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A SPEED CONTROL DEVICE FOR D-C MOTORS

This invention relates to speed control devices for d-c motors.

5 As we shall explain below with reference to Figure 1 of the accompanying drawings, previously proposed control devices have suffered from certain disadvantages.

The present invention has arisen from our work seeking to provide improved speed control devices for d-c
10 motors.

In accordance with the present invention, a speed control device for a d-c motor includes means for coupling a supply voltage to the armature windings of the motor, and a speed controlling integrated circuit for
15 controlling the application of said supply voltage thereto, which circuit is constructed so that in operation a reference voltage is generated across first and second terminals thereof, the first said terminal being arranged to be coupled to the armature wiring of
20 the motor, and the integrated circuit being constructed and arranged such that in operation a current proportional to the armature current flowing in the first terminal is maintained in the second terminal; a transistor with a first resistor connected in parallel
25 ^{the transistor emitter being connected to said second terminal and} across the base and emitter thereof, said transistor base being connected to the first terminal and to one terminal of the motor via a second resistor; and a third resistor, which third resistor is variable and is connected in parallel across the base and collector of the transistor;
30 said transistor collector being connected to the other terminal of the motor via a fourth resistor so as to permit the value of the third resistor and the speed of the motor to change in linear proportion to each other.

The invention is hereinafter more particularly
35 described by way of example only with reference to the accompanying drawings, in which:-

Fig. 1 shows the circuit configuration for a previously proposed type of motor speed control device;

Fig. 2 shows a first embodiment of speed control device constructed in accordance with the present invention; and

Fig. 3 shows a second embodiment of speed control device in accordance with the present invention.

Referring first to the previously proposed arrangement of Fig. 1, it will be seen that a resistance circuit comprising resistors R_1 , R_2 and R_3 and a variable resistor VR_1 is connected across the terminals of a d-c motor M. An integrated circuit control circuit 1 is arranged such that a current flowing in the d-c motor M is directed from terminal D of the control circuit to terminal C thereof, the current is controlled so as to keep at a constant level a counter-electromotive force generated in the d-c motor M. In the example shown in the figure, the current leaving the terminal D is arranged to be proportional to the current entering the terminal C, and the terminal A is used for starting the d-c motor M. Reactor L, and capacitor C, are adapted to eliminate ripples.

The speed (rate of revolution) of the d-c motor can be controlled by changing the resistance value of the variable resistor VR_1 . Changes in motor revolution caused by the temperature characteristics of the d-c motor are compensated by changes with temperature in the terminal voltage V_F of a diode D_1 connected between the resistance circuit and terminal C.

The inclusion of a diode D_1 makes the circuit configuration complex. Furthermore, where the rate of revolution of the motor is set by setting the resistance value r of the variable resistor VR_1 , a voltage applied

to the motor M is proportional to $1/r$. As a result, the relationship between the amount of change in the resistance r and in the rate of revolution N of the motor tends to be non-linear, making it difficult to ensure accurate control of motor speed.

Fig. 2 shows the circuit configuration of an embodiment of speed control device in accordance with this invention. In the figure, like reference letters and numerals are used for like circuit elements to those shown in Fig. 1. The resistor R_T corresponds to the parallel arrangement of resistor R_1 and R_2 shown in Fig. 1. A variable resistor R_s is connected across the base and collector of a transistor T_r , the emitter of which is coupled to terminal C. A resistor R is connected across the base and emitter.

In effect, the circuit configuration shown in Fig. 2 substitutes for the diode D_1 in Fig. 1 a transistor T_r and associated resistors. In Fig. 2, the reactor L_1 and the capacitor C_1 , which are shown by the same reference symbols as in Fig. 1, and are again used for eliminating the adverse effects of ripple components.

In Fig. 2, the speed of the motor M is set by setting the value of the variable resistor R_s . The voltage V across the collector terminal of the transistor T_r and the terminal D of the control circuit 1 can be expressed by the following equation:

$$\begin{aligned}
 V &= V_{\text{ref}} + V_{\text{BE}} \left(1 + \frac{R_s}{R} \right) \\
 &+ \frac{V_{\text{ref}} + V_{\text{BE}}}{R_3} \times R_s \\
 &= V_{\text{ref}} \left(1 + \frac{R_s}{R_3} \right) \\
 &+ V_{\text{BE}} \left(1 + \frac{R_s}{R} + \frac{R_s}{R_3} \right)
 \end{aligned}
 \tag{1}$$

where V_{ref} is the voltage across the terminals C and D, representing a reference voltage, and V_{BE} is the voltage across the base and emitter of the transistor.

Since the resistor R generally has a sufficiently high value, Equation (1) can be rewritten as follows:

$$(2) \quad V = V_{ref} \left(1 + \frac{R_s}{R_3}\right) + V_{BE} \left(1 + \frac{R_s}{R_3}\right)$$

The voltage V_M applied to the motor M can be expressed by

$$(3) \quad V_M = V + R_T \times I$$

where I is the current flowing in the resistor R_T . The current I can be expressed by

$$(4) \quad I = \frac{I_M}{K} + \frac{V_{BE}}{R} + \frac{V_{ref} + V_{BE}}{R_3}$$

where I_M is the current entering the terminal D, and K is a constant.

Assuming that the resistor R has a sufficiently high value, as noted earlier, the voltage V_M can be expressed by

$$(5) \quad V_M = V_{ref} \left(1 + \frac{R_s}{R_3} + \frac{R_T}{R_3}\right) + V_{BE} \left(1 + \frac{R_s}{R_3} + \frac{R_T}{R_3}\right) + \frac{R_T}{K} I_M$$

Now, simplifying Equation (5) as

$$(6) \quad V_M \equiv V + \frac{R_T}{K} I_M$$

yields

$$(7) \quad V + \frac{R_T}{K} I_M = E_a + R_a I_M$$

since the terminal voltage V_M of the motor M is the sum of the counter-electromotive force E_a of the motor M and the voltage drop $R_a I_M$ by the internal resistance R_a .

Furthermore, selecting R_T and/or K so as to satisfy

$$(8) \quad \frac{R_T}{K} = R_a$$

10

yields

$$V = E_a \quad \text{--- (9)}$$

15 Thus, the rate of revolution of the motor M can be maintained constant. And, since the voltage V is proportional to the value of the variable resistor R_s , the counter-electromotive force E_a of the motor M can be set by changing the value of the variable resistor R_s .
20 As a result, the rate of revolution of the motor M can be set at any desired value.

In addition, changes in the rate of revolution due to temperature characteristics of the motor M are compensated as the voltage V_{BE} in Equation (2) above becomes small in accordance with temperature rise, shifting
25 the voltage V in Equation (2) to a smaller region.

Fig. 3 shows another embodiment, in which the circuit configuration shown in Fig. 2 has been modified into a more practical configuration. In the figure,
30 numerals and symbols 1, M, T_r , R_T , R_s and R_3 correspond with like parts shown in Fig. 2, and L_1 and C_1 correspond with like parts shown in Fig. 1. A variable resistor R_4 is connected in parallel with R_T and further with an RC

circuit comprising a resistor R_5 and a capacitor C_2 in series. A further RC circuit comprising a resistor R_6 and capacitor C_3 is connected between the base of the transistor and the positive motor terminal.

5 The operation of the configuration shown in Fig. 3, is essentially the same as that of the configuration shown in Fig. 2, but is more practical in respect of the following points.

- 10 i) By adding the variable resistor R_4 , the value of the fixed resistor R_T by which the load characteristics of the motor M are determined can be fine-adjusted. Thus, the load characteristics of the motor M can be selected by fine-adjustment of R_4 .
- 15 ii) A capacitor or a series circuit comprising a capacitor and a resistor is connected across the collector and/or base of the transistor T_r and the positive or negative terminal so as to prevent hunting, and expand the range of fine-adjustment of motor characteristics. (In the particular illustration, the circuits are RC series circuits, both connected to the positive terminal, but the alternative arrangements are also feasible.)
- 20 iii) By turning on the switch SW to connect the base of the transistor T_r to the negative terminal, the transistor T_r is forcibly turned off, interrupting the output of the control circuit 1 to stop the d-c motor.
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- 30

In the specific embodiments it is possible to set the rate of motor revolution at any desired value and to maintain a linear relationship between the value of the

variable resistor R_s and motor revolution by adjusting the variable resistor R_s connected to the transistor T_r .

Furthermore, by providing a separate variable resistor R_4 on the collector side of the transistor T_r ,
 5 the load characteristics of the motor can be fine-adjusted over a wide range.

In addition, by connecting the base of the transistor T_r to the negative side via a switch, the motor operation can be easily stopped.

CLAIMS

1. A speed control device for a d-c motor including means for coupling a supply voltage to the armature
5 windings of the motor, and a speed controlling integrated circuit for controlling the application of said supply voltage thereto, which circuit is constructed so that in operation a reference voltage is generated across first and second terminals thereof, the first said terminal
10 being arranged to be coupled to the armature wiring of the motor, and the integrated circuit being constructed and arranged such that in operation a current proportional to the armature current flowing in the first terminal is maintained in the second terminal; a
15 transistor with a first resistor connected in parallel ~~the transistor emitter being connected to said second terminal and~~ across the base and emitter thereof, said transistor base being connected to the first terminal and to one terminal of the motor via a second resistor; and a third resistor, which third resistor is variable and is connected in
20 parallel across the base and collector of the transistor; said transistor collector being connected to the other terminal of the motor via a fourth resistor so as to permit the value of the third resistor and the speed of the motor to change in linear proportion to each other.
25 2. A speed control device according to Claim 1, wherein the resistance value of the first resistor is selected at a value sufficiently larger than the value of the third resistor so as to permit the speed of the motor to be set at any desired value by changing the value of
30 the third resistor.
3. A speed control device according to Claim 1 or Claim 2, wherein a fifth resistor is connected in parallel with the fourth resistor, the fifth resistor being variable so as to permit the load characteristics
35 of the motor to be fine-adjusted over a wide range.



4. A speed control device according to Claim 3,
wherein a capacitor or a series circuit comprising a
capacitor and a resistor is connected in parallel with
5 said fifth resistor so as to prevent the hunting
phenomenon.

5. A speed control device according to Claim 3,
wherein a capacitor or a series circuit comprising a
capacitor and a resistor is connected across the base of
10 the transistor and the other terminal of the motor.

6. A speed control device according to any preceding
Claim, wherein a switching means is provided across the
base of the transistor and a terminal of the device
arranged for connection to the negative terminal of a
15 power supply so as to permit the motor to be stopped by
the switching means.

7. A speed control device for a d-c motor,
substantially as hereinbefore described with reference to
Figures 2 and 3 of the accompanying drawings.

