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Automatic Feedback Control of A DC Motor Using PWM With P-Controller

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***Abstract*: An automatic feedback control system has been developed to regulate the speed of a dc motor by using PWM with P-controller. The voltage applied to the motor can be controlled by controlling the PWM duty cycle. The principle involved is armature voltage control of speed of a dc motor at varying load conditions. Adapting close-loop control system gives a better and more precise operating condition of a motor under varying load conditions which is often met in practical situations. Comparison of the output voltage with the reference value is carried out with the help of a feedback circuit which includes a P-Controller. It determines the deviation and generates a control signal to reduce the deviation to a small value. Other types of controller, namely PI and PID, are envisaged as a part of future work.**

Keywords- Automatic feedback control, Multi-vibrator, PWM technique, Duty cycle, Speed control, P-controller, Motor Driver.

1. INTRODUCTION

The drive systems used in industrial applications require high performance, reliability and variable speed. Electrical drives have the advantage of ease of controllability. The speed control of dc motor is very crucial in applications where loading conditions are fluctuating in nature. Speed control of dc motor could be achieved using mechanical or electrical techniques. In the past, speed control of DC drive was mostly mechanical requiring large-size hardware to implement. In contrast an electrical/electronic system results in a more compact reliable and accurate control.

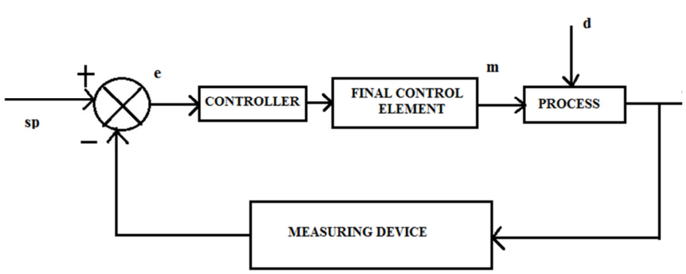

Fig.1. Closed loop negative feedback system

Automatic control is the regulation of processes without human intervention. In a feedback control loop (as shown in figure 1), a comparator compares the measured value of a process with a desired set value, resulting in an error signal to change the input to the process in such a way that the loop control provides better accuracy, as well as better transient- and steady-state response. Some important applications of feedback control systems are in: Rolling mills, Paper mills, Mine windows, Hoists, Machine tools, Printing presses, Textile mills, Excavators and Cranes. Fractional horse-power dc drives are widely employed for positioning and tracking.

In this work, an automatic feedback control on a dc motor has been implemented on a Motor-generator pair employed for electrical loading. A feedback control system for a dc motor using the PWM technique has been built for this purpose. . It is desired to obtain a drive that will maintain the desired speed (at close tolerance) at varying load/torque conditions at the driving shaft. The DC motor is an important part of equipments in many industrial applications requiring variable speed and load characteristics due to its ease of controllability. Pulse Width Modulation (PWM) technique offers many advantages in controlling the speed of dc motors. PWM signal is a method for generating an analog signal using digital source. PWM consists of two main components that define its behavior: a duty cycle and a frequency [1].

Many works on speed control of dc machine using PWM has been done. A recent paper has been presented in the study of D.C motor speed control through Pulse Width

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Modulation implemented by MATLAB Simulation. In this paper it has presented the realization of the speed control by using Pulse Width Modulation. PWM is generated using microcontroller 8051 and 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 [2]. A PWM control based on LM324 [3] was used to control the speed of a DC motor in both forward and reverse directions, from fully OFF to fully ON state . As it runs in switch mode, it is quite efficient. The proposed system offers many advantages such as simple structure, low cost, accurate, quite efficient, lightweight, small volume, and bi-directional speed control. PWM-based speed control of DC motor through RS232 interfaced with PC was used to control the speed of a dc geared motor [4]. PWM-based automatic closed loop speed control of DC Motor using microcontroller [5] have been used. The implementation of the work was done using ATmega8L microcontroller for speed control of DC motor fed by a DC chopper. The chopper is driven by a high-frequency PWM signal. Controlling the PWM duty-cycle is equivalent to controlling the motor terminal voltage, which in turn adjusts directly the motor speed. The speed control of dc motor using microcontroller (PIC 16F72) with PWM have been investigated [6]. It is a closed-loop real-time control system, where optical encoder is coupled to the motor shaft to provide the feedback speed signal to controller. PWM technique is used where its signal is generated in microcontroller. The PWM signal is sent to motor driver (using H bridge built with IGBT switches) to vary the voltage supply to the motor to maintain constant speed.

2. SCHEMATIC BLOCK DIAGRAM

The schematic block diagram of the system is given bellow:

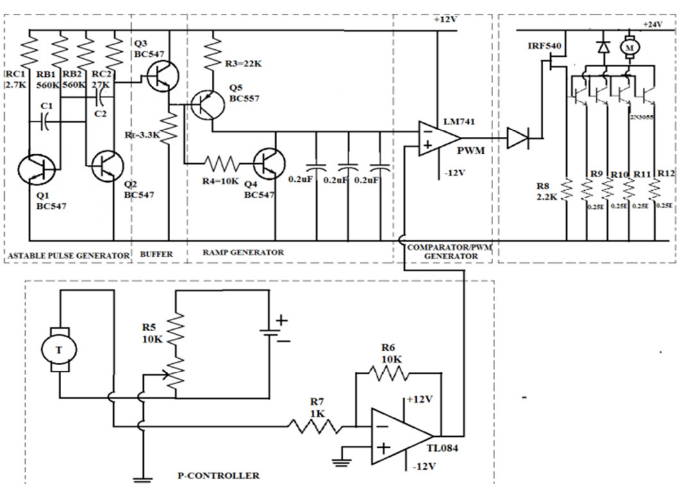

Fig.2. Schematic block diagram

The constituent blocks are described in the following sections:

2.1 PWM Generator Circuit

PWM generator circuit controls the duty-cycle of the applied voltage at the motor terminals. The main circuit components of the PWM generator circuits are as described below-

2.1.1 Astable Pulse Generator

In an Astable multivibrator, both coupling networks provide ac coupling through coupling capacitors. Each amplifier stage provides phase shift of 180^0 in the midband so as to provide an overall phase shift of 360^0 or 0^0 and thus a positive feedback. The circuit therefore oscillates, provided that the total loop gain is equal to or greater than unity. It has no stable state. The two states of operation of astable multivibrator are quasi-stable (temporary) states. The astable multivibrator, therefore, makes successive transitions from one quasi-state to the other one after a predetermined time interval, without the aid of an external triggering signal. The periodic time depends upon circuit time constant and parameters.

This is a classical circuit that has been used for many years for generating pulse waveforms.

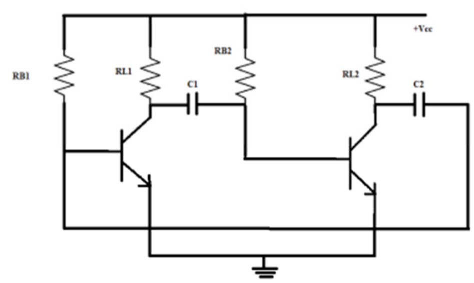

Fig.3. Classical circuit for generation of pulse waveform

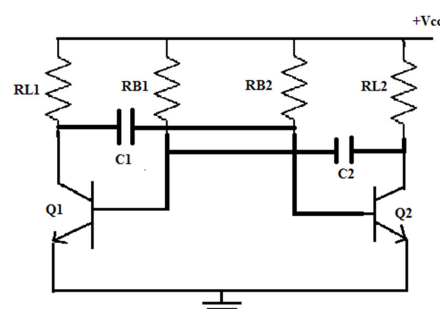

Fig.4. Multivibrator circuit for square wave generation

Fundamentally it has two cascaded amplifiers where the output of the last amplifier is connected to the input of the first amplifier as shown in Fig.3. This results in positive feedback and if the values of the coupling capacitors and registers are right the circuits will oscillate generating square waves. The multi-vibrator circuit is more often drawn as in

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Fig.4.When oscillating one transistor turns on (saturated) while the other turns off and after some time the situation reverses and the on off process continues indefinitely. Obviously this will raise a square waveform with a fixed frequency and duty cycle. The output waveform appears at either of the collector terminals.

2.1.2 Buffer Circuit

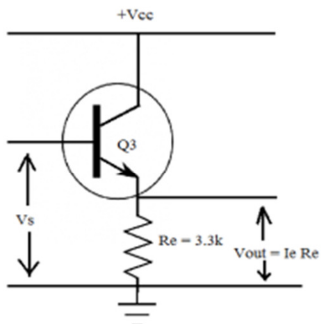

Fig.5: Buffer circuit

A Buffer circuit used is basically an emitter follower. It is also a negative feedback circuit. This circuit exhibits large input impedance, small output impedance, and a voltage gain of approximately unity. The output voltage tends to be in phase with the input voltage-hence the term follower. When input signal V_s is applied to the base, the resulting emitter current, I_e develops an output voltage V_{out} equal to I_eR_e across the emitter resistance R_e. This voltage opposes the ac signal voltage Vs as it is in phase opposition to V_s. Then it provides a negative current feedback. Moreover, this voltage (V_{out}) feedback to the input is proportional to the emitter current hence this circuit is called a negative current feedback circuit. The frequency of oscillation is given approximately by

$$F_1 = 0.65RB_2C_1$$

$$F_2 = 0.65RB_1C_2$$

$$F_0 = \frac{1}{F_1 + F_2}$$

Providing V_{cc}>>0.7 and that RB_1C_2>>$RL1C_1$ and RB_2C_1>>RL_2C_1

2.1.3 Ramp Generator

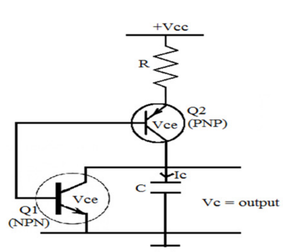

Fig.6. Ramp Generator

This comprises of two transistors Q1 and Q2. The PNP transistor has a capacitor as a collector load. Now when the base of Q2 goes low, on applying a low pulse (i.e. a zero voltage signal), the transistor turns on and the emitter voltage becomes approximately 0.7V above ground. Therefore the current through the resistor R (and hence the emitter current) is equal to

$$(V_{CC} - 0.7)/_R$$

This is also equal (approximately) to the collector current IC which is constant and independent of the collector voltage. The collector circuit behaves like a constant current source. The voltage across the capacitor C is given by

$$V_c = \frac{1}{C}\int idt$$

Here, $I=I_c$, which is constant

Therefore, $V_c = \frac{I_c}{C} \times t$

This equation for V_c generates a ramp waveform. The slope depends upon I_c /C. The transistor Q1 switches off, when the base voltage becomes low. But when the input voltage changes to high, Q1 turns on (and Q2 turns off) effectively shorting the capacitor C so that V_c goes to zero (equal to $V_{CE\ (Sat)}$).

The resultant waveform is shown in Fig.7

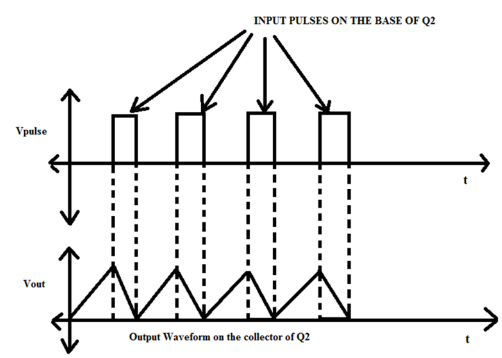

Fig. 7. Resultant waveform of Ramp Generator

2.1.4 Comparator Pulse Width Generator

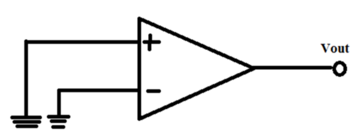

Fig. 8. Comparator

The circuit that generates width controllable pulses is build around a comparator. A comparator is a simple differential amplifier with high gain (ideally infinite). It basically has

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two inputs and one output. The output voltage is equal to the amplification of the voltage difference between the two inputs and because the gain of the amplifier is very high, a small difference between (ideally zero) the inputs, the output to swing to the positive supply voltage or the negative supply voltage (w.r.t. ground). One of the inputs is marked as inverting and the other as non-inverting w.r.t. the output voltage. If the non-inverting input is more positive w.r.t. to the inverting input the output will go positive and conversely if the inverting input is more positive w.r.t. the non-inverting input, the output will swing towards the negative supply.

Now if V_1, the non-inverting input to the comparator is a time-varying ramp waveform and V_2 is a fixed voltage (less the peak value of the ramp), then it is possible to generate the waveform (at the output of the comparator) as shown in Fig. 9.

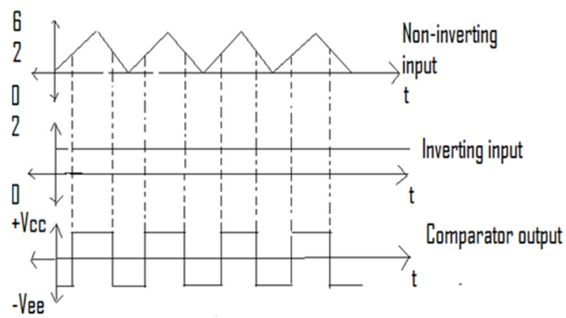

Fig.9. Comparator output

2.1.5 Motor Driver Circuit

A Darlington pair circuit is used as a Motor Driver circuit. The current gain provided by the Darlington pair is of the order of few thousands. This circuit is used for driving the motor for the following reasons:

1. Input impedance is $\beta^2 R_e$ whereas that of the emitter follower is βR_e.
2. Current gain is β^2, whereas that of emitter follower is β.
3. Voltage gains of the two are identical.

3. SYSTEM LOADING AND THE FEEDBACK CIRCUIT

3.1 Electrical Load

The controlled PWM output is fed to the motor terminals of the motor-generator set and thus controlling the PWM duty cycle is equivalent to controlling the motor terminal voltage. The principle involved is armature voltage control of speed of a dc motor. The generator which is coupled to the motor converts the mechanical power into electrical power and that electrical power is used for electrical loading.

3.2 PWM Generator

The operation of the PWM circuit is discussed in Section 2.1

The hardware components are briefly described in the following sections:

3.3. Power Supplies

3.3.1 Main Circuit Supply

A step-down transformer is used in the power supply which converts the 230V ac supply to 12V ac. The ac voltage is converted into ±12V dc using rectifier circuit for the other circuit applications.

3.3.2 Supply Providing Floating Ground

Five AA batteries of 1.5V each are connected in series to build a power supply of 7.5V for tacho-generator supply providing a floating ground.

3.3.3 Supply for M-G Set in Electrical Loading

For electrical loading, two Lead-Acid batteries of 12V dc each are connected in series to drive the Motor-Generator set.

3.4 Motor-Generator set

Motor

A 12V PMDC motor is used in the circuit. It is driven by a motor driver circuit giving PWM output. It is coupled to a dc generator and the assembly is mounted on a wooden base.

Generator

A PMDC machine of voltage rating of 12V is used as a generator. It is coupled to the motor and is used for electrical loading of the motor.

3.5. Feedback (Tacho) Generator

A 12V PMDC motor is used as a feedback generator. It is also mounted on the base and is coupled to the shaft of the M-G set through a belt-pulley arrangement. The speed ratio $N_{TG}/N_M = 4.4$.

3.6 Controller

Controller generates a control signal to the final control element depending upon the deviation between the set point and the measured value of the controlled variable. In this work a Proportional (P) controller is used [7].

3.6.1 .Proportional Controller [P]

A Proportional control system is a type of linear feedback control system. In Proportional controllers, the output c(t) and the error e(t) are related by

$$c(t) = K_p$$

Taking Laplace transform of Eq.(1), we have,

$$\frac{C(s)}{E(s)} = K_p$$

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The steady state error (e_{ss}) is given by

$$e_{ss} = \frac{A}{K_V}$$

4. EXPERIMENTAL RESULTS

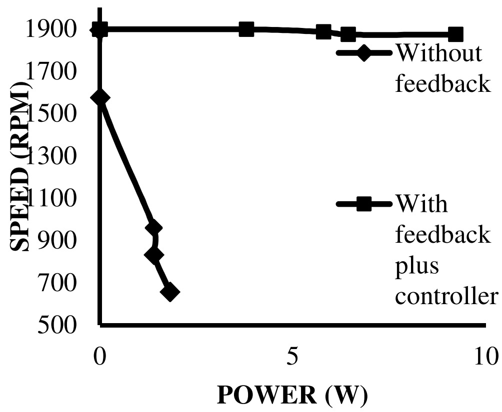

Fig. 10. Speed vs. output power

The Fig.10 shows the graph between speed and output power without feedback and, with feedback plus controller. It is observed that when the load power varies from 0W to 1.82W, the speed of the motor varies from 1894 rpm to 657 rpm. And when the load power varies from 0W to 9.22W, the speed of the motor will show a lesser variation from 1898 rpm to 1873 rpm i.e. feedback system gives a better control of speed at varying loads compared to an open-loop system and introduction of the P – type controller in the feedback loop gives better speed regulation of the motor

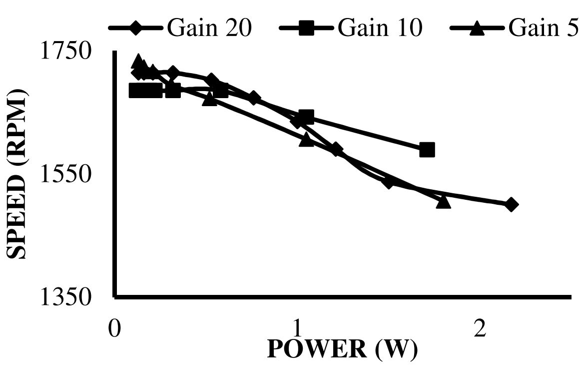

Fig.11. Plot between generator output and speed at different gains of the controller

The Fig.11 shows the graph between speed vs load current for an automatic feedback control of a dc motor using pwm with p-controller for gain 20, gain 10 and gain 5. It is observed that the speed variation is under an optimal level with gain 10. Increasing the gain of the controller upto a certain level improves the speed regulation. Excessive gain, on the other hand, deteriorates the speed regulations.

5. CONCLUSIONS

The work involves conceptualization, planning and development of a PWM control of dc motor using feedback that incorporates a controller (P-type).

All the electronic functional blocks in the system have been organized, built and independently tested to ensure correct and reliable performance. All the blocks are finally integrated to build up the control system.

The system has been tested for varying load conditions. The observations and results obtained have been analyzed to arrive at the following conclusions.

1. PWM control of a d.c motor gives a simple and convenient method of speed control preferably at higher duty cycles.

2. A feedback system gives a better control of speed at varying loads compared to an open-loop system.

3. Introduction of the P – type controller in the feedback loop gives better speed regulation of the motor.

4. Increasing the gain of the controller up to a certain level improves the speed regulation. Excessive gain, on the other hand, deteriorates the speed regulation.

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ABBREVIATION

1. M-G set: Motor-Generator Set.
2. P-Controller: Proportional Controller.
3. PI-Controller: Proportional-Integral Controller.
4. PID Controller: Proportional-Integral-Derivative Controller.
5. PMDC: Permanent Magnet Direct Current.
6. PWM: Pulse Width Modulation.

BIOGRAPHIES

Mayuri Sarmah Mazinder did her B.E in Applied Electronics and Instrumentation Engineering in 2015 and currently pursuing her M.Tech degree in Instrumentation and Control Engineering from GIMT Guwahati, Assam

Sohail Ahmed did his B.E in Applied Electronics and Instrumentation Engineering from GIMT Guwahati, Assam in 2015

Suditree Devya did her B.E in Applied Electronics and Instrumentation Engineering from GIMT Guwahati, Assam in 2015

Prof. P K Bordoloi is a Senior Professor in the Dept. of AEI Engineering at GIMT Guwahati. He did his Ph.D from Manchester University, UK and has 40 years of teaching experience in various institutions of Assam.

Prof. P K Brahma was the Former Director of GIMT Guwahati. He did his M.S. (Electrical Engineering), University of Califfornia, Berkeley. Currently, he is the Guest Faculty of the Dept. of CSE at GIMT Guwahati.

Tridib Roy is the Lab Technician in Applied Electronics, Assam. He has worked in different electronic companies and has rich experience in handling various types of electronic equipments.

Network Analysis laboratory of the Department. The PCB consists of the rectifier circuit, PWM controlling circuit and P-Controller circuit.

The following procedure has been followed for fabrication of the PCB:

Step 1: The layout of the PCB has been prepared by using the EXPRESS PCB software.

Step 2: The layout is printed on a transparent sheet.

Step 3: The image is transferred from the transparent sheet to a silk screen.

Step 4: The image is next transferred from the silk screen to the copper clade board.

Step 5: The copper plate is next treated in a Ferric Chloride ($FeCl_3$) solution to obtain the final PCB.

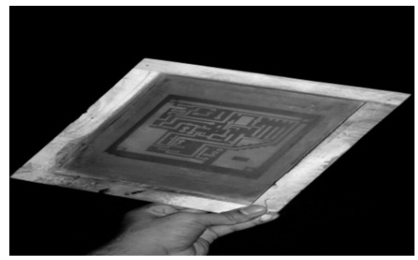

Fig.A1: Image of the PCB on the silk screen

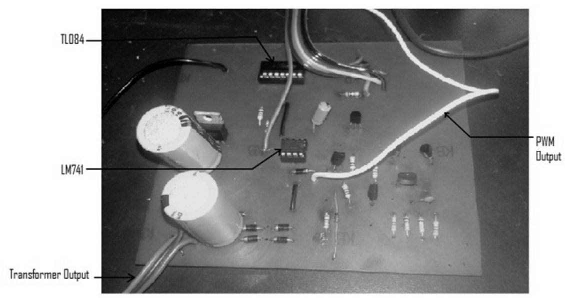

Fig.A2: Front view of the assembled PCB

A.2. OVERALL CIRCUITRY OF THE PROJECT

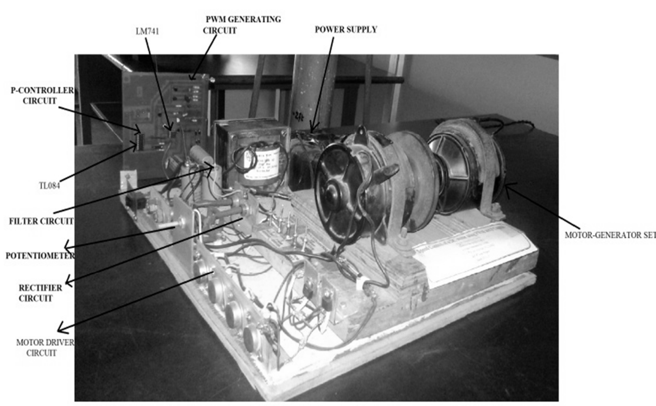

Fig.A3: Showing the overall hardware and circuitry of the project

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