ME 421
Microprocessor and Automatic Control Lab

Experiment 4: Running PMDC motor using PWM interface and amplifier *

P. S. Gandhi (gandhi@iitb.ac.in)

August 29, 2015

Solutions

Problem 1

Read datasheet Chapter 19 on PWM: to start with the functional description 19.4, specifically look at registers PWME, PWMCLK, PWMPOL, PWMPRCLK, PWMDTYx, PWMPERx and their functionality. Based on the task given below find their values. PWMPERx should be 0xFF should not be changed. Think why??
Identify registers responsible to set the PWM Frequency See section 19.4.2.5 : PWMx Frequency = Clock (A, B, SA, or SB) / PWMPERx.

Generate PWM signal with frequency of Y kHz (Y is last digit of your roll no. OR 1 if last digit is zero) and duty cycle of 5% 20% 50% and 100% on a PWM channel corresponding to the last digit of your roll number (consider digits 8 and 9 to be 4 and 3 respectively).

Problem 2

Using data in 1. Generate PWM and see the waveform output on the Easyscope oscilloscope. Show these to TA.

*We acknowledge assistance of Mr Jasvipul Chawla and Mr Akash Supe in preparing this solution

Solution : Say for example we desire PWM of approximately 1 kHz on channel 1 of PWM Port which is Port P (here it is pin PP1) We choose clock A for channel 1, choose pre-scalar 8.

A typical program would look like:

```
#include < hidef.h >
#include "derivative.h"
void main(void) {
/* put your own code here */

//pwm generator
PWME=0xFF;          /* This is to enable all the 8 PWM channels. One can selectively enable a particular channel as well*/
PWMCLK=0x00;   /* 0 chooses clock X (here X=A or B), 1 chooses clock SX */
PWMPOL=0xFF;      /*channels high at the beginning and go low when duty count is reached*/
PWMPRCLK=0b00000011; /*keeping B = bus clock/1 (default) and A = bus clock/8 */
```

(PWMSCLA and PWMSCLB are not assigned in this program hence default value 00 is taken which means clock SA = clock A/512 and clock SB = Clock B/512, however since clocks A and B are selected by setting PWMCLK, values of SA and SB does not matter)

```
//channel1
PWMDTY1=0xA0;      /* Duty cycle setting w.r.t. PERx = 100%, here FF = 100%*/
PWMPER1=0xFF;             /* To get highest resolution for PWMDTYx */

EnableInterrups;
for(;;) {
_FEED_COP(); /* feeds the dog */
} /* loop forever */
/* please make sure that you never leave main */
}
```

Note:
For Left Aligned PWM, where clock X = A or B
When clock X is used, PWM Frequency = Bus Clock / Pre scalar of clock X / PWMPERx value (which is 0xFF = 255)
When clock SX is used, PWM Frequency = Bus Clock / Pre scalar of clock X / Scalar of clock SX / PWMPERx value (which is 0xFF = 255)

Problem 3

Connect the motor to the amplifier and PWM and digital output signals from Port A to the input of amplifier. Observe running of motor using PWM signal in both directions for various duty cycles.

Solution: Connect pins IN A and IN B of amplifier (H-bridge) from either PORTA or from other PWM channels (with duty 0 or 100%). Program things accordingly. DDRA needs to be set to 0xFF (output mode) before direction bits in the register PORTA are issued.
The PWM pin of the amplifier need to be connected to the PWM output. The GND of the control side (the pin next to PWM pin of the amplifier) is connected to the GND of the microprocessor to bring the control inputs to the same reference.
e.g.
DDRA = 0xFF;
PORTA = 0x01; /* Pin PA0 is high and rest others are low */

Problem 4

Hold motor shaft of the running motor and see its effect on current drawn? Will more current be drawn from microprocessor?

Solution: The power to motor is supplied only from the power supply. The microprocessor is merely giving the control input to the amplifier. Microprocessor is thus completely isolated from power side and would not see any damage under such load condition. Also this experiment gives us a way to know back emf constant of the motor if we know the speed in running condition. $V = IR$ is electrical balance when the shaft is under hold condition which give R if V and I are measured from Power Supply readings (Assuming the other parts in power amplifier draw relatively low current). $V = IR + K \times \omega$ is balance under motor running condition. If omega is known in addition the value of back emf constant K can be found easily.

Note: The voltage (in most cases 12V) shown by the power supply is not the true voltage being supplied to the motor. The true voltage can be estimated by $D \times V$, where D is the duty cycle ($0 \leq D \leq 1$)and V is the voltage reading on the Power Supply.

Problem 5

Change PWM frequency to 50 Hz and observe motor behavior. You may reduce it further and see. Can you explain the behavior

Solution: To obtain PWM frequency of 50 Hz we will have to use PWMSCLx, programmable scale value used in scaling clock X to generate clock SX.
$ClockSX = ClockX/(2 * PWMSCLx)$ where X= A or B
When clock SX is used,
PWM Frequency = Bus Clock / Pre scalar of clock X / Scalar of clock SX / PWMPERx value (which is 0xFF = 255)
Bus Clock = 2000000 Hz
PWMPRCLK=0b00000000;
PWMSCLA=0xA0;
PWMPER1=0xFF;

You may hear humming sound from motor. Under this situation motor starts partially responding to the PWM frequency as well. At higher PWM frequencies motor is not able to respond to PWM frequency because of large inertia.

Problem 6

Theory*: Look into the slides and understand model of motor which considers its electrical circuit and mechanical free body diagram. With electrical circuit we have related Voltage to current (neglect the inductance of motor L di/dt term) and with free body diagram one can relate generated torque to inertia, damping and other load torques including friction torque. Think what are the terms causing coupling of mechanical to electrical domain?.*

Solution: Coupling from mechanical to electrical domain is back emf (which is function of speed of motor) and from electrical to mechanical domain is torque on motor (which is function of current of motor)

$$J_m \ddot{\theta_m} + B_m \dot{\theta_m} + \tau_f + \tau_l = \tau_m = K_t I_a. \tag{1}$$

$$V_a = I_a R_a + K_b \omega \tag{2}$$

- Study this model under different situations: I) Driving torque is just equal to friction torque II) driving torque is much more than friction torque, what will happen in transient and steady state domain. III) You are holding motor shaft even if it wants to turn (load torque). What will be balance of torques in this situation?
  Solution:
  I) Motor motion is not happening $\theta = 0, \dot{\theta} = 0$, $K_t I_a = \tau_f$, Thus if we know K_t and we measure currrent I_a we would be able to get the friction torque in the motor. -:)
  II)$J_m \ddot{\theta_m} + B_m \dot{\theta_m} = \tau_m - \tau_f$, With constant τ_m (τ_f will be constant for one direction) the motor is essentially driven in one direction till the steady state speed is reached. During transient, the speed will go on increasing (similar to a first order system) and once steady state is reached equation will reduce to $B_m \dot{\theta} = K_t I_a - \tau_f$. This is linear relation between $\dot{\theta}$ and I_a. Several steady state measurements with varying voltage can thus give this straight line if speed is measured. Slope and intersection with $\dot{\theta}$ axis correspond to K_t and τ_f respectively. In steady state equation for electrical part will be $V_a = I_a R_a + K_b \omega$, speed $\omega = \dot{\theta}$ is constant.
  III)$\tau_l + \tau_f = \tau_m = K_t I_a$ load torque balances the torque generated by motor. In this case since $\dot{\theta} = 0$, $V_a = I_a R_a$ so motor will start heating up since all the voltage would be consumed in driving current through resistor leading to dissipation.

- Can above mentioned situations be seen in the actual experiments?
  Solution:
  I) Theoretically motor will be on the verge of motion. Practically, intermittent motion would be observed.
  II) Transient state when the motor is accelerating, and eventually motor will settle into steady state motion at higher speed
  III) If we hold the shaft and do not allow motor to rotate, current drawn by motor would go up and motor may get heated depending on voltage applied.

Problem 7

Challenge problem: *Use Theory given to think about various kinds of experiments you can perform to estimate back emf constant of motor. Ask TA for* *facility to measure speed of motor.*

Solution: As soon as the coil in the motor starts rotating, a back e.m.f. will be induced in it due to the flux that it cuts, and this will tend to reduce the current through it. We can apply constant voltage to motor, motor will accelerate and settle into constant speed in steady state as discussed before. Under this situation $V_a = I_a R_a + E_b$; $\tau_m = K_t I_a$. So if we measure the current drawn by motor, we know V_a based on voltage supplied by the power supply and the % duty cycle in PWM. R_a resistance of the motor can be measured offline. Thus we will be able to calculate back emf. In addition if we measure the speed, we can find out back emf constant as $K_b = E_b/\dot{\theta}$.

Problem 8

Challenge problem: *Program microprocessor to generate triangular waveform output with frequency of approximately 0.1 Hz. for duty cycle 0% to say 30%. Implement this output on motor and observe the motor behavior. This can be used to estimate static friction and Coulomb friction. Think what else do you need to estimate friction values??*

Solution: Strictly speaking a triangular waveform cannot be generated directly from a microprocessor. It will be stepped waveform as shown below. A value can be held for small amount of time (which can be programed using delay; This is one of the factor which decide the triangular waveform frequency, other factor is the how many such steps are there in increasing fashion).

To implement a triangular waveform, the duty cycle need to be defined as triangular wave function. This can be achieved by varying the duty cycle value PWMDTYx in a for loop first in increasing fashion and then in a decreasing with each iteration delayed by some small amount of time (you can use for loop delays).

From the mechanical coupling equation of the motor (as mentioned in slides), we can observe that we would need motor constant to estimate static friction (in Nm) constant. Also we would need to know motor position to find at what point motor starts and stops in this experiment which will yield static friction and Coulomb friction values. You will find at very slow motions (low triangular waveform frequency) the point at which motor starts in either directions will be the value of static friction in that direction. The time plots of motor position and the triangular input waveform should be available for this.