper is in its effective on position or any one of the switches **11–16** has just been closed, the maximum armature current will be the same. Thus, the peak value of the starting current in each notch or control stage will remain constant.

To choose the value of the starting resistances, let it be assumed that the string voltage is E(V), the starting current is *Io*(A) and the velocity or motor speed of the eighth notch at that time is V8(Km/*h*), and that the electric current when commutation of the chopper **18** has become fully effective is *Ic*(A) and the velocity at that time is V8(Km/*h*). With these conditions being given, the resistivity of the resistance short-circuited by the switch **16** is obtained from the following equation wherein the value of the starting resistances are represented by R followed by their respective number:

$$R\,10 = Y\,8 - V\,7/V\,8 \times E \times 1/I\,o$$

Then, the velocity or speed for Ic(A) at seventh notch is obtained and it is assumed to be *V*6(Km/h).

The resistivity of the resistance short-circuited by the switch **15** at that time is given from the following equation:

$$R\,9 = V\,7 - V\,6/V\,7 \times E \times 1/I\,o$$

By following the above procedure in a similar manner, it is possible to obtain resistivities of the other resistances, down to the resistance R6 short-circuited by the switch **12**.

If the values of the resistance in the starting resistance sections obtained in the manner described above are controlled or matched by the chopper **18** successively from the section with highest resistance, there will be obtained the notching curve as shown in FIG. **4**. According to the plot of FIG. **4**, the starting current Io and the peak current Ic for each notch will be respectively constant, so that by bringing this peak value Ic up to the maximum level permissible for the main electric motor, it is possible to reduce the number of notches necessary and correspondingly the number of switching stages and starting resistances as shown in FIG. **5**.

The first embodiment of the present invention for producing the above-desired results, with the plots of FIGS. **4** and **5** being applicable, employs the above-identified structure except that the values of the starting resistances **5–10** are all different and chosen so as to produce notching curves that in plots of motor speed versus armature current would produce the characteristics as shown in FIGS. **4** and **5** such that the intersections between a constant starting current line and the notch curves would directly correspond to the same speed with the intersections of a constant maximum current line and the next succeeding notch curve. In addition, the current passage range of the chopper **18** may be varied to produce different current ranges in number corresponding to the number of resistance steps or starting resistances **5–10**. Further, each current passage range for the chopper **18** is such that it will, in parallel with the control resistance **19**, produce a change in effective resistance for the means **17** substantially identical to the resistance of the associated starting resistances **5–10**. While this is a specific example, it is, of course, recognized that the current passage for the chopper **18** may closely approximate the ultimate ranges to the point where the differences will produce negligible results with respect to current surge, for example, the end values for the chopper current transmission ranges may vary 10 percent. To obtain the best results by matching the change in effective resistance of means **17** with the starting resistance to be shunted, it is a feature of the present invention that the control resistance **19** is at least as large as the largest starting resistances **5–10**, and may be larger.

By way of a specific example, with switch **13** closed and the motor speed increasing to the point where the back e.m.f. increases and reduces the armature current to the predetermined constant minimum, for example *Io*, the chopper **18** is off, that is does not pass any current. Upon reaching Io, it will be desired to proceed to the next notch. At this point, the controller in response

to sensing the armature current reaching the minimum, that is reaching Io, will send a signal to the chopper **18** to increase its current transmission in a smooth and continuous manner to the point where it changes the effective resistance of means **17** an amount equal to the resistance to be shunted to correspondingly smoothly and continuously increase the armature current from Io to the maximum constant value, for example Ic, over a period of time sufficient to prevent undesirable current surge and shock but over a time short enough such that it may be assumed that the motor speed does not increase. At the moment of reaching Ic by at least partially short-circuiting the control resistance **19** by the chopper **18**, the controller closes switch **14** to short-circuit starting resistor **8** and simultaneously reduces the current transmission of chopper **18** in a substantially instantaneously manner corresponding to the operation of the switch **14** to zero, that is turns chopper **18** off. Thus, the range of no current transmission to partial transmission for the chopper **18** is different for each notching position and is so chosen that together with the fixed control resistor **19** will produce an effective resistance change for the means **17** respectively matched to the starting resistors **5–10**.

During the above switching, the switch **20** is normally open and will be closed at the end of the last notch to short-circuit the chopper **18** and the control resistor **19** when full motor speed is desired.

From the above, it is seen that it is one important feature of the present invention that the number of starting resistors or notches may be substantially decreased with respect to the number required in prior stepping resistor and chopper arrangements because the full armature current range between starting current and maximum permissible armature current may be utilized for each switching operation from starting resistor to the next starting resistor.

It is a second important feature of the present invention that the control resistor **19** is at least as large as the largest of the starting resistors. If this feature of the present invention were not complied with and the control resistor **19** was smaller in resistance value than the largest of the starting resistances, the current variation at the time of short-circuiting of this largest starting resistance would give rise to a current surge or shock for the entire system, which would manifest itself in an unpleasant sensation for vehicle passengers or perhaps an undesirable wheel slip. However, by making the control resistance at least as high as the highest starting resistance, it is possible to maintain the balance with the other starting resistors as well as the highest starting resistor by controlling the current transmission range of the chopper **18**.

A third important feature of the present invention relates to the changing of the effective control resistance for the means **17** connected in parallel with a chopper having a fixed range of current transmission. This is accomplished according to the second embodiment shown in FIG. **2**, which embodiment will produce plots identical to those shown in FIGS. **4** and **5**. Those elements of FIG. **2** that are identical to the correspondingly numbered elements in FIG. **1** have been provided with primes to show a separate embodiment and the above description with respect to FIG. **1** will suffice for the same element in FIG. **2**, with the following differences.

In FIG. **2**, the controller **22**, when operating under conditions such that switches **11'**, **12'**, **23**, **24**, and **20'** are open will sense the time when the motor speed increases to the point where its back e.m.f. produces a reduction in armature current to the predetermined minimum current, for example the starting current of FIGS. **4** and **5**, and at this time will send a signal to the fixed range chopper **25** to smoothly and continuously increase its current transmission to the point where it effectively short-circuits control resistor **19'**, which control resistor **19'** is substantially equal in value to the starting resistor **5'**;thereafter, the controller **22** will simultaneously close the switch **11'** to short-circuit the starting resistor **5'**, return the chopper **25** to substantially 0 transmission, and close switch **23** to place resistor **26** in parallel with control resistor **19'** to produce an effective resistance for the means **17'** that will be substantially the same as resistance for the starting resistor **6'**. When the motor speed again increases to the point where the controller **22** senses the reduction of the armature current to Io, the chopper **25** is again actuated to function over its fixed range, after which the chopper is turned off simultaneously with closing of switches **12'**, **20'**. In a manner similar to resistor **26** and switch **23**, resistor **27** and switch **24** may be used when there is a third starting resistor.

The chopper **25** of FIG. **2** while operating over a fixed transmission range, may have such range be **90** to 10 percent of full current transmission, rather than 100 to 0 percent of full transmission, or the like variation. A further advantage of the embodiment of FIG. **2** is that the effective resistance placed in parallel with the chopper decreases as the effective starting resistance decreases.

Further, resistor **27** and switch **24** may be used with resistor **26** and switch **23** to change the effective fixed resistance of means **17** in steps for matching the second starting resistor. Also, the chopper may be used to smooth out the switching in and out of resistors **26** and **27**.

Further embodiments, variations and modifications are contemplated according to the spirit and scope of the present invention, as defined by the following claims, although the specific details are important according to the more narrow aspects of the present invention.

What is claimed is:

1. A direct current rotary electric machine control circuit, comprising: a plurality of separate starting resistances in series and having different resistance values; means for placing said starting resistances in series with a source of electric power and a rotary D.C. electric machine for stepping power control; means for shunting each of said starting resistances in a predetermined order so that the thus controlled current minimum and maximum for each successive shunting remains respectively constant as determined by the different starting resistance values; current chopper and resistance means in series with said starting resistances for changing in effective resistance smoothly over a period of time immediately prior to shunting each starting resistance, with the resistance change being different for each shunting and matched with the starting resistance to be shunted, and substantially instantaneously adding the same effective resistance at shunting.

2. The control circuit of claim **1**, wherein said current chopper and resistance means includes at least one

control resistance means in series with said separate starting resistances and having a resistance value at least as great as the greatest resistance value of said starting resistances, and further having a current chopper in parallel with said control resistance means and in series with said starting resistances.

3. The control circuit of claim 2, wherein said current chopper and resistance means controls the operation of said current chopper to vary the current passed therethrough in a continuous manner from a predetermined minimum to a predetermined maximum constituting a range, with the range for each shunting step being different.

4. The control circuit of claim 3, wherein said current chopper and resistance means controls the operation of said current chopper so that the first chopper range will effectively reduce the resistance of said control resistance means in series with said starting resistances an amount equal to the resistance of the first starting resistance shunted, and the second chopper range will effectively reduce the resistance of said control resistance means an amount substantially equal to the second starting resistance shunted.

5. The control circuit of claim 1, wherein said current chopper and resistance means includes a selectively variable resistance means in parallel with a fixed range current chopper and means for varying the variable resistance means to successively match each of said starting resistances, in order, as they are shunted.

6. The control circuit of claim 5, wherein said variable resistance means and means for varying include a plurality of separate resistances in parallel with each other and in parallel with said current chopper and switch means for connecting and disconnecting at least some of said parallel resistances in circuit.

7. The control circuit of claim 6, in combination with a direct current rotary electric machine having an armature in series connection with said starting resistances, and in series connection with said current chopper and resistance means; said armature having a maximum permissible current level equal to said maximum current; and said armature further having a designed starting current equal to said minimum current level.

8. The control circuit of claim 4, in combination with a direct current rotary electric machine having an armature in series connection with said starting resistances, and in series connection with said current chopper and resistance means; said armature having a maximum permissible current level equal to said maximum current; and said armature further having a designed starting current equal to said minimum current level.

9. The control circuit of claim 1, in combination with a direct current rotary electric machine having an armature in series connection with said starting resistances, and in series connection with said current chopper and resistance means; said armature having a maximum permissible current level equal to said maximum current; and said armature further having a designed starting current equal to said minimum current level.

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