

Design of Closed Loop Electro Mechanical Actuation System

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ABSTRACT: An Actuator is basically a position servo control system used in industries and vehicles. A rotary electro mechanical actuation system is an angular positioning system used in aerospace applications such as control of rudder and ailerons of aero planes and control of control surfaces, jet vanes, etc. This position loop system is to steer the vehicle to move in required direction.

A servo controller is a driver to accurately control the position of the actuation system by getting the command signals from the on-board computer of the vehicle. It involves a class of DSP controller optimized for digital motor motion control and power conversion applications.

In this thesis, Closed loop Rotary Electro Mechanical Actuating system is designed for the derived specifications by using the CAD software UNIGRAPHICS, and simulated the design with the help of FEA software ANSYS and MATLAB.

KEYWORDS: Actuator, ANSYS, CAD, DSP controller, UNIGRAPHICS.

I. INTRODUCTION

This document covers the description, design, inputs and specifications of the Actuation System for aerodynamic control of an Aero-vehicle. The document also describes the actuator specifications, mechanical components, BLDC motor, position sensor and the control system including simulation.

1.1. Actuator

An actuator is a mechanism that converts energy into motion. It can also be used to apply a force. An actuator typically is a mechanical device that takes energy, usually created by air, electricity, or liquid, and converts that into some kind of motion. That motion can be anything from blocking to clamping to ejecting. Actuators are typically used in manufacturing or industrial applications and may be used in things like motors, pumps, switches, and valves. The most common type of actuator is powered by air — the pneumatic cylinder, also known as the air cylinder. Air cylinders are air-tight cylinders, typically made from metal, that use the energy of compressed air to move a piston. Air cylinders are most commonly used in manufacturing and assembly processes. Grippers, which are used in robotics, use actuators driven by compressed air to work much like human fingers. Actuators can also be powered by electricity or hydraulics. Much like there are air cylinders, there are also electric cylinders and hydraulic cylinders where the cylinder converts electricity or hydraulics into motion. Hydraulic cylinders are often used in certain types of vehicles.

Many actuators have more than one type of power source. Solenoid valves, for example, can be powered by air and electricity. Electricity powers the solenoid, and the solenoid, powered by air actuates the valve. Alternatively, the solenoid can be powered by hydraulics and electricity. Actuators can create a linear motion, rotary motion, or oscillatory motion. That is, they can create motion in one direction, in a circular motion, or in opposite directions at regular intervals. Hydraulic and air cylinders can be classified as single acting, meaning that the energy source causes movement in one direction and a spring is used for the other direction. Alternatively, these cylinders can be double acting cylinders, meaning the energy is used in two directions. While actuators are typically discussed in terms of mechanical implements, muscles are sometimes given as an example of an actuator. Energy (e.g., created by eating carbohydrates) is converted by the muscle (i.e., the actuator) into motion (e.g., kicking a ball).

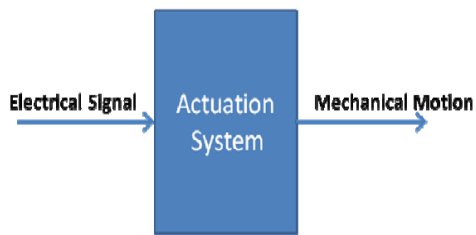


Fig 1. Mechanism of Actuator

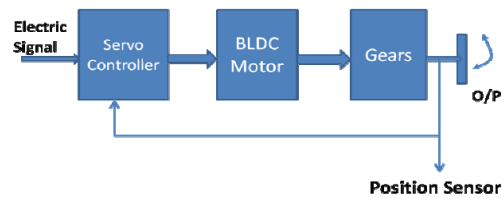


Fig 2. Block diagram of actuator

II. DESCRIPTION AND CONFIGURATION OF ACTUATOR

The actuator configuration is as follows....

- Prime mover is a 3 phase BLDC motor.
- Transmission by Planetary gear train.
- Position feedback element is Rotary potentiometer.
- Servo control by DSP controller.

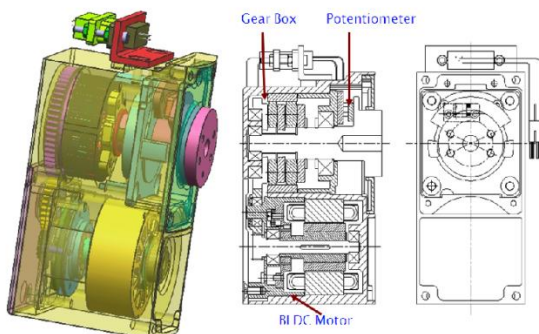


Fig 3. Electro mechanical actuator

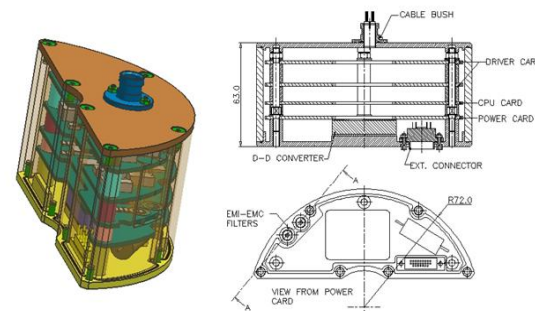


Fig 4. Servo controller

III. CONCEPTUAL DESIGN

Based on the available space, torque and speed specifications, the rated torque of the motor is taken as 0.075Nm. To get a rated torque of 2.5Nm, the gear ratio of the gear box is taken as approx.50:1. To meet this gear ratio at output shaft, the gear train taken is one simple gear train and two stage planetary gear train. Keeping in view of available space and above consideration that is taken, the conceptual design and final modeling is done in CAD software unigraphics.

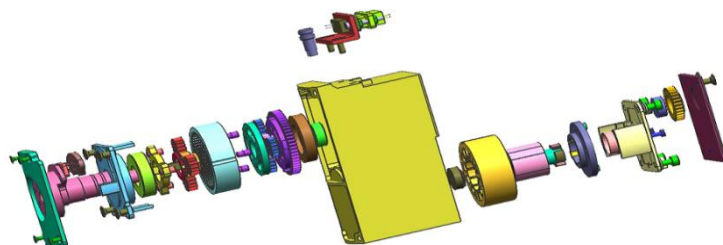


Fig 5. Exploded view of electro mechanical actuator

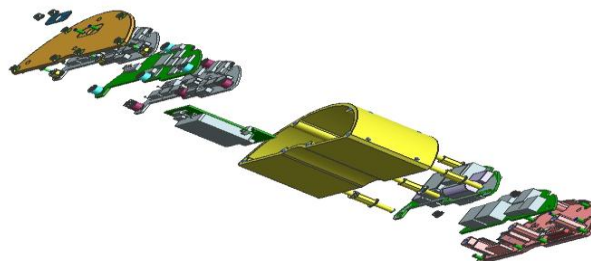


Fig 6. Exploded view of servo controller

IV. DESIGN OF ACTUATOR

4.1 Defining motor inputs for motor selection

To achieve the given specifications, the gear ratio is taken as 50 and after conceptual design by taking module of 0.6, the final gear ratio achieved is 49.25:1

4.2 Gear box efficiency

$$\text{Efficiency \%} = E = 100 - P$$

$$P = \frac{50 \mu}{F} \frac{(H_s^2 + H_t^2)}{(H_s + H_t)}$$

$$H_s = (R_g \pm 1) \left[\sqrt{\left(\frac{R_s}{R_g}\right)^2 - \cos^2 \alpha} - \sin \alpha \right]$$

$$H_t = \left(\frac{R_g \pm 1}{R_g}\right) \left[\sqrt{\left(\frac{r_o}{r_p}\right)^2 - \cos^2 \alpha} - \sin \alpha \right]$$

Gear Type	F	sign of R _g term
External spur	cos α	(R _g +1)
Internal Spur	α	(R _g -1)

- S —
- P
- u
- r
- G

gear Efficiency = 96.13 %

- Planetary Gear Efficiency = 79.28%
- Total Gear Box Efficiency = 76.21%
- Stall torque of motor should be considered greater than 0.1183 N-m for 49.25 gear
- Rated torque of motor should be considered greater than 0.0679 N-m for 49.25

4.3 Gear box design

From outline specifications and space availability the gear box sizes finalized as Ø40 x 41 and selected Gear Ratio as 49.25

The total gear ratio divided to spur gear reduction and planetary gear reduction.

- Spur Gear Reduction = 3.8
- Planetary Gear Reduction for two stages = 12.96
- Each Stage Planetary Reduction = 3.6

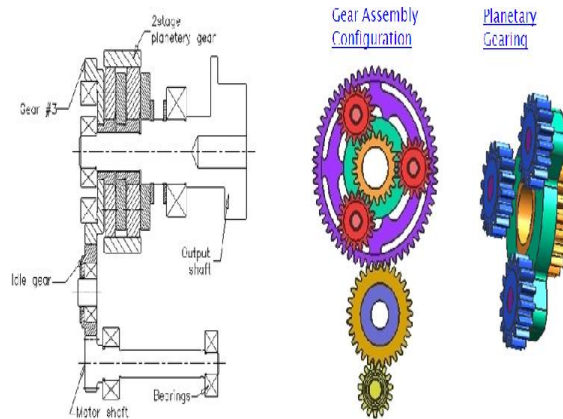


Fig 7. Gear box construction

1.3.1 spur gear & planetary gear design

Spur Gear Parameters			
SL No.	Gear	No. of teeth	PCD
1	Motor O/P Gear	15	9
2	Idle Gear	29	17.4
3	Gear # 3	57	34.2

Table 1. Spur gear design parameters

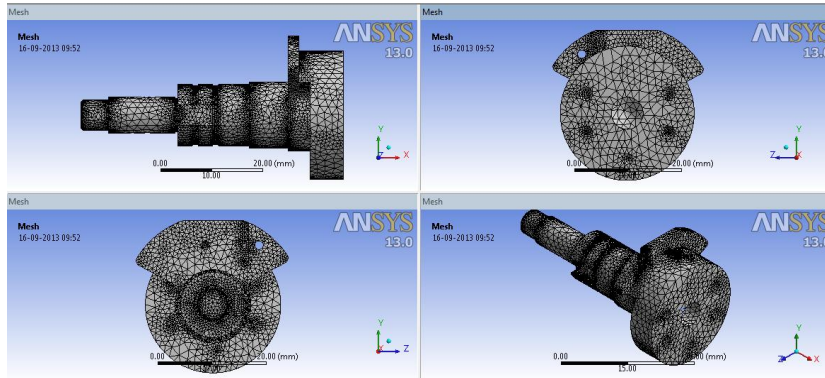
Planetary Gears parameters			
SL No.	Gear	No. of Teeth	PCD
1	Ring Gear	52	31.2
2	Sun Gear	20	12
3	Planet Gear	16	9.6

Table 2. Planetary gear design parameters

- If consider 3Nos of Planet Gears of 2.6 (Excluding chamfers) mm face width than Factor of safety = 5
- If consider 5Nos of Planet Gears of 4 mm (Excluding chamfers) face width than Factor of safety = 2.2 (Since we are calculated for Peak Torque)

V. STRUCTURAL ANALYSIS OF OUTPUT SHAFT

- Type of element: tetrahedron in ansys



- Stress developed in the shaft due twisting and bending force material : SS 420
- No. of nodes: 262440
- No. of elements: 181487

Fig 8. Meshing of output shaft

5.1 Supports & Load Conditions:

Cylindrical support at bearing surfaces Fixed support at key way Moment at output of shaft (4500 N mm)

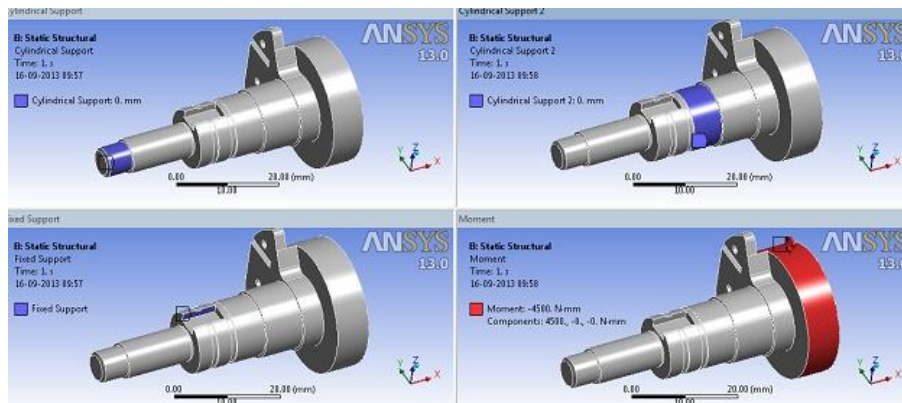


Fig 9. Supports and Loads on output shaft

5.2 Solution:

Equivalent stress (Von Mises)

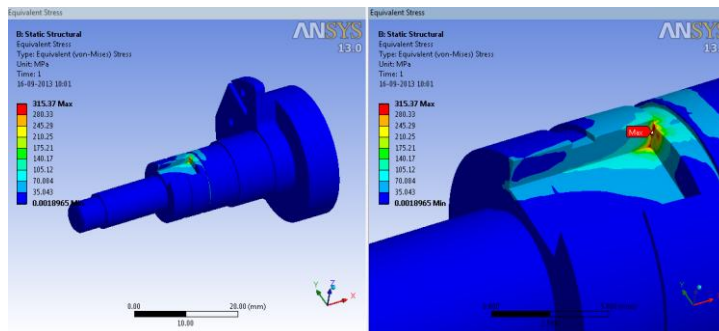


Fig 10. Equivalent stresses on output shaft

Part	Allowable stress(N/mm ²)	Results in ANSYS(N/mm ²),MAX
Output shaft	448	315.37

Table-3

Structural analysis of housing in ansys

- Stress developed in the housing due to twisting(motor and bending load):
- Material : 1. Output shaft= SS420
- 2. Housing= Al(HE 15)
- Type of element : Tetrahedron
- No. of nodes: 226198
- No. of Elements : 146290
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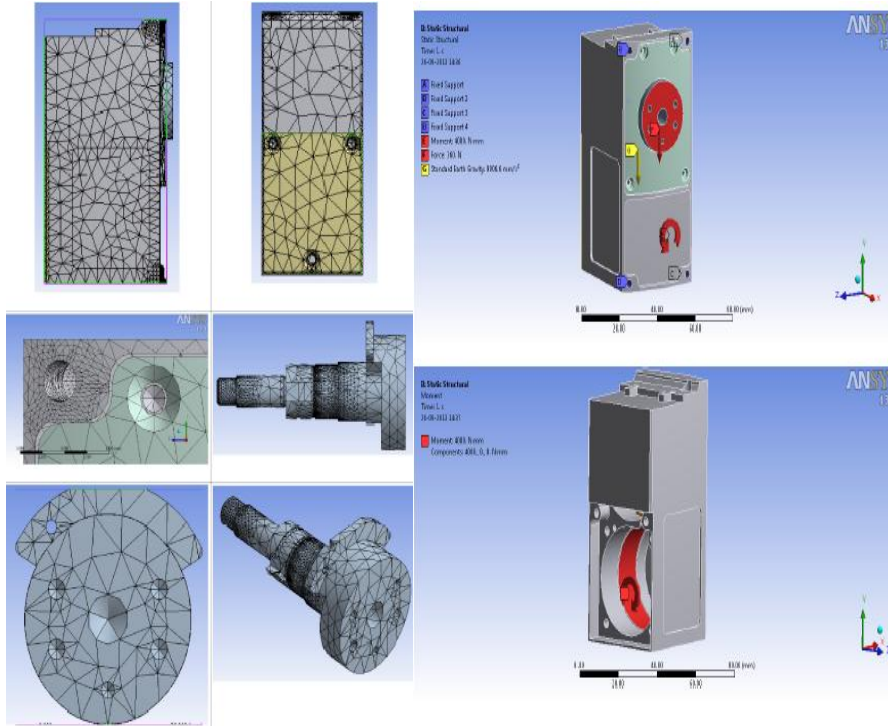


Fig 11. Meshing of stator housing and output shaft Fig 12. Boundary conditions on housing

6.1 Boundary Conditions

- 2 bearings are fixed to housing
- Output shaft is fixed to 2 bearings
- Bending load applied at shaft is 360N
- Moment applied at stator position is 4.5Nm

6.2 Solution

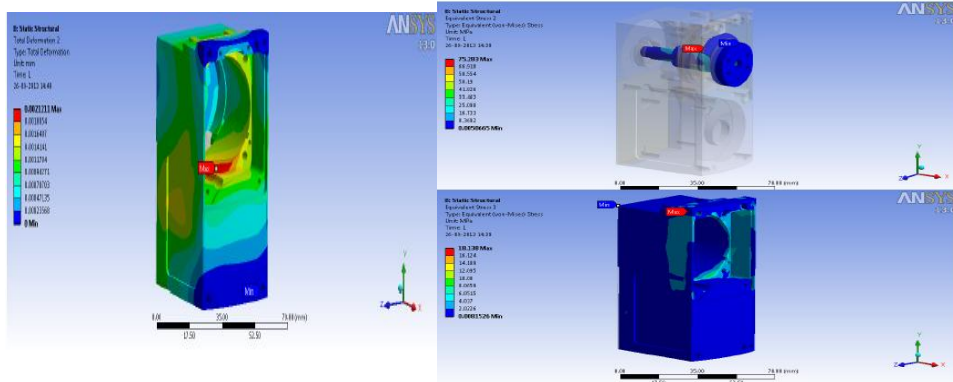


Fig 13. Equivalent stress on housing

Part	Allowable stress(N/mm ²)	Results in ANSYS(N/mm ²),MAX
Output shaft	448	75.283
Housing	37.5	18.138

Table- 4

VI. CONTROL SYSTEM SIMULATION BY USING MAT LAB

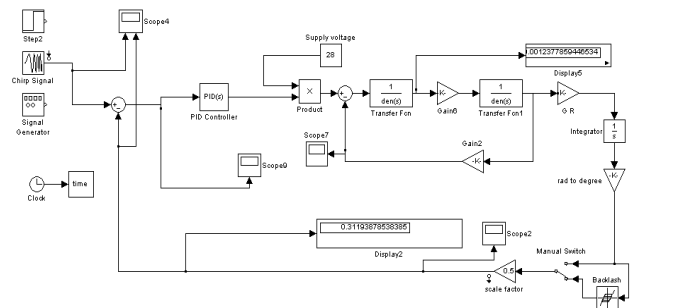


Fig 14. Actuator simulation model

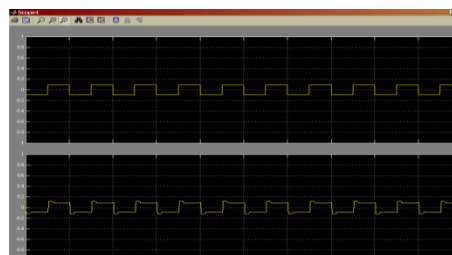


Fig 15. Dead band response at 90mV Based on system parameters given on table and explanation given at control block diagram, dynamic simulation model was prepared on matlab simulink and controller gains were tuned to its optimal values to meet required position output as well as frequency response specifications given.

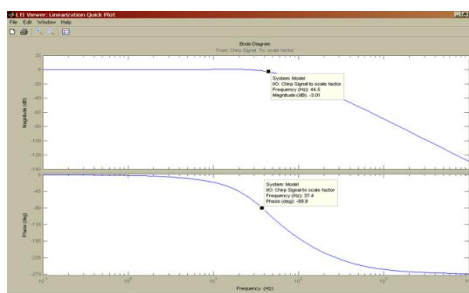


Fig 16. Frequency response at 1V

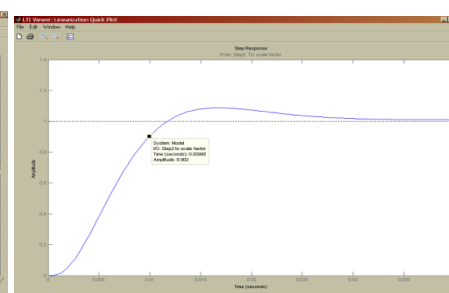


Fig 17. Step response

From the frequency response of the closed loop system, we get Bandwidth of the system at -90deg phase is equal to 37.4Hz

6.1 STEP RESPONSE

Applying step input to the model, response of the system as shown below.

Observations:

SL No.	Description	Specification value	Simulation Value	Remarks
1	Rise time	Less than 12 m sec	9.95m sec	

Table-5

VII. CONCLUSION

Based on the results achieved in ANSYS and MATLAB we conclude that the closed loop electro mechanical actuation system will meet the required design specification.

VIII. FUTURE SCOPE

Electro Pneumatic, Electro Hydraulic, and Hot Gas System etc. can be replaced with the Electro mechanical actuation system. An accurate position movement and sensing can be achieved with the Electro mechanical actuation systems. The high precision machinery and equipments in which Electro mechanical actuation systems used are robots, CNC machines, missile systems, spacecrafts etc. The Electro mechanical actuation system has to fulfill the requirements of being able to function reliably in a typical environment involving adverse and extreme climatic conditions, field transportation and storage conditions imposing severe vibrations, bumps, mechanical shocks and extreme temperature conditions.

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