ISSN 2229-5518

Modelling and Simulation Analysis of Position Control of Electromechanical Actuator

Priyanka C P, Sija Gopinathan

Abstract —This paper presents the position control of an Electromechanical actuator. The electrical part of the actuator is a three phase Brushless DC Motor. The mechanical part consist of a ball screw. The mathematical modelling of three phase BLDC motor and ball screw are done. The phase voltage is supplied by the inverter to drive BLDC motor. The commutation logic senses rotor position and gives gating pulses for the switches in the inverter circuit. Hall sensor are used for sensing the position. Bipolar switching is used for generating the triggering pulses for switches in the inverter. The position control is designed using PI controller and Cohen Coon tuning is done. The results of simulation are also presented.

Index Terms— Brushless DC Motor (BLDCM), Cohen Coon Tuning, Commutation Logic, Pulse Width Modulation(PWM), Electromechanical actuator(EMA)

1. INTRODUCTION

Electromechanical actuators are one of the key components contained in any industrial system. EMA are now a days widely used in industry for various applications. In aerospace it is mainly used in flight control system of missiles, aircraft or launch vehicles. The EMA is gaining more importance than hydraulic actuator due to technology advance in permanent magnet brushless dc motor with new magnetic materials and motor drive controllers with power semiconductor switching.The high efficient BLDC motor and ball screws composing the key part of EMA [3]. The DC motor is simplest and efficient motor used in EMA due to ease of control and low cost in manufacturing compared to other motors. The limitation of DC motor in reliability and robustness due to wear of brush and commutation. So it need time to time replacement. In aerospace and industrial application where high reliability and robustness required the brush dc motors.

————————————

Priyanka C P is currently Pursuing M.Tech in Power Electronics in Mar Athanasius College of Engineering, M G university, Kerala, India. EMAIL priyanka.cp03@gmail.com

The arrival of new switching device, digital technology and microprocessor popularise use of BLDC in electric/hybrid vehicle, ship propulsion, and industrial applications [1]-[4]. Permanent magnet ac motors are classified as sinusoidally fed Permanent synchronous motors and rectangular fed permanent magnet brushed dc motor. The construction of BLDCM is inside-out version of dc motor. The winding of BLDCM is wound in such a way that trapezoidal back emf is produced. The quasi rectangular current should fed to motor to produce constant torque.[1]

In this paper EMA based position control system is presented. The EMA consists of electrical part as three phase BLDCM and mechanical part as ball screw. The motor and ball screw is connected using suitable gearing system. The BLDCM provides high efficient operation. This paper explains the modeling of three phase BLDCM and drive, closed loop position control system is included. The parameter values are selected based on specification. The position control is done using PI feed back controller and tuning is done using cohen coon method. The simulation results are presented Matlab/Simulink. Finally the BLDCM model is

ISSN 2229-5518

extended to EMA model used in aerospace and automative industry.

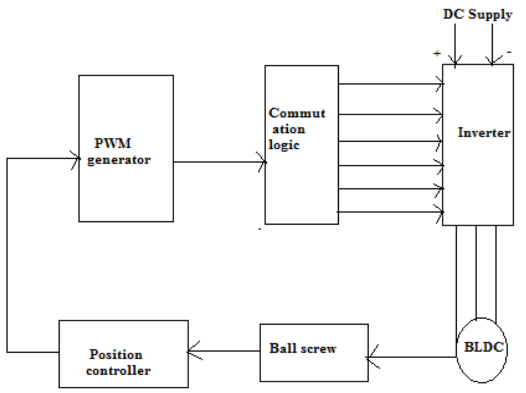

Fig. 1 Block Diagram of Position control Scheme

2 MODEL OF 3 PHASE BLDC MOTOR

The assumptions made are all the three phase windings are symmetrical, Eddy current loss and hysteresis loss are neglected, Magnetic saturation is not taken into account. The Stator resistance R, Self inductance L, Mutal inductance M.

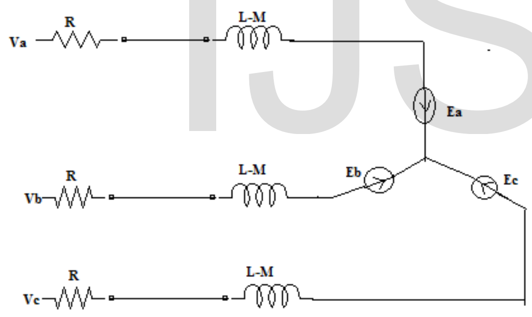

Fig. 2 Equivalent circuit of three phase BLDCM

The three phase balanced stator voltage equation can be expressed as follows

$$V_a = i_a R_a + L_{aa}\frac{di_a}{dt} + L_{ab}\frac{di_b}{dt} + L_{ac}\frac{di_c}{dt} + e_a (1)$$

$$V_b = i_b R_b + L_{bb}\frac{di_b}{dt} + L_{ba}\frac{di_a}{dt} + L_{cb}\frac{di_c}{dt} + e_b \; (2)$$

$$V_c = i_c R_c + L_{cc}\frac{di_c}{dt} + L_{ca}\frac{di_a}{dt} + L_{cb}\frac{di_b}{dt} + e_c \; (3)$$

Considering three phase symmetry and non salient rotor

$$L_{aa} = L_{bb} = L_{cc} = L$$

$$L_{ab} = L_{ba} = L_{ac} = L_{ca} = L_{bc} = L_{cb} = M$$

Considering stator phase current balanced

$$i_a + i_b + i_c = 0$$

The equation of voltage can written as

$$V_a = Ri_a + (L-M)\frac{di_a}{dt} + E_a (4)$$

$$V_b = Ri_b + (L-M)\frac{di_b}{dt} + E_b (5)$$

$$V_c = Ri_c + (L-M)\frac{di_c}{dt} + E_c \; (6)$$

The motion for a simple system with moment of inertia J and damping coefficient B and load torque T_l can be written as

$$T_e - T_l = J\frac{d\omega_m}{dt} + B\omega_m \qquad (7)$$

The rotor position and rotor speed can be related as

$$\frac{d\theta r}{dt} = \frac{P}{2} * \omega_r \qquad (8)$$

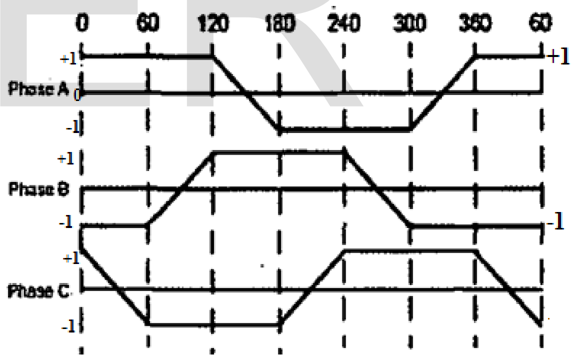

Fig. 3 Back Emf waveform of three phase BLDC

The back emf function can be written as

$$
\begin{aligned}
f_{\theta r} &= 1 && 0 \le \theta r \le 2\pi/6 \\
&= 1 && 2\pi/6 \le \theta r \le 4\pi/6 \\
&= (\pi - \theta r)\left(\frac{6}{\pi}\right) && \frac{4\pi}{6} \le \theta r \le \frac{6\pi}{6} \qquad (9) \\
&= -1 && 6\pi/6 \le \theta r \le 8\pi/6 \\
&= -1 && 8\pi/6 \le \theta r \le 10\pi/6 \\
&= (\theta r - 2\pi)\left(\frac{6}{\pi}\right) && 10\pi/6 \le \theta r \le 12\pi/6
\end{aligned}
$$

ISSN 2229-5518

Similarly equation for other phases as functions of rotor position are written. The above equation can be used to model the three phase BLDC motor.

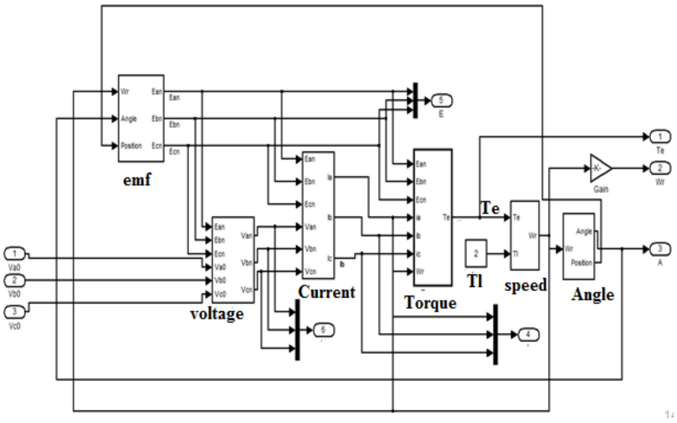

Fig. 4 Model of three phase BLDC

2.1 COMMUTATION LOGIC

The electric commutation means a way of PWM signal distribution to switches in inverter circuit. The sequencing depends upon signal which are sensed and feedback. The other factor it depends on is kind of PWM signal (unipolar/bipolar). The commutating logic is implementing using logic gates and output can be provided as driving signal for switches in the inverter. The position of rotor is sensed over every 60 degree interval.

The commutating logic was developed using sensing rotor position. After determining the rotor position it will start giving driving signals for switches in the inverter. By this a 120 degree conduction signal generator mode is implemented which can generate exact square wave switching patterns. The frequency of carrier signal is 5KHZ. The inverter is driven by 6 gating signal derived from the commutating logic.The diagram shows a three phase inverter and the output of three phase feed the three phase BLDC motor.

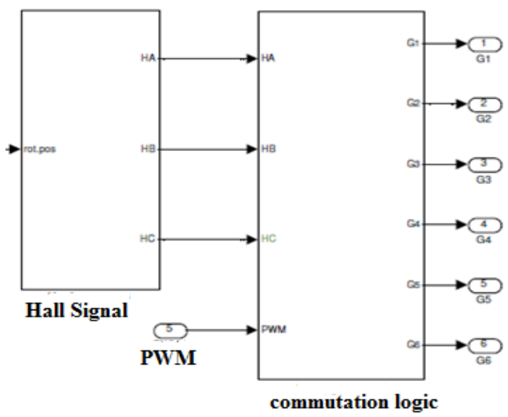

Fig.5 Commutation Logic

TABLE I

Commutation Sequence

Rotor Position (Degrees)	PWM	V_{an}	V_{bn}	V_{cn}
0-60	On	0.5Vdc	-0.5Vdc	0
	Off	-0.5Vdc	0.5vdc	0
60-120	On	0.5Vdc	0	-0.5Vdc
	Off	-0.5Vdc	0	0.5Vdc
120-180	On	0	+0.5Vdc	-0.5Vdc
	Off	0	-0.5Vdc	0.5Vdc
180-240	On	-0.5Vdc	0.5Vdc	0
	Off	0.5Vdc	-0.5Vdc	0
240-300	On	-0.5Vdc	0	0.5Vdc
	Off	0.5Vdc	0	-0.5Vdc
300-360	On	0	-0.5Vdc	0.5Vdc
	Off	0	0.5Vdc	-0.5Vdc

2.2 VOLTAGE SOURCE INVERTER

The inverter in the system is modelled by considering conduction 120 degree. Two phases conduct at a time in such a way that the inverter divides the supply voltage between two conducting phases. Bipolar switching is used.

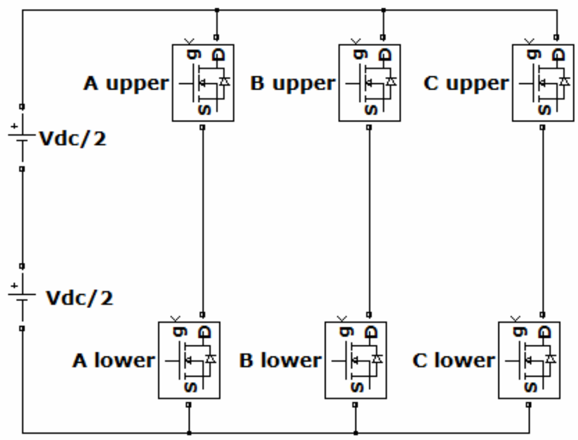

Fig. 6 Voltage Source Inverter

The gating pulses to the switches in the inverter is given according to the rotor position sensed by hall sensor and bipolar PWM switching is used. At each rotor position according to signals two phases conducts a positive and a negative phase

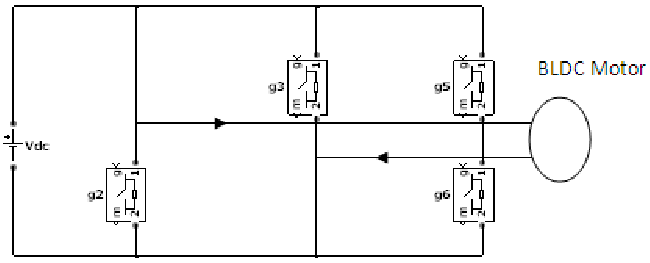

Fig. 7 Switching Action

3 MODELING OF ELECTROMECHANICAL ACTUATOR

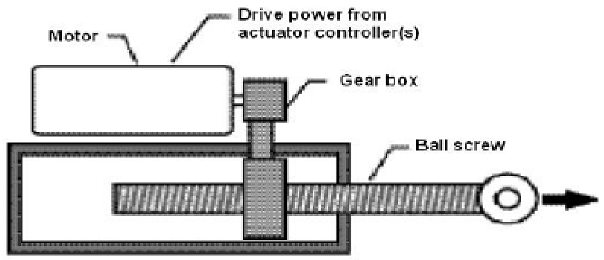

Fig. 8 Electromechanical Actuator

The three phase motor which forms the electric part of motor is then connected to a ball screw through a proper gearing mechanism. The function of gearing mechanism is to reduce the angular velocity before converting into linear displacement. This constitute the mechanical part. The electromechanical actuator model thus consist of a three phase BLDC, PWM generator, Inverter, Position feedback and a gear box mechanism

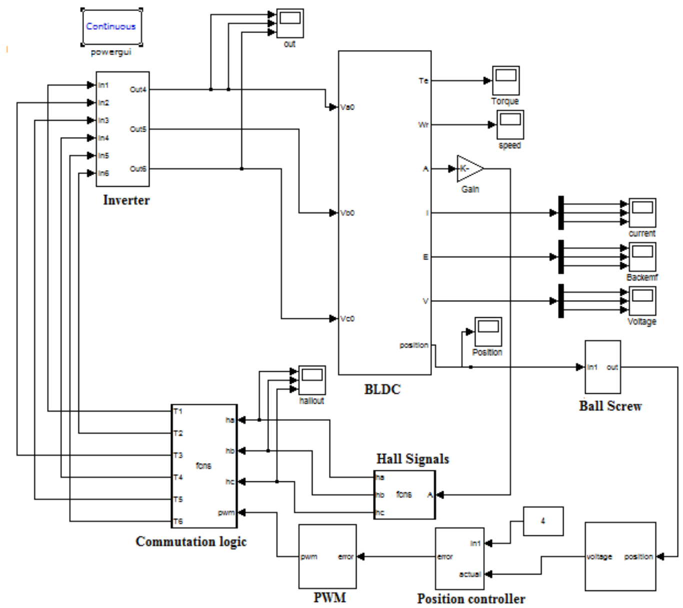

Fig. 9 Model of Electromechanical Actuator

3.1 POSITION CONTROLLER

The compensation selected for postion controlling is PI compensation. Integral compensation reduces steady state error and tracking position which increases the accuracy of the system. The tuning method used is Cohen coon method.

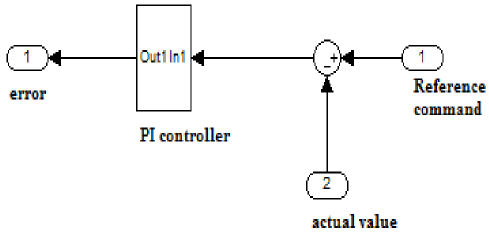

Fig. 10 Position Controller

4 SIMULATION RESULTS

The model of closed loop system of three phase BLDC is explained and simulation work have been conducted. The electrical input corresponding to actuator position is obtained as shown in figure. The simulation result of backemf , current , position are shown below.

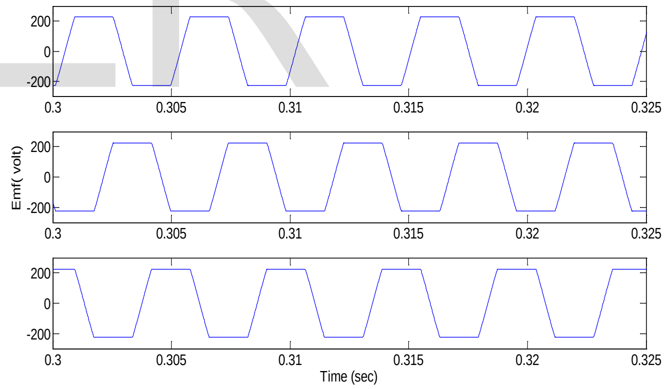

Fig 11.Emf

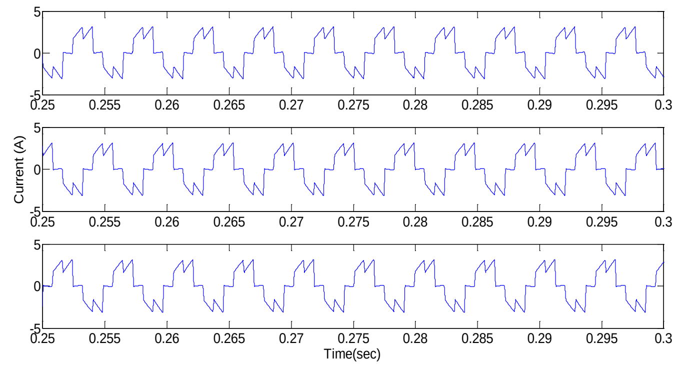

Fig. 12 Current

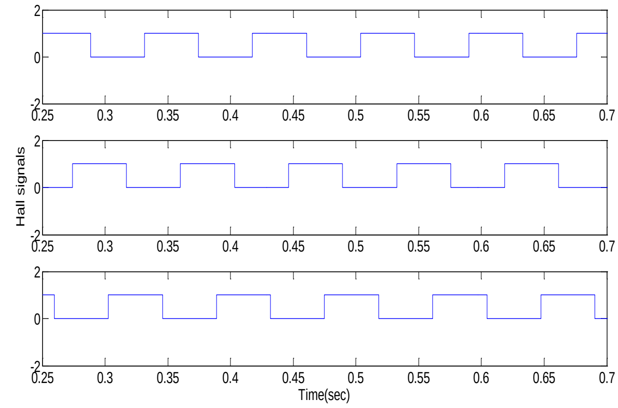

Fig. 13 Hall Signal

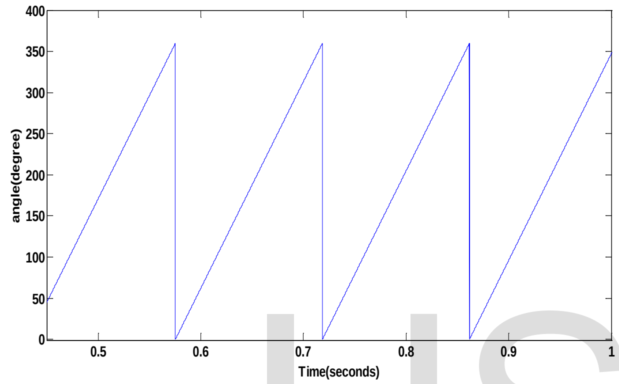

Fig. 14 Position

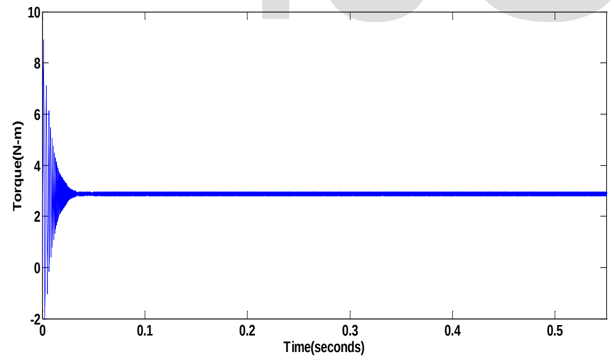

Fig. 15 Torque

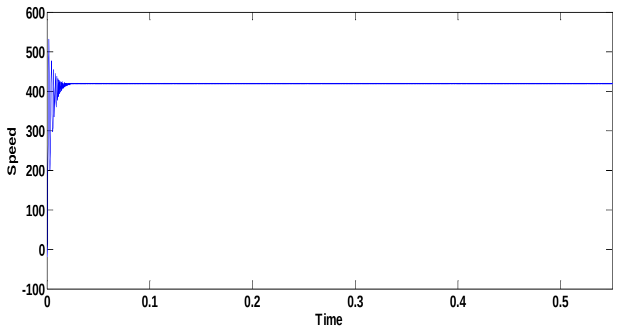

Fig. 16 Speed

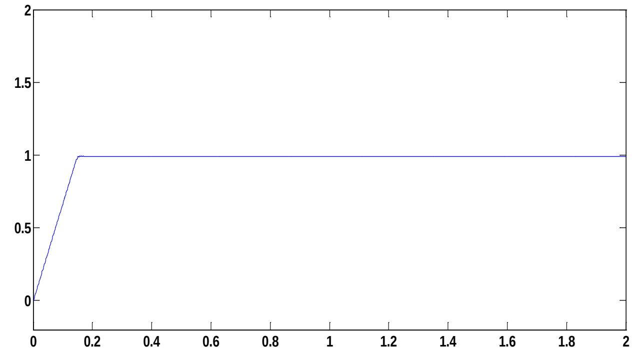

Fig. 17 Position Control for an input of 1V

5. CONCLUSION

The EMA based position control system is designed. The results of simulation are also presented. The modelling of a three phase BLDC motor is done. The results from simulation shows it is fit with theoretical studies. The position controller provided will give a stable response with rise time less than 200ms and reduced steady state error.

REFERENCES

[1] P. Pillay and R. Krishnan, "Application characteristics of permanent magnet synchronous and brushless DC motors for servo drives," *IEEE Trans.Ind. Appl.*, vol. 27, no. 5, pp. 986–996, Sep/Oct. 1991.

[2] P. Pillay and R. Krishnan, "Modeling of permanent magnet motor drives,"*IEEE Trans.Ind. Electron*., vol. 35, no. 4, pp. 537–541, Nov. 1988.

[3] Anas S R, HemanthJaison, Anish Gopinath, M.N Namboothiripad, M.P Nandakumar(2011)" Modelling and simulation analysis of a redundant electromechanical actuator bases positionservo system" *International conference on computer communication and electrical technology*

[4] P. Pillay and R. Krishnan, "Modeling, simulation, and analysis of permanent-magnet motor drives, part ii. The brushless dc motor drive,"*IEEE Trans. Ind*. Appl., vol. 25, no. 2, pp. 274–279, Mar./Apr.1989.

[5]L.Parsa and H. Toliyat, "Multi-phase permanent-magnet motor drives," *IEEE Trans. Ind. Appl.*, vol. 41, no. 1, pp. 30–37, Jan./Feb. 2005.

[6] L. Parsa, "On advantages of multi-phase machines," in *Proc. IEEE Ind.Electron. Soc. Annu. Conf.*, Nov. 2005, pp. 1574–1579.

[7] R.Krishnan, Electric Motor Drives Modelling, Analysis and Control©2001 Prentice Hall, India.