Speed Control Of DC Motor Using Analog PWM Technique

Nandkishor P. Joshi,Member ISTE[1], Ajay P. Thakare,Member IEEE,Member ISTE[2]
Department of Instrumentation and control, SCET, Surat[1], Department of Electronics Engineering, SIPNA, Amravati[2]

Abstract

Direct current (DC) motor has already become an important drive configuration for many applications across a wide range of powers and speeds. The ease of control and excellent performance of the DC motors will ensure that the number of applications using them will continue to grow for the foreseeable future. In this paper, a method to control the speed of DC motor using Pulse Width Modulation (PWM) is explained. PWM is generated using Microcontroller 8051. To drive the motor, H-bridge is used which is made up of four MOSFETs. Precise control of low torque DC motor is obtained by using simple and inexpensive hardware. This paper shows that accurate and precise control of small DC motors can be done effectively and efficiently without using complicated circuitry and costly components.

Keywords

DC motor, H-bridge, Pulse Width Modulation

1. Introduction

DC motor plays a significant role in modern industries. They are widely used in industry because of its low cost, less complex control structure and wide range of speed and torque. DC motors provide high starting torque which is required for traction applications. There are several types of applications where the load on the DC motor varies over a wide range. These applications may demand high-speed control accuracy and good dynamic responses. Higher torques can be obtained using geared motors. The term geared motor is used to define a motor that has a gear reduction system (or gearbox) integrally built into the motor. The gearbox increases the torque generating ability of the motor while simultaneously reducing its output speed.

DC motors are used in portable machine tools supplied from batteries, in automotive vehicles as starter motors, blower motors, and in many control applications as actuators and as speed and position sensing devices. High-volume everyday items, such as hand drills and kitchen appliances, use a dc servomotor known as a universal motor. Those motors can work well on both AC and DC power. One of the drawbacks (precautions) about series-wound DC motors is that if they are unloaded, the only thing limiting their speed is the wind age and friction losses. When compared to AC or wound field DC motors, PM motors are usually physically smaller in overall size and lighter for a given power rating.

There are mainly three methods of speed control of DC drives namely field control, armature voltage control and armature resistance control methods. In general, armature voltage control method is widely used to control the DC drives. In thyrister method, a controlled rectifier, or chopper is used to vary the supplied voltage by changing the firing angle but due to involvement of power electronics elements, nonlinear torque speed characteristics are observed which are undesirable for control performance. Phase locked loop control technique is also used for precise speed control and zero speed regulation. Pulse width modulation is a widely used method to control the speed of motor. In the basic Pulse Width Modulation (PWM) method, the operating power to the motors is turned on and off to modulate the current to the motor using MOSFETs. In this paper, method of analog pulse width modulation is discussed that drives DC motor by switching the MOSFETs connected in H-bridge.

2. Bidirectional full bridge circuit

Driving a brushed DC motor in both directions, by reversing the current through it, can be accomplished using a full-bridge circuit which consists of four N-channel MOSFETs. A full bridge circuit is shown in the figure 1. Each side of the motor can be connected either to battery positive, or to battery negative. Note that only one MOSFET on each side of the motor must be turned on at any one time otherwise they will short out the battery and burn out.

To make the motor go forwards, Q4 is turned on, and Q1 has the PWM signal applied to it. The current path is from Q1 to Q4. Note that there is also a diode connected in reverse across the field winding. This is to take the current in the field winding when all four MOSFETs in the bridge are turned off.

Q4 is kept on so when the PWM signal is off, current can continue to flow around the bottom loop through Q3's intrinsic diode.

To make the motor go backwards, Q3 is turned on, and Q2 has the PWM signal applied to it.

Q3 is kept on so when the PWM signal is off, current can continue to flow around the bottom loop through Q4's intrinsic diode.

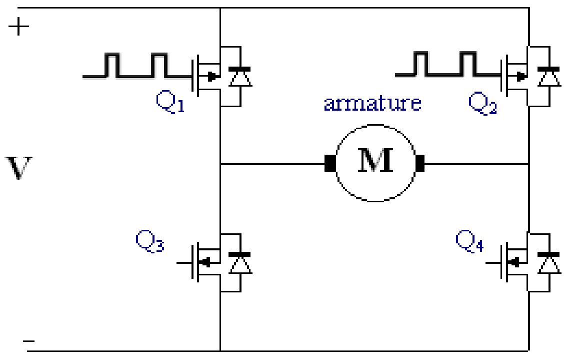

Figure 1. Full H-bridge driver circuit diagram

For regeneration, when the motor is going backwards for example, the motor (which is now acting as a generator) is forcing current right through its armature, through Q2's diode, through the battery (thereby charging it up) and back through Q3's diode.The speed of a DC motor is directly proportional to the supply voltage, so if we reduce the supply voltage from 12 Volts to 6 Volts, the motor will run at half the speed. A better way is to switch the motor's supply on and off very quickly. If the switching is fast enough, the motor doesn't notice it, it only notices the average effect. This on-off switching is performed by power MOSFETs. This is the principle of switch mode speed control. Thus the speed is set by Pulse Width Modulation(PWM).

3. Pulse Width Modulation

A simplest method to control the rotation speed of a DC motor is to control its driving voltage. Higher the voltage, higher is the speed the motor tries to reach. In many applications simple voltage regulation would cause lot of power loss on control circuit, so a pulse width modulation method (PWM) is used in many DC motor controlling applications. The ratio of “on” time to “off” time is what determines the speed of the motor. When doing PWM controlling, keep in mind that a motor is a low pass device. The reason is that a motor is mainly a large inductor. It is not capable of passing high frequency energy, and hence will not perform well using high frequencies. Reasonably low frequencies are required, and then PWM techniques will work. Lower frequencies are generally better than higher frequencies, but PWM stops being effective at too low a frequency. The idea that a lower frequency PWM works better simply reflects that the “on” cycle needs to be pretty wide before the motor will draw any current (because of motor inductance). A higher PWM frequency will work fine if you hang a large capacitor across the motor or short the motor out on the “off” cycle. The reason for this is that short pulses will not allow much current to flow before being cut off. Then the current that did flow is dissipated as an inductive kick - probably as heat through the fly back diodes. The capacitor integrates the pulse and provides a longer, but lower, current flow through the motor after the driver is cut off. There is not inductive kick either, since the current flow isn’t being cut off. Knowing the low pass roll-off frequency of the motor helps to determine an optimum frequency for operating PWM. Here the motor is tested with a square duty cycle using a variable frequency, and then the drop in torque is observed as the frequency is increased. This technique can help determine the roll off point as far as power efficiency is concerned.However, when we work out the power dissipation in the stray resistances in our motor and speed controller, for the DC case:

$$P= I^2R$$

and for the switching case, the average power is

$$P=(2I)^2R/2 + O^2R/2$$

$$P = 2I^2R$$

So in the switching waveform, twice as much power is lost in the stray resistances. In practice the current waveform will not be square wave like this, but it always remains true that there will be more power loss in a non-DC waveform.

4. Choosing PWM frequency based on motor characteristics

The frequency of the resulting PWM signal is dependant on the frequency of the ramp waveform. One way to choose a suitable frequency is this: Say, for example, that we want the current waveform to be stable to within 'p' percent. Then we can work out mathematically the minimum frequency to attain this goal.

Figure 2 shows the equivalent circuit of the motor, and the current waveform as the PWM signal switches on and off. This shows the worst case, at 50:50 PWM ratios, and the current rise is shown for a stationary or stalled motor, which is also worst case.

'T' is the switching period, which is the reciprocal of the switching frequency. Just taking the falling edge of the current waveform, this is given by the equation

$i = Ie^{t/c} = Ie^{-tR/L}$

τ is the time constant of the circuit, which is L / R.

So the current at time t = T/2 (i_1) must be no less than P% lower than at t = 0 (i_0). This means there is a limiting condition:

$i_1 = (1 - P/100)i_0$

$I\, e^{-TR/2L} = (1-P/100)Ie^{0}$

$e^{-TR/2L} = (1-P/100)e^{0}$

$-TR/2L = \ln(1 - P/100)$

$T = -2L/R\, \ln(1 - P/100)$

since the frequency $f = 1/T$

$f = R/-2L\, \ln(1 - p/100)$

Some values are tried to get different frequencies. The motor parameters are as follows:

R = 0.04Ω and L = 70µH

We must also include the on-resistance of the MOSFETs being used, 2 x 10mΩ, giving a total resistance of R = 0.06 Ω.

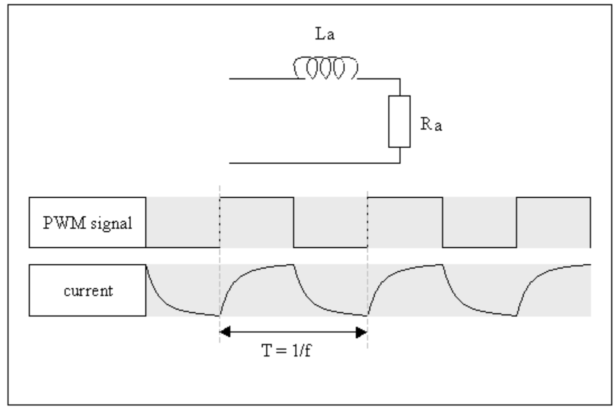

Figure 2. Effect of L/R on current

Table 1

Frequency and allowable ripple **Percentage**	**frequency**
1	42 kHz
5	8.2 kHz
10	4 kHz
20	1900 Hz
50	610 Hz

A graph can be drawn for this particular motor:

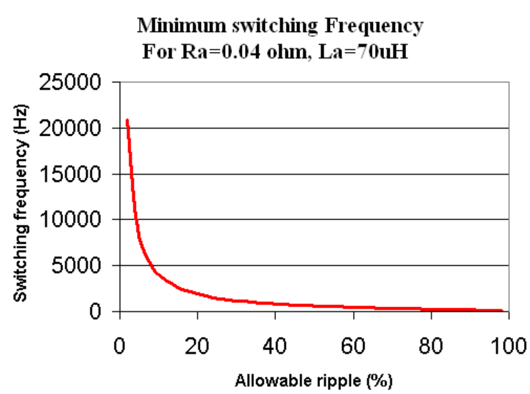

Figure 3. Allowable ripple versus switching frequency

As shown in above graph, a reasonably low ripple can be achieved with a switching frequency of as little as 5kHz.

Unfortunately, motor manufacturers rarely publish values of coil inductance in their datasheets, so the only way to find out is to measure it. This requires sensitive LCR bridge test equipment which is rather expensive to buy.

5. Calculation of the Trajectory

The motion trajectory describes the motion controller board control or command signal output to the driver/amplifier, resulting in a motor/motion action that follows the profile. The typical motion controller calculates the motion profile trajectory segments based on the parameter values you program. The motion controller uses the desired target position, maximum target velocity, and acceleration values you give it to determine how much time it spends in the three primary move segments (which include acceleration, constant velocity, and deceleration).
For an acceleration segment of a typical trapezoidal profile, motion begins from a stopped or previous move and follows a prescribed acceleration ramp until the speed reaches the target velocity for the move. Motion continues at the target velocity for a prescribed period until the controller determines that it is time to begin the deceleration segment and slows the motion to a stop exactly at the desired target position.

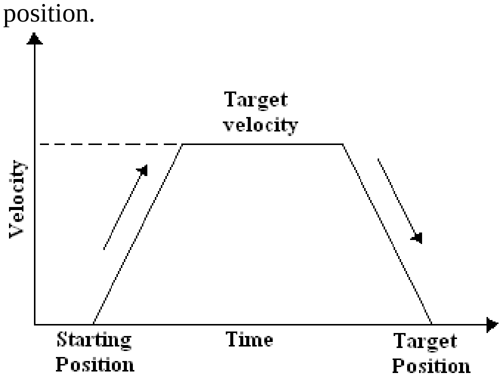

Figure 4. Fixed velocity profile

A velocity profile is a graph of the velocity of a motor vs. time. The area inside the curve that the velocity profile creates is the distance travelled. Velocity profiling is useful for application where specific velocities are necessary at specific times. Two typical velocity profiles are shown in figure 4 and figure 5.

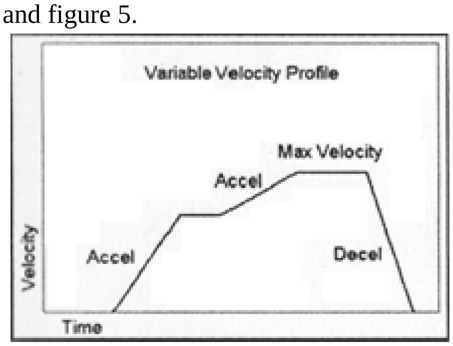

Figure 5. Variable velocity profile

These two figures are both examples of velocity profiles. In the first examples, motor simply accelerates to a target velocity at a specified acceleration, runs at the target velocity, and then decelerates after a certain amount of time. In the second example, the motor accelerates to a certain velocity, runs at that target velocity for a period of time, accelerates to a higher velocity, then travels at that velocity for a period of time, and then decelerates to zero. A concept that is related to velocity profiling is blending. Using blending, you can "blend" two velocity profiles together to make a smooth transition between the two.

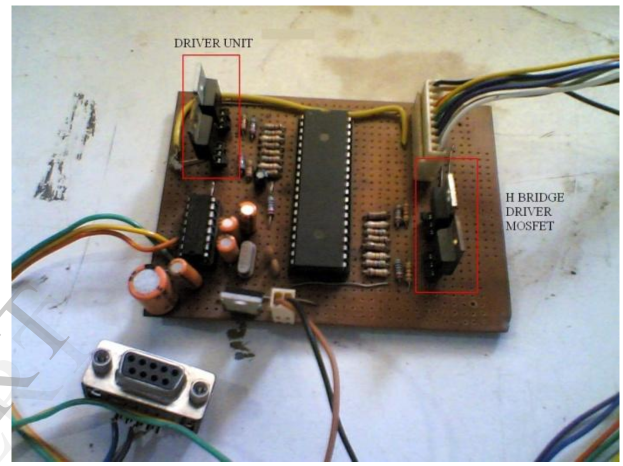

Figure 6. Schematic diagram of driver circuit

6. Simulation results

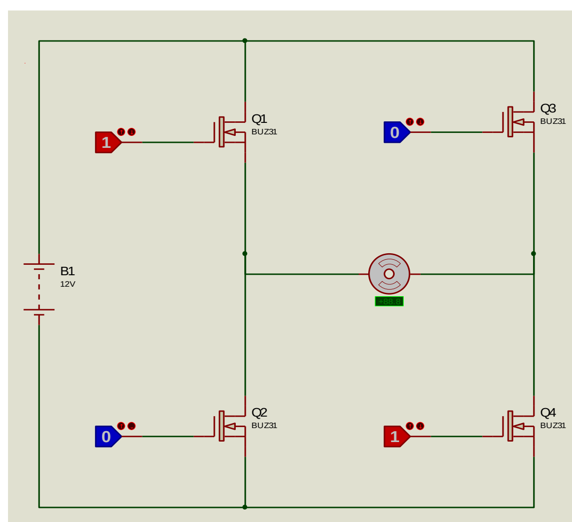

Figure 7. H-bridge driving DC motor

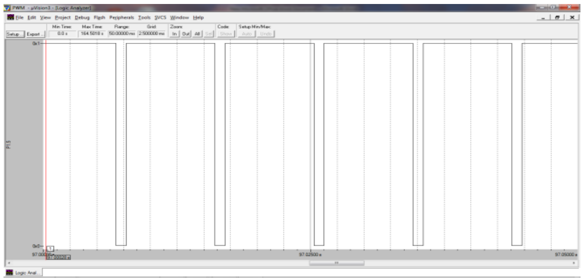

Figure 8. PWM signal with 90% duty cycle

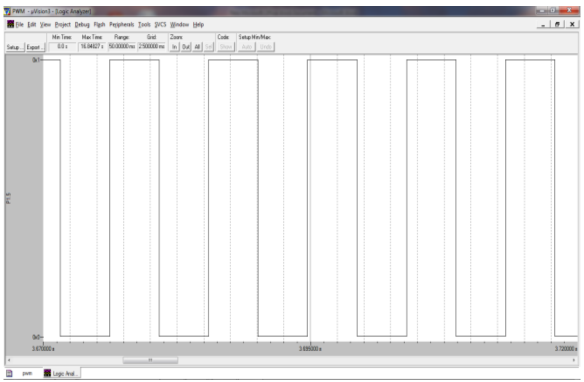

Figure 9. PWM signal with 50% duty cycle

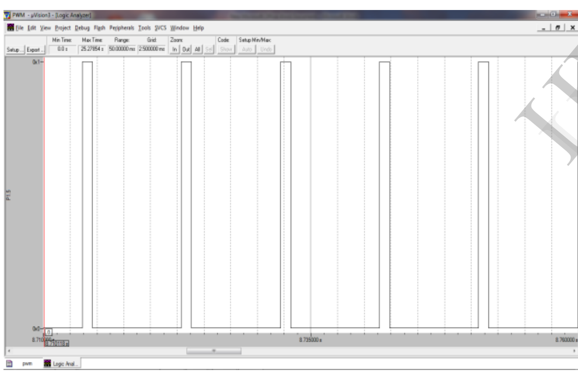

Figure 10. PWM signal with 10 % duty cycle

7. Conclusion

Speed control of DC motor can be achieved using Digital or Analog Pulse Width Modulation technique. When digital PWM is used, control is obtained at two levels, high and low. Whereas using analog PWM, control can be obtained over a wide range of values. In the proposed method, duty cycle is varied from 0 percent to 90 percent and motor is controlled at different speeds. Intervals are taken at every 10 percent. At 50 percent of duty cycle, speed of DC motor is observed to be half of that at full voltage. More precise control can be obtained by dividing the scale into more number of intervals

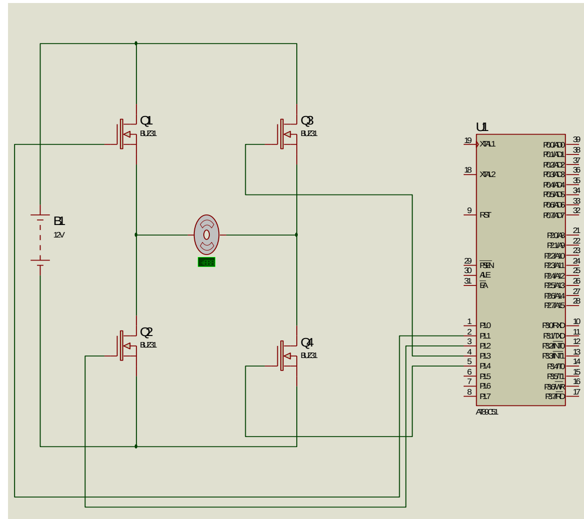

Figure 11. microcontroller interfacing with DC motor

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