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Microcontroller based Closed Loop Speed Control of DC Motor using PWM Technique

A.S.M. Bakibillah
Department of EEE
American International
University Bangladesh

Nazibur Rahman
Department of EEE
American International
University Bangladesh

Md. Anis Uz Zaman
Department of EEE
American International
University Bangladesh

ABSTRACT
Speed control of DC motor is very important especially in the fields including industrial applications, robotics and so on. So, speed control of DC motors at different load conditions is a prominent field of research in order to achieve a robust system. This paper presents the design and implementation of microcontroller based speed control of DC motors which emphasize the design of PWM control using ICs like SG3524, TL494 in the field of motor speed control. For PWM generation microchip PIC16F877A microcontroller is used. The feedback loop is created by using ADC which is available in the microcontroller IC. This ADC reads the voltage level of the motor and correspondingly the voltage level of the motor can be maintained at a fixed level. A driver circuit is used to drive the motor. Hence, a closed loop motor speed control circuit is designed and the total amount of power delivered to the motor is varied depending on load conditions. In this technique, the regulation of motor's speed is realized by changing the voltage of the motor which is adjusted by the duty ratio of PWM.

General Terms
DC motor, speed control.

Keywords
PIC16F877A microcontroller, PWM generation, feedback loop, driver circuit.

1. INTRODUCTION
Rapid progress in microelectronics and microcontrollers in recent years has made it possible to apply modern control technology to control efficient and reliable operation of many applications such as the engine, anti-lock braking system (ABS), cruise, steering, and vehicle traction [1]. Many of these operations including DC motor and therefore there is a need for implementing effective control strategies with digital control of these motors. The speed of DC motor is directly proportional to armature voltage and inversely proportional to field flux [2] and adjustable speed drives can be operated over a wide range by controlling armature or field excitation. Development of various solid state switching devices such as diode, transistor and thyristor along with various analog/digital chips used in firing/controlling circuits, have made dc drives more handy for control in numerous areas of applications [3]. For DC motor speed control, closed-loop PWM technique is widely used and well known [4]. In this technique, the regulation of motor's speed is realized by changing the voltage of motor which is adjusted by the duty ratio of PWM. In order to improve the performance of motor's speed regulation and to reduce the steady-state error of the rotational speed of motor, a high- performance microcontroller can be used [5]-[6]. In this work, a PIC16F877A microcontroller is used for implementation. The great advances of microcontroller based control system are due to microcontroller flexibility and versatility. This is because all the control algorithms can be implemented in the software [7]. It causes the PWM voltage control with high accuracy. PWM signal is generated by inner timer of microcontroller. In the process of varying the pulse by controlling the switching of the input voltage for the off and on duration, a time dependent varying output voltage can be achieved and the speed can be controlled at a desired value accordingly.

The paper is organized as follow. In section 2, the block representation of the control mechanism of motor is discussed. Section 3 depicts with the DC motor model and speed equation. In section 4, the PWM generation mode to control the speed of DC motor is discussed. This section also details PWM period and PWM duty cycle at various speed conditions of motor. In section 5, the motor driving circuit is discussed. Section 6 details the control algorithm development for the motor while section 7 shows the test results observed. Lastly, section 8 points out the conclusion inferred from the work.

2. BLOCK REPRESENTATION
The block representation of the proposed control circuit is given below (Figure 1):

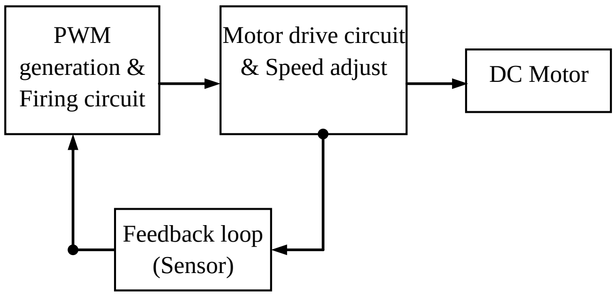

Fig 1: Block diagram of motor control circuit

First of all the PWM signal is generated. Then the signal is fed to the driver network which drives the motor. Driver circuit contains energy bank. The feedback loop is created between the microcontroller and the energy bank by the application of ADC. When the voltage level of the motor varies from the fixed point for different load conditions, speed of the motor also varies. ADC gets this error signal and corresponding PWM signal is generated to retain the fixed voltage level [8]. Thus maintain a fixed motor speed at different load conditions.

3. DC MOTOR MODEL
The speed of DC motor can be controlled by one of the methods - armature voltage control, field flux control or armature resistance control. The field arrangement can be separately excited, self excited or permanent magnet which determines the motor operation over the mechanical load's range and the speed-torque characteristics varies accordingly.

For conventional application purpose, separately excited shunt DC motor is very popular. The equivalent circuit of a separately excited dc motor is shown below (Figure 2):

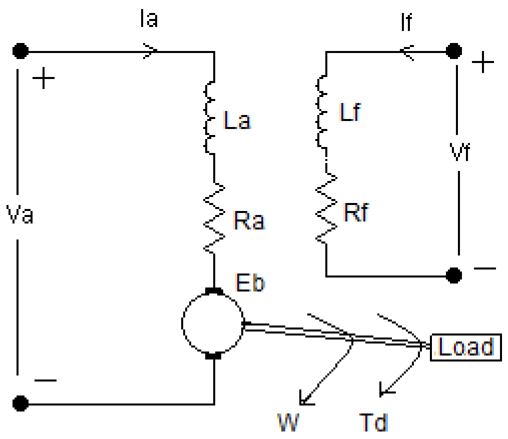

Fig 2: Equivalent circuit of separately excited DC motor

When a separately excited motor is excited by a field current of I_f and armature current of I_a flows in the armature circuit, the motor develops a back emf and a torque to balance the load torque at a particular speed. The equation of speed is given below:

$$N = \frac{E_b}{K_b Ø} = \frac{V_a - I_a R_a}{K_b Ø} \dots\dots\dots\dots\dots\dots\dots\dots (1)$$

Where, N = motor speed, E_b = counter emf, ϕ = flux, V_a = motor input voltage, I_a = armature current, K_b = constant, and R_a = motor resistance.

From equation 1, it is found that motor speed is proportional to the armature voltage so controlling the armature voltage the speed can be controlled at different load conditions.

4. PWM GENERATION TECHNIQUE

In this work, each PWM (CCP) module in microcontroller contains a 16 bit register which can operate as 16 bit capture register, 16 bit compare register, or PWM master/slave duty cycle register.

In CCP1 module, PWM Register 1 (CCPR1) is comprised of two 8-bit registers: CCPR1L (low byte) and CCPR1H (high byte) [9]. The CCP1CON register controls the operation of CCP1. The special event trigger is generated by a compare match and will reset Timer1. In CCP2 module, PWM Register 2 (CCPR2) is comprised of two 8-bit registers: CCPR2L (low byte) and CCPR2H (high byte). The CCP2CON register controls the operation of CCP2 [9]. The special event trigger is generated by a compare match and will reset Timer1 and start an A/D conversion (if the A/D module is enabled).

4.1 PWM Mode

In Pulse Width Modulation mode, the CCPx pin produces up to a 10-bit resolution PWM output. Since the CCP1 pin is multiplexed with the PORTC data latch, the TRISC<2> bit must be cleared to make the CCP1 pin an output. Clearing the CCP1CON register will force the CCP1 PWM output latch to the default low level. This is not the PORTC I/O data latch [9].

The following figure (Figure 3) shows the simplified block diagram of CCP module in PWM mode:

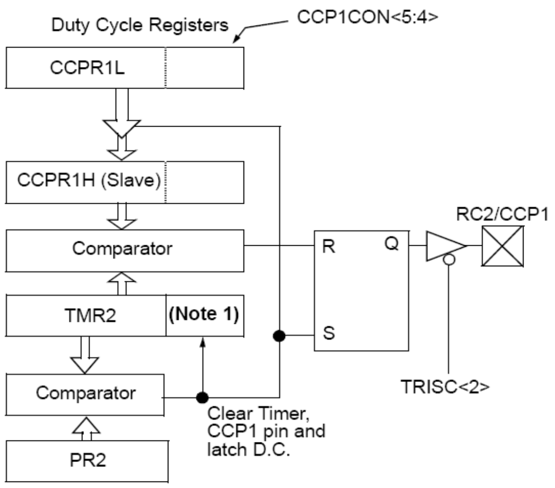

Fig 3: Block diagram of PWM generation [9]

A PWM output, shown in the following figure (Figure 4) has a time base (period) and a time that the output stays high (duty cycle). The frequency of the PWM is the inverse of the period (1/period).

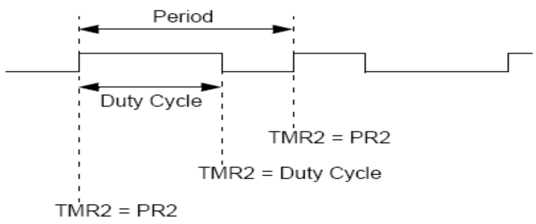

Fig 4: PWM output

The PWM period is specified by writing to the PR2 register and is calculated using the following formula [9]:

PWM Period = [(PR2) + 1] × 4 × TOSC × (TMR2 Prescale Value)... ... ... (2)

4.2 PWM Duty Cycle

The PWM duty cycle is specified by writing to the CCPR1L register and to the CCP1CON<5:4> bits. In this case up to 10-bit resolution is available. The CCPR1L contains the eight MSBs (Most Significant Bits) and the CCP1CON<5:4> contains the two LSBs (Least Significant Bits). This 10- bit value is represented by CCPR1L:CCP1CON<5:4>. The following equation can be used to calculate the PWM duty cycle in time [9]:

PWM Duty Cycle = (CCPR1L:CCP1CON<5:4>) × TOSC × TMR2 Prescale Value)... ... ... (3)

CCPR1L and CCP1CON<5:4> can be written at anytime, but the duty cycle value is not latched into CCPR1H until after a match between PR2 and TMR2 occurs (i.e., the period is complete). In PWM mode, CCPR1H is a read-only register. The CCPR1H register and a 2-bit internal latch are used to double-buffer the PWM duty cycle. This double-buffering is essential for glitch-free PWM operation. When the CCPR1H and 2-bit latch match, concatenates with an internal 2-bit Q clock or 2 bits of the TMR2 prescaler, the CCP1 pin is cleared. The resolution is given by [9]:

$$Resolution = \frac{\log(\frac{Fosc}{Fpwm})}{\log(2)} \dots\dots\dots\dots\dots\dots\dots\dots (4)$$

If PWM duty cycle value is longer than the PWM period, the CCP1 pin will not be cleared.

4.3 Setup for PWM Operation

The following steps should be taken when configuring CCP module for the PWM operation:

Step 1: Set the PWM period by writing to the PR2 register.

Step 2: Set the PWM duty cycle by writing to the CCPR1L register and CCP1CON<5:4> bits.

Step 3: Make the CCP1 pin an output by clearing the TRISC<2> bit.

Step 4: Set the TMR2 prescale value and enable Timer2 by writing to T2CON.

Step 5: Configure the CCP1 module for PWM operation.

5. MOTOR DRIVING CIRCUIT

In motor driving circuit there should be a switching element. In this work MOSFET is used as a switching element. The output of the switching element is connected to the energy bank which consists of inductor and capacitor. The values of inductor and capacitor used in the energy bank are calculated as follows:

$$L = (V_1 - V_0) \times t_{on}/\Delta I_L \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (5)$$

Where, t_{on} = on time = (1/f) × d; d = duty cycle

$$C = \Delta I_L / (8 \times f \times \Delta V_0) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (6)$$

The circuit diagram of driving circuit is given below (Figure 5):

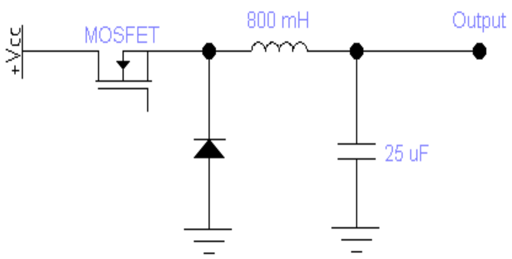

Fig 5: Motor Driving Circuit

The output of the energy bank circuit is connected to the input of the motor. One important factor is the load current requirement of the motor. Thus the current amplification procedure is important even though the digital value of the motor voltage can be derived from the output port. Transistors or integrated circuit (IC) chips can carry out the amplification procedure. In this implementation MOSFET IRS 540 is used as a driver of the energy bank. According to watt rating its current capabilities vary but this device can carry maximum 49 ampere current.

6. CONTROL ALGORITHM

The 16F877A microcontroller (MCU) can control the speed of DC motor accurately with minimum hardware at low cost [10]. The flow chart of the control algorithm is shown (Figure 6) below. The program is written in micro C.

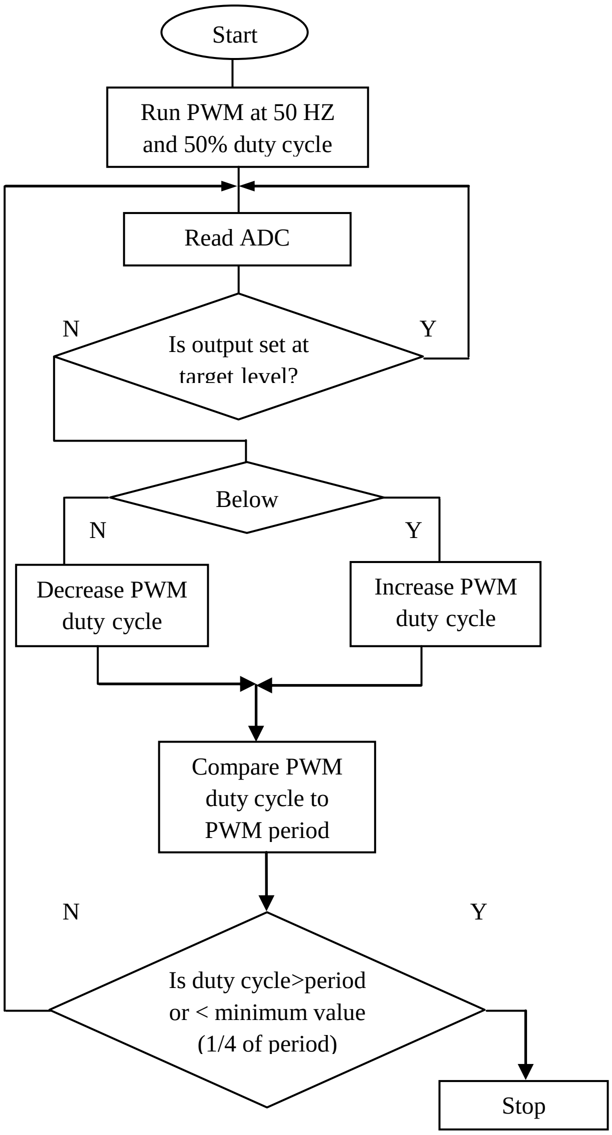

Fig 6: Algorithmic Flowchart

7. EXPERIMENTAL RESULT

In this experiment, the speed of the motor is observed at different load conditions and duty cycles. The duty cycle is set at 50% of the rated voltage (Figure 7) and the speed is measured. Then load is varied to observe the effect on motor speed. The closed loop system is able to maintain the desired speed at various loads. It is observed when load is decreased; the speed of the motor tends to increase so according to algorithm the controller decrease the PWM duty cycle to maintain the desired speed (Figure 8) and vice-versa (Figure 9).

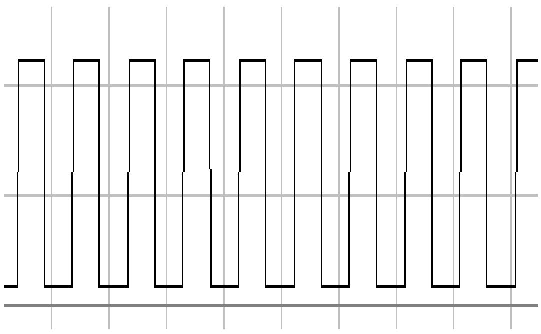

Fig 7: PWM set at 50% duty cycle

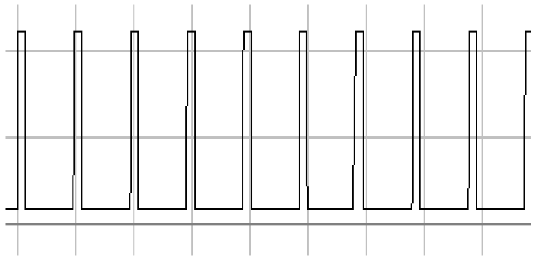

Fig 8: Duty cycle reduced to 15% as load is decreased

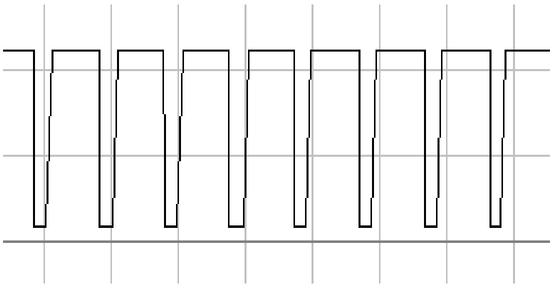

Fig 9: Duty cycle increased to 75% as load is increased

8. CONCLUSION

In this paper we have demonstrated the speed control mechanism of DC motor using PWM technique. The variation of load does not change the speed of the motor as expected. For industrial applications the control mechanism can be developed using PID controller and more powerful ICs.

9. ACKNOWLEDGMENTS

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