Mathematical modeling and analysis of an Actuator for aerospace vehicle

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Abstract- *Electro-mechanical actuator is a servo system used for various applications in different areas of science and technology. The typical applications of electro mechanical actuator are in the areas of robotics, medical, industrial automation an aerospace. The application of the actuator in this project is for an aerospace vehicle.*

The electro-mechanical actuators are used in aerospace vehicle is used for attitude control of vehicle. Actuators used in aerospace vehicle require very accurate positioning accuracy, high dynamic requirements. Hence the actuator design in aerospace vehicle is very critical and plays very important role in total performance of the vehicle. The actuators are to be designed very compactly with high torque to weight ratio and meeting high dynamic performance.
The electromechnical actuator is used to move the fin. First selecting the actuator and then deciding the different parameter such as armature resistance, torque constant, back e.m.f constant. Based on these parameter the designer will design the actuator.

Keywords- Electromechanical actuator, brushless dc motor, position feedback

I. INTRODUCTION

A missile is aerodynamically controlled for pitch, yaw and roll by four rear mounted control surfaces operated by four individually controlled Actuators. The preference is given to Electro Mechanical Actuation System, Due to space limitation and low power requirement. The Actuators and control surfaces are mounted at the tail end of the missile.

The actuator assembly consists of the Brushless DC Motor, Gear Trains, Feedback Sensor, Electronics controller; all these sub systems are packed together in a closed box. At the missile boat tail inner surface this box is mounted. Four such actuators are mounted in four sectors of two concentric cylinders between nozzle housing and the boat tail.

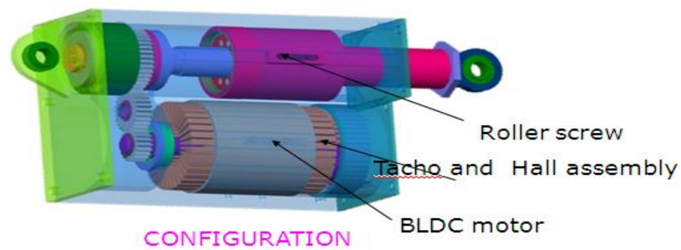

Figure 1: Typical Electro Mechanical Actuator used in Missiles

1.1 Brushless dc motor

Bldc motors are one of the synchronous motor. Synchronous motor means that the magnetic field generated by the stator and the magnetic fields generated by the rotor rotate at the similar frequency. In Bldc motors there is no “slip” that is normally seen in induction motors. Bldc motors come in single-phase, 2-phase and 3-phase configurations. Corresponding to its type, the stator has the same number of windings. Out of these, 3-phase motors are widely used and the most popular.

Hall sensor is used in a brushless dc motor, the commutation of a bldc motor is controlled electronically. To rotate the bldc motor, the stator windings should be energized in a sequence and for this it is important to know the rotor position in order to understand which winding will be energized. To sense the rotor position Hall Effect sensors are used and they are embedded into the stator.

1.2 Gears

The wheels which mesh with each other through interlocking teeth are called as Gears .and if there is rotation of one wheel then it will produces rotation on the other wheel without any slip between them. The shape of the gear teeth is important in order to produce a smooth transfer of the motion.

In this actuator we are using only Spur Gears. In Spur gears the teeth are parallel to the axis and are used for transmitting power between two parallel shafts. They are simple in construction, cost less and easy to manufacture. They have excellent precision rating and highest efficiency.

They are used in high speed and high load application in all types of trains and a wide range of velocity ratios.

1.3 Rotary potentiometer

Rotary potentiometer is a conductive plastic film potentiometer and is used on the output shaft with infinite resolution as a feedback sensor for closed loop control of the Actuator.

1.4 Servo electronic

The position of the output shaft is electronically controlled according to the input signal. The potentiometer sense the error between the command and the actual position of the output shaft which is proportional to the voltage applied to the motor. Tachogenerator and LVDT are used as feedback transducers.

II. MATHEMATICAL MODELING AND SIMULATION

The design of actuator involves multi disciplinary knowledge which includes mechanical design of actuator components, Electrical machine design (for prime mover design, i.e. Dc motor or BLDC motor or solenoid valve), Power electronics design (for controller of actuator) and control systems (for control system design of actuator).

2.1 Control system analysis:

Armature resistance of the motor plays very important role in the motor performance as well as control system performance of the actuator. For motor, its better to have less resistance as it will reduce the copper losses and increases the efficiency of motor. Also the drop in speed torque characteristics will be reduced if armature resistance is less.

The importance of resistance is very important from control system point of view as it is one of the parameter which affects the damping of the system. Hence the armature resistance is very important parameter both from the motor and control system point of view for the actuation system. Analysis is carried out with 4 different values of resistances varying from 0.125 to 0.425 ohms.

III. MATHEMATICAL MODELING OF COMPLETE ACTUATOR

The actuator consist of a bldc motor as a prime mover, reduction gear and transmission mechanism with ball screw and actuator is connected to control surface by means of linkage mechanism.

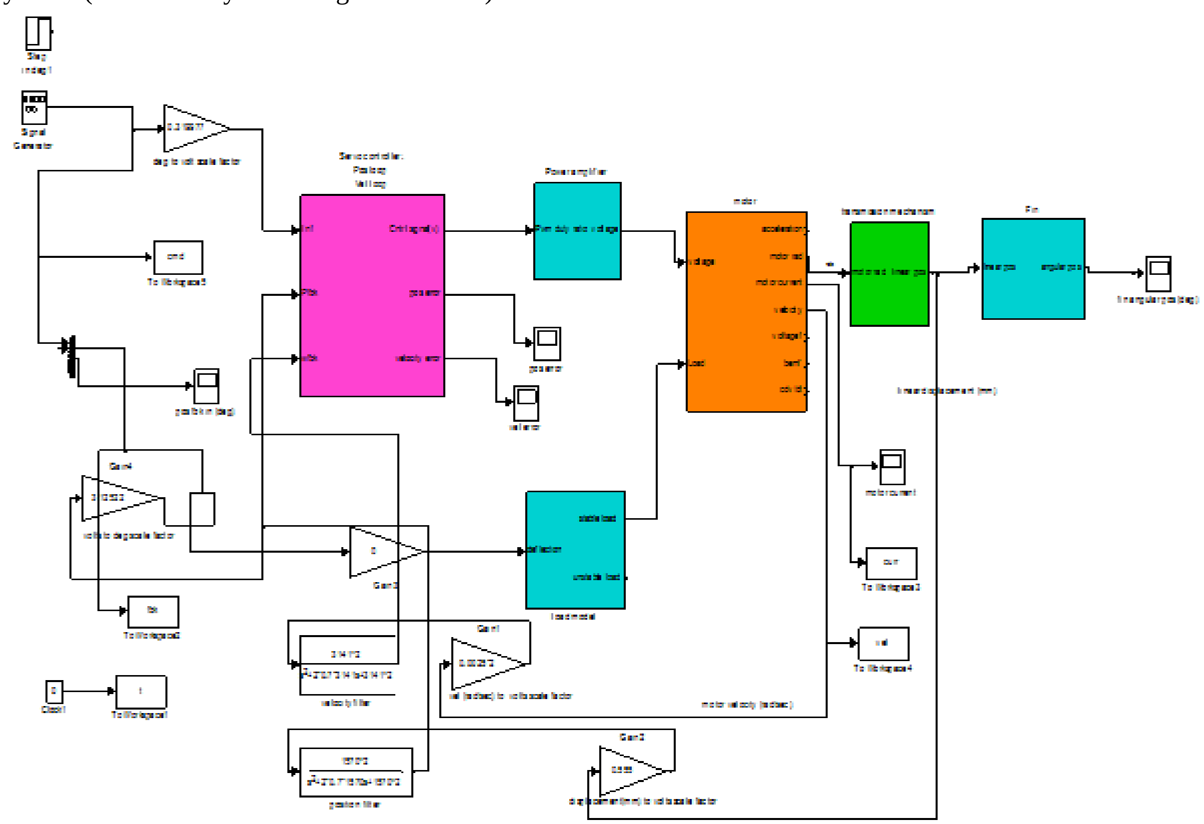

Figure 2: Actuator model

The parameter required for modelling are

Motor supply Voltage (V) : 56 V

Armature resistance (R_a) : varying between(.125 to 0.425) Ω

Armature inductance (L_a) : 0.18 mH

Torque constant(K_t) : 0.0425 N-m/A

Back Emf constant (K_b) : 0.0425 V/rad/sec

Gear ratio (gear) : 2.2

Lead of Ball Screw (lead) : 5 mm/rev

Motor inertia (J_m) : $0.51*10^{-5}$ kg-m^2

Following equations apply for the motor Speed and torque:

$$V-E_b = I_aR_a+L_a dIa/dt \quad .$$

$$T_m(t) = k_t * I_a \quad .$$

$$E_b(t) = K_bW_{n.} \; .$$

The actuator is connected to fin tip through linkage mechanism. The actuator force is converted to torque through the linkage mechanism. The load torque is given by

$$T_1 = J_1(d0_n^2/dt^2) + B_1(d0_n/dt) + K_10_n.$$

Where $0_n = \theta_n$ = nozzle angular position.

In all the plots red is position command, blue is position feedback, magenta is current feedback. (The current feedback is scaled by 1/8 Amps)

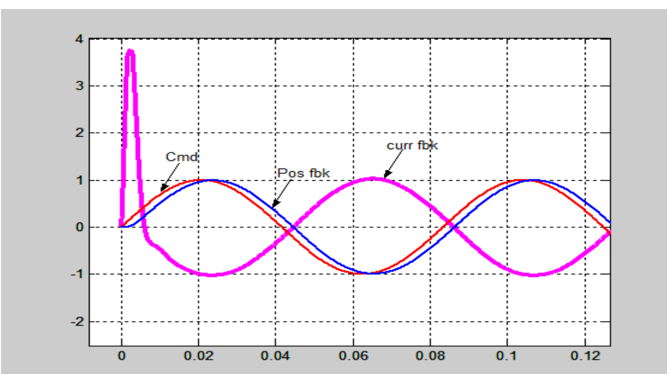

Figure 3: Sinusoidal response showing current, position command and position feedback

In the figures the command is sine command of 1v and 12Hz, with Ra: 0.425 ohms, Kt=Kb=0.035, J=$0.51*10^{-5}$Kg-m^2.

Since the frequency is less than the bandwidth frequency, the command and feedback are following closely and current is also not saturating.

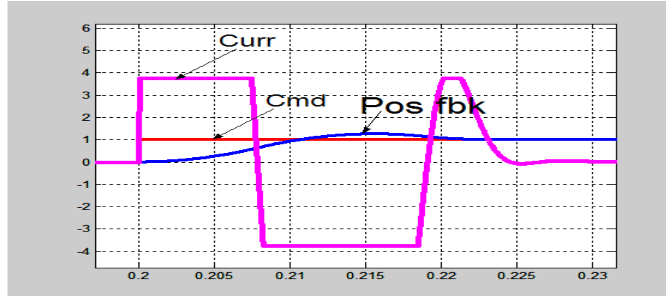

Figure 4: Step response with current fbk (Ra: 0.425ohms, Kt=Kb=0.035, J=$0.51*10^{-5}$Kg-m2)

The above graphs shows the step response, it can be seen that the over shoot is also very high than the specified limit.

In all the above analysis we have seen that the resistance effects the damping of the system and less resistance reduces the damping and hence the feedback is oscillatory, but the bandwidth didn't improved with increase in the resistance. The reason being the bandwidth is the function of speed and acceleration, hence Kt and Kb variation can be studies to see the effect on the bandwidth.

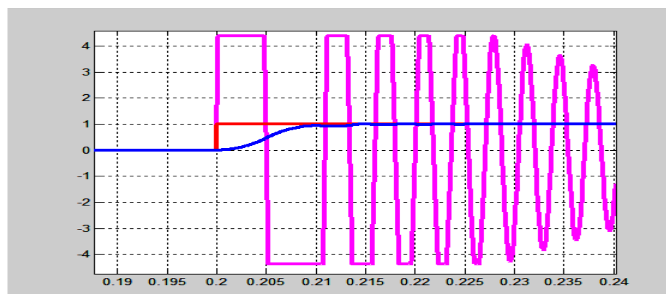

Figure 5: step response with kt=kb=0.055, Ra: 0.125ohms (I limit: 35Amps)

From the above plots step response plot, overshoot is almost negligible, settling time is 10msec.

IV. CONCLUSION

Complete mathematical modeling of BLDC motor based electro mechanical actuator has been carried out including the transmission mechanism, feedback sensor dynamics and filters. The simulation of the model is carried out in mat lab/simulink.

Complete control system analysis carried out by changing important critical parameters to arrive at the step response and frequency response characteristics of the system. Based on the analysis the designer can be able to select actuator components to meet the required control specifications of the actuator.

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