# LAB 4:
# PWM DC MOTOR SPEED CONTROL

## Overview

In this task you are to perform a number of experiments related to digital velocity control of a DC servomotor system. The plant is an actual small robot base assembly (waist joint) with a Pittman gearhead servomotor.

You will be tracking step and trapezoidal reference velocities.

## Preparation

1. Study the discussion on pulse width modulation.

2. Study Appendix B about timer interrupts and PWM.

3. Derive a detailed mathematical model (transfer function and state-space) of the DC motor from voltage applied, to the angular position of the load in radians. Your derivation should be explicitly in terms of the parameters of the system. *Then* substitute the values of the parameters into your derived model. Reduce the order of the model as necessary. (See the Section "The Plant" for intermediate results you should obtain.)

4. Consider the implications of the motor pole locations and the discrete nature of optical encoders.

5. Design required controllers and prepare required programs.

## Task Description

Apply PI and PII control to the system.

You should demonstrate that your system works by attempting to track some typical velocity profiles such as a step input and a trapezoidal input. Plot your results with the desired (reference) trajectories in each case.

You should note that the motor's poles are already quite fast, and that attempting to use control to modify those poles would result in a prohibitively fast sampling rate.

Make sure that you include a discussion of the software issues encountered in the implementation of this system.

## Discussion Of Pulse Width Modulation

The major reason for using pulse width modulation in DC motor control is to avoid the excessive heat dissipation in linear power amplifiers. The heat dissipation problem often results in large heat sinks and sometimes forced cooling. PWM amplifiers greatly reduce this problem because of their much higher power conversion efficiency. Moreover the input signal to the PWM driver may be directly derived from any digital system without the need for any D/A converters.

The PWM power amplifier is not without disadvantages. The desired signal is not translated to a voltage amplitude but rather the time duration (or duty cycle) of a pulse. This is obviously not a linear operation. But with a few assumptions, which are usually valid in motor control, the PWM may be approximated as being linear (i.e., a pure gain).

The linear model of the PWM amplifier is based on the average voltage being equal to the integral of the voltage waveform. Thus

$$V_S \; * \; T_{on} \; = V_{eq} \; * \; T_{sw}$$

where

| | | |
|---|---|---|
| $V_S$ | = | The supply voltage (+12 volts) |
| $T_{on}$ | = | Pulse duration |
| $V_{eq}$ | = | The average or equivalent voltage seen by the motor |
| $T_{sw}$ | = | Switching period $(1/f_{sw})$ |

The recommended switching frequency is 300Hz.

The switching frequency ($1/T_{sw}$), is determined by the motor and amplifier characteristics. A good rule of thumb for the lower limit is that the switching frequency should be at least 10 times the motor bandwidth. For the Pittman motors the bandwidth is approximately 10Hz. Once chosen, the switching frequency remains fixed.

The control variable is the duty cycle which is $T_{on}$ / $T_{sw}$ . The duty cycle must be recalculated at each sampling time. The voltage that the motor sees is thus $V_{eq}$ , which is equal to the duty cycle times the supply voltage. (See Figure 1)

## The Plant: Robot Base With Pittman Motor

The plant to be controlled is the actual a small robot base assembly with a simulated inertial load (aluminum disk). The simulated moment of inertia is less than the actual robot body moment of inertia. The effective gear ratio is 7860:18 (from the motor armature shaft to the actual load). Therefore the reflected load inertia seen by the motor is very small.

The sensor used is a 500--line optical encoder. It is directly mounted to the armature shaft, so that it rotates at the armature speed. Either of the two encoder signals, A~or~B can be used to measure velocity. Since there are 500 pulses per armature revolution, the number of pulses per load revolution is

(7860 shaft rev./18 load rev.) * ( 500 pulses /shaft rev.)

The transfer function of the Pittman Motor GM9413H529 can be derived from the following data (taken from the Pittman motor spec sheets for winding 114T32):

| | | |
|---|---|---|
| $R_a$ | Armature resistance | 8.33 Ω |
| $L_a$ | Armature inductance | 6.17 mH |
| $K_e$ | Back emf constant | 4.14 V/krpm=0.03953 V/rad/s |
| $K_t$ | Torque constant | 5.60 oz-in/A=0.03953 N-m/A |
| $J_a$ | Armature inertia | $3.9 \times 10^{-4}$ oz-in-s$^2$ = $2.75 \times 10^{-6}$ Kg-m$^2$ |
| $J_L$ | Load inertia | Calculate[1] |
| $J$ | Total inertia | Motor + load = $J_a + J_L/N^2$ |

1: The aluminum disk has a radius of 15.24 cm, a thickness of 0.6 cm and a density of 2699 Kg/m$^3$

$$1/T_e = R_a / L_a = 1350 \quad (rad/\sec)$$

$$1/T_m = \frac{K_e K_t}{R_a J} = 66.43 \quad (rad/\sec)$$

If $L_a << \dfrac{R_a^2 J}{K_e K_t}$, (which it is)

$$G(s)=\frac{\omega_a(s)}{V_{eq}(s)}=\frac{1/K_e}{(1+T_e s)(1+T_m s)}$$

$$=\frac{25.3}{(1+\frac{s}{1350})(1+\frac{s}{66.4})}\left(\frac{rad/\sec}{V}\right)$$

$$=\frac{2.27\times10^6}{(s+1350)(s+66.4)}\left(\frac{rad/\sec}{V}\right)$$

$$G_2(s)=\frac{1}{N}G(s)=\frac{\omega_L(s)}{V_{eq}(s)}=\frac{5194}{(s+1350)(s+66.4)}\left(\frac{rad/\sec}{V}\right)$$

$$\frac{1rev}{\sec}=\frac{2\pi\, rad}{\sec}=\frac{500\,p.c.}{\sec}$$ p.c. = pulse counts

$$G_3(s)=\frac{(25.3)(1350)(66.4)}{(s+1350)(s+66.4)}\left(\frac{rad}{\sec\cdot volt}\right)\frac{500}{2\pi}\left(\frac{p.c./\sec}{rad/\sec}\right)$$

$$=\frac{1.80\times10^8}{(s+1350)(s+66.4)}\left(\frac{p.c.}{\sec\cdot volt}\right)$$

## Timing Considerations

Figure 3 shows a block diagram of the system structure. One timer explicitly appears within the loop. In addition a second timer must be used to generate the sampling interval, Ts. Since the two timing functions are independent of each other, the system cannot be implemented with fewer than 2 timers.

Timer 1 is used to generate the variable duty cycle PWM signal. In order to generate PWM signal you should know what to write into GPTCONA, T1CON and COMCONA registers. To learn it, look at the Appendix B given in the first week of the quarter and for further information you can read the pdf file under the web address

http://www-s.ti.com/sc/psheets/spru357b/spru357b.pdf.

Your switching frequency and duty cycle will be determined by the T1PR and CMPR1 registers respectively.

Timer 2 is used to generate the sampling interval. To generate periodic interrupt, you need to change the values of T2CON and T2PR registers.

To count the pulses on either of the two encoder channels, the capture property of the DSP chip will be used. You can select and configure the capture pins using MCRA and CAPCONA registers. Enable CAP1 of the DSP for this experiment. . To learn it, look at the Appendix B given in the first week of the quarter and for further information you can read the pdf file at the web address

http://www-s.ti.com/sc/psheets/spru357b/spru357b.pdf.

## Hardware Wiring

Besides providing +12 VDC power directly to the PWM amplifier, all other connections are made with the breadboard that is wired to the amplifier. The blue connector plugged into the breadboard has 14 pins, numbered on the top. The table below gives the pin--out assignments of this connector. The hardware connections that you must make include power for the optical encoder, the PWM control signal and motor direction, and encoder feedback signals.

| PIN | SIGNAL |
|---:|:---:|
| 1 | - |
| 2 | +5 VDC ( encoder supply ) |
| 3 | - |
| 4 | PWM |
| 5 | - |
| 6 | GND |
| 7 | - |
| 8 | - |
| 9 | +5 VDC ( opto-isolator supply ) |
| 10 | ENCODER B |
| 11 | ENCODER A |
| 12 | - |
| 13 | - |
| 14 | - |

**List of Figures:**


1. The switching operation.
2. Equivalent diagram of the DC motor
3. Block Diagram of the PWM Motor Control System.