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CLOSED LOOP IMPLEMENTATION OF SPEED CONTROL OF A BRUSHED PMDC MOTOR OF AN X-RAY SYSTEM AND VALIDATION OF RELIABILITY OF THE CONTROLLER

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Abstract— **The advancement of Power Electronics has brought progress in the control and conversion of electric power. Power electronic systems have good efficiency, flexibility of control and high reliability. Motor drives application is one classic application. Motor drives has the advantage of adjustable characteristic like torque-speed, speed-current by using control technique. With DC motor, precise control of speed that is required in many industries can be achieved.**

An efficient speed controller for a Permanent Magnet Direct Current (PMDC) motor for an X-ray system using PIC18F4620 is presented. An H-bridge feeds the PMDC motor. The PIC (Peripheral Interface Controller) generates the necessary Pulse Width Modulated (PWM) gate pulses for the H-bridge switching devices for driving the PMDC motor. By controlling the duty cycle of the PWM gate signals, the motor armature voltage is controlled and the motor speed is adjusted. Reliability of the controller is demonstrated through Accelerated Life Testing (ALT). ALT includes test such as Highly Accelerated Life test (HALT) and Highly Accelerated Stress Test (HAST) which are used to test the robustness and ruggedness of the product.

Index Terms— **PMDC Motor, PIC Microcontroller, H-Bridge, PWM, ALT, HALT, HAST.**

I. INTRODUCTION

. There is an increase in demand for energy efficient systems in industries leading to the rise in the use of electric motors. In addition, the development of Power Electronic technology has made the control of electric motors much simpler and more efficient. Electric motors gives the advantage of its characteristic like Speed-current, Torque-speed etc. to be adjustable using control mechanisms.

According to the load demand, operating conditions of electric motors can be varied and also it has good starting torque [1].

Industries require precise speed control systems that can be achieved by the use of suitable speed control technique of electric motor. It can be fixed speed control or Adjustable speed control. Commonly used electric motor is the DC motor. DC motors have flexible control design, adjustable speed and simple operating characteristics. However DC motor have commutator problem. Sparking at the brushes of the motor also limits the speed of operation and making the design capability complex. These problems are overcome with introduction of PMDC motor. In PMDC motor, the pole structure and field windings are replaced by permanent magnets which reduces the stator diameter and field losses [2]-[4].

H-bridge converter is popularly used for DC motor control due to its simple design and provides the advantage of direction and speed control of the motor. PWM techniques are used for switching the power electronic devices to control the motor load in the desired manner. Digital processors like PIC are used to implement the control algorithm and generates the switching PWM pulsed signals [5]. PIC presents the benefits of low cost, simple and easy realization of the control technique.

Most of the industries focus on producing reliable and rugged systems too. Reliability demonstration includes analysis of the changes of electronic and mechanical components as a function of stress parameters like environmental and operational specific to the product. Thereby giving information regarding the durability and life span of the product. Accelerated life tests like HALT and HAST are conducted to identify the design problems associated with the product and by implementation of corrective measures the design can be made more sturdy and reliable [6]-[8].

II. SPEED CONTROL OF DC MOTOR

For the implementation of speed control of a DC motor, characteristics such as current, flux, torque, electromotive force and speed are considered. Wider range of speed control has become possible due to the development of power electronics converters [9]. According to the type of application, input power supply, noise issues, power factor and cost of implementation, the type of power converter for use is selected.

There are two methods of speed control available for DC motor, armature and field control. In the field control method, the armature voltage is kept constant and field current is varied accordingly to change the motor speed and direction of rotation. Field control is normally used for speed desired at and above the rated speed. However, the control time response is large and system response becomes sluggish. In armature control, the field is kept constant and the armature voltage is varied to obtain the desired speed and direction of rotation. This control is used when the desired speed is lower than the rated speed [10].

III. PROPOSED SPEED CONTROL SYSTEM

The speed controller is designed for the PMDC motor that is to be used in an X-ray system for motion control. Thus precision of the speed accuracy is required. The proposed design of the speed controller is implemented by considering the system requirements and specifications. The system specifications are listed in Table I.

Table I Specifications of the system

Sl. No	Parameter	Specification
1	Motor desired speed	209.439rad/sec Or 2000 rpm
2	Switching frequency of MOSFET	20 kHz
3	Supply voltage for H-bridge Converter	48V DC
4	PWM control	Bipolar switching

The block diagram representation of the proposed system is as shown in Fig. 1.

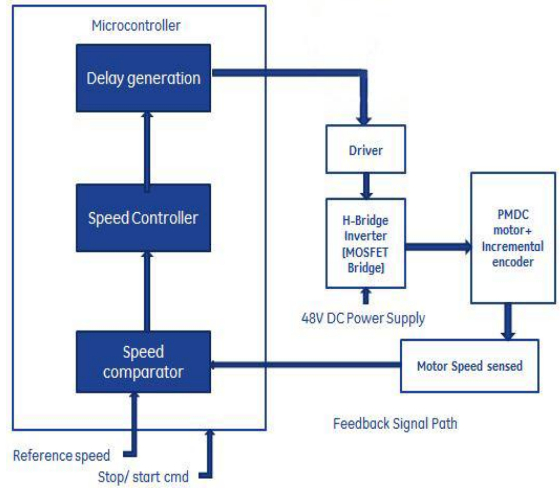

Fig. 1 Block diagram of the Proposed System

The desired speed is 209.439 rad/sec or 2000 rpm that is lower than the rated speed of 2200 rpm of the PMDC motor selected. Thus armature voltage control method is implemented for speed control. 48V DC is supplied to the H-bridge converter which in turn feeds the PMDC motor. The MOSFETs devices of the H-bridge are switched by PWM signals generated by the PIC microcontroller. Bipolar switching is the PWM technique used.

The armature voltage of the motor is varied to achieved the desired duty cycle by varying the duty cycle of the PWM pulsed signals. The variation in the duty cycle of the PWM signals is implemented using the feedback encoder signals fed to the PIC microcontroller. The encoder is inbuilt with the motor and produces two pulsed signals. The frequency of the encoder pulses is proportional to the motor speed and the phase difference between them gives the motor direction of rotation.

The selection of the discrete components of the proposed system is carried out. It includes MOSFET selection by evaluation of its characteristic parameters, Driver IC selection considering the input to output delay propagation, current ratings and power dissipation, bootstrap diode and capacitor selection required for the typical operation of the driver IC. The schematic diagram of the system with the selected components is as shown in Fig. 2.

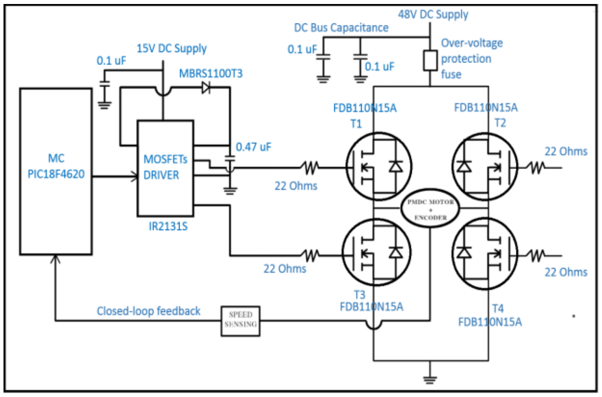

Fig. 2 Schematic diagram of the system

IV. CLOSED-LOOP SIMULATION AND RESULTS

Closed-loop simulations for clockwise direction of the motor are carried out for using PI controller and PID controller. The simulations are implemented using MATLAB software. The closed-loop circuits using PI controller and PID controller are as shown in Fig. 3 and Fig. 4 respectively. The resultant PI and PID gain values are as shown in the Simulink models.

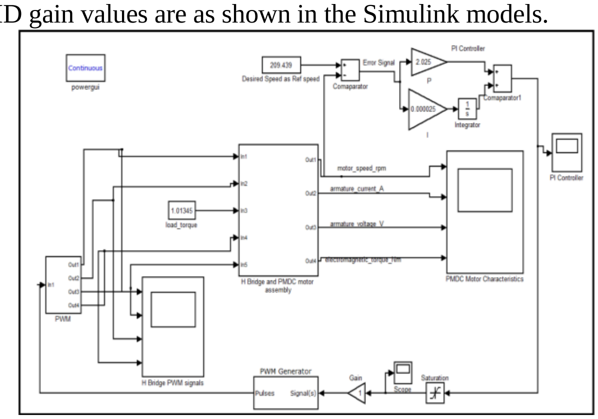

Fig. 3 Closed-loop simulation circuit using PI controller

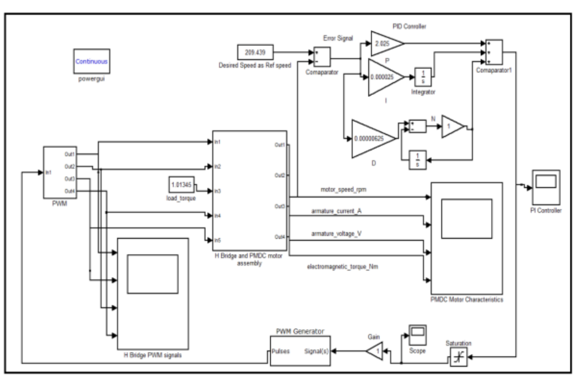

Fig. 4 Closed-loop simulation circuit using PID controller

The subsystems used in both the simulation circuit are similar. The H-bridge converter and PMDC motor assembly subsystem is as shown in Fig. 5.

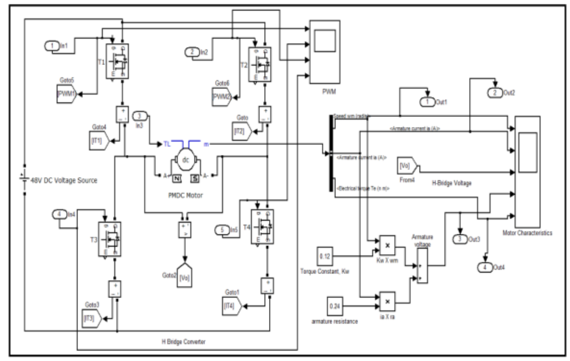

Fig. 5 H-bridge and PMDC motor assembly subsystem

The results of simulation of closed-loop motor control using PI and PID controllers are as shown in Fig. 6 and Fig. 7 respectively.

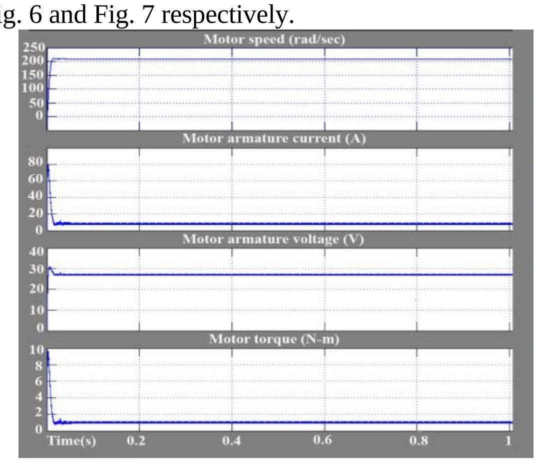

Fig. 6 Motor characteristics with PI controller

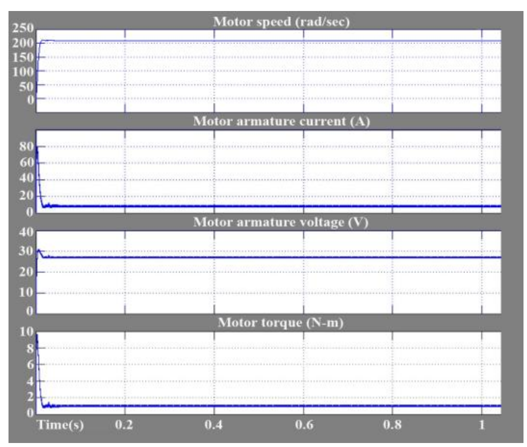

Fig. 7 Motor characteristics with PID controller

The resultant motor characteristic responses of the simulation using PI and PID controllers are listed in Table II. The responses are closely matched and the accuracy is almost the same, thus in the PIC algorithm, PI controller method is implemented.

Table II Resultant responses of PI and PID controllers

Parameter	PID (CW)	PI (CW)
Time delay	4msec	4msec
Rise time	8.5msec	8.8msec
Settling time	35msec	38msec
Percentage overshoot	6.2%	6.9%

V. CLOSED-LOOP CONTROL ALGORITHM FOR PIC18F4620

The Flowchart for the closed-loop control realization of clockwise direction using PIC18F4620 is as shown in Fig. 8. The algorithm is implemented to control the motor speed at around the desired speed of 2000 rpm in the clockwise direction.

The PIC microcontroller is operated at 8MHz by configuring the oscillator control register. Timer 1 and Timer 2 are used for Capture mode operation and generation of PWM signals respectively. Initially all the control registers for the capture mode and PWM mode are configured accordingly. The interrupt control registers are also configured.

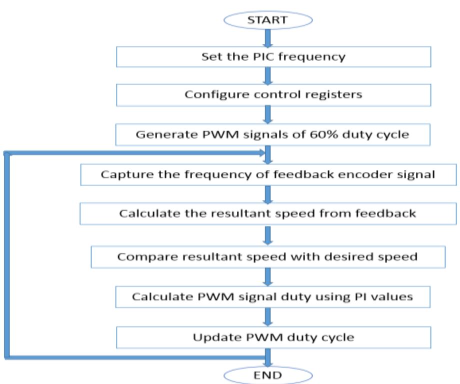

Fig. 8 Flowchart for the closed-loop control

Then a PWM signal of 60% of duty cycle w.r.t PWM pulses of switch T1 and a complementary signal of 40% duty cycle are generated to rotate the motor in clockwise direction. A dead band of 1µsec is programmed to avoid shoot-through of switches. The first and second rising edges of the encoder feedback signal are captured according to the status of the capture interrupt. Then the speed sensed is calculated and compared with the desired speed. The resulting error between the speed sensed and the desired speed is used to calculate the new duty cycle with PI controller values obtained from closed-loop simulation.

VI. HARDWARE IMPLEMENTATION

The hardware setup of the speed controller is as shown in Fig. 9 and includes the H-bridge converter, the PIC18 demo kit and the PMDC motor.

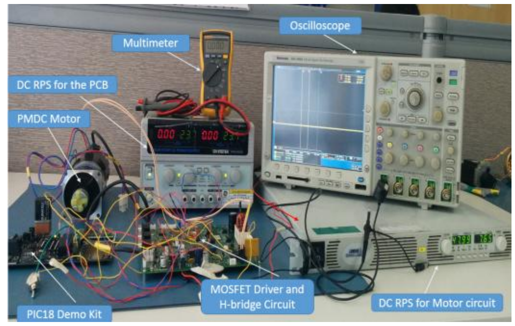

Fig. 9 Hardware setup

VII. RELIABILITY TESTING

The reliability is a measure of the electronic and mechanical robustness of the system. It is presented using Accelerated life testing. HALT temperature and HALT vibration are conducted for the controller. In HALT temperature, the controller is subjected to increasing steps of temperature and its performance is tested at every step change of temperature until it fails. The chamber used for the HALT temperature test is as shown in Fig. 10.

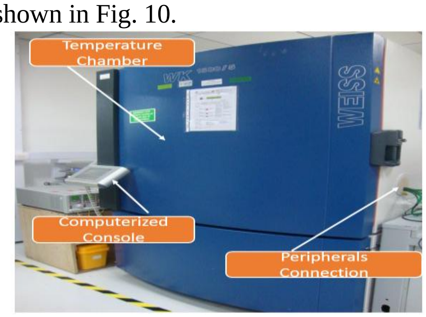

Fig. 10 HALT temperature test chamber

In HALT vibration, the controller is subjected to vibration in three axes separately. The vibration is increased step-wise and its performance is tested. The different axes position of the controller and the respective vibration test setup are shown in Fig. 11.

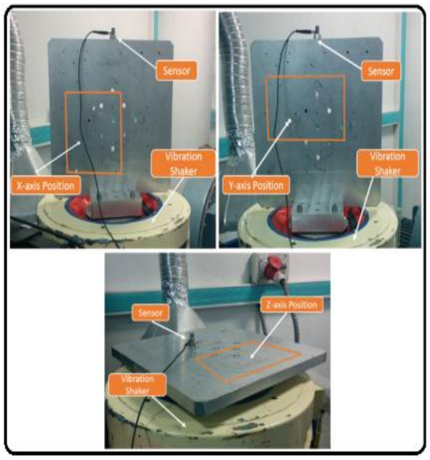

Fig. 11 Vibration setup for X, Y and Z-axes

VIII. HARDWARE IMPLEMENTATION AND RELIABILITY TEST RESULTS

The PWM pulsed signals at the PIC IC pins are as shown in Fig. 12. The frequency of the switching pulses is 19.841 kHz and a dead band of 1µsec is observed. The voltage level of the pulses is 4V.

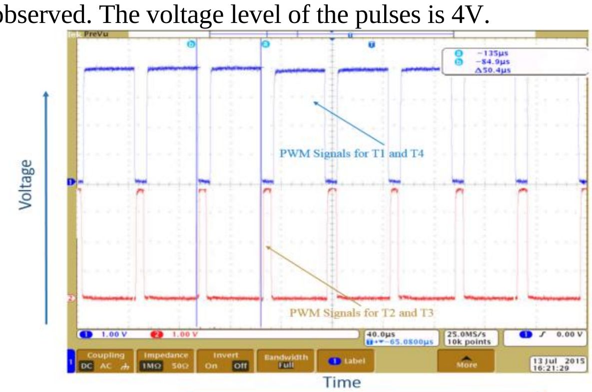

Fig. 12 PWM pulsed signals at PIC IC pins

The PWM signals at the high-side MOSFET switches are as shown in Fig. 13. The voltage level of the pulses is 15V. The frequency is 19.841 kHz. The duty cycles is 79.36% w.r.t PWM pulses of switch T1.

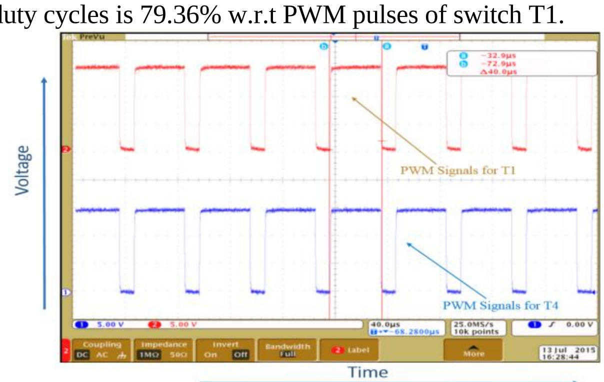

Fig. 13 PWM pulsed signals of high-side MOSFETs

The PWM signals at the low-side MOSFET switches are as shown in Fig. 14. The duty cycles is 19.44% w.r.t PWM pulses of switch T1. The frequency is 19.841 kHz. The voltage level of the pulses is 15V.

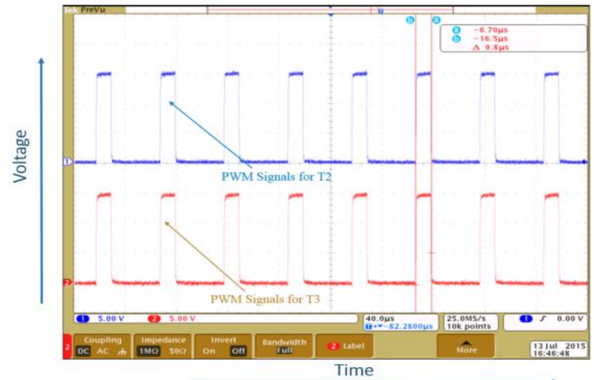

Fig. 14 PWM pulsed signals of low-side MOSFETs

The feedback encoder pulsed signal sensed is as shown in Fig. 15. The encoder channel A signal leads channel B signal for the clockwise direction.

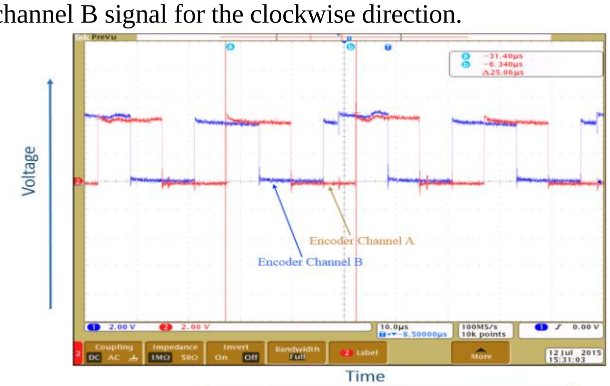

Fig. 15 Encoder feedback signal

The encoder feedback signal is related to the motor speed by the following equation:

RPM= frequency x 60/ PRR

Where, RPM is the resultant speed of the motor

Frequency is the frequency of the encoder signal

PRR is the pulsed sensed per revolution=1200 for the encoder.

The frequency of the encoder signal is 39.904 kHz and the resultant speed is 1995.1 rpm that is close to the desired value of 2000 rpm.

The HALT temperature is conducted for the controller and it passes 105^{0}C of temperature effectively. The HALT temperature test results are as shown in Table III.

Table III HALT Temperature test results

S l. No	**Temper ature (Celsius)**	**Perfor mance Test Result**

1	25	Passed
2	35	Passed
3	45	Passed
4	55	Passed
5	65	Passed
6	75	Passed
7	85	Passed
8	95	Passed
9	105	Passed
10	115	Failed
11	105	Passed

The HALT vibration test results are as shown in Table IV. The controller successfully passes its performance test with 4grms of vibration level in all three axes.

Table IV HALT Vibration test results

Vibration level	**X-axis**	**Y-axis**	**Z-axis**
0.5grms	Passed	Passed	Passed
1grms	Passed	Passed	Passed
1.5grms	Passed	Passed	Passed
2grms	Passed	Passed	Passed
3grms	Passed	Passed	Passed
4grms	Passed	Passed	Passed

IX. CONCLUSION

The speed controller for the PMDC motor is successfully implemented. The deviation between the desired and the observed speed is less than 1%. The control is simple to achieve and has the advantage of lesser cost. The complexity of the hardware is also reduced. The reliability testing proves the controller is rugged and can withstand a temperature of 105^0C and 4 grms of vibration. DSP based controller application, filter circuits for noise reduction can be implemented in future. Wider range of other stress parameters can also be used for the accelerated life testing.

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