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APPLICATION BULLETIN
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DC MOTOR SPEED CONTROLLER: Control a DC Motor without Tachometer Feedback

by Bruce Trump

DC motor speed is often regulated with a closed-loop speed controller using tachometer feedback (Figure 1). It is possible, however, to control dc motor speed without tachometer feedback.

Figure 2 shows an open-loop type speed control circuit that drives a dc motor at a speed proportional to a control voltage, V_{IN}. It does this by exploiting a basic characteristic of dc motors—its speed-dependent reverse EMF voltage. The motor is modeled as a series winding resistance, R_M, and a reverse EMF generator. The op amp circuitry provides a negative resistance drive equal to the winding resistance. This causes the reverse EMF to be proportional to the input control voltage. Motor speed and direction are determined by the magnitude and polarity of the control voltage.

Operation can be visualized by first imagining a perfect frictionless motor with no mechanical load. An input voltage provides a proportional op amp output voltage, V_O. Without a mechanical load, the motor draws no current because the reverse EMF exactly matches motor drive voltage.

When a mechanical load is applied, current flows through the motor and the sense resistor, R_S. This creates a voltage, V_S, that is summed with the input control signal at the non-inverting op amp input. This positive feedback increases the drive voltage applied to the motor, maintaining constant speed. Proper speed control is achieved by setting the gain at the non-inverting input so that it compensates for the voltage drop in the series winding resistance and the sense resistor.

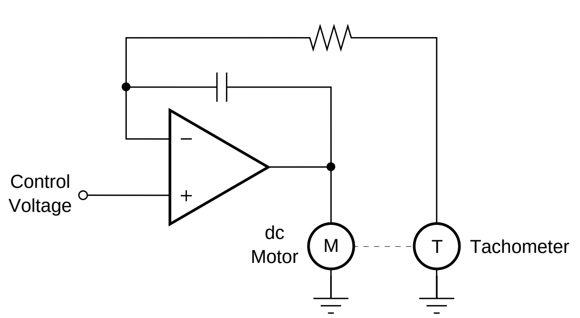
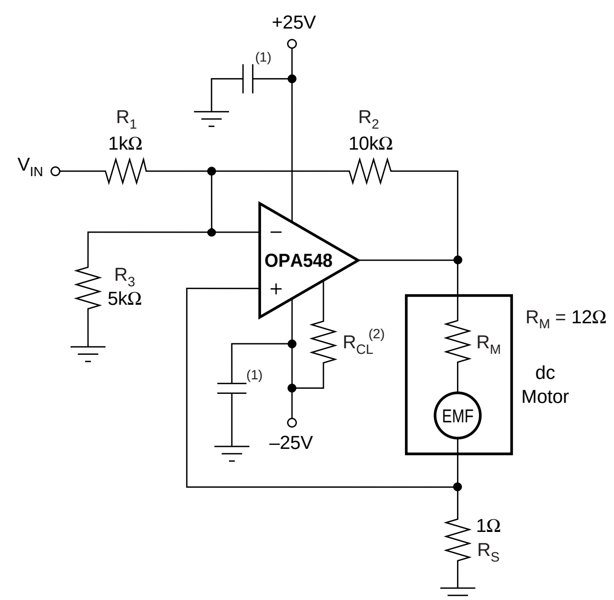


FIGURE 1. Tachometer-Feedback Speed Controller.

Circuit values are calculated with the following design procedure. Example values correspond to Figure 1.

1. Determine gain. The input control voltage must be capable of producing the needed output voltage swing to drive the motor. In the example circuit, a ±2V input must deliver ±20V to the motor with no mechanical load. R_1 and R_2 are chosen to provide the required gain of –10. $G = -R_2/R_1$.
2. Determine the winding resistance, R_M, by measuring with an ohmmeter. Use the average of several readings taken at different rotor positions.
3. Choose the value of the sense resistor, R_S. Use a convenient value that is less than $R_M R_1/R_2$. This assures that a reasonable value of R_3 can be used to adjust the speed regulation behavior. In the example (12Ω)(1kΩ)/10kΩ = 1.2Ω, a standard value of 1Ω is chosen.
4. Calculate the nominal value of R_3:

$$R_3 = \frac{R_2}{R_M / R_S - R_2 / R_1} = \frac{10k\Omega}{12\Omega / 1\Omega - 10k\Omega / 1k\Omega} = 5k\Omega$$



NOTES: (1) 4.7µF tantalum recommended. (2) Current limit set resistor 14.7kΩ = 2.5A.

FIGURE 2. Open-Loop Motor Speed Controller.

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The speed regulation can be fine-tuned. A tendency to slow down under load means that the gain through the positive feedback path is insufficient (undercompensated)—decrease the value of R_3 to increase positive feedback. Too much gain in the positive feedback path causes the motor speed to surge or increase with load (overcompensated)—increase the value of R_3. If the speed regulation is overcompensated with R_3 removed, the value of R_S must be reduced.

Motor resistance increases with temperature, so the compensation should be tuned at operating temperature. Although performance may fall somewhat short of a well-designed tachometer feedback system, this approach is cost-effective and often yields adequate regulation. It provides a dramatic improvement over simple uncompensated voltage drive.

CHOOSING AMPLIFIER A1

The op amp, A1, is chosen for an appropriate voltage and current rating. A variety of monolithic op amps are capable of extended voltage and current outputs (see Table I). Single-supply types have an input common-mode voltage range that includes the negative power supply voltage. These devices can be operated from dual (±) supplies or a single power supply (with unidirectional motor rotation). A negative input control voltage is required.

PRODUCT	$\pm V_S$ MAX (V)	MAX CURRENT (A)	SINGLE SUPPLY
OPA544	±35	2	
OPA547	±30	0.5	✔
OPA548	±30	3	✔
OPA549	±30	9	✔

TABLE I. Power Op Amp Selection.