ECE 311S LAB, 1999
SPEED CONTROL OF A DC MOTOR

1 Introduction

Servomotors are found throughout industry, used mainly as actuators in systems such as robotic manipulators, aircraft, automobiles, etc. Almost everything that requires precision movement is powered by a servomotor. Moreover, servomotors exhibit a number of characteristics found in other control systems, including nonlinearities, unmodeled dynamics, and sensor noise. Thus, they make an excellent laboratory testbed.

The purpose of this lab is to design and implement an analog controller for the speed control of a DC motor.

2 Motor Description

The armature-controlled DC motor in open loop is a first-order system when the input is the voltage v_m applied to the power amplifier and the output is the motor speed w in rad/s (this assumes the armature inductance is negligible). The motor speed and the tachometer output voltage v_t are related by the equation $v_t = K_t w$. The block diagram is shown here:

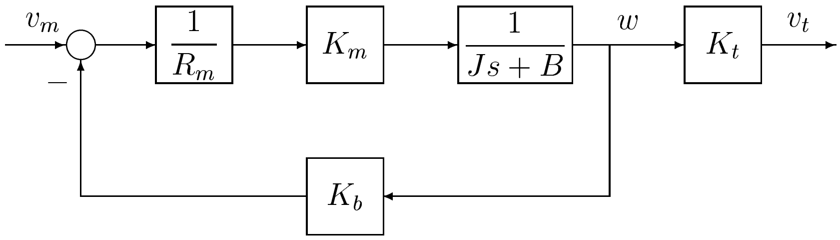

Figure 1: DC motor.

Motor Parameters from Manufacturer

Tachometer Sensitivity, K_t	0.00955 $V/rad/s$
Motor Torque Constant, K_m	0.027 Nm/A
Motor Back EMF Constant, K_b	0.027 $V/rad/s$
Motor Armature Resistance, R_m	5.3 $Ohms$
Motor Friction, B	6×10^{-6} Nms
Motor Armature Inertia, J	1.57×10^{-6} Kgm^2

The transfer function $H(s)$ from v_m to v_t is first-order,

$$H(s) = \frac{K}{\tau s + 1}, \tag{1}$$

where K is the DC gain and τ is the time constant.

3 P and PI Controllers

Proportional Controller

A proportional controller generates an actuating signal proportional to the error signal. For our DC motor system, the control law is therefore

$$v_m = K_P(w_d - w),$$

where w_d is the desired motor speed and K_P is the proportional gain. Since $v_t = K_t w$, we are led to define the desired tachometer output voltage $v_d := K_t w_d$, and then we get the control law

$$v_m = \frac{K_P}{K_t}(v_d - v_t).$$

Defining $K_P' := K_P/K_t$, we have the block diagram shown in Fig. 2. The closed-loop transfer

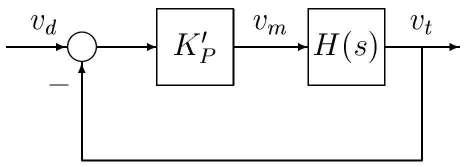

Figure 2: Proportional control of motor.

function from v_d to v_t is still first-order.

Proportional + Integral Controller

In a PI controller there is an additional term in the actuating signal that is proportional to the integral of the error signal. The PI control law for the DC motor is

$$v_m = \left(K_P + \frac{K_I}{s}\right)(w_d - w).$$

Defining $K_I' := K_I/K_t$, we have the block diagram shown in Fig. 3. The transfer function

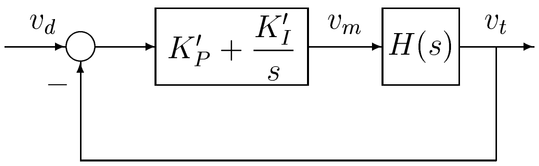

Figure 3: PI Control of Motor.

of the closed-loop system from v_d to v_t is now second-order.

4 Experimental Set-up

Equipment

- RC-01 Rate Control Experiment DC Motor Kit
- Function Generator
- Oscilloscope
- Voltmeter

Caution So as not to saturate the power amplifier, you should limit the amplitude of the input v_m to not more than 2.5 V zero-to-peak.

5 Preparation

1. Determine K and τ from the manufacturer's table. (In practice, you could identify them by doing experiments on the motor. For example, you could apply a DC input and measure the DC output to get K.)

2. Design a proportional controller so that the time constant of the closed-loop transfer function $H_{CL}(s)$ from v_d to v_t equals 0.005 s. Does the DC gain of $H_{CL}(s)$ depend on K'_P?

   Note: The desired DC gain is 1, for then v_t asymptotically perfectly tracks a step v_d.

3. Using MATLAB, plot the step response of v_m and infer what the magnitude of v_d can be so that the saturation constraint $|v_m| \leq 2.5$ isn't violated.

4. Design an analog circuit as shown in Figure 4 to implement the proportional controller you designed. Take $R_e = R_f = 100\ K\Omega$ and the value of R_1 to achieve the designed K'_P. Note: You'll likely have to compromise on R_1 to the nearest standard resistor available.

5. With a PI controller, the closed-loop transfer function $H_{CL}(s)$ is second order, but non-standard because of the presence of the zero. Using MATLAB and trial-and-error, select the PI gains so that for the step-response of $H_{CL}(s)$ the peak time is about 0.005 s and the overshoot about 20%.

6. Again, determine the maximum allowed magnitude of v_d for the PI controller.

7. Design an analog circuit as shown in Figure 5 to implement the PI controller. Take $R_e = R_f = 100\ K\Omega$, $C_i = 1\ \mu F$, the value for R_1 to obtain the designed K'_P, and the value for R_i to obtain the designed K'_I. Again, you'll likely have to compromise to standard values.

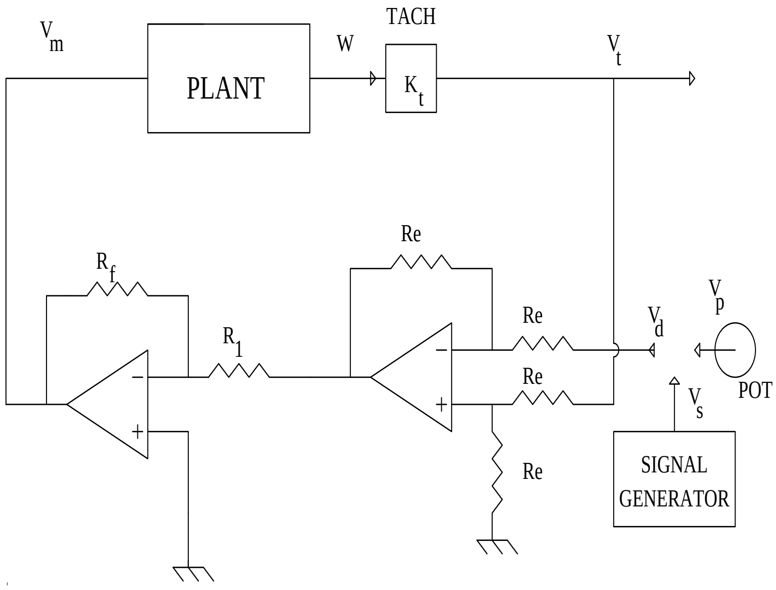

Figure 4: Proportional controller in closed loop.

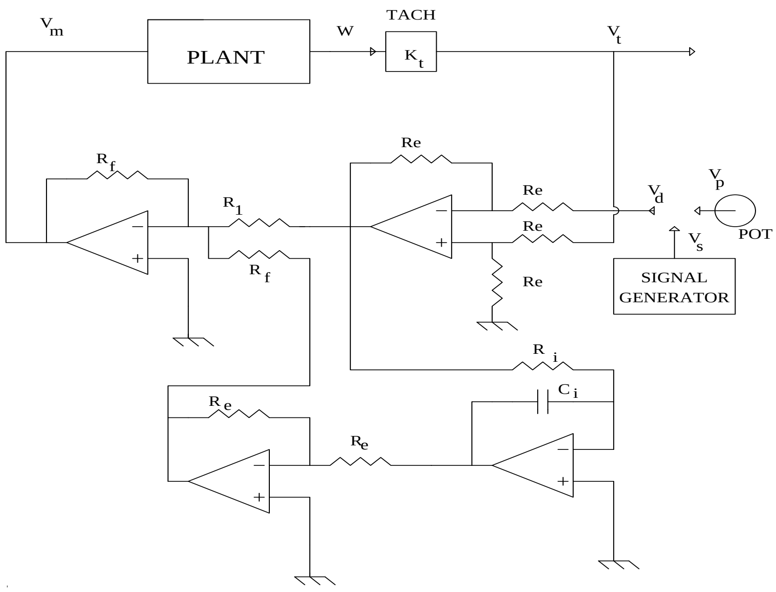

Figure 5: Proportional + Integral controller in closed loop.

6 Experiment

1. Implement the proportional controller on the motor. Measure the time constant and DC gain of the closed-loop system.

2. Implement the PI controller. Apply a train of square pulses to system input v_d. Observe the tachometer output voltage v_t on the oscilloscope and measure the peak time and overshoot. Record the closed-loop DC gain.

7 Results and Discussion

1. Compare the performance of the real system with the design specifications. Note: If you compromised on the resistors used, you'll have to re-run your simulations to be consistent.

2. Discuss the advantages and limitations of the two controller structures.