

## **DESIGN OF A PC-BASED DC MOTOR SPEED CONTROLLER**

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**ABSTRACT:** - This paper is concerned with the interfacing process between a personal computer and a permanent magnet DC motor. A practical interface circuit has been designed and implemented in order to control the speed of a permanent-magnet DC motor using a C++ control program.

The proposed circuit technique involves receiving the digital signals from the parallel port of the PC and providing them to a transistor driver circuit through an IC buffer. The transistors in the driver circuit are used to increase the current level of the incoming signals into an adequate value in order to drive control relays that are connected to the motor circuit. The control relays are utilized, in turn, to split or insert certain number of resistors connected in series with the motor circuit and thus changing its speed according to a prescribed digital sequence generated by the computer program. The circuit was implemented and tested successfully at the laboratory.

**Keywords:** PMDC Motor, Interface Circuit, DC Motor Speed Control, PC Parallel Port.

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### **1. INTRODUCTION**

Permanent-magnet brushed DC (PMDC) motors are very popular in fractional horsepower applications due to their low cost, predictable characteristics, stable operation, and ease of speed control. Since there is no field winding included in the stator poles of these motors, the flux of the poles is approximately constant and the only method for adjusting the motor speed is through the applied voltage. This can be carried out either by directly changing the motor supply voltage, or by varying the average value of the applied voltage by means of the pulse width modulation (PWM) method<sup>[1]</sup>.

The control process of the motor speed can be carried out via personal computers (PCs) with the aid of a program stored in the computer memory. In order to implement the interfacing process between the PMDC motor and the PC, it is required to design an electronic circuit to connect the DC motor into one of the PC's ports. This circuit is utilized to control the signals transmitted from the PC port. In addition to that, a specific computer program should be written to direct the control process automatically. The most widely used PC ports for interfacing is the parallel port (LPT port), communication ports (COM Ports), and the USB ports<sup>[2]</sup>.

In this paper, an interface electronic circuit has been designed to connect a permanent magnet small DC motor to the PC's parallel port in order to control its speed, in three levels, using a computer program written in C++ programming language.

### **2. RELATED WORK**

There are various methods, techniques, and algorithms for controlling the speed of DC motors via the personal computer. Each technique depends on the specific application and the required task.

An interesting method for interfacing the PMDC motor with the parallel port of the PC is performed through a circuit consisting of a buffer, digital to analog converter, current to voltage converter, voltage follower, and a power transistor driver [3]. In this technique, a 16 different voltage levels and motor speeds can be obtained by means of the LabVIEW software.

Another method for interfacing the PMDC motor with the parallel port of the PC utilizes an interface circuit constituted from a 3-8 decoder, resistor network, timer circuit, and a transistor driver [4]. A control program is written in C-language to increase or decrease the speed of the motor with a total of 8 possible speeds. The resistor network in this circuit is considered as part of the timing components of the 555 timer.

The PWM modulation technique is also widely used in controlling the average value of the voltage supplied to the DC motor. A method uses this technique by controlling a number of mechanical relays for changing the timing resistors of an astable multivibrator is also adopted [5]. The control program in this technique is written in C++ language and generates three different speed levels.

Closed loop control methods can also be used to maintain the speed of the DC motor against variations in load torque. When the torque of the DC motor increases, it draws additional current and a comparator circuit senses this increase in current and signals the parallel port of the PC. A program written in Visual Basic is used to increase the applied voltage of the motor via control signals from the parallel port so as to keep the motor speed constant [6].

Microprocessor-based boards are also used to control the speed, position, and direction of DC motors in closed loop systems [7]. This technique uses an optical encoder to monitor the speed of the DC motor in addition to digital to analog converter and driver modules.

The serial port (COM port) of the PC is also widely used in the control process of DC motors with the aid of a microcontroller [8-12]. The PC is interfaced with the microcontroller through the RS232 port so that a graphical user interface (GUI) software environment can be developed.

Finally, fuzzy logic controllers [13-14] and neural networks [15] are used for efficient and stabilized speed control of DC motors.

### 3. CHARACTERISTICS OF PMDC MOTORS

Permanent magnet DC motors are simple in construction, have low cost and compact size, and possess linear speed-torque characteristic. PMDC motors are extensively used where small DC motors are required. They are usually used in fractional and sub-fractional kW applications such as starters of automobiles, toys, wipers, washers, hot blowers, air conditioners, computer disc drives and in many more applications [16].

The basic principle of operation for the PMDC motor is similar to that of the general DC motor. In this motor, the stator field is produced by a permanent magnet. When a current carrying conductor is placed inside a magnetic field, a mechanical force will be experienced by the conductor and the direction of this force is given by Fleming's left hand rule. In the permanent magnet DC motor, the armature (or rotor) is placed inside the magnetic field of the permanent magnet stator and rotates in the direction of the generated force. Each conductor of the armature experiences the mechanical force  $F = B.I.L$ , where  $B$  is the flux density,  $I$  is the current flowing through that conductor and  $L$  is length of the conductor. The combination of these forces produces a torque, which tends to rotate the armature [17]. The construction of the PMDC motor is depicted in Figure (1).

Figure (2) presents the equivalent circuit of the PMDC motor [1]. As shown from this circuit, there is no field winding since the field of the stator poles is constant. Accordingly, the supply voltage is equal to the back induced e.m.f on the armature  $E_b$  plus the voltage drop on armature winding's resistance:

$$V = E_b + I_a \cdot R_a \quad (1)$$

Where  $I_a$  is the armature current which equals the supply current and  $R_a$  is the total resistance of the armature winding. Since the flux of the permanent-magnet stator is constant, the speed of the motor changes solely with the back induced armature e.m.f.:

$$N = K_v \cdot E_b \quad (2)$$

Where  $N$  is the motor speed, and  $K_v$  is a constant. Substituting for  $E_b$  from equation (1) leads to:

$$N = K_v \cdot (V - I_a \cdot R_a) \quad (3)$$

Therefore, the speed of the motor is dependent on the supply voltage. So, the speed of the motor can be adjusted by varying the supply voltage.

These types of motors have linear speed-torque characteristics as shown in Figure (3) with the capability of producing high torque at low speed.

#### 4. METHODS OF PMDC MOTOR SPEED CONTROL

There are, in general, two techniques used for PMDC motor speed control. Since the stator magnetic field of the PMDC motor is constant, field control method is not used with these types of motors.

##### 4.1 Input Voltage Control Method

It is well-known that the speed of DC motors is dependent on the supply input voltage. The speed-voltage characteristic for the PMDC motor is approximately linear as shown in Figure (4), and can be estimated from equation (3). When changing the value of the applied voltage, the motor speed can thereby be varied. This method is considered as the simplest way for speed control and is adopted throughout the work in this paper.

##### 4.2 Pulse Width Modulation Method

This method is very efficient for varying the speed of PMDC motors. In this technique, the average value of the motor applied voltage is changed by applying a pulse width modulated waveform to the motor as shown in Figure (5). The width of applied pulses can be adjusted from the control program <sup>[5]</sup>.

As can be seen from Figure (5), the average value of the applied voltage to the motor is related to the supply voltage by:

$$V_{av} = D \cdot V_{max} \quad (4)$$

Where  $V_{max}$  is the supply voltage, and  $D$  is the duty cycle which equals to  $\tau/T$ . As shown in Figure (5),  $\tau$  represents the pulse width and  $T$  is the pulse interval.

#### 5. THE PC PARALLEL PORT

The interface circuit is to be connected into the PC's parallel port. The PC parallel port (LPT1) contains 8 data lines (D<sub>0</sub>-D<sub>7</sub>), 5 status lines (S<sub>3</sub>-S<sub>7</sub>), and 4 bi-directional control lines (C<sub>0</sub>-C<sub>3</sub>) as shown in Figure (6). Other pins are grounded <sup>[18]</sup>. The data lines of the parallel port send the necessary control digital signals for motor operation. In this design, only three data lines (D<sub>0</sub>-D<sub>2</sub>) of the parallel port have been used.

#### 6. DESIGN OF THE CONTROL CIRCUIT

The design idea of the control circuit depends on inserting external resistors in series with the motor and adjusting the net supplied voltage electronically by means of relays connected across each resistor <sup>[19]</sup>. Figure (7) presents the equivalent circuit of the PMDC motor with the addition of two equal series resistors  $R_1$  and  $R_2$  controlled by two switches,  $S_1$  and  $S_2$  respectively.

When switches  $S_1$  and  $S_2$  in Figure (7) are open, both  $R_1$  and  $R_2$  are inserted in the motor circuit reducing its speed to:

$$N_1 = K_v \cdot (V - I_a \cdot (R_1 + R_2 + R_a)) \quad (5)$$

When  $S_1$  is closed while  $S_2$  remains open, resistor  $R_1$  is omitted from the motor circuit and the speed becomes:

$$N_2 = K_v \cdot (V - I_a \cdot (R_2 + R_a)) \quad (6)$$

In the third case, when  $S_1$  and  $S_2$  are closed, both  $R_1$  and  $R_2$  are omitted from the circuit and the motor will run at its full speed:

$$N_3 = K_v \cdot (V - I_a \cdot R_a) \quad (7)$$

It is obvious that  $N_3 > N_2 > N_1$ .

The circuit idea has been implemented by using two relays to replace switches  $S_1$  and  $S_2$  of Figure (7), with additional third relay in series with the motor for ON/OFF operation. Figure (8) illustrates the block diagram of the proposed control circuit. The buffer is used to isolate the parallel port of the PC from the control circuit, and the transistors are used to increase the currents necessary to drive the coils of the three relays. The contact switches of the relays are connected with the motor circuit.

Figure (9) presents the schematic diagram of the proposed circuit. The selected motor is the EG-530AD-9F of Mubachi Motor, Inc. This is a 12V PMDC motor with a maximum speed of 2400 r.p.m at no-load. As shown in Figure (9), the DC motor is connected to the PC through an interface circuit consisting of a 4-bit binary counter IC 74LS193, three current limiting resistors, three NPN transistors, and three 5V relays. The PMDC motor is connected to the 12V DC supply via two 100Ω resistors. The counter inputs A, B, and C are connected to three data pins of LPT1 (D<sub>0</sub>-D<sub>2</sub>) using a suitable cable. This IC is used as a buffer to strengthen the weak signals outgoing from the PC parallel port. Any other IC buffer like 74LS244 can be used for such task. The counter outputs Q<sub>A</sub>, Q<sub>B</sub>, and Q<sub>C</sub> are connected to three NPN transistors (like 2N2222) through current limiting resistors. These transistors are used to drive three relays by increasing the current level of the PC generated signals. The motor circuit consists of the two resistors, R<sub>1</sub> and R<sub>2</sub>, connected in series with the motor. The contacts of Relays 2 and 3 are connected across these resistors. Each relay can insert or suppress the required resistor in the motor circuit, thereby reducing or increasing the net voltage applied to the motor terminals and hence controlling its speed according to equations (5), (6), and (7) above. Relay 1, on the other hand, is connected to turn on or turn off the DC motor. The ON/OFF operation of the control relays depends on the digital sequence generated by the computer program.

Table (1) shows the four different ON/OFF states of the circuit with the corresponding speed for each case. Other states are not used by this circuit. For each running state, the motor speed has been measured with the aid of a digital tachometer together with the armature voltage and current. Table (2) presents the measured net applied voltage across the armature of the motor, the drawn armature current and motor speed for the three cases. These results show an approximate linear characteristic between the applied voltage and the measured speed as illustrated in Figure 10.

The circuit has been implemented practically on a breadboard, and connected with LPT1 via a parallel cable. Figure (11) depicts the implemented circuit.

## 7. THE COMPUTER PROGRAM

As stated previously, the control program has been written using the programming language C++. When executing the computer program, a starting screen will appear. Pressing any key will move the user into another screen containing a selection menu. From this menu the user can select the appropriate speed, or to exit from the program. After running the motor

with the selected speed, it can be stopped by pressing any key from the keyboard through the use of the function *kbhit()*. In this case, the selection menu will appear again. An integer variable named as *speed* is used to store the selection case of the user. Based on the value of this variable, the necessary digital sequence is generated in hexadecimal form and stored at another integer variable called *sequence*. The function *outportb()* places the suitable digital signal at the data lines of the parallel port which is identified through its address. Figure (12) presents a simplified flow chart for the program.

## 8. CONCLUSION

In this paper, an interface electronic circuit was designed and implemented to control the speed of a small DC motor from the computer. When compared with other adopted techniques, this controller has the features of simplicity, low cost, and the possibility of extension and modification. After testing the circuit practically, it was noticed that the current capability of the driving transistors is very important for relays operation. A general-purpose current driver IC, like ULN2003, can be used as a replacement of the transistors. On the other hand, opto-isolator ICs can also be used for a similar task. These ICs contain LEDs and photo transistors, and can provide electrical isolation between relay coils and the remaining parts of the interface circuit. Solid state relays can replace the mechanical relays to reduce the generated noise and for fast switching. The number of obtainable motor speeds can be increased by increasing the number of resistors connected in series with the motor circuit. This will however increase the complexity of the circuit because additional relays and transistors are needed in this case.

The designed speed controller can find a wide range of applications including the motion control of robotic and industrial applications.

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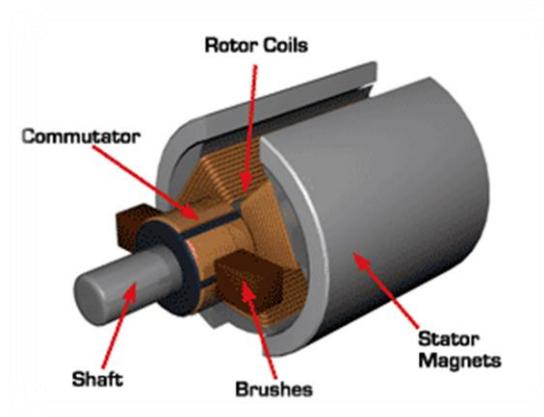
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**Table (1):** The Four States of the Control Circuit with the Equivalent Digital Sequences

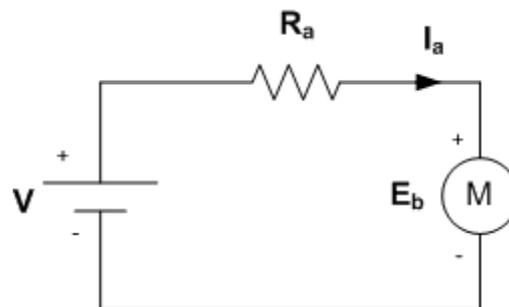
State Number	Q <sub>3</sub>	Q <sub>2</sub>	Q <sub>1</sub>	Equivalent Digital Sequence	Motor Speed
1	ON	ON	ON	111	Maximum
2	OFF	ON	ON	011	Medium
3	OFF	OFF	ON	001	Minimum
4	OFF	OFF	OFF	000	Stop

**Table (2):** Measured Speed with the Applied Net Voltage

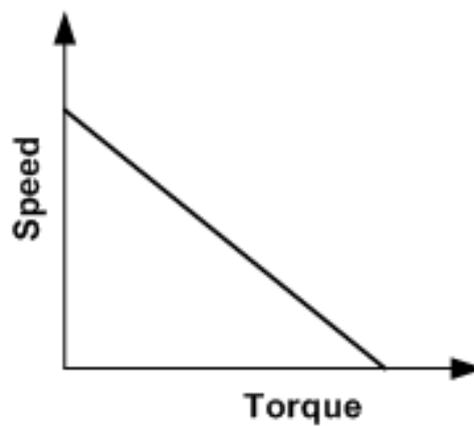
Applied Voltage (V)	Motor Current (mA)	Motor Speed (r.p.m)
12	210	2342
4.2	85	806
2.5	51	485



**Figure (1):** Construction of the PMDC Motor



**Figure (2):** Equivalent Circuit of the PMDC Motor



**Figure (3):** Speed-Torque Characteristic for the PMDC Motor

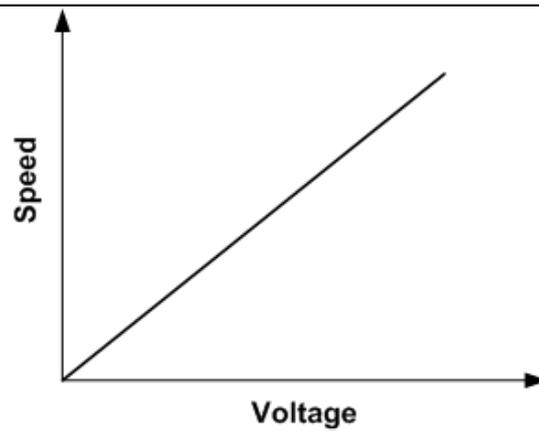


Figure (4): Speed-Voltage Characteristic for the PMDC Motor

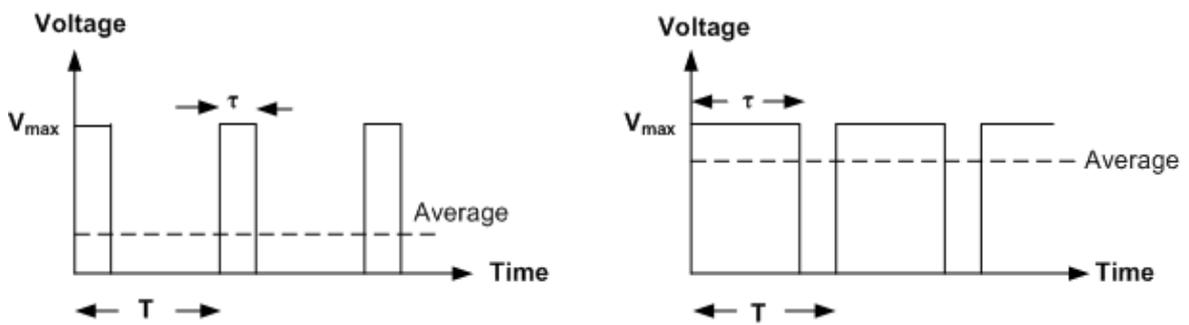


Figure (5): The Applied Motor Voltage using the PWM Method

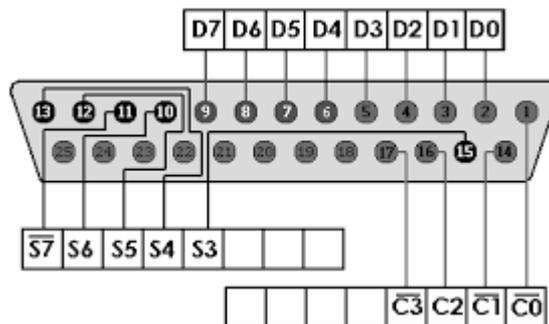


Figure (6): The DB-25 PC Parallel Port

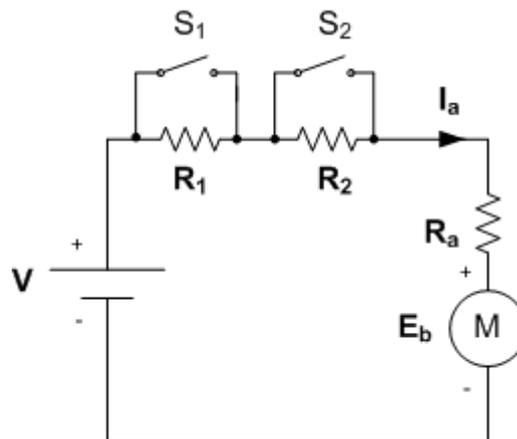


Figure (7): Equivalent Circuit of the PMDC Motor with Two External Resistors

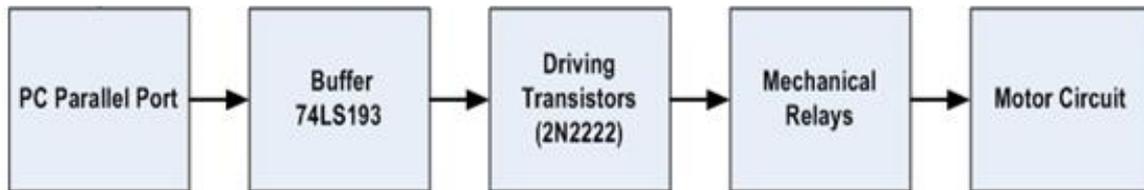


Figure (8): The Block Diagram of the Proposed Control Circuit

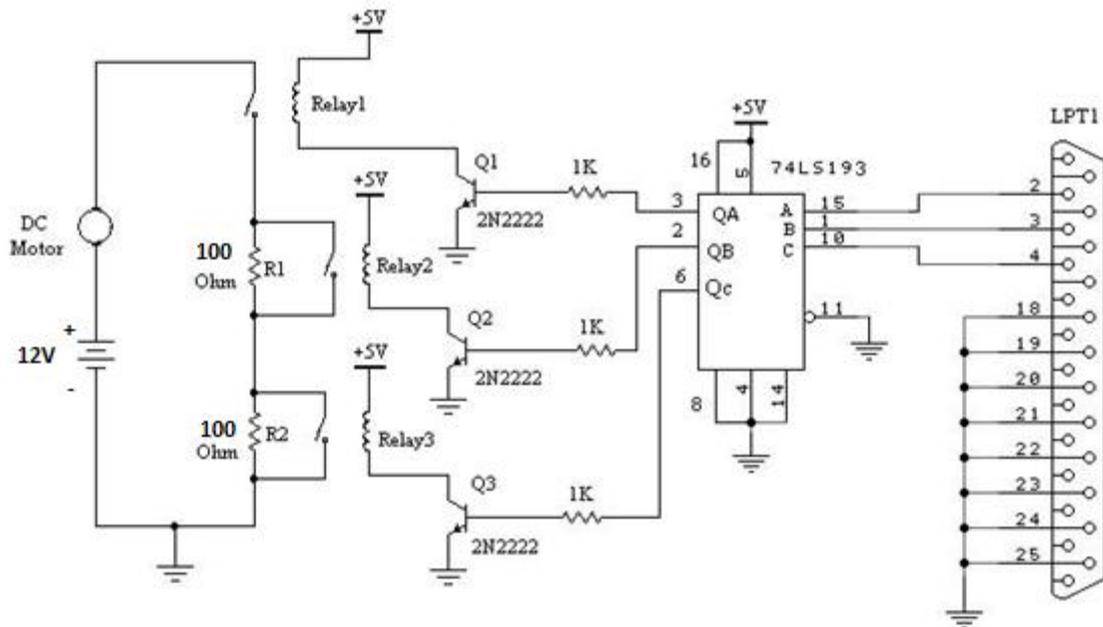


Figure (9): The Schematic Diagram of the Designed Interface Circuit

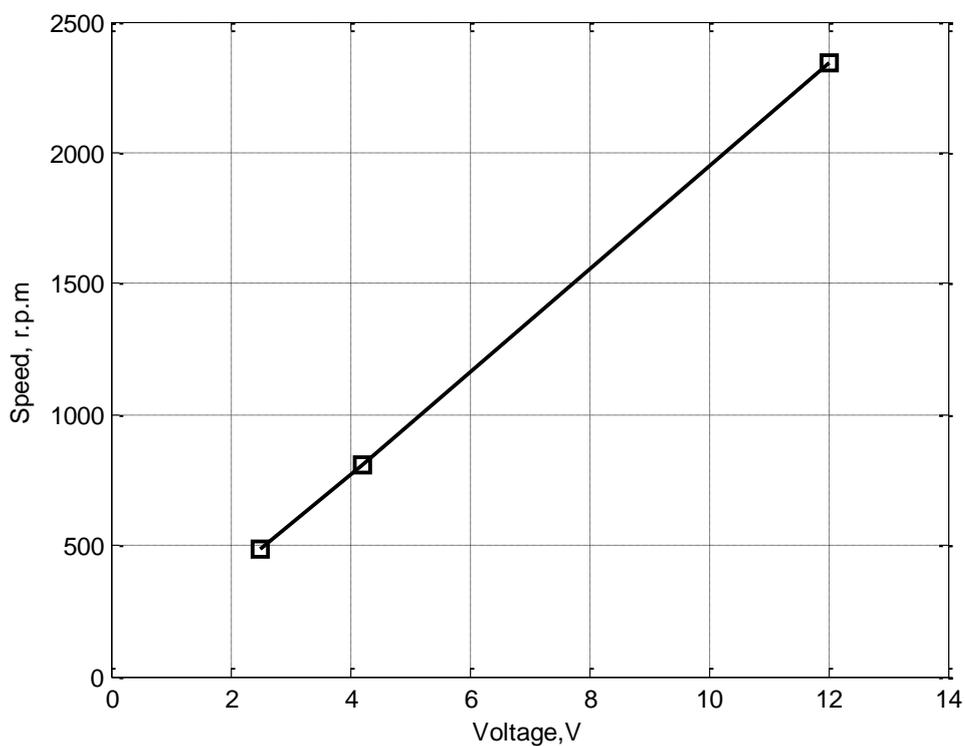


Figure (10): Measured Motor Speed versus Net Applied Voltage



Figure (11): A Picture for the Implemented Interface Circuit

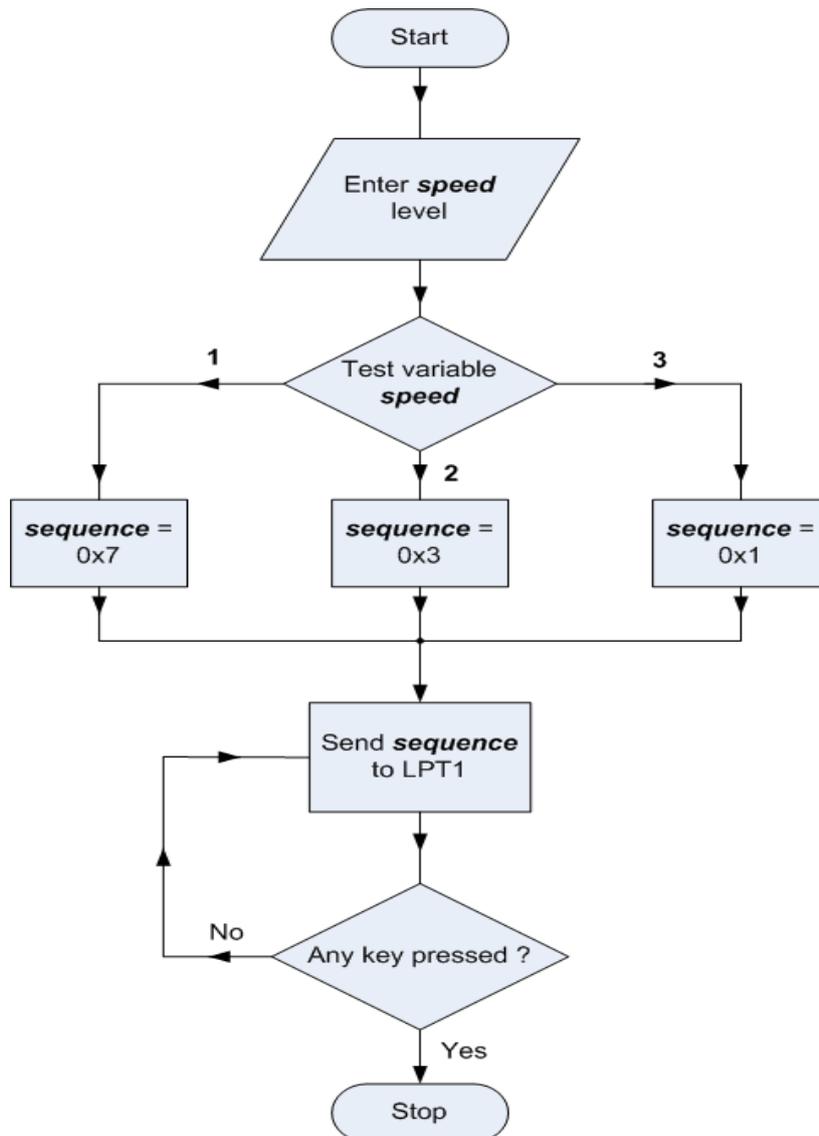


Figure (12): Flow Chart of the C++ Control Program

## تصميم دائرة تحكم بسرعة محرك تيار مستمر بواسطة الحاسوب

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### الخلاصة:

يختص هذا البحث بعملية الترابط البيني بين الحاسوب ومحرك التيار المستمر ذو المغناطيس الدائمي. حيث تم تصميم وتنفيذ دائرة ترابط بيني للتحكم بسرعة محرك تيار مستمر ذو مغناطيس دائمي باستخدام برنامج مكتوب بلغة ++C. تتضمن التقنية المقترحة في تصميم الدائرة استلام الإشارات الرقمية من المأخذ المتوازي للحاسوب وتزويدها إلى دائرة تشغيل المحرك عن طريق دائرة عازل. يتم تكبير هذه الإشارات بواسطة ترانزستورات لتشغيل مرحلات ميكانيكية مربوطة مع دائرة المحرك. حيث تستخدم هذه المرحلات بدورها في إدخال أو فصل مقاومات معينة مربوطة على التوالي مع دائرة المحرك لتغيير سرعته وحسب التتابع الرقمي الذي يتم توليده بواسطة برنامج التحكم. وقد تم تنفيذ واختبار الدائرة بنجاح مختبرياً.