ISSN: 2278 – 7798
International Journal of Science, Engineering and Technology Research (IJSETR)
Volume 5, Issue 8, August 2016

Enhancement of Dynamic Performance of A BLDC Motor Based Actuator by Using FLC for Aerospace Applications

SK.Mahaboob Jan, B.V.Ravi Kumar

Abstract— An **actuator is a kind of motor, which is used for the attitude control of aerospace vehicle and it is a main element of the aerospace control system. The actuator which is used in this project is Electro mechanical Actuator (EMA). EMA is compact, dynamic and robust to meet the control system performance requirement of aerospace vehicle. BLDC motor is the best choice of electric drive to be used in the actuator due to its controllability and high efficiency, compact form, reliability and low maintenance. The aim of this research is to design a simulation model of Brushless Direct Current (BLDC) based actuator in MATLAB/SIMULINK. It involves to study and analyze the control system performance of a BLDC motor based actuator which is built with PID control algorithm .To optimize performance of a given control system, a fuzzy logic controller (FLC) is applied. In this fuzzy logic controller, Mamdani method is used for position control of an actuator. Simulation results showed that fuzzy logic control provides more efficient closed loop response for position control of BLDC based actuator. It optimizes the performance of an actuator in terms of settling time, peak over shoot. The two control algorithms are compared under different torque conditions.**

Index Terms— **BLDC Motor, Fin Actuation System, Fuzzy Logic Controller (FLC) and MATLAB tool.**

I. INTRODUCTION

An Actuator is an electric motor, generally the motor will be a brushed DC motor, brushless DC motor, stepper motor or switch reluctance motor. The motor is controlled using analog controller or a digital controller. The rotary motion of a motor is converted into linear motion.

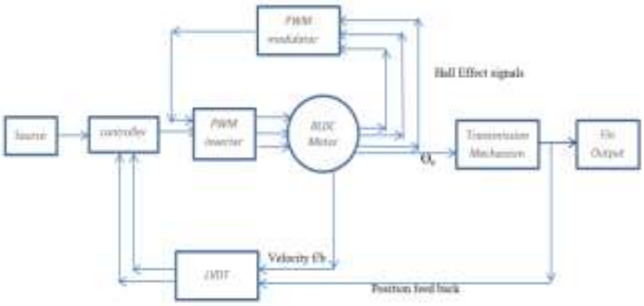

Fig.1. Block diagram of an Actuation system

Manuscript received Aug, 2016.
***SK.Mahaboob Jan**, M-Tech (Control Systems), EEE, JNTU, Anantapur, India, 8886035230.*
***B.V.Ravi Kumar**, Scientist (Sc_E), CSL, RCI, Hyderabad, India, 040-24306615.*

In this project we are dealing with only electro-mechanical actuator, which consists of a BLDC motor, transmission mechanism and lvdt as shown in the fig.1.

A BLDC motor converts electrical energy into mechanical energy as rotatory motion which is given to ball screw transmission mechanism, where it converts the rotatory motion into the linear motion. LVDT is put in the feedback where it converts the actuator position and rotor velocity into voltage's, which is fed back to a controller of an actuation system.

A BLDC based actuator has been steadily used in fin position systems of guided missile, because of their momentary overdrive capability, low quiescent power, low maintenance characteristics and long-term storability. But, during the flight of missile, the parameters of fin actuation systems may be changed by many uncertainties such as aerodynamic load disturbances, parameter variations, electrical noises, and so on.

To resolve this problem, there are various control strategies are proposed for the optimal control design of BLDC motor. However, these methods are complex in nature and require excessive computation. In order to improve control performance of the BLDC based actuator, intelligence controllers such as fuzzy logic controller is used.

Design objectives that are difficult to express mathematically can be easily incorporated in a fuzzy controller by linguistic rules. In addition, its implementation is simple and straight forward. In this project, a complete simulation model with mamdani fuzzy logic control method for BLDC based actuator is proposed using Matlab/Simulink. Section 2 describes mathematical modeling of Actuator, section 3 explains the design of controller using Mamdani method, section 4 gives the simulation results and section 5 concludes the paper.

II. MATHEMATICAL MODELING

A. *Modeling of a three phase PMBLDC motor*

A BLDC motor which is modeled in this paper is a 3 phase 4 pole motor. A synchronous machine with Permanent magnet rotor can also be considered as BLDC motor and the only difference is the rotor construction due to which the dynamic characteristics of the machine changes and the three phase voltage source is fed to the motor. A sinusoidal square wave is not necessarily used as source or the other wave shape can also be used but it should not exceed the maximum voltage limits. The modeled equations for the armature winding are as follows:-

$V_a = RI_a + L\, dI_a/ dt$ (1)
$V_b = RI_b + L\, dI_b/ dt$ (2)
$V_c = RI_c + L\, dI_c/dt$ (3)

Where L-armature self-induction in [H]
R-armature resistance in [Ω]
V_a, V_b, V_c –terminal phase voltage in [V]
I_a, I_b, I_c - motor input current in [A]
E_a, E_b, E_c -motor back- emf in [V]

Back-Emf of each phase has a phase difference of 120 electrical degrees and back- Emf and rotor position are related via some function. Equation of each phase for back-Emf is as follows:-

$E_a = F_a(\theta_e) * \omega$ (4)
$E_b = F_b(\theta_e - 2\pi/3) * \omega$ (5)
$E_c = F_c(\theta_e + 2\pi/3) * \omega$ (6)

Where
θ_e - rotor angle in electrical degree
ω- rotor speed [rad.S^{-1}]

Rotor angel electrical [θ_e] and Rotor angle mechanical [θ_m] are related as:-

$\theta_e = \frac{P}{2}\theta m$ (7)

Where P is the no of poles on rotor

Thus the total electromagnetic torque T_e in N-M can be expressed as follows:-

$T_e = (E_aI_a+E_bI_b+E_cI_c)/ \omega$ (8)

The mechanical torque transferred to the motor shaft:-

$T_e - T_l = Jdw/dt + B\omega$ (9)

Where T_l = load torque [N-M]
J= inertia of the rotor shaft [Kgm2]
B = friction constant [Nms.rads-1].

B. Model of the other parts of an Actuation system

The rotor position of a BLDC motor can be obtained as below

$\Theta_m = \int \omega_r\, dt$ (10)

Where ω_r is the mechanical speed of the motor

Electrical position of rotor can be calculated from the mechanical angular speed by the expression given as

$\theta_e = P/2\theta_m$ (11)

Where P is the no of poles on rotor
θ_m is mechanical rotor angle [rad].

The rotor position is given as input to the transmission mechanism. By using the following formula rotatory motion is converted into linear motion. The transmission ball screw change the output torque θ_m to directional force F_E

$F_E = \frac{l}{2\pi}\theta_e$ (12)

Where F_E is output force of EMA,
l is lead of the ball screw.

The obtained linear output is given to the level arm which converts the linear position into angular position by using the following formula

$F_o = \frac{180}{33*\pi}$

Where F_o is fin output.

III. FUZZY LOGIC CONTROLLER

Unlike other conventional control schemes, Fuzzy logic controller (FLC) is a model-free controller. It does not require an exact mathematical model of the controlled system and, therefore, is less sensitive to system parameter changes. In addition, rapidity and robustness are the most profound and interesting properties in comparison to the classical control methods. The structure of the proposed controller for BLDC based actuator is shown in Figure 5. The proposed controller consists of fuzzy logic controller for position control in the completed closed loop system. The designation of fuzzy logic controller is based on expert knowledge which mean the knowledge of skillful operator during the handling of actuation system is adopted into the rule based design of fuzzy logic controller.

The block diagram of position control of a actuation system using a fuzzy logic controller is shown in Fig.2. The most significant variables used in the fuzzy logic position controller have been selected as the position error. The output of this controller is *U*.

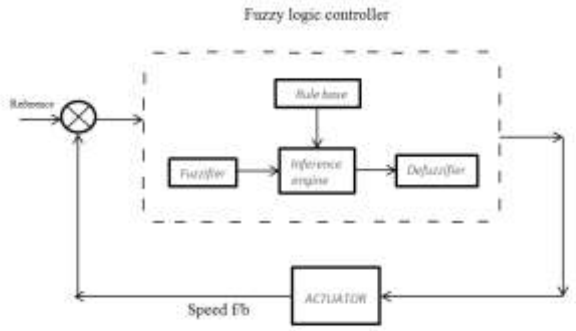

Fig.2. Block diagram of a Fuzzy Logic Controller

The FLC consists of three stages: Fuzzification, Rule Base and Defuzzification.

ISSN: 2278 – 7798
International Journal of Science, Engineering and Technology Research (IJSETR)
Volume 5, Issue 8, August 2016

- *Fuzzification*

The most important step in fuzzification interface element is to determine the state variables or input variables and the control variables or output variables. There is one input variables for actuation system in terms of position control which is error. Error can be described as a reference of position set point minus actual position. The voltage applied to the BLDC motor of an actuation system is defined as output variable. In this stage, the crisp variables are converted into fuzzy variables as

$E=k*e$ (13)
$U=u/k_u$ (14)

Ke is the proportional coefficients and they transform the input to the universe of fuzzy sets. *Ku* is used to transform. The output of the fuzzy control to the actual control value. These transformations are closely associated with the control variables, according to the prescribed membership functions. The membership functions have been chosen with trapezoidal shapes. The universe of discourse of input fuzzy variable *E* and output *U* are divided from -100 to 200 and -1000 to 2480. Each universe of discourse is divided into three fuzzy sets: S, M and B as shown in Fig. 3.

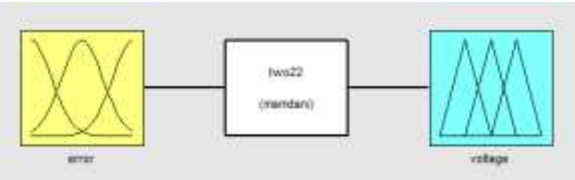

Figure.3. Membership function for input and output of fuzzy logic controller

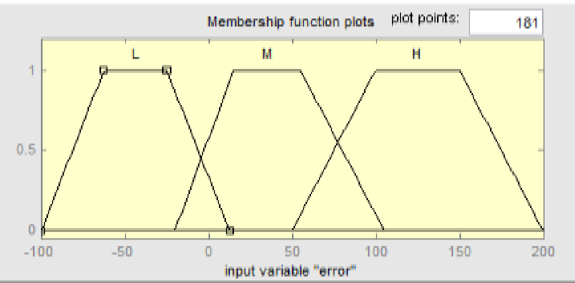

Fig.3.a. error(e)

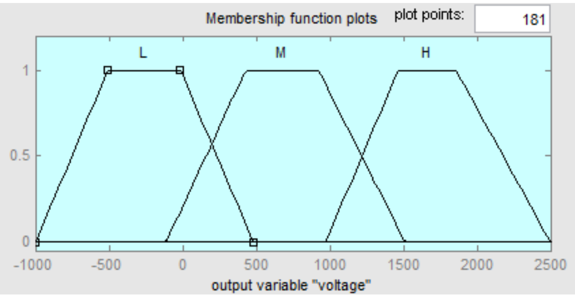

Fig.3.b. output

The linguistic variables of the fuzzy sets need to be defined which are represented:
(i) Input variables:
• Error (e)
The membership function:
Small S (e), Medium M (e) and Big B (e).
(ii) Output variables:
• Voltage
The membership function:
Small (S), Medium (M) and Big (B).

- *Fuzzy Rule Execution*

The fuzzy rules are actually experience rules based on expertise or operators' long-time experiences. Fig. shows the fuzzy rules table. The variables are processed by an inference engine which executes 3 (3X1) fuzzy rules. Each rule is expressed in the form as shown in figure

Figure.4. Structure of rule editor

- *Fuzzy inference mechanism*

In general, inference is a process of obtaining new knowledge through existing knowledge. In the context of fuzzy logic control system, it can be defined as a process to obtain the final result of combination of the result of each rule in fuzzy value. There are many methods to perform fuzzy inference method and the most common two of them are Mamdani and Takagi Sugeno Kang method. Mamdani's fuzzy inference method is the most commonly seen inference method which was introduced by Mamdani and Assilian (1975). An example of a Mamdani inference system is shown in Figure.

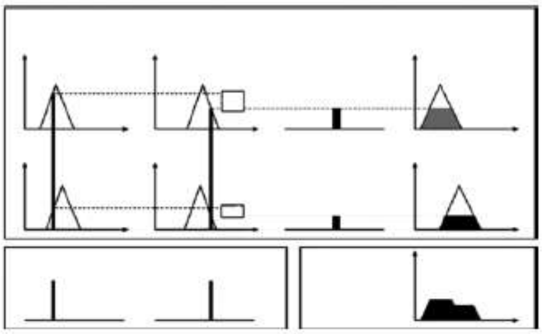

Fig.5. A two input, two rule Mamdani FIS with crisp inputs

To compute the output of this FIS given the inputs, six steps have to be followed.

1. Determining a set of fuzzy rules
2. Fuzzifying the inputs using the input membership functions
3. Combining the fuzzified inputs according to the fuzzy rules to establish rule strength
4. Finding the consequence of the rule by combining the rule strength and the output membership function
5. Combining the consequences to get an output distribution

6. Defuzzifying the output distribution (this step is only if a crisp output (class) is needed).
Mamdani method is intuitive, widespread acceptance and well suited to human input.

- *Defuzzification*

Defuzzification is a process that maps a fuzzy set to a crisp set and has attracted far less attention than other processes involved in fuzzy systems and technologies. Four most common defuzzification methods.
• Max membership method
• Center of gravity method
• Weight average method
• Mean-max membership method

MATLAB/Fuzzy Logic Toolbox is used to simulate FLC which can be integrated into simulations with Simulink. The FLC designed through the FIS editor is transferred to Matlab-Workspace by the command “Export to Workspace”. Then, Simulink environment provides a direct access to the FLC through the Matlab-Workspace in BLDC motor drive simulation.

IV. SIMULATION RESULTS

The simulation results includes variation of different parameters of BLDC motor like hall signals in fig(6.a), , three phase stator currents in fig(6.b), three phase back EMF’s in fig(6.c), electromagnetic torque in fig(6.d), rotor speed in fig(6.e) and rotor angle/position in fig(6.f) with respect to time.

Table.1: Specifications of a BLDC motor

No. of poles	4
Stator resistance	3.18 Ω
Stator inductance	8.5 mH
Moment of inertia	0.0005 Kg-M^2
Frictional force	0.000002 N-M-sec
Torque constant	0.318 N-M/A
Rated speed	3000 rpm
Rated torque	1.5 N-M

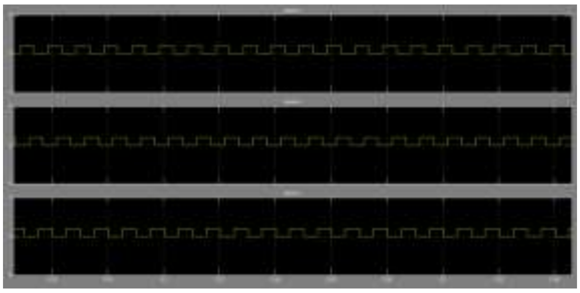

Fig.6.a. Hall signals of a BLDC motor

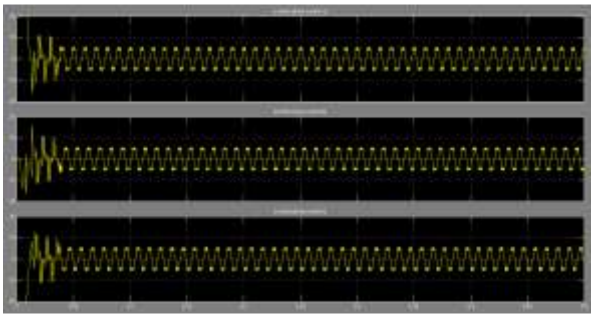

Fig.6.b. Stator currents of a BLDC motor

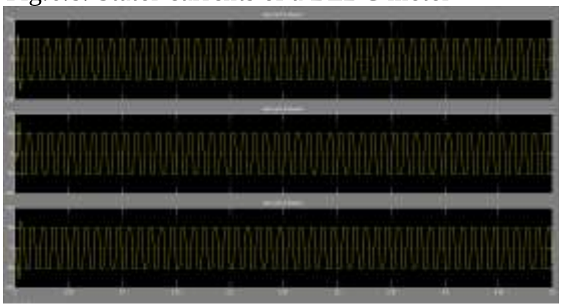

Fig.6.c. Back emf’s of a BLDC motor

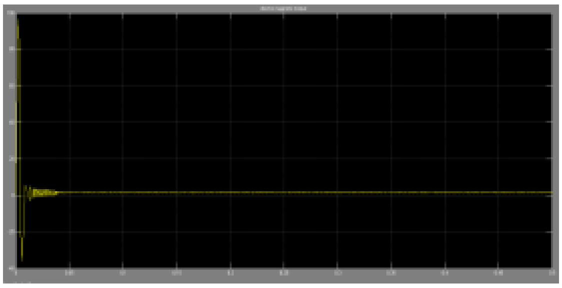

Fig.6.d. Electro Magnetic Torque of a BLDC motor

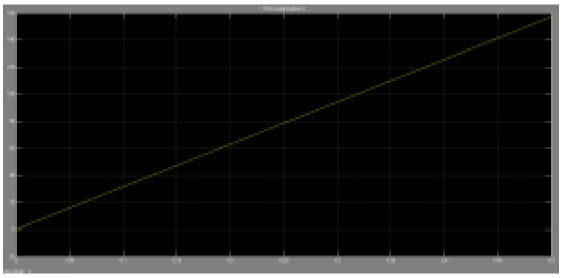

Fig.6.e. Rotor position of a BLDC motor on before of position control

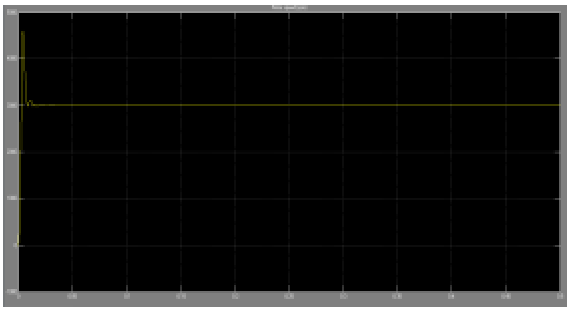

Fig.6.f. Rotor speed of a BLDC motor

The simulation diagram of an actuation system by using a PID controller is shown in fig.7. When applying a 4v of step response to a actuation system, the output of an actuator is shown in fig.7.a and speed of a bldc motor in fig.7.b. When applying a 4v of sine wave to an actuation system, the output

ISSN: 2278 – 7798
International Journal of Science, Engineering and Technology Research (IJSETR)
Volume 5, Issue 8, August 2016

of an actuator is shown in fig.7.c and speed of a bldc motor in fig.7.d.

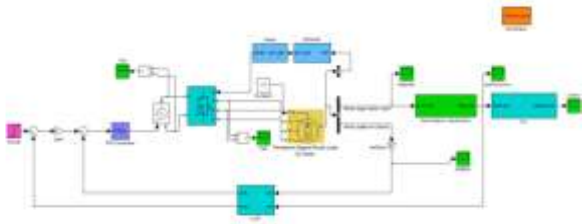

Fig.7. Simulink diagram of a BLDC based actuator by using PID controller

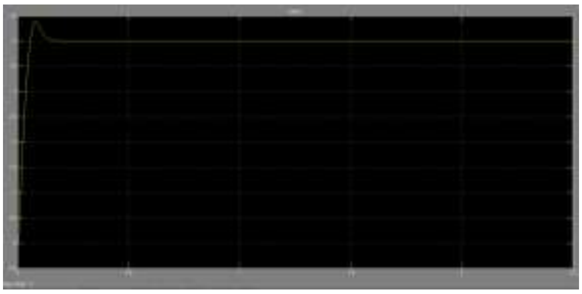

Fig.7.a. output of an actuator when applying the 4v step response

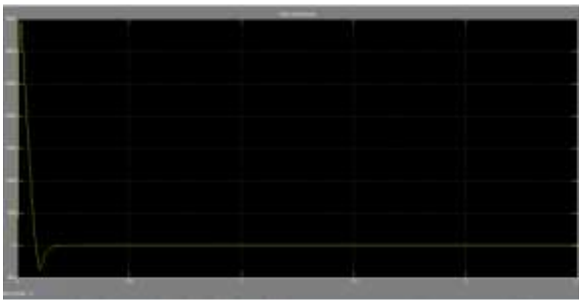

Fig.7.b. speed response of a bldc-based actuator when applying the 4v step response

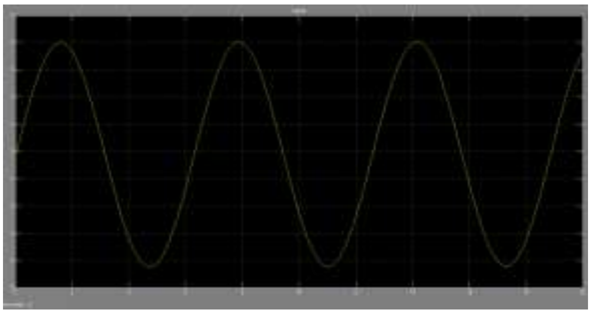

Fig.7.c. output of an actuator when applying the 4v sine wave

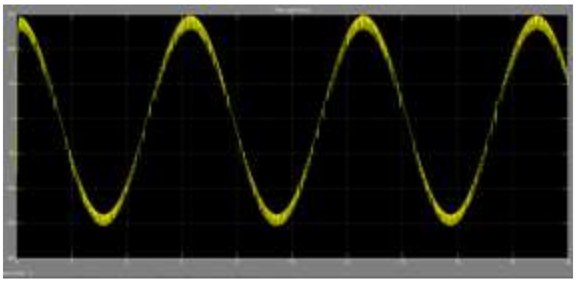

Fig.7.d. speed response of a bldc-based actuator when applying the 4v sine wave

The simulation diagram of an actuation system by using a Fuzzy Logic Controller is shown in fig.8. When applying a 4v of step response to a actuation system, the output of an actuator is shown in fig. (8.a) and speed of a bldc motor in fig (8.b). When applying a 4v of sine wave to an actuation system, the output of an actuator is shown in fig (8.c) and speed of a bldc motor in fig (8.d).

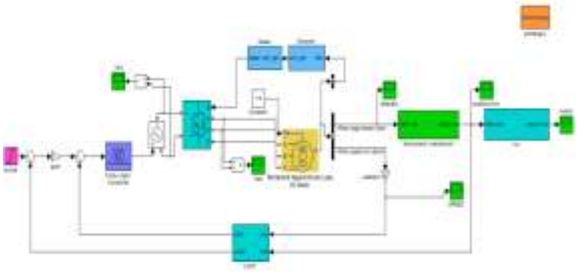

Fig.8 Simulink diagram of a BLDC based actuator by using FLC controller.

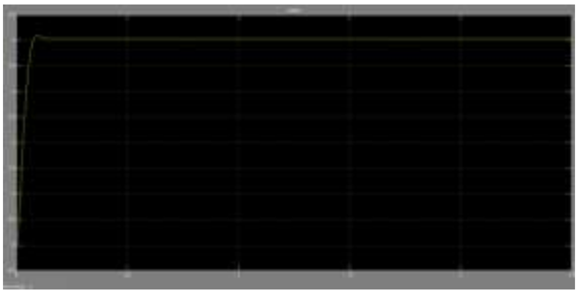

Fig.8.a. output of an actuator when applying the 4v step response

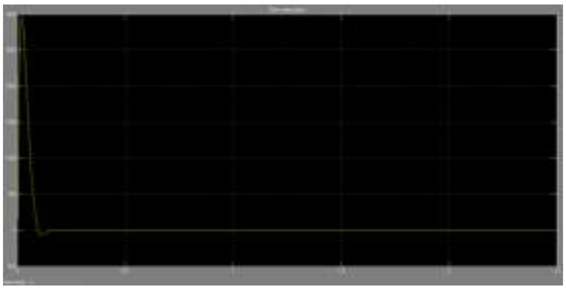

Fig.8.b. speed response of a bldc-based actuator When applying the 4v step response

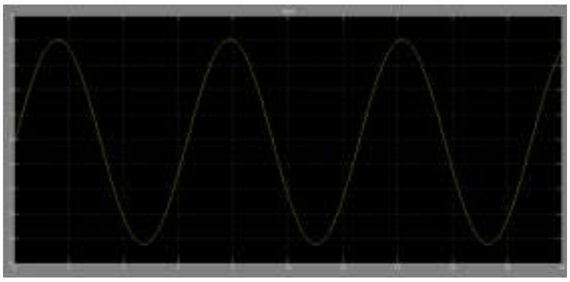

Fig.8.c. output of an actuator when applying the 4v sine wave

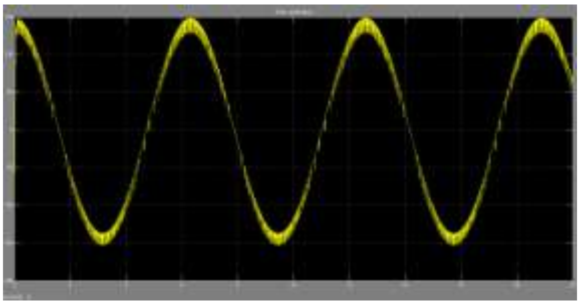

Fig.8.d. speed response of a bldc-based actuator when applying the 4v sine wave.

The dynamic characteristics of an actuation system when operating with different values of torques is shown in table.2

Table.2.performance of an actuator

Torque	Controllers	Time domain characteristics		
		Rise time (T_r sec)	Settling time (T_s sec)	Peak over shoot (%)
0.1	PID	0.0481	2.606	93.00
	FLC	0.0692	1.426	48.50
0.2	PID	0.0346	1.231	81.25
	FLC	0.0423	0.738	40.50
0.5	PID	0.0327	0.456	55.75
	FLC	0.0481	0.315	22.00
1.0	PID	0.0365	0.244	28.00
	FLC	0.0442	0.236	15.50
1.5	PID	0.0403	0.175	10.00
	FLC	0.0422	0.092	0

V. CONCLUSION

A fuzzy logic controller (FLC) has been employed for the position control of PMBLDC based actuator and analysis of results of the performance of a fuzzy controller using mamdani method is presented. Simulation results showed that FLC control reduces overshoot and settling time and this controller also provides more efficient closed loop response for position control of actuation system.

.

REFERENCES

[1] Andreas Wilde, Peter Schneider, Wellington Presto, "Modeling Electro-Mechanical Actuators", Ieee Conference On Computer Aided Control Systems Design Munich, Germany, October 4-6, 2006

[2] Kaiping Yu*, Hong Guo, Dayu Wang, Lanfeng Li, "Design Of Multi-Redundancy Electro-Mechanical Actuator Controller With Dsp And Fpga", International Conference On Electrical Machines And Systems 2007, Oct. 8~11, Seoul, Korea

[3] Yongling Pu, Weixing Zhou, Ye Zhang, Lianqiang Zheng, And Yao Pang, "Robust And Perfect Tracking Control For Direct Drive Ema System", International Conference On Intelligent Control And Information Processing August 13-15,2010 - Dalian, China

[4] Yan Li, Dongyang Research on Electro-Mechanical, "Actuator System Based On Discrete-Time Variable Structure Control", 2010 Second Wri Global Congress On Intelligent Systems.

[5] Jeong-Hoi Gu, Chi-Young Song And Sang-Yeal Lee, "A New Velocity Measurement Method Using Linear Type Hall-Effect Sensor For An Electro-Mechanical Fin Actuator",Sice Annual Confference 2007 , Kagwa University, Japan

[6] Liliana De Lillo "A 20 Kw Matrix Converter Drive System For An Electro-Mechanical Aircraft (Ema) Actuator" Power Electronics Machines And Control Group,University Of Nottingham Nottingham, Uk