Control of the Speed of a DC Motor by Employing Pulse Width Modulation (PWM) Technique

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Abstract

This paper is mainly focused on the technique of pulse width modulation for controlling the speed of a 12 volt DC motor more efficiently. A potentiometer was used to generate a wide variety of pulses. The output of the controlling circuit (Pulse Width) was connected to the second circuit as input for direction control. Here a single push switch was used to change the state (stop-forward-stop-reverse) of the DC motor. These two circuits were combined into one for ease of use. Third circuit was designed to measure the speed of the motor by employing an opto-electronic sensor, an amplifier and a two blade fan to interrupt the signal transmission of the sensor. Finally, the output of the sensor was connected with an oscilloscope through an amplifier and a train of square was found. By measuring the time period of the square waves, the duty cycle and Rotation per Minute (RPM) was calculated. After calculating the result from the observation proves that pulse width modulation is an efficient technique for controlling DC motor rather than other conventional technique.

Keywords: DC Motor, IED, PWM, RPM.

I. INTRODUCTION

Modulation is the process of varying some characteristic of a periodic wave with an external signal. It is utilized to send an information bearing signal over long distances. Modulation is an essential process in communication since it enables multiple signals to be transmitted simultaneously over a common medium or communication channel.[1] Digital communication systems can be implemented using a variety of different modulation schemes, one of which is based on Pulse Width Modulation (PWM) methods. PWM is an attractive scheme for transmission of analogue and data signals compared with purely digital modulation techniques. In PWM the width of a constant amplitude pulse carrier is changed according to the sample values of the modulating signal.[2], [3].

A conventional linear output stage applies a continuous voltage to a load. This can waste plenty of power. On the other hand, PWM applies a pulse train of fixed amplitude and frequency, only the width is varied in proportion to an input voltage. The end result is that the average voltage at the load is the same as the input voltage; but with less wasted power in the output stage. Pulse-width modulation control works by switching the power supplied to the motor on and off very rapidly.

The DC voltage is converted to a square-wave signal, alternating between fully on (nearly 12V) and zero, giving the motor a series of power "kicks". If the switching frequency is high enough, the motor runs at a steady speed due to its fly-wheel momentum. [4] By adjusting the duty cycle of the signal (modulating the width of the pulse, hence the PWM) i.e., the time fraction it is "on", the average power can be varied and hence the motor speed. [5], [6].

A PWM circuit works by making a square wave with a variable on-to-off ratio, the average on time may be varied from 0 to 100 percent. In this manner, a variable amount of power is transferred to the load. The main advantage of a PWM circuit over a resistive power controller is the efficiency, at a 50% level, the PWM will use about 50% of full power, almost all of which is transferred to the load, a resistive controller at 50% load power would consume about 71% of full power, 50% of the power goes to the load and the other 21% is wasted heating the series resistor. Load efficiency is almost always a critical factor in solar powered and other alternative energy systems which we are using in our daily life. [7], [8].

II. FEEDBACK SYSTEM

Pulse Width Modulation (PWM) is used to control the electrical power delivered to the motor. The reason behind this idea is that a closed loop controller will regulate the power delivered to the motor to reach the required velocity.

If the motor is to turn faster than the required velocity, the controller will deliver less power to the motor. Closed-loop control systems typically operate at a fixed frequency. The frequency of changes to the drive signal

Fig. 1. Flowchart of closed loop feedback control system
is usually the same as the sampling rate, and certainly not any faster. For example, if the feedback system indicates that your car is going too quickly, the cruise control system can temporarily reduce the amount of fuel fed to the engine.[9],[10] The closed loop feedback system concept is used to control the speed of the 12 volt DC motor, where the input is a voltage signal and the output is Rotation per Minute (RPM).

In figure 1, at the first stage a comparator is used to compare the input signal (\( V_i \)) with the voltage signal (\( V_R \)) from the feedback element (optical sensor). Then the comparator checks whether the input voltage (\( V_i \)) is greater than (\( V_R \)) or not. The result of the comparator \( V_E \) is then amplified to the control variable (Motor). Finally, based on the motor rotation we can decide that how the mechanical signal will be changed.

### III. FUNCTIONAL DESCRIPTION

The whole experiment design phase is divided into 3 parts. As the main concern of this experiment is to develop a system for controlling the speed of a motor, in first stage a system for PWM to control the speed was made, then the system for control the direction was developed and finally, a small system to calculate the rotation of the motor was designed.

#### A. Controlling the Speed of the Motor

The PWM circuit required a steadily running oscillator to operate. The first and fourth OPAMP of IC LM324N formed a square/triangle waveform generator with a frequency of around 400 Hz. From the circuit we got saw-tooth wave coming from the output pin on fourth OPAMP of IC LM324N. It generates a frequency about 130 Hz with the components where the amplitude is swinging between 3.5 V and 9.5V on a 12V supply. We found that the reference voltage system was designed to apply a level ranging from 3V to 7.5V to the comparator. At 3V the fan was getting power all the time, at 7.5V about 30% of the time (when the sawtooth wave went over 7.5V). The pulse power applied to the fan at the minimum setting, which was just enough to keep my test fan spinning.

Third OPAMP of IC LM324N was used to generate a 6 Volt reference current which was used as a virtual ground for the oscillator and it was necessary for the oscillator to run off of a single supply instead of a +/- voltage dual supply. Second OPAMP of IC LM324N was wired in a comparator configuration and was the art of the circuit that generates the variable pulse width. IC LM324N’s pin 6 received a variable voltage from the R6, VR1, and R7 voltage ladder. This was compared to the triangle waveform from fourth output pin 14. When the waveform was above the pin 6 voltage, IC LM324N produces a high output. Conversely, when the waveform was below the pin 6 voltage, IC LM324N produces a low output. By varying the pin 6 voltage, the on/off points were moved up and down the triangle wave, producing a variable pulse width. Resistors R6 and R7 were used to set the end points of the VR1 control, the values shown allowed the control to have a full on and a full off setting within the travel of the potentiometer. These part values were varied to change the behavior of the potentiometer. Finally, the N channel MOSFET worked as the power switch, it received the modulated pulse width voltage on the gate terminal and switched the load current on and off through the Source-Drain current path. When the N channel MOSFET was on, it provided a ground path for the load and when it was off the load’s ground was floating. The load had the supply voltage on the positive side at all times. LED gave a

![Fig. 2. Circuit Diagram of the Motor Speed Controller](image-url)
variable brightness response to the pulse width. Capacitor C3 smoothed out the switching waveform and removed some RFI. Diode D1 was a flywheel diode that shorted out the reverse voltage kick from inductive motor loads. The speed controller worked by varying the average voltage sent to the motor, which was done by simply adjusting the voltage sent to the motor.

The time that it took a motor to speed up and slow down under switching conditions was dependant on the inertia of the rotor means the weight of it and how much friction and load torque there was. If the supply voltage was switched fast enough, it won’t have time to change speed much, and the speed would be quite steady. This was the principle of switch mode speed control. Thus the speed was set by Pulse Width Modulation.

B. Controlling the Direction of the Motor

We can run the DC motor in clockwise or anti-clockwise direction and stop it using a single switch. It provided a constant voltage for proper operation of the motor. The glowing of LED1 through LED3 indicated that the motor was in stop, forward rotation and reverse conditions, respectively. Here, timer IC1 was wired as a monostable multivibrator to avoid false triggering of the motor while pressing switch S1. Its time period was approximately 500 milliseconds (ms). Suppose, initially, the circuit was in reset condition with Q0 output of IC2 being high. Since Q1 and 3 outputs of IC2 were low, the outputs of IC3 and IC4 were high and the motor didn’t rotate. LED1 glowed to indicate that the motor was in stop condition. When you momentarily press switch S1, timer 555 (IC1) provided a pulse to decade counter CD4017 (IC2), which advanced its output by one and its high state shifted from Q0 to Q1. When Q1 went high, the output of IC3 at pin 3 went low, so the motor started running in clockwise (forward) direction. LED2 glowed to indicate that the motor was running in forward direction. By pressing S1 again, the high output of IC2 shifted from Q1 to Q2. The low Q1 output of IC2 made pin 3 of IC3 high and the motor did not rotate. LED1 glowed (via diode D2) to indicate that the motor was in stop condition. Pressing switch S1 once again shifted the high output of IC2 from Q2 to Q3. The high Q3 output of IC2 made pin 3 of IC4 low and the motor started running in anti-clockwise (reverse) direction. LED3 glowed to indicate that the motor was running in reverse direction. If S1 was pressed again, the high output of IC2 shifted from Q3 to Q4. Since Q4 was connected to reset pin 15, it reset the decade counter CD4017 and its Q0 output went high, so the motor did not rotate. LED1 glowed via diode D1 to indicate that the motor was in stop condition. In Fig. 3 the circuit diagram is given.

C. Speed Measurement

The optical coupler was used to measure the speed of the motor. The optical sensor had very little space between the emitter and the detector through which the blades of a small fan attached with the motor can pass. The opto-interrupter consists of an Infrared Emitting Diode (IED) and a photo-detector. A constant current (a constant voltage difference) was supplied across the terminals of the IED, which emitted a light with a constant intensity. With no obstruction between the IED and photo-detector, the opposing photo-detector received this constant intensity light and outputs a constant current (or constant voltage difference), say IC, across its two leads. When an opaque object is placed between the IED and the photo-detector, the photo-detector output goes essentially to zero. When the small
fan with two blades attached to the motor shaft, rotating at a constant RPM, is passed between the IED and the photo-detector, the photo-detector output becomes periodic. The photo-detector output signal peaks occurred once every revolution of the single blade, when the light from the IED is passed to the photo-detector through the center of the blade. Ideally these periodic signals would have very sharp rise and fall edges associated with the pulses. In actuality, these periodic pulses were fairly rounded, or mound shaped. This rounding of the pulses was primarily due to the finite width of the blade. When the leading edge of the blade just passed in front of the IED, the photo detector current output began to climb. The photo detector output current continued to climb as more of the IED was "seen" by the photo-detector. When the center of the IED was aligned with the center of the blade, the photo-detector current was at a maximum, or was at its peak. As the trailing edge of the blade began to pass the IED, the photo-detector output current began to decrease. The photo-detector current dropped to zero, when the trailing edge of the blade passed the IED completely. The photo-detector current remained zero until the leading edge of the blade was again "seen". The time between peaks was equal to the time for one revolution of the two blades fan. The output came from the cathode terminal of the sensor. A UA741 operational amplifier was used to receive and amplify the produced signal. The output terminal was directly connected to the positive input of the operational amplifier. The operating voltage of the operational amplifier was feed (+5V in pin 7 and -5V in pin 4) through 10kΩ resistor individually to drop some voltage across it for getting the desired output voltage. The negative input terminal was grounded through a 680Ω (RG) resistor. It was also connected to the output of the operational amplifier through another 680Ω (RF) resistor. In this part of the experiment same value had been chosen for RG and RF to make the sensor’s output signal double. Operational amplifier follows the following formula for gain in its output,

\[ V_o = (1 + \frac{RG}{RF}) \times V_i \]  

(1)

The output of the operational amplifier was then connected to the oscilloscope to view the output graph. The time period (ΔT) was calculated from the oscilloscope and it was multiply by two as the fan. Finally, the speed i.e. the Rotation per Minute (RPM) is then calculated by following the formula,

\[ \text{RPM} = \frac{60}{\Delta T \times 2} \]  

(2)

IV. GRAPHICAL VIEW OF THE RESULT AND PERFORMANCE OF THE SYSTEM

![Actual graph for V_out vs RPM](image)
V. CONCLUSION

The main purpose of this experiment was to build DC motor speed controller that consumes less power and can perform more efficiently by using PWM technique. When considering a design for DC motor speed controller, a number of key elements have to be considered, such as a good understanding of the concept of modulation schemes and the electronic circuitry that goes into creating the scheme. These experimental circuits were designed for 12 volt DC motor or less.

The designs practically performed well in the laboratory. The Pulse Width Modulator along with the direction controller gave out good performance. The
hardware part of this experiment successfully controlled the speed of the motor. The opto-electronic sensor design for speed measurement was also good and gave better and clearer wave shape for measuring the RPM for a certain range. The software implementation will work really well if carried out with proper simulator and interfacing. Again, the design will work more efficiently, if we can use proper element for the project. As in some cases, it was very tough to find the appropriate IC for this experiment. The decade counter (CD4017), sometimes did not perform accordingly. As a result the direction control of the motor was not working as expected. If any other equivalent counter can be replaced with the current one, it can perform well. The duty cycle of the pulse width can not be measured in terms of high efficiency. If we can use better oscilloscope with high frequency response then the problem can be overcome. However, the designs can be implemented in practical systems with great patience and a lot of time. The values of the components can be decided upon by calibrating the design manually on trial and error basis. Once the values are fixed the designs will work really well and it can be used in various applications.

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REFERENCES


