Construction of A Pulse Width Modulation, (Pwm) Dc Motor Controller

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Abstract

Control is very important in all mechanical systems. Given the very valuable role DC motor play in our everyday life and in industries, there is need for a control system in other to apply them efficiently and effectively to achieve desired goal. This project aim at constructing a Pulse Width Modulation DC motor control, using microcontroller and Arduino Programming Language. The system is powered from a 5v rectified power source which pulse was determined by a potentiometer. The varying pulse width generated by the microcontroller as affected by the DC analogue sensor regulates the speed with which the Motor runs. It also incorporates a Dc drive through which the motor is supplied in a manner that prevents a back EMF. The construction was carried out on a Vero board by soldering each component permanently after testing it temporarily on a bread board. Result shows that output tests confirmed the workability of the construction and can therefore be recommended for use.

Keywords — *Motor Controller, Pulse Width Modulation, Direct Current, Microcontroller, DC Motor.*

I. INTRODUCTION

Ever since early industrial revolution, there has been a growing need for the use of electric motors in order to drive processes across all areas of applications [1]. An electric motor is an electrical machine that converts electrical energy into mechanical energy. Most electric motors operate through the interaction between the motor's magnetic field and electric current in a wire winding to generate force in the form of rotation of a shaft [2]. Electric motors can be powered by direct current (DC) sources, such as from batteries, motor vehicles or rectifiers, or by alternating current (AC) sources, such as a power grid, inverters or electrical generators. An electric generator is mechanically identical to an electric motor, but operates in the reverse direction, converting mechanical energy into electrical energy [1].

According to [2] Electric motors may be classified by considerations such as power source type, internal construction, application and type of motion output. In addition to AC versus DC types, motors may be brushed or brushless, may be of various phase (single-phase, two-phase, or three-phase), and may be either air-cooled or liquid-cooled. General-purpose motors with standard dimensions and characteristics provide convenient mechanical power for industrial use. The largest electric motors are used for ship propulsion, pipeline compression and pumped-storage applications with ratings reaching 100 megawatts. Electric motors are found in industrial fans, blowers and pumps, machine tools, household appliances, power tools and disk drives [2], [3]. Small motors may be found in electric watches [2]. Pavel [3] explains that, in certain applications, such as in regenerative braking with traction motors, electric motors can be used in reverse as generators to recover energy that might otherwise be lost as heat and friction.

A motor controller is a device or group of devices that serves to govern in some predetermined manner the performance of an electric motor [4]. A motor controller might include a manual or automatic means for starting and stopping the motor, selecting forward or reverse rotation, selecting and regulating the speed, regulating or limiting the torque, and protecting against overloads and faults [4]. According to Zulkefli [5] the simplest case is a switch to connect a motor to a power source, such as in small appliances or power tools. The switch may be manually operated or may be a relay or contactor connected to some form of sensor to automatically start and stop the motor. The switch may have several positions to select different connections of the motor. This may allow reduced-voltage starting of the motor, reversing control or selection of multiple speeds. According to Preeti [4] overload and over current protection may be omitted in very small motor controllers, which rely on the supplying circuit to have over current protection. Small motors may have built-in overload devices to automatically open the circuit on overload. Larger motors have a protective overload relay or temperature sensing relay included in the controller and fuses or circuit breakers for over current protection. An automatic motor controller may also include limit switches or other devices to protect the driven machinery [1], [5], [6], [7].

More complex motor controllers may be used to accurately control the speed and torque of the connected motor (or motors) and may be part of closed loop control systems for precise positioning of a driven machine [8]. Electric motors are now more diverse and adaptable than ever before. Some of the most common electric motors used today include: AC Brushless Motors, DC Brushed Motors, DC Brushless Motors, Direct Drive, Linear Motors, Servo Motors, and Stepper Motors [8], [5], [7]. In this study, the focus is on the dc motor. A simple DC motor works on the principle that when a current carrying conductor is placed in a magnetic field, it experiences a mechanical force [9]. According to [10] there are four (4) main types of DC motors: Permanent Magnet DC Motors, Series DC Motors, Shunt DC Motors, and Compound DC Motors. A Dc motor controller is a device that works alongside a microcontroller, the batteries and motors. Most controllers have under-voltage, over-voltage, short circuit protection, current limit protection, thermal protection, and voltage transients. Without these protections, the motor is exposed to threats that can result in permanent electrical or mechanical damage [10].

Pulse Width Modulation (PWM) uses digital signals to control power applications, as well as being fairly easy to convert back to analog with a minimum of hardware [11]. Analog systems, such as linear power supplies, tend to generate a lot of heat since they are basically variable resistors carrying a lot of current. Digital systems don't generally generate as much heat. Almost all the heat generated by a switching device is during the transition (which is done quickly), while the device is neither on nor off, but in between. PWM can have many of the characteristics of an analog control system, in that the digital signal can be freewheeling [11]. This study seeks to eliminate voltage loss by using PWM, which applies full voltage to the motor in burst of pulses and produce more torque in the motor by overcoming the internal motor resistances more easily.

The research will be based on PWM for the reasons that; conversion into its analog equivalent value is straightforward. PWM can be produced by using a saw tooth waveform and a comparator. The saw tooth need not be symmetrical, but the linearity of the waveform is important. The frequency of the saw tooth waveform is the sampling rate for the signal. If there isn't any computation involved PWM can be fast. The limiting factor is the comparators frequency response. This may not be an issue since quite a few of the uses are fairly low speed [12]. Motors as a class require very high currents to operate. Being able to vary their speed with PWM increases the efficiency of the total system [13]. While series of resistors wasted energy and reduces torque using transistors dissipated a substantial amount of heat making these methods inefficient. Therefore, PWM is more effective at controlling motor speeds at low RPM than linear methods. Pulse Width Modulation, provides low cost, lightweight, small volume simple structure yet very efficient method of constructing the Dc motor. This work will be suitable for toys, lamp dimmers, and small heater controller and even speed control for solar powered electric train.

II. MATERIALS AND METHOD

A. *Materials*

The major materials used for the design and construction of the pulse width modulation dc motor controller includes a PIC 12F675 Micro Controller, 7805 Voltage Regulator, IN4007 Junction Diodes, TIP41 NPN Power Transistor, 5.1 V Zener Diode, Motor and assorted Resistors and Capacitors.

B. *Method*

The method involved a stage by stage construction of the circuit, followed by testing the output for proper functionality and optimum performance.

a) Construction Method:

The Construction of the PWM dc controller circuit was carried out following the block diagram as shown in Fig. 1.

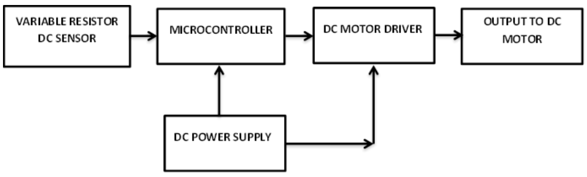

Fig. 1: Block diagram of a PWM DC motor controller

When armature windings are connected to a DC supply, an electric current sets up in the winding. Magnetic field may be provided by field winding (electromagnetism) or by using permanent magnets. In this case, current carrying armature conductors experience a force due to the magnetic field. The commutator was made segmented to achieve unidirectional torque. Otherwise, the direction of force would reverse every time when the direction of movement of conductor is reversed in the magnetic field. The power supply was constructed using a center taped 230 V ac transformer and two diodes, connected in full wave rectifier manner in order to beat down ripples. A capacitor wired across the rectifier output helps in smoothening. A regulator 7805 helps to limit the supply voltage to the microcontroller, within safe values.

b) Testing Method:

Tests carried out were voltage test using multimeter while varying the values of the dc analog sensor (potentiometer) and speed of the dc motor as detected by the potentiometer. By connecting a voltmeter at the potentiometer output, varying voltage values will be recorded, corresponding to different adjusted values of the potentiometer. Also, a speedometer will be used to determine the changing speed of the electric motor.

III. RESULTS

A. *Circuit Construction Analysis*

a) Analog DC Sensor (Potentiometer):

The potentiometer is a displacement transducer. – It is an active transducer that consists of a uniform coil of wire or a film of high-resistive material (e.g., carbon, platinum, conductive plastic) whose resistance is proportional to its length. – A fixed voltage V_{ref} is applied across the coil or film using an external, constant DC voltage supply. – The transducer output signal V_o is the DC voltage between the moving contact (wiper arm) sliding on the coil and one terminal of the coil. – Slider displacement is proportional to the output voltage, which assumes that the output terminals are open-circuit i.e. an infinite-impedance load (or resistance in the present DC case) present at the output terminals, so that the output current is zero. – In actual practice, the load (the circuitry into which the potentiometer is fed) has a finite impedance and so the output current (through the load) is nonzero. – The output voltage thus drops, even if the reference voltage V_{ref} is assumed to remain constant under load variations (i.e., the voltage source has zero output impedance).

b) PIC Microcontroller:

PIC (Programmable Interface Controllers) microcontrollers are the world's smallest microcontrollers that can be programmed to carry out a huge range of tasks. They are programmed and simulated by circuit-wizard software [14].

Every PIC microcontroller architecture consists of some registers and stack where registers function as Random Access Memory (RAM) and stack saves the return addresses. The main features of PIC microcontrollers are RAM, flash memory, Timers/Counters, EEPROM, I/O Ports, USART, CCP (Capture/Compare/PWM module), SSP, Comparator, ADC (analog to digital converter), PSP (parallel slave port), LCD and ICSP (in circuit serial programming). The 8-bit PIC microcontroller is classified into four types on the basis of internal architecture such as Base Line PIC, Mid-Range PIC.

The PIC microcontroller architecture comprises of CPU, I/O ports, memory organization, A/D converter, timers/counters, interrupts, serial communication, oscillator, and CCP module. The PIC 12F675 microcontroller Pin out is as shown in Fig. 2.

USART: The Universal synchronous and Asynchronous Receiver and Transmitter which is a serial communication for two protocols is used for transmitting and receiving the data bit by bit over a single wire with respect to clock pulses. The PIC microcontroller has two pins TXD and RXD. These pins are used for transmitting and receiving the data serially.

SPI Protocol: The Serial Peripheral Interface protocol is used to send data between PIC microcontroller and other peripherals such as SD cards, sensors and shift registers. PIC microcontroller supports three wire SPI communications between two devices on a common clock source. The data rate of SPI protocol is more than that of the USART.

I2C Protocol: The Inter Integrated circuit is a serial protocol which is used to connect low speed devices such as EEPROMS, microcontrollers, A/D converters, etc. PIC microcontroller supports two wires Interface or I2C communication between two devices which can work as both Master and Slave device. PIC16 series consists of five ports, such as Port A, Port B, Port C, Port D and Port E.

Port A: Is a 16-bit port, which can be used as input or output port based on the status of the TRISA register.

Port B: Is an 8-bit port, which can be used as both input and output port. 4 of its bits when used as input can be changed upon interrupt signals.

Port C: Is an 8-bit port whose operation (input or output) is determined by the status of the TRISC register.

Port D: Is an 8-bit port, which apart from being an I/O port, acts as a slave port for connection to the microprocessor bus.

Port E: It is a 3-bit port that serves the additional function of the control signals to the A/D converter.

Timers: PIC microcontrollers consist of 3 timers, out of which the Timer 0 and Timer 2 are 8-bit timers and the Time-1 is a 16-bit timer, which can also be used as a counter.

A/D Converter: The PIC Microcontroller consists of 8-channels, 10-bit Analog to Digital Converter. The operation of the A/D converter is controlled by these special function registers: ADCON0 and ADCON1. The lower bits of the converter are stored in ADRESL (8 bits), and the upper bits are stored in the ADRESH register. It requires an analog reference voltage of 5V for its operation.

Oscillators: Oscillators are used for timing generation. PIC microcontrollers consist of external oscillators like crystals or RC oscillators. In case of crystal oscillators, the crystal is connected between two oscillator pins, and the value of the capacitor connected to each pin determines the mode of operation of the oscillator. The different modes are low-power mode, crystal mode and the high- speed mode. In case of RC oscillators, the value of the Resistor and Capacitor determine the clock frequency. The clock frequency ranges from 30 kHz to 4 MHz

CCP module: A CCP module works in three modes:

Capture Mode: This mode captures the time of arrival of a signal, or in other words, captures the value of the Timer1 when the CCP pin goes high.

Compare Mode: It acts as an analog comparator that generates an output when the timer1 value reaches a certain reference value.

PWM Mode: It provides pulse width modulated output with a 10-bit resolution and programmable duty cycle.

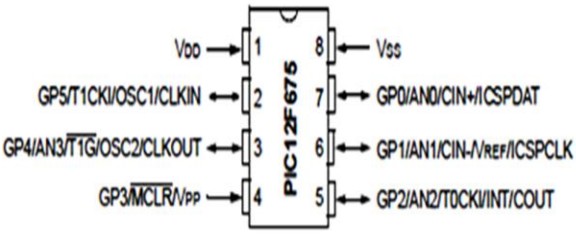

Fig. 2: PIC 12F675 pin out [15]

c) DC Motor Driver:

In armature controlled DC drives, drive unit provides a rated current and torque at any speed between zero and the base of the motor. By varying the armature voltage, variable speed is obtained. Generally, a fixed field supply is provided in these DC drives. As the torque is constant (which describes a load type) over the speed range, the motor output horsepower is proportional to the speed.

In case of armature and field controlled drives, the armature voltage to the motor is controlled for constant torque-variable HP operation up to the base speed of the motor. And for the above base speed operation, drive switches to the field control for constant HP- reduced torque operation up to maximum speed. In this case, reducing the field current increases the speed of the motor up to its maximum speed.

d) Circuit Construction:

The components specified by the general circuit arrangement as shown in Fig. 3 were first wired up in a Bread Board. Having ascertained the functionality of the project, they were transferred to a Vero Board and soldered as shown in Fig. 4. Basically the system operates in such a way that it receives a 12 v dc from the power supply unit which is regulated by the 7805 regulator to 5v dc. The 5v dc is fed into V_{CC} of the microcontroller in order to generate pulse varying voltages, the rate of change of the width of the voltage which is subject and controlled by the value of the potentiometer. The microcontroller output voltage is then fed into the DC motor through a switching transistor/driver and a diode to ensure a unidirectional flow and prevent back EMF.

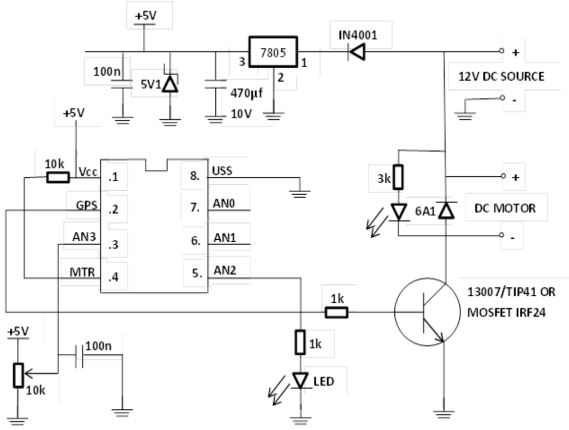

Fig. 3: General circuit of PWM, DC motor controller

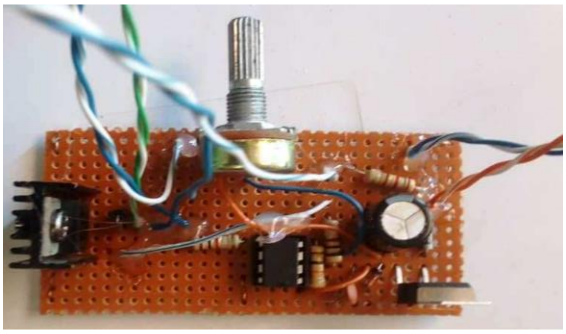

Fig. 4: Circuit construction on Vero board

e) Casing and Packaging:

The assembled device is housed in a plastic casing measuring 75mm x75mm x 45mm and properly packaged. Fig. 5 shows the package assembling after construction of the circuit, indicating how the arrangement was done in the casing.

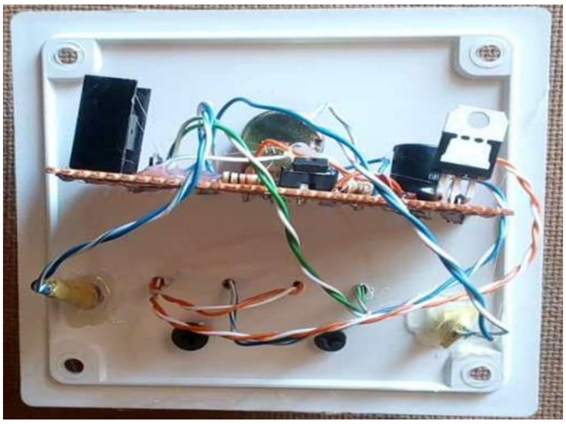

Fig. 5: Constructed Circuit in casing

Fig. 6 shows the complete packaged PWM, DC motor controller system.

Fig. 6: Complete pakaged PWM, DC motor controller system

B. Theory and Calculations

Assuming the flux (ϕ) and armature current (I_a) are kept constant, such that the parameter that could effect change in speed are voltage (V) and armature resistance (R_a). Then the speed of the DC motor can be altered by varying any of the parameters according to the following equations.

$$N = \frac{V - I_a R_a}{\Phi} \quad (1)$$

where,

$$V = E_b + I_a R_a \quad (2)$$

$$V_{max} = \frac{V_{rms}}{0.707} \quad (3)$$

$$V_{dc} = 0.636 V_{max} \quad (4)$$

$$r = \sqrt{\left(\frac{V_{rms}}{V_{dc}}\right)^2 - 1} \quad (5)$$

where, V_{max} is the peak voltage, V_{rms} is the root mean square voltage, V_{dc} is the dc voltage, and r is the ripple factor. Then using equations (3) to (5) we have:

$$V_{max} = \frac{6}{0.707} = 8.49V$$

$$V_{dc} = 0.636 \, x \, 8.49 = 5.4V$$

With capacitor,

$$V_{dc} = 8.49V$$

$$V_{rms} = 0.707 \, x \, 8.49 = 6.0024$$

$$r = \sqrt{\left(\frac{6.0024}{8.49}\right)^2 - 1}$$

$$r = \sqrt{(0.707)^2 - 1} = 0.23$$

For potentiometer values of 50Ω and using equation (1), we calculate the number of revolution per minute as follows:

$$N = \frac{1 - 50Ia}{\Phi} = 49RPM$$

Similarly, we calculate for potentiometer values of 50, 100, 150, 200, and 250Ω, and the results are presented in Table 1.

TABLE I
Output Test Result

V (volts)	1	2	3	4	5
R ohms	50	100	150	200	250
N rpm	49	98	147	196	245

From Table 1 we obtain the variations of speed with resistance and variation of speed with voltage as presented in Fig. 7 and 8 respectively.

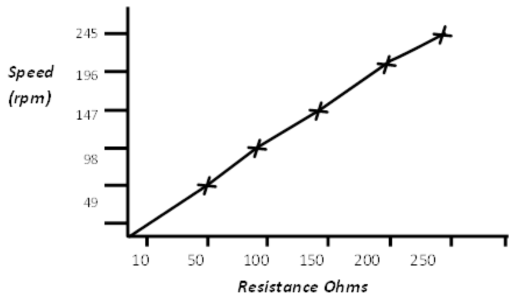

Fig. 7: variation of speed with resistance

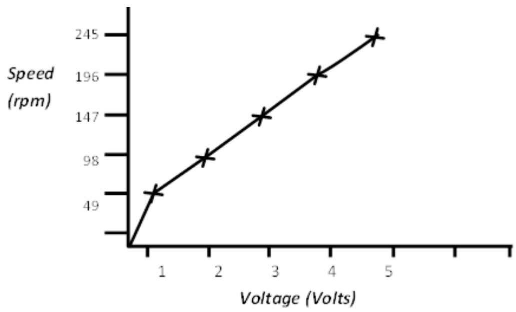

Fig. 8: Variation of speed with voltage

From Fig. 7 and 8 we can see clearly that the variation of speed with both resistance and voltage all shows a linear relationship, indicating that when other parameters are kept constant the speed level of the DC fan depends on variation of any one of these quantities.

IV. DISCUSSION

From the analysis of the output test it can be seen that the relationship between the speed and the resistance value is linear. Increase in the resistance value results in an increase in the speed of the motor, indicating that the potentiometer acts as a signal pickup for directly increasing the voltage available to the circuit. The relationship between speed and voltage also shows a linear relationship with increase in voltage resulting to an increase in the speed of the motor. This indicates that the speed of the DC motor can be altered by varying either the potentiometer value or the voltage applied to the armature for selecting and regulating/limiting the speed as a linear or rotary force (torque) intended to propel some external mechanism such as fan or elevator. This is in line with the works of [4], [6], [16], and [7]. But contrary to that of [17] who used a PWM and a method of space vector modulation with hysteresis current to administer control. Though, this gave high power quality but reduction of torque.

V. CONCLUSIONS

Control is very important with mechanical systems. One of the benefits of Dc motor is that, it can be adequately and properly controlled by adjusting or regulating certain parameters. This is possible by varying either the supply voltage, armature resistance or the flux. In this work, speed control was achieved by varying the width of voltage pulse in a PIC microcontroller PWM technology by adjusting the potentiometer. The experimental result for this project is the control of PWM on DC motor. In line with [7], [16], and [6], the running duty of a DC motor can be changed by changing the duty-cycle value that supplies the DC motor and by modifying the potentiometer. The project is easy to implement and can be used in industrial applications, robot system and kid's toys. Though, it can be improved by using automatic systems of inputting resistance values at predetermined time using timers and appropriate controllers.

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