

ROTATIONAL SPEED CONTROL APPARATUS FOR DC MOTOR

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The present invention relates to rotational speed control apparatus for a motor, e.g. rotational speed control apparatus for a DC brushless motor which is driven by a relatively low voltage from a DC power source.

Recently, high quality audio apparatus has been developed, and a high grade motor is required for use in such high quality audio apparatus. Particularly in rotational speed control of a DC brushless motor, rapid and accurate control is required.

A conventional method for controlling the rotational speed of the DC motor is elucidated hereafter with reference to FIG. 7, FIG. 8, FIG. 9 and FIG. 10. FIG. 7 is circuitry of a first example of a rotational speed control apparatus for a DC motor in the prior art. Three driving coils 41, 42 and 43 of the motor are connected to the positive line 40 of a DC power supply at one end. The other ends of the driving coils 41, 42 and 43 are coupled to the collectors of driving transistors 44, 45 and 46, respectively. The collectors of the transistors 44, 45 and 46 are grounded through capacitors 47, 48 and

49, respectively. The emitters of the driving transistors 44, 45 and 46 are grounded, and the bases of the driving transistors 44, 45 and 46 are also grounded through resistors 51, 52 and 53, respectively.

Position sensors 54, 55 and 56 for sensing the rotational position of the rotor are mounted in the DC motor. The position sensors 54, 55 and 56 are Hall devices, for example. The outputs of the position sensors 54, 55 and 56 are inputted to a current switching circuit 58. A motor driving circuit 20A comprises the transistors 44, 45, 46 and the current switching circuit 58. The outputs of the current switching circuit 58 are applied to the respective bases of the driving transistors 44, 45 and 46. The collectors of the driving transistors 44, 45 and 46 are connected to the invert inputs (-) of differential amplifiers 62, 63 and 64 of amplifiers 121, 122 and 123 through resistors 59, 60 and 61, respectively. The noninvert inputs (+) of the differential amplifiers 62, 63 and 64 are connected to the positive line 40 through resistors 65, 66 and 67, respectively.

The outputs of the differential amplifiers 62, 63 and 64 are connected in common, and resistors 68, 69 and 70 are connected across the invert inputs and the outputs of the differential amplifiers 62, 63 and 64, respectively. A series connection of resistors 71 and 72 is connected between the positive line 40 and the outputs

of the differential amplifier 62, 63 and 64 connected in common. A capacitor 73 is connected between the positive line 40 and the junction point between the resistors 71 and 72. The junction point is connected to the invert input of a differential amplifier 74 through a resistor 75. The output of the differential amplifier 74 is connected to the invert input thereof through parallel connected resistor 76 and capacitor 77.

The output voltage of a reference voltage generator 78 for generating a reference voltage V_{ref} is applied to the noninvert input (+) of a differential amplifier 79 of a rotating speed setting circuit 93. The output of the differential amplifier 79 is connected to the base of a transistor 81 which is grounded at the collector. The emitter of the transistor 81 is connected to the positive line 40 through a constant current source 80 and is connected to the base of a transistor 83, too. The emitter of the transistor 83 is grounded through a resistor 84 and is connected to the invert input (-) of the differential amplifier 79, too. The collector of the transistor 83 is connected to the positive line 40 through a resistor 82 and is also connected to the noninvert input of a differential amplifier 85.

The output of the differential amplifier 85 is connected to the invert input thereof and thereby a "voltage follower circuit" is formed. The output voltage

"f" of the differential amplifier 85 is applied to the noninvert input of the differential amplifier 74. The output of the differential amplifier 74 is connected to the current switching circuit 58 through a resistor 87.

The operation of the prior art is elucidated with reference to FIGs. 8(a) --- 8(g). Signals output from the position sensors 54, 55 and 56 are inputted to the current switching circuit 58. In the current switching circuit 58, current-switching signals which are applied to the bases of the transistors 44, 45, 46 are generated on the basis of the signals output from the position sensors 54, 55, 56. The waveforms of the current-switching signals are shown in FIGs. 8(d), 8(e) and 8(f). The current-switching signals shown in FIGs. 8(d), 8(e) and 8(f) are applied to the bases of the driving transistors 44, 45 and 46, respectively, and the currents flowing the driving coils 41, 42 and 43 are controlled thereby. In FIGs. 8(d), 8(e) and 8(f), the high level represents a period of 120 electrical degrees of instructing current flow.

Counter electromotive voltages shown in FIGs. 8(a), 8(b) and 8(c) are generated in each driving coil 41, 42, 43 by revolution of the rotor of the DC motor. In the waveforms shown by FIG. 8(a), 8(b) and 8(c), shaded areas represent waveforms made by driving currents flowing in the driving coils 41, 42, 43. The counter electromotive

voltages are inputted to the amplifiers 121, 122, 123, respectively, and are amplified thereby. The outputs of the amplifier 121, 122 and 123 are added at the respective output terminals of the differential amplifiers 62, 63, 64, and a pulsating current output VD is output as shown in FIG.8(g). The level of the output VD varies in compliance with the rotating speed of the rotor. The output VD is smoothed to a DC voltage "e" by a filter circuit composed of the resistors 71, 72 and the capacitor 73, and the DC voltage "e" is applied to the invert-input of the differential amplifier 74.

The rotating speed setting circuit 93 generates the output signal "f" for designating the rotating speed of the rotor on the basis of the reference voltage V_{ref} of the reference voltage generator 78. A difference between the output "f" and the output "e" is applied to the current switching circuit 58. In the current switching circuit 58, the levels of the current-switching signals shown in FIGs. 8(d), 8(e) and 8(f) are varied by the difference, and thereby the currents flowing in the driving coils 41, 42 and 43 are controlled to rotate the rotor at a predetermined rotating speed.

In the prior art, as mentioned above, the output VD for controlling the rotating speed of the rotor is generated on the basis of the counter electromotive voltages generated in the driving coils 41, 42, 43.

Therefore, in the event that the magnetic force of the permanent magnet mounted in the rotor varies owing to a temperature change during continuous operation of the motor, for example, the counter electromotive voltages of the driving coils 41, 42, 43 vary. Consequently, the level of the output VD is varied, and thus the output of the differential amplifier 74 is varied. Accordingly, the output of the current switching circuit 58 is varied, and the rotating speed of the rotor varies.

A second example of rotational speed control apparatus of the prior art is elucidated hereafter. FIG.9 is circuitry of the second example of the rotational speed control apparatus. Referring to FIG.9, a motor 21 is driven by the motor driving circuit 20 which is identical with that of the first example. The rotational position of the rotor of the motor 21 is detected by position sensors 54, 55 and 56 which are mounted on the motor. The outputs of the position sensors 54, 55 and 56 are inputted to a rotating speed detecting circuit 4, and a rotating speed pulse signal PFG is output. The rotating speed pulse signal PFG is a pulse signal having a period TFG which is inverse proportional to the rotating speed of the rotor. The rotating speed pulse signal PFG is applied to a rotating speed error signal generator 31. A rotating speed reference signal generator 23 comprises a first timer 24 and a second timer 25, and the first output PFG

of the rotating speed error signal generator 31 is applied to the first timer 24. An output signal AC and an output signal BR are output from the rotating speed error signal generator 31 and are applied to a current control circuit 30. The current control circuit 30 is composed of a constant current source 26, a first switching circuit 27, a second switching circuit 28 and a second constant current source 29 which are coupled in series with each other in the named order. The first constant current source 26 is connected to a positive line Vcc of a DC power source, and the second constant current source 29 is coupled to the ground.

The first switching circuit 27 is controlled by the output signal AC, and the second switching circuit 28 is controlled by the output signal BR. The junction point between the first switching circuit 27 and the second switching circuit 28 is connected to the invert input of a differential amplifier 104 of an integrating circuit 100, and the positive line of a reference voltage source 103 of a reference voltage Vref1 is connected to the noninvert input thereof. A series connected resistor 101 and capacitor 102 are connected across the output terminal of the differential amplifier 104 and the invert input thereof, and thereby an integrating circuit 100 is formed. Moreover, a diode 120 is coupled across the output terminal and the invert input of the differential

amplifier 104 in a manner that the cathode of the diode 120 is connected to the output terminal. A capacitor Ch is of a small capacitance as a high pass filter for noise reduction. The output of the integrating circuit 100 is applied to the motor driving circuit 20 to control the rotating speed of the motor 21.

The operation of the rotating speed control apparatus of the second prior art example is illustrated by waveform charts shown in FIGs. 10(a) --- 10(d). In FIG.9, the frequency of the rotating speed pulse signal PFG is in proportion to the rotating speed of the rotor. In the rotating speed reference signal generator 23, a first square wave signal representing a first reference time interval is generated by the first timer 24, and then, by receiving the first square wave signal, a second square signal representing a second reference time interval is generated by the second timer 25. A rotating speed reference time T is defined by the sum of the first reference time interval and the second reference time interval.

In the rotating speed error signal generator 31, when the period of the rotating speed pulse signal PFG is longer than the rotating speed reference time T, it is determined that the rotating speed of the rotor is lower than a predetermined rotating speed which is set by the first timer 24 and the second timer 25. Thus, the output

signal AC for increasing the rotating speed is output from the rotating speed error signal generator 31 and is applied to the first switching circuit 27. On the other hand, when the period of the rotating speed pulse signal PFG is shorter than the rotating speed reference time T, it is determined that the rotating speed of the rotor is higher than the predetermined rotating speed, and the output signal BR for decreasing the rotating speed is output from the rotating speed error signal generator 31, and is applied to the second switching circuit 28 of the current control circuit 30. The above-mentioned configuration for controlling the rotating speed is familiar to one skilled in the art as the "double-monomulti-vibrator method".

FIG.10(a) is the waveform chart of an example of the output signal AC and FIG.10(b) is the waveform chart of an example of the output signal BR.

The first switching circuit 27 closes during the high level period of the output signal AC, and a constant current flows into the invert input of the differential amplifier 104 of the integrating circuit 100 from the constant current source 26. On the other hand, the second switching circuit 28 closes during the high level period of the output signal BR, and a constant current flows from the invert input of the differential amplifier 104 to the constant current source 29. Consequently, an invert input

current CPO of the differential amplifier 104 is generated at the junction point between the first switching circuit 27 and the second switching circuit 28 as shown by the waveform of FIG.10(c).

The output voltage VT of the differential amplifier 104 is shown by the waveform of FIG.10(d). Referring to FIG.10(d), when the rotating speed is lower than a predetermined value, since the output signal AC is output a current flows into the invert input of the differential amplifier 104, and the inflow of the invert input current CPO is represented by a positive level in FIG.10(c). Consequently, the level of the output voltage VT of the differential amplifier 104 is lowered. However, since the diode 120 is coupled across the invert input terminal and the output terminal of the differential amplifier 104 in a manner that the anode thereof is connected to the output terminal, the level of the output voltage VT is kept to the value of a difference between the forward voltage V_{BE} of the diode 120 and the reference voltage Vref1.

On the other hand, when the rotating speed is larger than the predetermined value, the output signal BR is output, and a constant current flows from the invert input of the differential amplifier 104 to the ground. The outflow of the invert input current CPO is represented by a negative level in FIG.10(c), and the level of the

output voltage V_T increases as shown in FIG. 10(d). The output voltage V_T becomes equal to the reference voltage V_{ref1} when the rotating speed reaches the predetermined value.

Since the integrating circuit 100 has an extremely large gain, input of the invert current CPO which exceeds a predetermined time length results in saturation of the integrating circuit 100, and the output voltage V_T is held to a minimum value which is lower than the reference voltage V_{ref1} . Consequently, the response characteristic of the integrating circuit 100 is deteriorated. In the integrating circuit 100, saturation is prevented by the diode 120. In general, the forward voltage V_{BE} of a diode is about 0.7 volts. Therefore, at least 2 volts of DC power source is required to activate the integrating circuit 100. For example, in a rotating speed control apparatus using only one battery with an output voltage of 1.5 volts, a device having 0.2 --- 0.3 volts of forward

voltage is required, and such a diode is not commercially available.

According to a first aspect of the present invention, there is provided rotational speed control apparatus for a motor, comprising: at least one position sensor mountable on said motor for sensing the rotational position of a rotor of said motor, a current switching circuit for generating current-switching signals for switching currents flowing in driving coils of said motor, on the basis of the output(s) of said position sensor(s), an amplifier for amplifying said current-switching signals to a level corresponding to a predetermined rotational speed of said rotor, a pulse generator for generating a pulse signal having a frequency proportional to the rotational speed of said rotor, on the basis of said output(s) of said position sensor(s), a timer circuit for generating a sawtooth waveform signal in synchronism with said pulse signal, and a rectangular

wave signal which steps up in response to said pulse signal and steps down when said sawtooth waveform signal reaches its peak level, an acceleration pulse generating circuit for generating an output signal having a phase opposite to said rectangular wave signal, a deceleration pulse generating circuit for generating a rectangular wave signal which steps up in response to said pulse signal and steps down when said sawtooth waveform signal reaches a predetermined voltage, a current control circuit comprising a series arrangement of a first constant current source, a first switching circuit, a second switching circuit and a second constant current source which are couplable between both ends of a DC power source and are arranged to generate a current in response to switching of said first switching circuit by said output signal from said acceleration pulse generating circuit and said second switching circuit by said rectangular wave signal from said deceleration pulse generating circuit, and an

integrating circuit for integrating said current output from said current control circuit and outputting an output signal for controlling the gain of said amplifier.

Because it uses the rotational position of the rotor and not the back-e.m.f. of the rotor coils, the rotational speed control apparatus is free from the influence of external conditions such as temperature.

According to a second aspect of the present invention, there is provided rotational speed control apparatus for a motor, comprising: at least one position sensor mountable on said motor for sensing the rotational position of a rotor of said motor, a pulse generator for generating a pulse signal having a frequency proportional to the rotational speed of said rotor, on the basis of the output(s) of said position sensor(s), a rotational speed reference signal generator for generating a time length signal having a predetermined time length corresponding to a reference

rotational speed of said rotor, a rotational speed error signal generator for generating an acceleration signal which is for instructing increase of said rotational speed of said rotor when the period of said pulse signal from said pulse generator is larger than said time length of said rotational speed reference signal generator, or a deceleration signal which is for instructing decrease of said rotational speed when the period of said pulse signal is smaller than said time length of said rotating speed reference signal generator, a current control circuit comprising a series arrangement of a first constant current source, a first switching circuit, a second switching circuit and a second constant current source which are couplable between both ends of a DC power source and are arranged to generate a current in response to switching of said first switching circuit by said acceleration signal and said second switching circuit by said deceleration signal, an integrating circuit for integrating said current output from said current control circuit and outputting an output signal for controlling a motor driving circuit, and a clamp circuit for clamping the level of said output signal of said integrating circuit to a predetermined level.

Because of the clamp circuit, a lower power supply voltage may be used.

The invention will now be described by way of non-limiting embodiments with reference to the accompanying drawings, in which:-

FIG.1 is a block diagram of a first embodiment of rotational speed control apparatus for a DC motor in accordance with the present invention;

FIGs. 2(a), 2(b), 2(c), 2(d), 2(e), 2(f), 2(g) and 2(h) are waveform charts of the operation of the first embodiment;

FIGs. 3(a), 3(b), 3(c), 3(d), 3(e), 3(f) and 3(g) are waveform charts for constant rotational speed operation of the first embodiment;

FIGs. 4(a), 4(b), 4(c), 4(d), 4(e), 4(f), 4(g) and 4(h) are waveform charts for variation of rotational speed of the first embodiment;

FIG.5 is the circuitry of a second embodiment of rotational speed control apparatus for a DC motor in accordance with the present invention;

FIGs. 6(a), 6(b), 6(c), 6(d), 6(e), 6(f), 6(g) and 6(h) are waveform charts of the operation of the second embodiment;

FIG.7 is the circuitry of a first prior art example of rotational speed control apparatus for a DC motor;

FIGs. 8(a), 8(b), 8(c), 8(d), 8(e), 8(f) and

8(g) are waveform charts of the operation of the first prior art example;

FIG.9 is the circuitry of a second prior art example of rotational speed control apparatus for a DC motor; and

FIGs. 10(a), 10(b), 10(c) and 10(d) are waveform charts of the operation of the second prior art example.

FIG.1 is a block diagram of a rotating speed control apparatus for a DC motor of a first embodiment in accordance with the present invention. Referring to FIG.1, the DC motor of the embodiment comprises three driving coils 1A, 1B and 1C. One end of each driving coil 1A, 1B, 1C is coupled to a DC power source Vcc, and the other end of each driving coil 1A, 1B, 1C is coupled to the collectors of driving transistors 2A, 2B and 2C, respectively. The emitters of the driving transistors 2A, 2B and 2C are connected to the ground and the bases of these transistors are coupled to the amplifier 7.

Three position sensors 54, 55 and 56 are mounted on the motor and are spaced apart 120 degree of electrical angle around the rotor.

The outputs of the position sensors 54, 55 and 56 are applied to a position sensing circuit 13, and square wave signals VA, VB and VC are output from the position sensing circuit 3 as shown in FIGs. 2(a), 2(b) and 2(c). The signals VA, VB and VC are inputted to

a current switching circuit 6, and current-switching signals TU, TV and TW are generated as shown by FIGs. 2(d), 2(e) and 2(f).

The current-switching signals TU, TV and TW are applied to the amplifier 7. In the amplifier 7, base input signals of the driving transistors 2A, 2B and 2C for switching current flowing the driving coils 1A, 1B and 1C are generated on the basis of the current-switching signals TU, TV and TW. A motor driving circuit 20 is composed of the current switching circuit 6, the amplifier 7 and the transistors 2A, 2B and 3C.

The signals VA, VB and VC are applied to a rotating speed sensing circuit 14, and a rotating speed signal FG is output as shown in FIG.2(g). The rotating speed signal FG is applied to a rotating speed pulse signal generator 5, and rotating speed pulse signals PFG which synchronize with rise edges of the rotating speed signal FG are generated as shown in FIGs. 3(a) and 3(b). The rotating speed pulse signal PFG is applied to a deceleration pulse signal generator 8, an acceleration pulse signal generator 9 and a timer circuit 10.

In the timer circuit 10, charging process of a capacitor C is started at the time of input of the rotating speed pulse signal PFG, and the voltage across both terminals of the capacitor C increases from zero volt to a voltage V1 as shown in FIG.3(c). The voltage across

both the terminals of the capacitor C rapidly falls to zero volt when it reaches the voltage V_1 , and the operation is repeated each input of the rotating speed pulse signal PFG. Thus, a sawtooth wave signal VS is generated as shown in FIG.3(c). The rise time TVS of the signal VS is determined by a current flowing into the capacitor C and is changed by an adjusting means which is not shown in the figure. The change of the current results in the change of the rotating speed of the motor as described in detail hereinafter.

In the deceleration pulse signal generator 8, as shown in FIG.3(f), the output signal PBR of the deceleration pulse signal generator 8 turns a high level at the time of input of the rotating speed pulse signal PFG, and when the saw tooth wave signal VS reaches a predetermined voltage V_2 , the output signal PBR turns to a low level. Consequently, the pulse width TBR of the output signal PBR is determined by the voltage V_2 , and therefore can be changed by varying the voltage V_2 .

On the other hand, the other output signal PTO of the timer circuit 10 turns to a high level when the signal VS starts to rise, and turns to a low level when the level of the signal VS reaches the voltage V_1 as shown in FIG.3(d).

In the acceleration pulse signal generator 9, an output signal PAC turns to a high level at the fall edge

of the output signal PT0, and turns to a low level by input of the rotating speed pulse signal PFG as shown in FIG.3(e). Consequently, the output signal PAC has substantially an opposite phase of the output signal PT0.

The output signals PBR and PAC are applied to a current control circuit 30 composed of a first constant current source 26, a first switching circuit 27, a second switching circuit 28 and a second constant current source 29 which are coupled in series with each other in the named order. The first constant current source 26 is connected to a positive line Vcc of a DC power source, and the second constant current source 29 is coupled to the ground. In the current control circuit 30, the output signal PAC is applied to the first switching circuit 27, and the output signal PBR is applied to the second switching circuit 28.

An invert input current CPO of the current control circuit 30 is output from the junction point between the first switching circuit 28 and the second switching circuit 29. The inflow or outflow of the invert input current CPO is shown in FIG.3(g). In FIG.3(g), the inflow and outflow of the invert input current CPO are represented by a positive waveform and a negative waveform, respectively. The invert input current CPO is inputted to the invert input of an integrating circuit 11 which is comprised of a differential amplifier 11A, a

capacitor C and a resistor R. The differential amplifier 11A is coupled across the power source Vcc and the ground. Inflow of a current from the first constant current source 26 to the invert input of the differential amplifier 11A is controlled by the switching circuit 27 which is closed by application of the output signal PAC, and outflow of the current from the invert input to the second constant current source 29 is controlled by the second switching circuit 28 which is closed by application of the output signal PBR. Since the constant current characteristic of the first constant current source 26 is identical with that of the second constant current source 29, average invert input current CP0 is proportional to a difference between the time length TAC of the output signal PAC (FIG.3(e)) and the time length TBR of the output signal PBR (FIG.3(f)). A reference voltage Vref1 of the reference voltage source 103 is applied to the noninvert input of the differential amplifier 11A. Consequently, an output signal VT is output from the integrating circuit 11. The output signal VT is applied to the amplifier 7. The waveform of the output signal VT is shown in FIG.3(h).

Referring to FIGs. 3(e) and 3(f), when motor speed reaches the predetermined target value, the time length TAC is equal to the time length TBR.

Therefore, the invert input current CP0 becomes substantially zero, and hence the output signal VT of the

integrating circuit 11 is equal to the reference voltage V_{ref1} which is applied to the noninvert input of the differential amplifier 11A, by the imaginary shortcircuit effect of the differential amplifier.

The output signal VT is applied to the amplifier 7, in order to control the base currents of the driving transistors 2A, 2B and 2C. Consequently, the currents flowing in the driving coils 1A, 1B and 1C are controlled to control the rotating speed of the rotor.

FIGs. 4(a) --- 4(h) are waveform charts of the operation of the rotating speed control apparatus in which the rotating speed of the rotor is lowered by increase of a load, for example. Referring to FIG.4(a), the period TFG of the rotating speed signal FG is prolonged by decrease of the rotating speed. Consequently the period of the pulse signal PFG also increases as shown in FIG.4(b). The period PVS of the signal VS is increased by extending the time length ZVS at the zero level as shown in FIG.4(c). Therefore, the time length TT0 at the zero level of the output signal PTO increases, and the time length TAC at the high level of the output signal PAC also increases as shown by FIGs. 4(d) and 4(e). The time length TBR of the output signal PBR is maintained constant if the voltage V2 is not changed. Therefore the time length of the positive level of the invert input current CPO is larger than the time length at the negative level

thereof as shown in FIG.4(g). Consequently, the level of the output signal VT of the integrating circuit 11 decreases as shown in FIG.4(h). The output currents of the amplifier 7 are increased by decrease of the output signal VT, and the currents flowing the driving coils 1A, 1B and 1C are increased and thereby the rotating speed of the rotor increases.

In the first embodiment of the rotating speed control apparatus, the output signal VT is generated on the basis of the output signals PAC and PBR which are obtained from the rotating speed signal FG, which is made by the output of the position sensors 54, 55 and 56 for detecting the position of the rotor. Therefore, unlike the prior art of using counter-electromotive voltage, the output signal VT is free from the variation of the magnetic force of the rotor magnet due to a temperature change, for example. Thus, the variation of the rotating speed due to the temperature change is prevented and accuracy of the rotating speed is improved.

FIG.5 is circuitry of a second embodiment of the rotating speed control apparatus in accordance with the present invention. Referring to FIG.5, a motor 21 is driven by the motor driving circuit 20 which is identical with that of the first embodiment. The rotational position of the rotor of the motor 21 is detected by position sensors 54, 55 and 56 which are mounted on the

motor. The outputs of the position sensors 54, 55 and 56 are inputted to a rotating speed detecting circuit 4, and a rotating speed pulse signal PFG is output therefrom. The rotating speed pulse signal PFG is a pulse signal having a period TFG which is inverse proportional to the rotating speed of the rotor. The rotating speed pulse signal PFG is applied to a rotating speed error signal generator 31.

A rotating speed reference signal generator 23 comprises a first timer 24 and a second timer 25, and the rotating speed pulse signal PFG from the rotating speed error signal generator 31 is applied to the first timer 24. An output signal AC and an output signal BR are output from the rotating speed error signal generator 31 and are applied to a current control circuit 30. The current control circuit 30 is composed of a constant current source 26, a first switching circuit 27, a second switching circuit 28 and a second constant current source 29 which are coupled in series with each other in the named order. The first constant current source 26 is connected to a positive line Vcc of a DC power source, and the second constant current source 29 is coupled to the ground.

The first switching circuit 27 is controlled by the output signal AC, and the second switching circuit 28 is controlled by the output signal BR. The junction point

between the first switching circuit 27 and the second switching circuit 28 is connected to the invert input of a differential amplifier 104 of an integrating circuit 100, and the positive line of a reference voltage source 103 of a reference voltage V_{ref1} is connected to the noninvert input thereof. A series connected resistor 101 and a capacitor 102 are connected across the output terminal of the differential amplifier 104 and the invert input thereof, and thereby an integrating circuit 100 is formed. A small capacitance C_h is a high pass filter for noise reduction. The output of the integrating circuit 100 is applied to the motor driving circuit 20, which controls the rotating speed of the motor 21.

A clamp circuit 105 is connected across the output terminal and the invert input of the differential amplifier 104 to clamp the level of the output signal V_T .

Configuration of the clamp circuit 105 is elucidated hereafter. Two transistors 109 and 113 which are coupled at the bases with each other are connected to the positive line of the DC power source V_{cc} at both the emitters. The collector of the transistor 109 is connected to the collector of a transistor 110 and is also connected to the base of a transistor 106. A positive voltage of a reference voltage V_{ref2} is applied to the base of the transistor 110. The reference voltage V_{ref2} is set to a clamp voltage which is lower than the

reference voltage V_{ref1} . The output signal V_T is prevented from being lowered to less than the clamp voltage.

The emitter of a transistor 107, which is connected to the DC power source V_{cc} at the collector, is connected to one end of a constant current source 108, which is grounded at the other end. The emitter of the transistor 110 is also connected to the constant current source 108. The collector of a transistor 113 is coupled to the base itself and is connected to the ground through a constant current source 111.

A current mirror circuit 119 is composed of the transistors 109 and 113 and the constant current source 111. The current of the constant current source 111 is set smaller than that of the constant current source 108. In the current mirror circuit 119, the current flowing in the transistor 109 is equal to that of the transistor 113, and a constant current flows through the transistor 109 by means of the constant current source 111. The current mirror circuit 119 is operable at about 1 volt of a DC power source.

The base of the transistor 107 is connected to the collector of the transistor 106 and is connected to the output terminal of the differential amplifier 104 of the integrating circuit 100. Moreover the emitter of the transistor 106 is connected to the invert input of the differential amplifier 104.

The operation of the rotating speed control apparatus of the second embodiment is elucidated with reference to waveform charts shown in FIG.6(a) --- 6(h).

In the rotating speed sensing circuit 4, a rotating speed pulse signal PFG is generated on the basis of the outputs of the position sensors 54, 55 and 56 as shown in FIG.6(b). The rotating speed pulse signal PFG is generated at each fall edge of the rotating speed signal FG shown in FIG.6(a). The rotating speed pulse signal PFG is inputted to the rotating speed error signal generator 31.

In the rotating speed reference signal generator 23, the output signal PT1 of the timer 24, as shown in FIG.6(c), turns to a high level by input of the rotating speed pulse signal PFG from the rotating speed error signal generator 31, and turns to the low level after the first reference time T1 has passed. Then the output signal PT2 of the timer 25 turns to a high level upon falling

of the output signal PT1. The output signal PT2 turns to the low level after the second reference time length T2 has passed as shown in FIG.6(d).

In the second embodiment of FIG.5, the rotating speed of the rotor is set by the time length T which is the sum of the first reference time length T1 and the second reference time length T2 (namely, $T = T1 + T2$). Therefore, when the time length T is equal to the period

TFG of the rotating speed pulse signal PFG, the rotating speed of the rotor is equal to the "reference rotating speed" set in the rotating speed reference signal generator 23.

Referring to FIG.6(b), in an electrical angle range "a", the period TFG of the rotating speed pulse signal PFG is longer than the time length T. Therefore, it is determined that the rotating speed is lower than the reference rotating speed. On the other hand, the rotating speed has been increased in an electrical angle range "b", and the period TFG has decreased. Since the period TFG is smaller than the time length T in the electrical angle range "b", the rotating speed is larger than the reference rotating speed. In an electrical angle range "c", the period TFG is equal to the time length T, and thus the revolution speed is equal to the reference rotating speed.

In operation in the electrical angle range "a", the acceleration signal AC turns to a high level at the time of fall edge of the output signal PT2 of the timer 25 as shown in FIG.6(e), and then turns to the low level by input of the successive rotating speed pulse signal PFG. The acceleration signal AC serves to increase the rotating speed.

In the electrical angle range "b", since the period TFG is smaller than the time length T, the successive rotating speed pulse signal PFG is inputted

during a high level period of the output signal PT2 of the timer 25. Consequently, the deceleration signal BR turns to a high level as shown in FIG.6(f). The deceleration signal BR turns to the low level at the time of fall edge of the output signal PT2 of the timer T2. The deceleration signal BR serves to decrease the rotating speed.

The acceleration signal AC for accelerating the rotating speed output from the rotating speed error signal generator 31 is applied to the first switching circuit 27, and the deceleration signal BR for decelerating the rotating speed output from the rotating speed error signal generator 31 is applied to the second switching circuit 28.

The first switching circuit 27 closes during the high level period of the acceleration signal AC, and a constant current flows into the invert input of the differential amplifier 104 of the integrating circuit 100 from the constant current source 26. On the other hand, the second switching circuit 28 closes during the high level period of the deceleration signal BR, and a constant current flows from the invert input of the differential amplifier 104 to the constant current source 29. Consequently, the invert input current CPO for the differential amplifier 104 is generated at the junction point between the first switching circuit 27 and the second switching

circuit 28 as shown by the waveform of FIG.6(g).

Referring to FIG.6(g), when the rotating speed is lower than a predetermined value, since the acceleration signal AC is output, an invert input current CPO flows into the invert input of the differential amplifier 104.

Consequently, the level of the output voltage VT of the differential amplifier 104 is lowered from the reference voltage Vref1 as shown in FIG.6(h).

On the other hand, when the rotating speed is higher than the predetermined value, the deceleration signal BR is output, and the invert input current CPO flows in the direction from the invert input of the differential amplifier 104 to the ground. Consequently, the level of the output voltage VT rises from the reference voltage Vref1 as shown in FIG.6(h).

The operation of the clamp circuit 105 is elucidated hereafter. When the level of the output signal VT of the integrating circuit 100 is higher than the level of the reference voltage Vref2, the transistor 107 turns ON and the transistor 110 turns OFF. Therefore, the transistor 106 turns OFF, and the shortcircuiting between the output terminal of the differential amplifier 104 and the invert input thereof is canceled. When the level of the output signal VT is lower than the level of the reference voltage Vref2, the transistor 107 turns OFF, and the transistor 110 turns ON. Therefore, a current flows

from the base of the transistor 106 to the collector of the transistor 110. Thus, since the base current of the transistor 106 flows through the transistor 110 and the constant current source 108, a current which is larger than the current flowing the transistor 109 flows into the constant current source 108 through the transistor 110, and the transistor 106 turns ON. Consequently, the invert input 104 and the output of the differential amplifier 104 are shortcircuited with each other, a current flows from the invert input of the differential amplifier 104 to the output terminal thereof through the transistor 106, and the level of the output signal VT is maintained at the voltage of the reference voltage Vref2. In the clamp circuit 105, the forward voltage across the collector and emitter of the transistor 106 is 0.1 --- 0.2 volts in ON state thereof. Moreover, as mentioned in the foregoing, since the current mirror circuit is operable by the DC power source of about 1 volt, the rotating speed control apparatus in the second embodiment is operable by a DC power source of 1.5 volts which is the output voltage of a conventional dry cell.

Although the present invention has been described in terms of the presently preferred embodiments, it is to be understood that such disclosure is not to be interpreted as limiting. Various alterations and modifications will no doubt become apparent to those

skilled in the art after having read the above disclosure.

CLAIMS

1. Rotational speed control apparatus for a motor, comprising:
 - at least one position sensor mountable on said motor for sensing the rotational position of a rotor of said motor,
 - a current switching circuit for generating current-switching signals for switching currents flowing in driving coils of said motor, on the basis of the output(s) of said position sensor(s),
 - an amplifier for amplifying said current-switching signals to a level corresponding to a predetermined rotational speed of said rotor,
 - a pulse generator for generating a pulse signal having a frequency proportional to the rotational speed of said rotor, on the basis of said output(s) of said position sensor(s),
 - a timer circuit for generating a sawtooth waveform signal in synchronism with said pulse signal, and a rectangular wave signal which steps up in response to said pulse signal and steps down when said sawtooth waveform signal reaches its peak level,
 - an acceleration pulse generating circuit for generating an output signal having a phase opposite to said rectangular wave signal,
 - a deceleration pulse generating circuit for generating a rectangular wave signal which steps up in response to said pulse signal and steps down when said sawtooth waveform signal reaches a predetermined voltage,
 - a current control circuit comprising a series arrangement of a first constant current source, a first switching circuit, a second switching circuit and a second constant current source which are couplable between both ends of a DC power source and are arranged to generate a current in response to switching of said first switching circuit by said output signal from said acceleration pulse generating circuit and said second switching



circuit by said rectangular wave signal from said deceleration pulse generating circuit, and

an integrating circuit for integrating said current output from said current control circuit and outputting an output signal for controlling the gain of said amplifier.

2. Rotational speed control apparatus for a motor, comprising:

at least one position sensor mountable on said motor for sensing the rotational position of a rotor of said motor,

a pulse generator for generating a pulse signal having a frequency proportional to the rotational speed of said rotor, on the basis of the output(s) of said position sensor(s),

a rotational speed reference signal generator for generating a time length signal having a predetermined time length corresponding to a reference rotational speed of said rotor,

a rotational speed error signal generator for generating an acceleration signal which is for instructing increase of said rotational speed of said rotor when the period of said pulse signal from said pulse generator is larger than said time length of said rotational speed reference signal generator, or a deceleration signal which is for instructing decrease of said rotational speed when the period of said pulse signal is smaller than said time length of said rotating speed reference signal generator,

a current control circuit comprising a series arrangement of a first constant current source, a first switching circuit, a second switching circuit and a second constant current source which are couplable between both ends of a DC power source and are arranged to generate a current in response to switching of said first switching circuit by said acceleration signal and said second switching circuit by said deceleration signal,



an integrating circuit for integrating said current output from said current control circuit and outputting an output signal for controlling a motor driving circuit, and

a clamp circuit for clamping the level of said output signal of said integrating circuit to a predetermined level.

3. Rotational speed control apparatus according to claim 2, wherein said clamp circuit comprises:

a current mirror circuit having an output connected to the collector of a first transistor which has a base which is connectable to a reference voltage source so as to receive a reference voltage,

a second transistor having a collector which is connectable to a power source and an emitter which is connected to the emitter of the first transistor,

a constant current power source connected at one end to the emitter of the first transistor and connectable at the other end to ground, and

a third transistor having an emitter connected to the input of said integrating circuit, a collector connected to the output of said integrating circuit and the base of the second transistor and a base connected to the output of the current mirror circuit.

4. Rotational speed control apparatus for a motor, substantially as herein described with reference to, or with reference to and as illustrated in, Figures 1 to 4 or Figures 5 and 6 of the accompanying drawings.

