

Speed Control of BLDC Motor Using DSPIC30F4011 Processor

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Abstract- Traditionally inexpensive analog components are used for the design purposes of Motor drives. The weakness of analog systems is their susceptibility to temperature variations and component aging. Another drawback is the difficulty of upgrading the systems. Digital control structures eliminate drifts and, by using a programmable controller, the upgrades can be easily accomplished by software. The high performance of digital signal controllers allows them to perform high-resolution control and minimize control loop delays. These efficient controls make it possible to reduce torque ripples, harmonics and improve dynamic behavior in all speed ranges. The motor design is optimized due to lower vibrations and lower power losses such as harmonic losses in the rotor [2].

Moreover designers have recognized the opportunity to redesign existing systems to use advanced algorithms. For improved efficiency and torque performance, brushless DC (BLDC) motors require a phase advance circuit. Because of the problem of controlled phase advance in BLDC motor we need digital control methodology instead of conventional analog control for the speed control of PMBLDCM. By applying direct digital control it will substantially increase the effective speed range and facilitates a constant power profile. Here the DSP controller is designed to meet the needs of control-based applications of Brushless DC Motor. BLDC motors are becoming popular in Aerospace applications due to better speed v/s torque characteristics, higher efficiency, and high power to frame size, silent operation and reliability.

Index Terms- BLDC motor, DSPIC30F4011, closed loop system.

I. INTRODUCTION

Speed Control of BLDC motor using DSP controller requires more hardware, and with the availability of DSP controller with versatile features motivated to develop a cost effective and reliable control with variable speed range. The proposed hardware and the program are found to be efficient and the results are promising.

II. BLOCK DIAGRAM OF SYSTEM

The proposed control for BLDC motor control using DSP controllers of MICROCHIP with device name DSPIC30F4011. The system consists of following blocks are 1 ϕ

Bridge rectifier, BLDC motor, hall sensor, signal conditioner, DSP- DSPIC30F4011, opto-coupler, MOSFET driver, keypad.

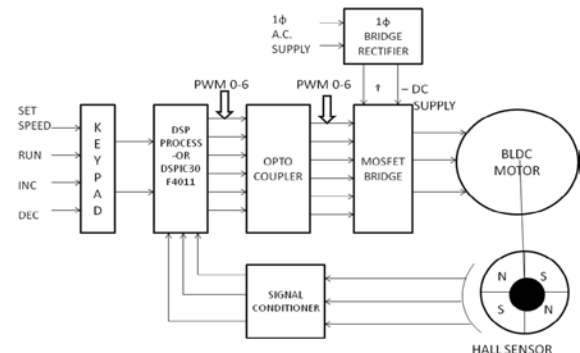


Fig 1 Block diagram of speed control of BLDC motor using DSP

The system takes 1 ϕ , 230v supply; this supply is converted into 24V, DC supply through bridge rectifier. The 24V, DC supply gives to MOSFET Bridge. MOSFET bridge consists of six MOSFET (IRF640) connected in bridge format. According to the sequence these MOSFETs are Switch ON and OFF.

Rotor position senses by hall sensor. The output of hall sensor is amplifying through signal conditioner, this signal given to DSP processor. DSP processor takes input from keypad if we want to change speed and from signal conditioner. In DSP processor compare current speed with reference speed and according to that gives output which control MOSFET Bridge. In MOSFET Bridge switching transistors and flow current through two windings of stator winding and the other winding is inactive and hence commutation is done electronically and hence rotor starts rotating. This is closed loop system.

The base drive to the MOSFETs in the Inverter circuit is given by the DSPIC30F4011 controller through driver (IR2101). The Hall signals from the motor are fed as inputs to the DSPIC30F4011 device and based on the Hall position and the direction of rotation of the motor specified by the manufacturer the corresponding gate drive is made active by the microcontroller and fed to the stator of the BLDC motor. The commutation sequence for rotating the motor in clock wise direction when viewed from the non driving end is given in the Table 1.

Hall Sensor Code			Phase Sequence	Driver Transistor Activating sequence		Phase Current		
A	B	C				A	B	C
0	0	1	1	Q1 (PWM1)	Q6 (PWM6)	+D	OF	-D
0	0	0	2	Q1 (PWM1)	Q4 (PWM4)	+D	-DC	OF
1	0	0	3	Q5 (PWM5)	Q4 (PWM4)	OFF	-DC	+D
1	1	0	4	Q5 (PWM5)	Q2 (PWM2)	-D	OF	+D
1	1	1	5	Q3 (PWM3)	Q2 (PWM2)	-D	+DC	OF
0	1	1	6	Q3 (PWM3)	Q4 (PWM4)	OFF	+DC	-D

Table 1: Sequence for rotating motor in clockwise direction

Based on the Hall sensor input to the DSP controller, the corresponding transistors are made active and current flows through two windings and the other winding is inactive and hence commutation is done electronically with the use of a DSP controller.[4]

Thus by properly exciting the corresponding winding based on the hall signal, the motor is commutated and is made to run at the desired speed. Initially irrespective of the rotor position, the windings are excited in the given sequence and once the motor starts rotating, rotor position is sensed by the Hall sensor and then the motor is excited based on the Hall signal and according to the direction of rotation of the motor.

The speed can be controlled in a closed loop by measuring the actual speed of the motor. If the speed is greater than the desired rated speed, then all the transistors are turned off for a short duration and then again excited based on the Hall position and accordingly speed can be adjusted to get constant speed. The demand of PMSBLDC motors in high power servo applications is increased because of its High efficiency due to reduced losses, low maintenance and low rotor inertia. Also the invention of modern solid state devices like MOSFET, IGBT and high energy rare earth Permanent Magnets have widely enhanced the applications of PMSBLDC motors in variable speed drives.

As the opto-coupler (HPCL817) provides the electrical isolation between circuits, it is called opto-isolator. In KEYPAD SET SPEED key sets the speed of motor and direction of motor clockwise/anticlockwise. RUN/STOP key runs the motor and stop the running motor. INC key increments the set speed by 100 rpm. DEC key decrements the set speed by 100rpm

A. BLDC Motor

BLDC motors are basically inside-out DC motors. In a DC motor the stator is a permanent magnet. The rotor has the windings, which are excited with a current. The current in the rotor is reversed to create a rotating or moving electric field by means of a split commutator and brushes. On the other hand, in a BLDC motor the windings are on the stator and the rotor is a permanent magnet. Hence the term inside-out DC motor.

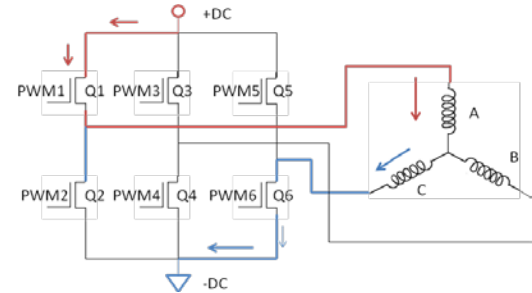


Fig (a)

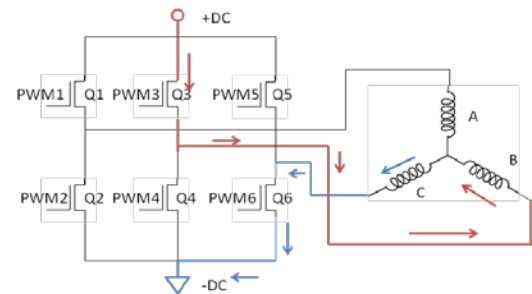


Fig (b)

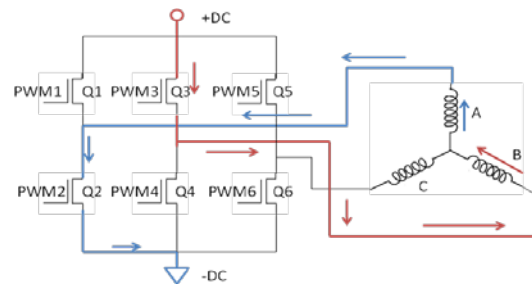


Fig (c)

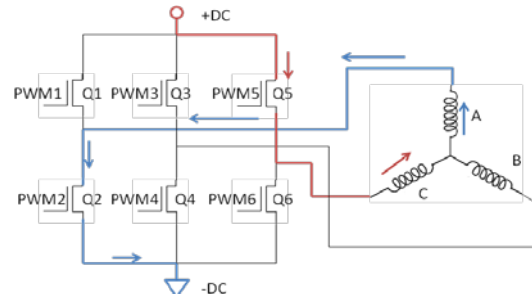


Fig (d)

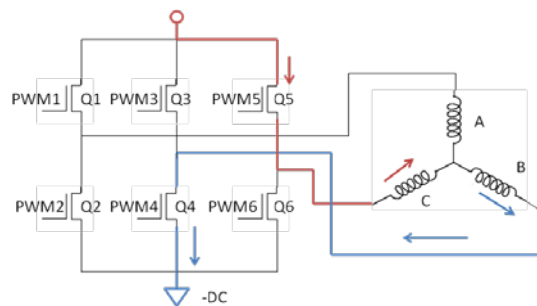


Fig (e)

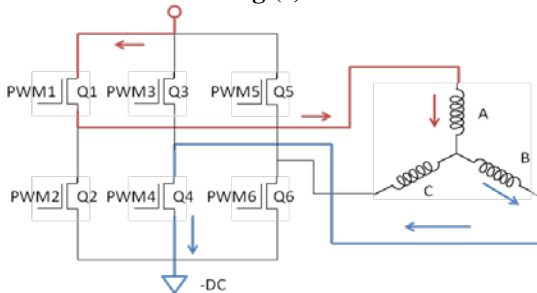


Fig (f)

Figure 2(a-f): Winding energizing sequence with respect to the hall sensor

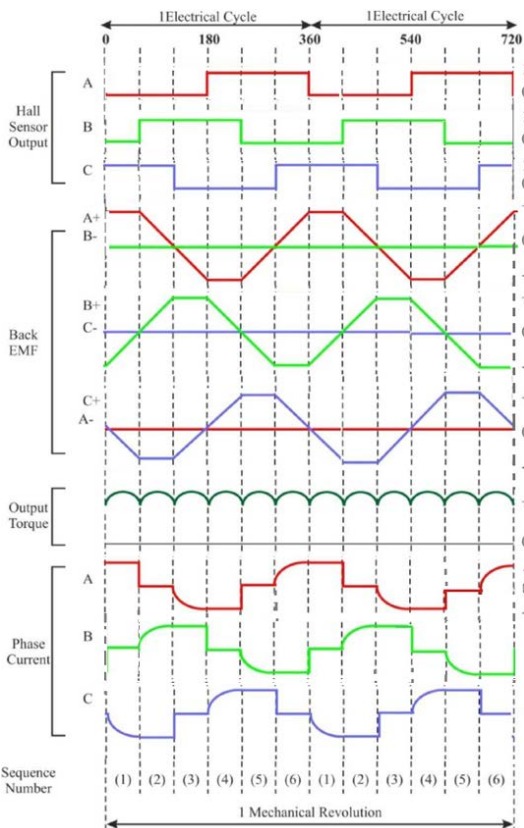


Fig 3 hall sensor signal, back emf, and phase current

To make the rotor turn, there must be a rotating electric field. Typically a three-phase BLDC motor has three stator phases that are excited two at a time to create a rotating electric field (fig 2(a-

f)). This method is fairly easy to implement, but to prevent the permanent magnet rotor from getting locked with the stator; the excitation on the stator must be sequenced in a specific manner while knowing the exact position of the rotor magnets. Position information can be gotten by either a shaft encoder or, more often, by Hall Effect sensors that detect the rotor magnet position. For a typical three phase, sensored BLDC motor there are six distinct regions or sectors in which two specific windings are excited. These are as shown in Figure 3.

B. dsp processor

The dsPIC30F4011 is a 40-pin 16-bit MCU specifically designed for embedded motor control applications. AC Induction Motors (ACIM), Brushless DC (BLDC) and DC are some typical motor types for which the dsPIC30F4011 has been specifically designed. Some of the key features on the dsPIC30F4011 are[9]:

- 6 independent or 3 complementary pairs of dedicated Motor control PWM outputs.
- 9 input, 500 kbps, ADC with up to 4 simultaneous sampling capabilities.
- Multiple serial communications: UART, I²C™ AND SPI
- DSP engine for fast response in control loops.

In this application we discuss how the dsPIC30F4011 used to control a sensored BLDC motor. Hall sensor is connected to dsPIC30F4011. By reading the Hall Effect sensors, a 3-bit code can be obtained with values ranging from 1 to 6. Each code value represents a sector on which the rotor is presently located. Each code value, therefore, gives us information on which windings need to be excited. Thus a simple lookup table can be used by the program to determine which two specific windings to excite and, thus, turn the rotor.

i) PWM CONTROL SYSTEM

The MCPWM has a dedicated 16-bit PTMR time base register. This timer is incremented by a user defined clock tick, which can be as low as TCY. The user also decides the period required for the PWM by selecting a value and loading it in the PTPER registers. The PTMR is compared to the PTPER value at every TCY. When there is a match, a new period is started. The duty cycle is controlled similarly, by loading a value in the three duty cycle registers [6].

Unlike the period compare, the value in the duty cycle register is compared at every TCY/2 interval (i.e., twice as fast as the period compare). If there is a match between the PTMR value and the PDCx value, then the corresponding duty cycle output is driven low or high as dictated by the PWM mode selected. The three outputs from the duty cycle compare are channeled to a complementary output pair where one output is high while the other is low, and vice versa. The two outputs can also be configured as independent outputs. When driven as complementary outputs, a dead time can be inserted between the time the high level goes low and the low level goes high.

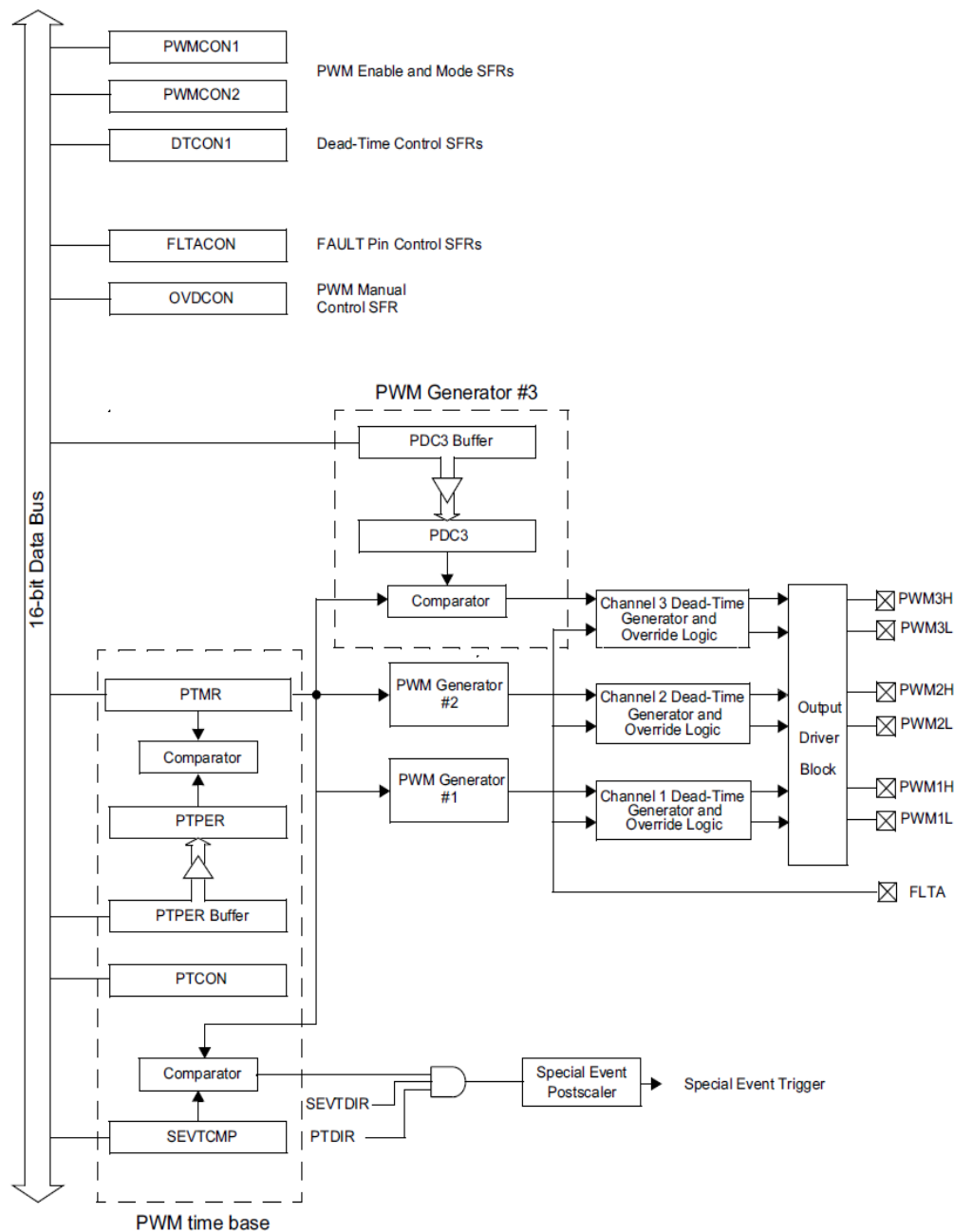


Fig 4 PWM module block diagram.

This dead time is hardware configured and has a minimum value of TCY . Dead time insertion prevents inadvertent shoot-through in output drivers. There are several modes in which the MCPWM module can be configured. Edge aligned output is probably the most common mode. The operation of an edge aligned PWM. At the start of the period, the outputs are all driven high. As the PTMR increments, a match with the duty cycle registers causes the corresponding duty cycle output to go low thereby marking the end of the duty cycle. The PTMR match with PTPER register caused a new period to start and all outputs go high to start a whole new cycle.

The important feature of the MCPWM used in this application is the Override Control. The Override Control is the last stage of the MCPWM module. It allows the user to directly

write to the OVDCON register and control the output pins. The OVDCON register has two 6 bit fields in it. Each of the six bit fields corresponds to an output pin. The high byte portion of the OVDCON register, determines if the corresponding output pin is driven by a PWM signal (when set to 1) or (when set to 0) driven Active/Inactive by the corresponding bit field in the low byte portion of the OVDCON register. This feature allows the user to have PWM signals available, but not driving, at all output stages of the pins.

For BLDC motors, the same value is written to all PDCx registers. Depending on the value in the OVDCON register, the user can select which pin gets the PWM signal and which pin is driven active or inactive. When controlling the BLDC sensed motor it is necessary to excite two winding pairs depending on

where the rotor is located and dictated by the value of the hall sensors. In the CN Interrupt service routine the hall sensors are read and then the value of the sensors is used as an offset in a lookup table which corresponds to the value which will be loaded

in the OVDCON register. Table 2 and Figure 5 show how different values are loaded in the OVDCON register depending on which sector the rotor is located in and thereby which windings need to be excited.

BIT 15	BIT 14	BIT 13	BIT 12	BIT 11	BIT 10	BIT 9	BIT 8
POVD4H	POVD4L	POVD3H	POVD3L	POVD2H	POVD2L	POVD1L	POVD1L

BIT 7	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0
POUT4H	POUT4L	POUT3H	POUT3L	POUT2H	POUT2L	POUT1H	POUT1L

POVD								POUT							
-	-	3H	3L	2H	2L	1H	1L	-	-	3H	3L	2H	2L	1H	1L
0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0
0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0
0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0
0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0

Table 2 OVDCON register values

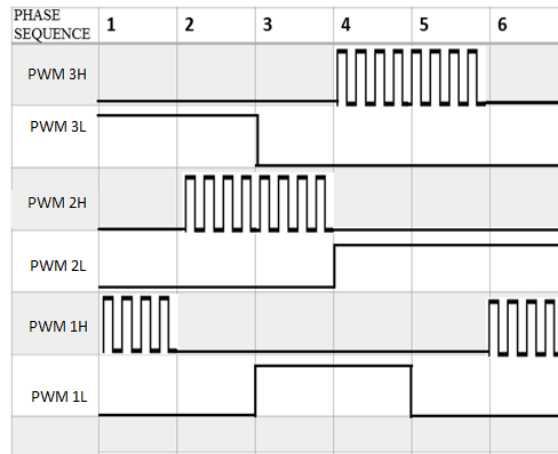


Fig 5: PWM waveform

iii) CHANGE NOTIFICATION INPUTS

The Hall Effect sensors are connected to the Change Notification Pin. The CN interrupt is enabled. As the rotor spins, the position of the rotor magnet changes and the rotor enters a different sector. Each new position is signaled by a CN Interrupt. In the CN Interrupt routine, this is shown CN Interrupt Flow, the Hall Effect sensors are read and based on the value, and a table lookup value is got and written to the OVDCON register. This action will insure that the correct windings are excited in the right sector and the motor will continue to spin.

ii) cLOSED loop control

As system make SWITCH ON .It initialize MCPWM, ADC, Timers & Ports. System reads hall sensor signals and read last set speed. Set speed stored in the period registers PDC1, PDC2, and PDC3. As START Key is pressed. According to hall sensor signal read lookup table, Load the OVDCON register and ON the PWM signals and motor starts to rotate. As STOP key is pressed.

DSP processor disables PWM signals. This closed loop system explains in following flowchart.

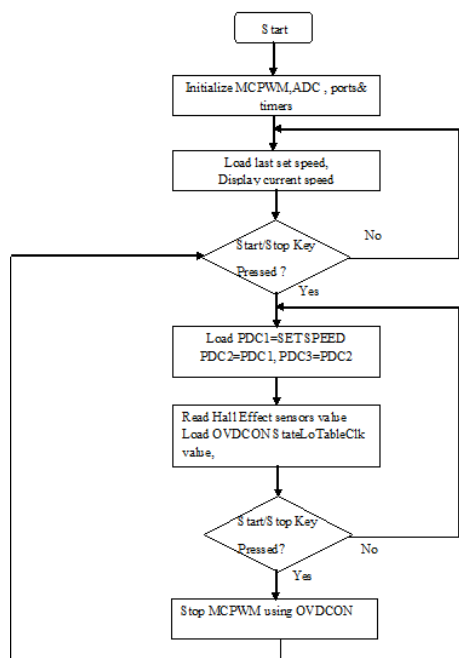


Fig 6 Flow chart of closed loop control.

III. RESULTS

These PWM signals are shown in fig 7(a), 7(b), 7(c) for speed range 400rpm, 600rpm & 1000rpm respectively. From waveforms it is seen that as speed increased time period of pulses decreased. The phase to phase voltage signals are shown in fig 8(a), 8(b) & 8(c) for speed range 400rpm, 600rpm & 1000rpm. From waveform it is seen that as speed increased the number of pulses are increased and time period of pulses decreased.



Fig 7(a) Waveform of PWM at speed 400 rpm.



Fig 7(b) Waveform of PWM at speed 600 rpm.



Fig 7(c) Waveform of PWM at speed 1000 rpm.



Fig 8(a) Waveform of phase to phase voltage (red-black) at speed 400 rpm.



Fig 8(b) Waveform of phase to phase voltage (red-black) at speed 600 rpm.

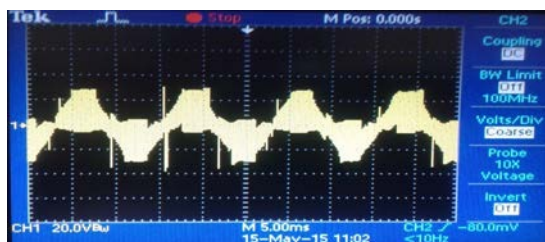


Fig 8(c) Waveform of phase to phase voltage (red-black) at speed 1000 rpm.

IV. CONCLUSION

1. The results obtained outlined the success of the prototype circuit for its intended application. System runs successfully. When change set speed, motor takes 2.77 sec to rotate. The transient response of system is 2.77sec, after motor rotating at set speed, and then motor comes to steady state response after 1.57 sec.
2. LCD is displaying the approximate current speed of the motor. The motor rotated at given speed range, and rotated in both directions clockwise and anticlockwise. The rotor speed can be regulated to operate within $\pm 5\%$ speed error band
3. The speed control parameter is duty cycle of PWM signal. It is seen that as duty cycle is changed speed of motor is changing. Speed is directly proportional to frequency.

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