Speed and position control of BLDC motor using internal hall sensors and hardware design

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Abstract **: In this research, a system was designed and implemented on hardware to control speed and angular position of shaft of the gear box with reduction ratio 10:1 attached to a BLDC motor of 3000 RPM by taking feedback from internal hall sensors of motor. A microcontroller processes feedback and drives motor to its target angular position which is fed to it by user via USART. By processing same hall feedback at same time, speed of motor can also be controlled. System can be used for replacing costly servo motors in low precision application in industry such as box picking and placing. Also stepper motor can be replaced by this system to achieve more accurate position control as the system involves feedback.**

Keywords—gear box: BLDC; hall sensors; USART; servo

I. Introduction

BLDC motors, now days, are more popular because of their robustness, long life, and efficiency. This document explains hardware design for BLDC motor driver, speed control of BLDC motor and position control of gear shaft attached to BLDC motor with help of hall sensors. Position control is achieved precisely using PID control with hall sensors. Hall sensors, in this case, are used as position sensors to get accurate position of rotor.

II. Construction of Basic BLDC Motor Driver

A. Functional blocks of BLDC motor drive

BLDC motor does not have brushes for commutation hence a 3-phase inverter is used for commutation. It consists of three N-channel MOSFETs for low side and three P-channel MOSFETs for high side.

A microcontroller reads status of hall sensors, and switches high and low side MOSFETs ON or OFF to excite respective windings. Hall sensors give information about position of permanent magnet placed on rotor. Switching sequence of MOSFETs for motor used in experiment is given in TABLE I with respective hall sensor outputs.

Each unique hall sensor output set can be called as step. After each excitation step, motor shaft moves forward to generate new hall signals due to the change in position of permanent magnet on rotor. This process results in continuous motion of rotor. Figure 1 shows block diagram of motor driver.

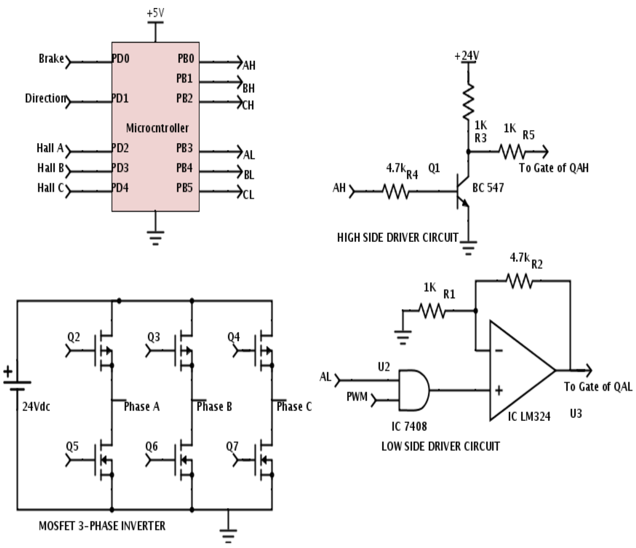

Fig. 1. Block diagram of BLDC motor driver

TABLE I.

Hall sensor outputs			MOSFET Status					
Hall A	Hall B	Hall C	Q2 AH	Q5 AL	Q3 BH	Q6 BL	Q4 CH	Q7 CL
1	0	1	1	0	0	1	0	0
1	0	0	0	0	0	1	1	0
1	1	0	0	1	0	0	1	0
0	1	0	0	1	1	0	0	0
0	1	1	0	0	1	0	0	1
0	0	1	1	0	0	0	0	1

1: ON 0: OFF

B. Working and explanation of driver blocks

1. MOSFET 3-phase inverter :

This block serves as electronic commutator. It basically consists of 3 half bridges. Each phase of motor is connected at the junction of drains of high and low side MOSFETs. MOSFET can be selected for handling certain amount of power on the basis of its current and voltage specification given in datasheets.

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2. Low and high side gate drivers:

These are low cost and very efficient circuits to drive gates of MOSFETs at very high speed required for application. High side driver consists of NPN transistor and a pull up resistor. Pull up resistor charges gate of P-channel MOSFET up to Vs making VGS = 0V to switch the MOSFET OFF. When 5V signal is applied at base of transistor, transistor conducts and connects base of MOSFET to ground generating VGS = -24V, and MOSFET goes to ON state. If MOSFET specifications do not allow VGS as high as -24V, a series resistance R can be added between collector of transistor and resistance R3 to get desired VGS. Modified values of R and R3 can be calculated by formula:

$$VGS = \frac{R}{R+R3} \times Vs - Vs$$

Here, Vs = Supply voltage

Using this formula, gate driver for system using higher power supply can be designed.

Low side MOSFET driver circuit is basically an amplifier which amplifies 5V signal from microcontroller to desired voltage to drive gate of N-channel MOSFET. Again, values of resistance in amplifier can be modified to get required allowable VGS.

To achieve PWM speed control, low side MOSFET control signals are ANDED with PWM with help of an AND gate for each low side MOSFET driver.

3. Brake and Direction control:

To apply electronic brake to motor, all N-channel MOSFETs are made off and all P-channel MOSFETs are made ON to short three phases of motor.

For changing direction, hall sensor inputs are inverted and MOSFET status for inverted inputs in TABLE.I is used.

For example,
If hall input is “110”, then say
x =~ (110) = 001
Then MOSFET status for sequence “001” is employed which is “100001”, in this case.

4. Microcontroller:

Microcontroller reads status of hall sensors and switches MOSFETs ON or OFF for particular hall input with the help of MOSFET gate driver circuit. Also it reads Brake and Direction input from user to perform related actions. It also calculates speed of motor using interrupts, employs PID algorithm for speed control and position control, at the same time. Here, one set of three hall sensor outputs is acquired once and processed for all three functions mentioned above, making system faster.

III. Speed Control of BLDC Motor Using PID Algorithm

A. *Speed measurement of BLDC motor*

Speed of BLDC motor can be measured using internal hall sensors; it does not require any external encoder. Motor used in experiment completes one rotation within 3 sets of 6 hall sequences or steps i.e. total 18 steps, each step covers angle of 20°. It can be understood how motor covers 20° in each step from following diagram.

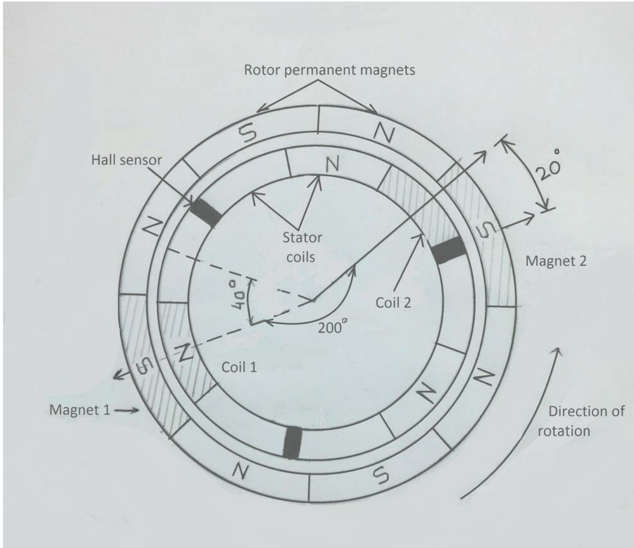

Fig. 2. Mechanical structure of BLDC motor

Above diagram shows mechanical structure of BLDC motor used in the experiment. Above 3phase BLDC motor has 9coils (3 coils per phase) on stator and 8 permanent magnet on rotor. Angle between 2 adjacent coils is 40° degree and angle between in 2 adjacent magnets is 45°. Angular offset of 5° is essential for rotation. For understanding the process of rotation, two excitation steps are shown during the rotation of motor. Consider a excitation step in which coil 1, as shown in diagram, is magnetized as N-pole attracting permanent magnet1 which is S-pole, hence it gets aligned with the magnetic field of coil 1.In this state, magnet 2 is 20° apart from coil 2. Now, during next excitation step coil 2 is magnetized to N-pole, therefor magnet 2 with S-pole gets aligned with magnetic field of coil 2 resulting in rotation of 20° in the direction shown. This rotation of rotor causes the change in hall signals and next excitation step is applied accordingly. It should be noted that coil 2 is 200° degree apart from coil 1 and only coil 2 should be magnetized to maintain rotation. If any other coil is magnetized, rotation will not be maintained. Hence only that coil should be magnetized which is 200° apart from currently excited coil to get another 20° rotation in same direction. Switching sequence given in TABLE.I governs the excitation of correct coil for each particular step.

For understanding purpose, excitation of only one coil at a time is shown in above diagram, but in actual case one other coil also gets magnetized each time. It is magnetized such a way that it repels a particular magnet facing it to add certain amount of additional torque in same direction.

Above demonstration of mechanism of excitation and rotation is applicable for motor used during experiment. Step angle was actually measured for the same motor. Step angle and excitation sequence may vary for motor with different manufacturer and mechanical structure.

By counting steps covered by rotor in specific duration of time, RPM of motor can be calculated. Alternatively, by measuring time required to complete one step, speed can be calculated by following formula:

$$RPM = \frac{1}{\Delta t \times S} \times 60 \text{ Revolutions/minute}$$

S = Number of steps motor needs to complete one rotation

Δt =time required to complete one step

Unit of Δt is second.

B. PID algorithm for speed control

Once speed of motor is measured, PID algorithm can be employed for speed control. PWM applied to motor is precisely controlled by PID algorithm to control speed of motor. Basic PID equation is:

$$P = K_p E_r + K_i \int E_r dt + K_d \frac{dE_r}{dt}$$

Where, P = Output PWM
K = Constants
Er = Error (Difference between desired and actual speed)

But in digital system, entity to be controlled is measured at regular intervals of time. It ensures that the time factor is constant. Hence above equations can be reduced to:

$$P = K_p E_r + K_i \sum E_r + K_d (E_r - E_{rl})$$

Where, Erl = error in previous sample of speed
Er = error in current sample of speed

In digital system, where samples of quantity to be controlled are taken at fixed and regular intervals of time, time factor is compensated in constants Ki and Kd while tuning to minimize processing load on the processor. Care must be taken to limit value of integration terms within certain limits to forbid system from being unstable.

C. Algorithm for motor drive and speed control

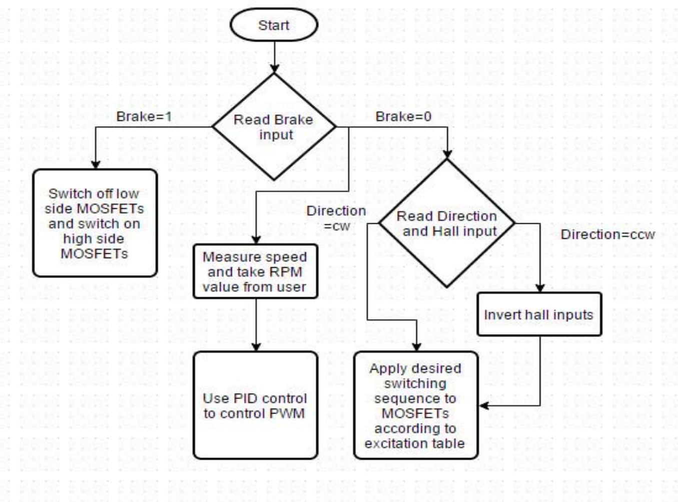

Fig. 3. Algorithm for motor drive and speed control

IV. POSITION CONTROL OF BLDC MOTOR

Servo motors use analog sensors for position sensing. In BLDC motor internal hall sensors can be used to sense position of rotor. But hall sensors do not show continuous change in output, output changes after fixed amount angular change in rotor position. Motor used in experiment rotates by 20 degree to generate next combination of hall sensor output. Hence motor shaft can attain only those position which are integer multiple of 20 degree. Therefor it gives maximum resolution of 20 degree. It seems very poor initially, but it can be improved by attaching appropriate gear box. In the experiment, gear box with gear ratio 10:1 was used to get resolution (minimum step size) of 2 degree. It can be improved further by increasing gear ratio.

Value of angle by which shaft is to be rotated is fed to the microcontroller by USART or analog input to ADC. As shaft can attain only those angular positions which are integer multiples of minimum step size, input is needed to be quantized.

A. Input methods and quantization of input.

a) Analog Voltage to ADC of microcontroller:

ADC of microcontroller digitizes the voltage given as input to scale of 0 to 1024 and a program maps this data to 0 to 360.

b) Input via USART:

Value of angle by which motor is to be rotated is directly sent to microcontroller by USART.

Once value of angle is acquired, it is needed to calculate number of steps by which rotor of motor to be rotated. Number of steps is calculated by the formula:

$$N = \theta / R$$

Here, N = number of steps
θ = Angle
R = resolution

Value of N is approximated to nearest integer.

For motor used in experiment, R is 2 degree. Value of R for general case can be calculated by:

$$R = 360/(M \times G)$$

Here, M = Number of steps motor requires to complete 1 rotation
G = Gear reduction ratio

B. Driving motor to desired position

Once number of steps motor to be rotated is known, PWM can be applied to achieve that position. PWM is controlled by PID control. PID equation for PWM is:

$$P = K_p(e_n) + K_i \sum (e_n) + K_d (e_n - e_{np})$$

Here, e_n = Error (difference between number of steps to be covered and actual steps covered at the current time instance)

e_{np} = Error calculated at previous instance

Number of steps covered by shaft is calculated by a program running in parallel with main control loop. Initial motor position, before system is powered ON, can be referred as zero position or additional sensor can be mounted on external surface to get a fixed reference point as zero position.

Current motor position at any time can be calculated by formula:

$$\theta_c = n_c \times R + \theta_0$$

Here, n_c = number of steps covered since new angle input is given

θ_0 = Previous angular position with respect to zero reference point.

C. Algorithm for position control of BLDC motor

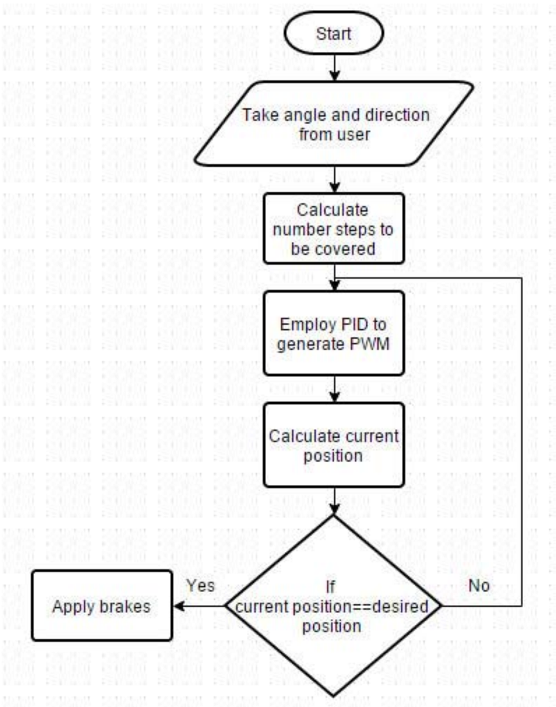

Fig. 4. Algorithm for position control of BLDC motor

In experimental setup, after desired position is achieved by the gear shaft, electronic brake is applied. But in industrial application, appropriate amount of current can be made to flow through windings which are supposed to be excited at that position to hold the same position if system is being used to drive some load. Amount of current depends upon load applied.

D. Posible error in position of shaft

As BLDC motor shaft can attain only discrete angular positions which are integer multiples of minimum step size, input angle needs to be approximated to nearest achievable position. This introduces error in the system. Maximum error which can occur in actual position of shaft is half of resolution. Equation for maximum error, considering all the factors can be given by:

$$E_{\max} = \frac{180}{M \times G}$$

Here, M = Number of steps motor requires to complete 1 rotation

G = Gear reduction ratio

Error can be brought down to desired level by increasing gear ratio to appropriate amount.

E. Comparison of proposed system using BLDC motor with servo motor and stepper motor

Servo motor has the highest accuracy amongst all systems mentioned. But cost of servo motor and driver is also very high as compared to BLDC motor. Hence, in the application where moderate level of accuracy is required, servos can be replaced with much economical BLDC motors.

Stepper motors don’t use any feedback system. Hence accuracy of the system greatly depends on drive precision. If stepper motor makes any step error or skips a step, there is no way to correct it or control it. Above proposed solution has advantage over stepper motor as it involves feedback from hall sensor. It eliminates any chances of step error or skipping over a step.

Resolution of stepper motor can be increased using micro stepping technique whereas resolution of BLDC motor can be increased by increasing gear ratio.

V. CONCLUSION

Designs for BLDC motor driver explained in this document were implemented on hardware and tested under load conditions. Motors and motor drivers were used to drive robotic vehicle. This design is a cost effective way of controlling BLDC motor.

System error is precisely known up to certain extent in position control of BLDC motor. Error can be optimized for desired application. This system is cheap and basically using BLDC motor which is superior to any other motor in terms of efficiency, control, robustness, reliability. Hence, if implemented successfully, it can replace servo motors which are costly and less efficient than BLDC motors.

REFERENCES

[1] Adel S. Sedra and Kenneth C. Smith, “Microelectronics Circuits” Theory and applications, 6th ed., Oxford, 2013.

[2] M. D. Singh and K. B. Khanchandani, Power Electronics, 2nd ed., Tata McGraw-Hill Education, 1998.

[3] Norman S. Nise, Control System Engineering, 6th ed., Wiley, 2010.

[4] K. Ogata, Discrete-Time Control Systems, Prentice Hall 1987.

[5] Brushless DC Motor Control using ATmega32M1,AVR194, Atmel.