

# Finite Element Analysis and Optimization of Aircraft Electro Mechanical Actuator

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**Abstract-** Electro-mechanical actuators (EMA) are finding increasing use in aerospace applications, especially with the trend towards all all-electric aircraft and spacecraft designs. However, electro-mechanical actuators still lack the knowledge base accumulated for other fielded actuator types, particularly with regard to fault detection and characterization. Methods for data acquisition and validation of algorithms on EMA test stands are described. A variety of condition indicators were developed that enabled detection, identification, and isolation among the various fault modes. A diagnostic algorithm based on an artificial neural network is shown to operate successfully using these condition indicators and furthermore, robustness of these diagnostic routines to sensor faults is demonstrated by showing their ability to distinguish between them and component failures. The analysis and optimization of the EMA has been done with the help of solid works simulation software. EMA is designed and checked properly to achieve the requirements. Before optimization the mass of the EMA is 1022.92 gm and after optimization the mass of the EMA is yielded to 303.08 gm. Optimization is done by reducing the diameter of ball screw and reducing the thickness of gear of EMA. After optimization we got maximum stress induced in the ball screw and the gear are 62 MPa and 42.1 MPa respectively which are less than the yield stress of 505 MPa. In addition decrease in size of the ball screw and the gear leads to component failure or deformations are induced. The total weight reduced is 719.84 gm. Hence the cost is saved by Rs. 5,188,104 per year.

**Key words:** maximum deformation, maximum stress, and optimization

## 1. INTRODUCTION

Actuation is more and more used in all air, space and self-protective vehicle (Aircraft, helicopters, space craft, ground vehicles, robots) to situation parts (ex mirrors in telescopes), deploy equipment (ex antennas) and to direct the position and outlook Of the vehicle (ex flaps in

helicopters). Actuation is very often protection critical system

In aircraft control power- by -wire (PBW) actuation is the next major advance. Just as the fly-by-wire flight control system replace the need for mechanical interface power-by-wire actuators replace the need for inner hydraulic systems. Manage power comes openly from the aircraft electrical systems. Central hydraulic systems are complex and hard to maintain. Removing these systems would greatly lessen the amount of support apparatus and recruits required to continue and active current air and space vehicles. In addition, PBW actuators have the possible to be more efficient than their hydraulic counter parts. A central hydraulic system must generate and maintain important hydraulic pressure (3,000 to 6,000 pounds per square inch) at all times, apart from of demand. PBW actuators only use electrical power when required. Finally, PBW actuation systems can be finished far more liability tolerant than those depending on a central hydraulic supply. Once a hydraulic line is compromised, it usually leads to the loss of that entire hydraulic circuit. As a result, multiple hydraulic circuits are necessary to preserve some level of being without a job. With a PBW system, a failed actuator can simply be switched off, separating the problem to a single surface.

## 1. Analysis materials and methods

### 2.1 analysis material

The key purpose of production and precipitation harden learn is to observe the full microstructure and property of nanocrystalline 7075 Aluminium alloy in which the 7075 Aluminium alloy fine particles is synthesizes by automatic alloying and then it is combine by burning pressing technique then the structural and stage changes during automatic alloying, annealing and precipitation hardening was deliberated. The 7075 Aluminium alloys are the most usually used in automotive, aerospace, military, sports and marine industries because of their beneficial properties mainly high definite stiffness, light heaviness, high definite strength, high-quality strength and brilliant rust resistance and a new class of Aluminium based alloys that is nanocrystalline are receiving a great concentration over the previous few years and this type of alloys are equipped by

using two techniques those are Rapid Solidification (RS) or Sevier Plastic Deformation (SPD).

The most frequent technique used is Sevier plastic deformation which includes accumulated rolling, equivalent canal angular pressing and automatic alloying. The automatic alloying process consists of common cold welding and fracturing of fine particles combination in an important energy ball mill and it is extensively used as a processing path for synthesis of a diversity of phases such as intermetallic, ceramics, composites and nanostructure material.

The powders of Aluminium, Zinc, Copper and Magnesium are used as beginning materials in arrangement to manufacture a nanostructure of 7075 Aluminium alloy and the automatic alloying process was carried out in a high force planetary ball mill at room temperature under argon environment, the rotation speed of 500 rpm and 10:1 ball to fine particles ratio is used. The fine particles are acidic bonded to one another mainly when the material is yielding more because of high the plasticity experienced by them while grinding course and then a course control agent also referred as oil or surfactant of 0.2 wt percent of stearic acid is additional to the attention while crushing to reduce the joining effect.

while producing disk of 50 mm diameter and 15 mm thickness the milled 7075 Aluminium fine particles were squashed at 500°C under 400 MPa uniaxial die and chilled at air and the time for burning pressing was 20 min and in order to eliminate the pores configuration the pressure on the sample was removed after chilling down to 300°C and then Archimedes system is used to calculate the bulk density of complex sample.

While studying the anatomical changing of powder while grinding, burning pressing, annealing a X-ray diffractometry is used in which a diffractometer of 30 kV with Cu-K $\alpha$  radiation of wavelength 0.14506 Nano meter is used for estimate and this sample is well-known in 2 $\theta$  ranges.

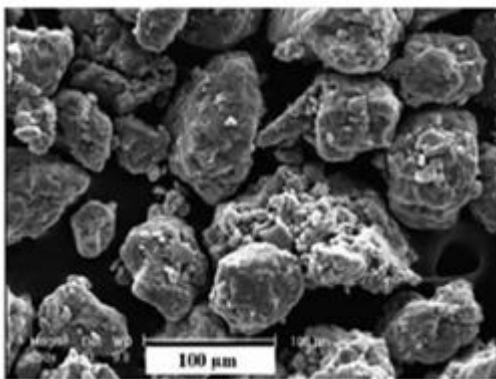


Fig. 1 7075 Aluminium alloy

### 2.3 properties of the 7075 aluminium alloy

Table 2.1 properties of the 7075 aluminium alloy

Elastic modulus	7200 Mpa
Poisson's ratio	0.33
Tensile strength	570 Mpa
Yield strength	505 Mpa
Mass density	2810kg/m <sup>3</sup>

### 2.4 solid works simulation

This design test the computerization application software with completely included with Solid Works and this software also uses FEM in the direction of simulating the prepared state of affairs of a design, it is also make the designer to confirm the consistency of their design in order to discover the best potential solution and also it would reduce the time to market by verify the design on the workstation in its place of using expensive and time overpowering field examination.

Solid works simulation software provide the solution for stress, frequency, thermal, buckling and optimization analysis which is mechanical by quick solvers and also used by that software we would get lot of profit and this is very to use and some of the profits are scheduled below:

1. This will decrease the costs by examination the model in workstation instead in place of using costly and time overpowering field examinations.
2. Using this software the product of development cycles were enlarged with growing the market time.
3. This will increases the manufactured goods with quick examination of several perceptions hence it would offer more time to think for new design.

Ahead of going to analysis the following factors are to be defined;

1. Replica dimensions
2. Type of study and associated options to identify the analysis intent
3. objects properties
4. Loads and limit condition

Recreation of modeling is a method of increasing and investigate of a significant work piece to compute the activity and it is used to help out the designers and engineers

for accepting that whether under which circumstances the part is going to be unsuccessful and at which type of loads and constraint are applied and also this software help to expect fluid flow and heat relocate problems.

The replication modeling pursue a following procedure

1. The first step is 2D or 3D CAD tool is used to enhance a model to symbolize for design.
2. Then a 3D mesh is generating for examination calculation function.
3. Then finite element analysis data was defined it includes loads, constraints based upon the analysis type such as structural, thermal and then boundary conditions are applied to the model in order to show how the model will be restrained during use.

### 3. Calculation results

The calculation and validation of the ball screw after the optimization process

#### For Ball screw:

Diameter of ball screw,  $d=24$  mm

Length of ball screw,  $L=90$  mm

Elastic modulus,  $E=7200$  N/mm<sup>2</sup>

Force applied,  $F=20468.8$  N

$$\text{Area (A)} = \frac{\pi}{4} (d)^2 = \frac{\pi}{4} (24)^2 = 452.16 \text{ mm}^2$$

$$\text{Stress } (\sigma) = \frac{F}{A} = \frac{20468.8}{452.16} = 45.26 \text{ N/mm}^2$$

$$\text{Deflection } (\delta) = \frac{F \times L}{A \times E} = \frac{20468.8 \times 90}{452.16 \times 7200} = 0.56 \text{ mm}$$

The calculation and validation of the gear after optimization process

#### For Gear:

Width of the gear,  $b=20$  mm

Diameter of the gear,  $d=2.38$  mm

Force applied,  $F=850$  N

Height of the teeth gear,  $h=3$  mm

Depth tapered teeth gear,  $y=.5$  mm

$$\text{Moment of inertia (I)} = \frac{bd^3}{12} = \frac{20 \times 2.38^3}{12}$$

$$= 22.46 \text{ mm}^4$$

$$\text{Maximum bending moment (M)} = F \times h = 850 \times 3$$

$$= 2550 \text{ N-mm}$$

$$\text{Stress } (\sigma) = \frac{M \times y}{I} = \frac{2550 \times .5}{22.46} = 56.76 \text{ N/mm}^2$$

## 4. Modeling, Analysis and validation of ball screw and gear

### 4.1 Analysis of the Ball Screw before optimization

#### 4.1.1 Create the model

The model is created in the solid work simulation is 3D by using software therefore the geometry of the model is as shown below

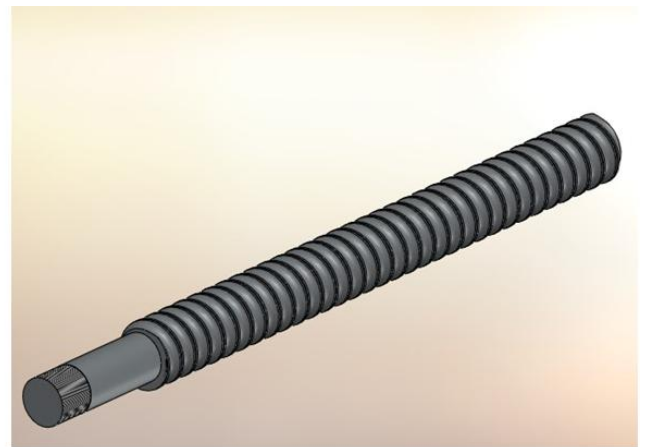


Fig 2 Geometry of the model

#### 4.1.2 Meshing

Once the geometric model is created then the program subdivides the model into small pieces of simple shapes called elements which are connected at common points called as nodes and the process of subdividing the model into small pieces is called meshing. In this COSMOS Works creates a mesh of solid elements that is tetrahedron and which is appropriate for bulky or complex 3D models and the accuracy of the solution is depends on the quality of mesh, finer the mesh better the accuracy and the meshed model was shown below

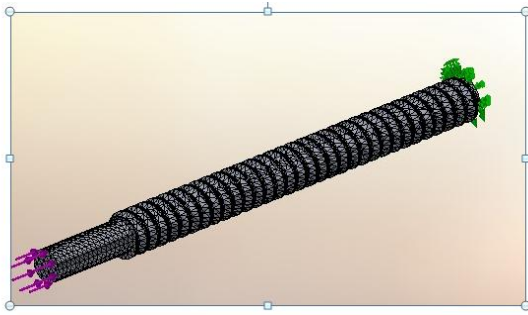


Fig 3 Meshing of ball screw

4.1.3 Force applied

20468.8 N compression force is applied on the ball screw, as shown in below figure

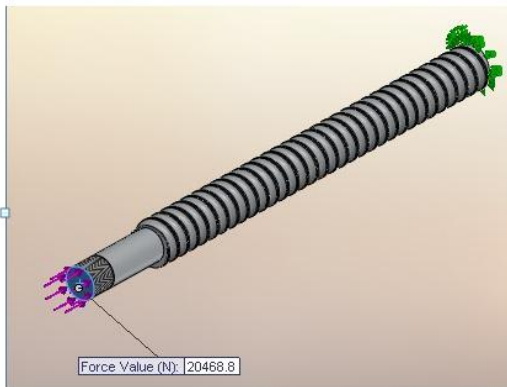


Fig 4 Force applied on the ball screw

4.1.4 Stress and deformation

After applying the loads the stresses and deformations are induced. The loads are applied on the lines, nodes, key points or model. If the load is applied on the model it is transmitted to the nodes of the body.

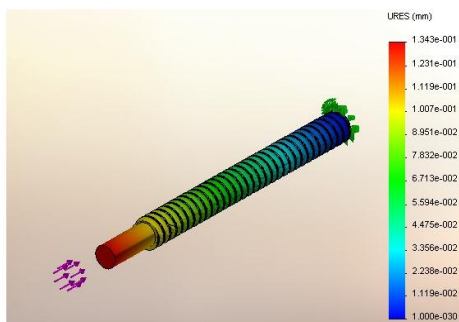


Fig 5 Deformation on the ball screw

From the solid works simulation analysis we have got the maximum deflection is 0.01343 mm.

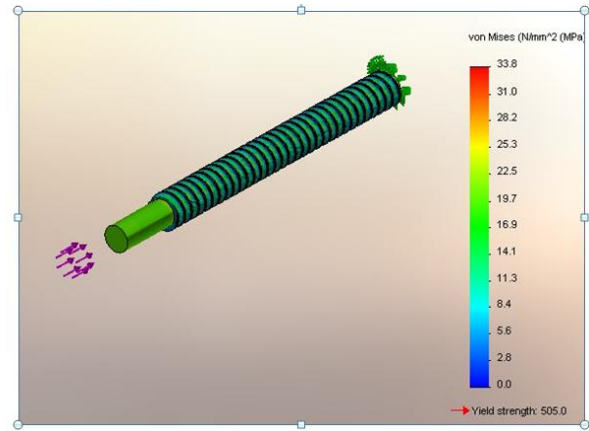


Fig 6 Stress induced on the ball screw

From the solid works simulation analysis we have got the maximum stress is 33.8 MPa.

4.1.5 Results- Values are achieved from analysis

'Maximum stress' build up on the ball screw= 33.8 MPa

'Maximum deformation' induced = 0.1343 mm

The maximum stress (33.8MPa) induced in the ball screw is less than the yield stress of 7075 aluminium alloy that is 505 MPa.

4.2 Analysis the Gear before optimization

4.2.1 Create the model

The model is created in the solid work simulation is 3D by using software therefore the geometry of the model is as shown below.

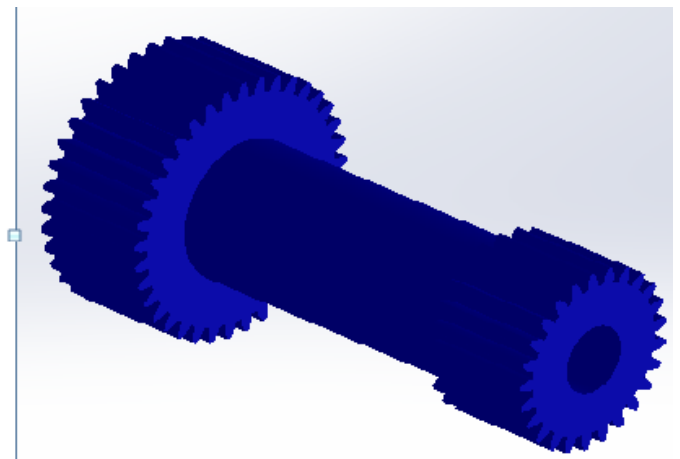


Fig 7 Geometry of the gear

#### 4.2.2 Meshing

The mesh is solid type mesh. The total nodes and elements are 23876 and 14156 respectively.

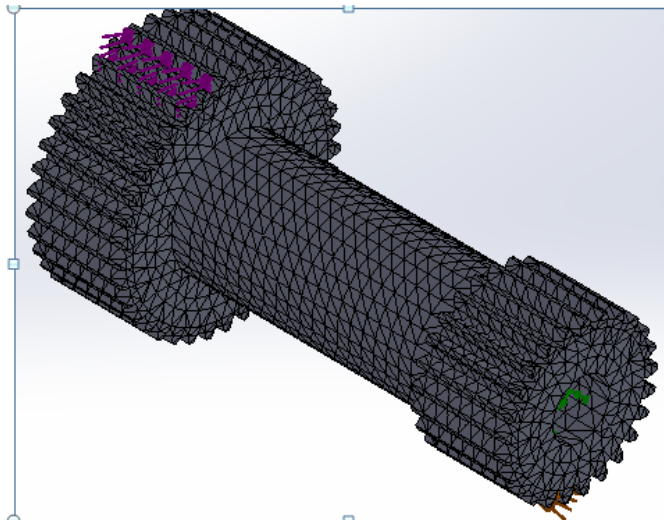


Fig 8 Meshing of gear

#### 4.2.3 Force applied

850 N transmission forces are applied on the gear, as shown in below figure.

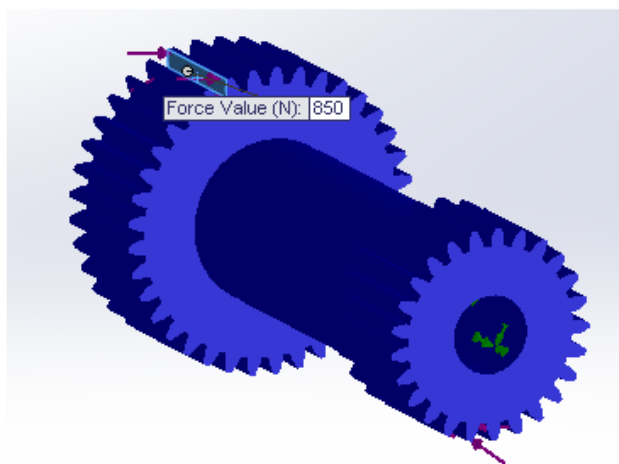


Fig 9 Force applied on the gear

#### 4.2.2.4 Stress and deformation

After applying the loads the stresses and deformations are induced. The loads are applied on the lines, nodes, key points or model. If the load is applied on the model it is transmitted to the nodes of the body.

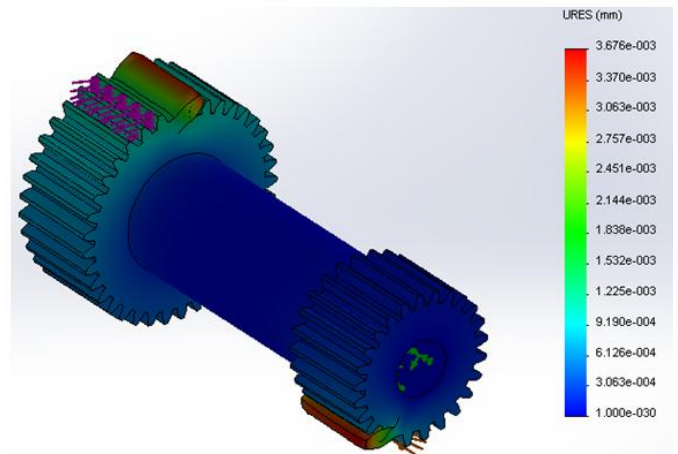


Fig 10 Deformation of the gear

From the solid works simulation analysis we have got the maximum deflection is 0.0033676 mm.

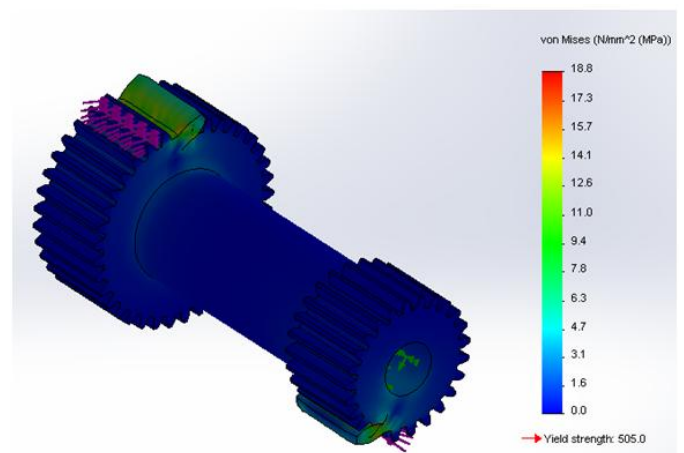


Fig 11 stress induced on the gear

From the solid works simulation analysis we have got the maximum stress is 18.8 MPa.

#### 4.2.2.5 Results- Values are achieved from analysis

'Maximum stress' build up on the gear= 18.8 MPa

'Maximum deformation' induced = 0.003676 mm

The maximum stress (18.8 MPa) induced in the gear is less than the yield stress of 7075 aluminium alloy that is 505 MPa.

### 4.3 Analysis of the Assembly before optimization

#### 4.3.1 Create the model

The model is created in the solid work simulation is 3D by using software therefore the geometry of the model is as shown below.

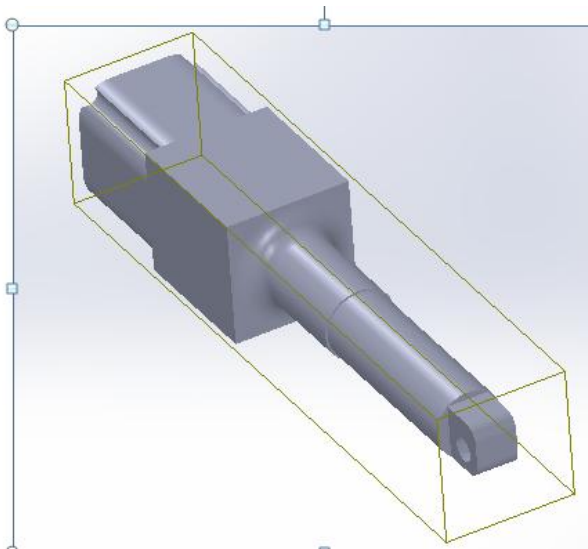


Fig 12 Geometry of the assembly

#### 4.3.2 Meshing

Once the geometric model is created then the program subdivides the model into small pieces of simple shapes called as nodes and the process of subdividing the model into small pieces is called meshing. In this COSMOS Works creates a mesh of solid elements that is tetrahedron and which is appropriate for bulky or complex 3D models and the accuracy of the solution is depends on the quality of mesh, finer the mesh better the accuracy and the meshed model was shown below,

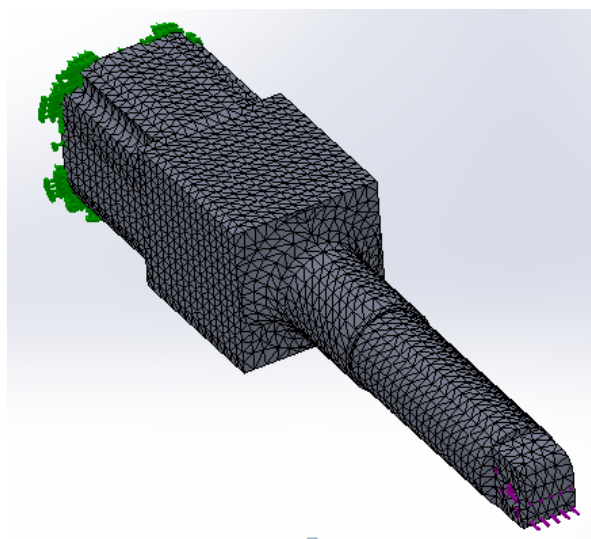


Fig 13 meshing of the assembly

#### 4.3.3 Force applied

20468.8 N compression force is applied on the assembly, as shown in below figure

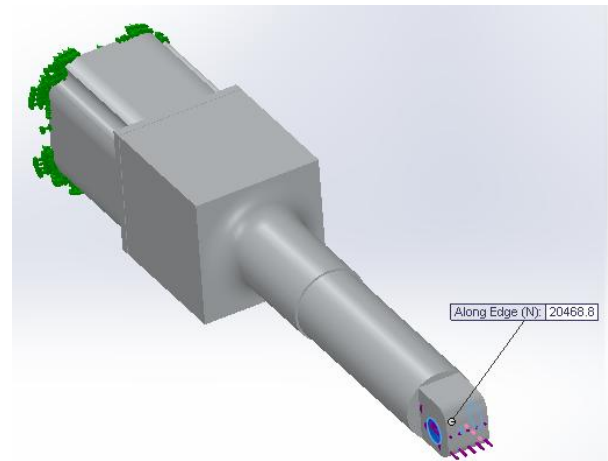


Fig 14 force applied on the assembly

#### 4.3.4 Stress and deformation

After applying the loads the stresses and deformations are induced. The loads are applied on the lines, nodes, key points or model. If the load is applied on the model it is transmitted to the nodes of the body.

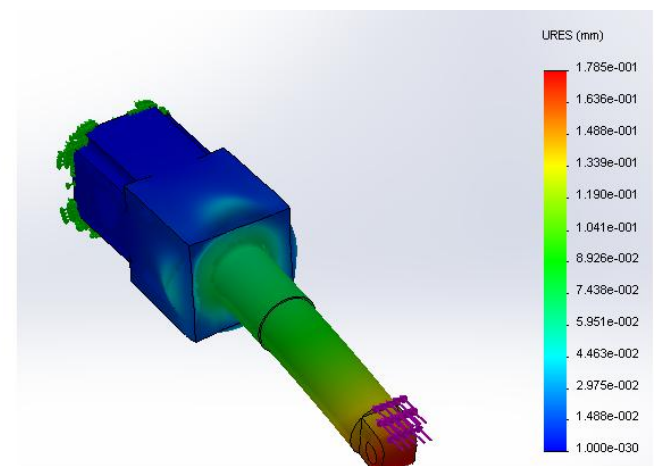


Fig 15 deformation of the assembly

From the solid works simulation analysis we have got the maximum deflection is 0.1785 mm.

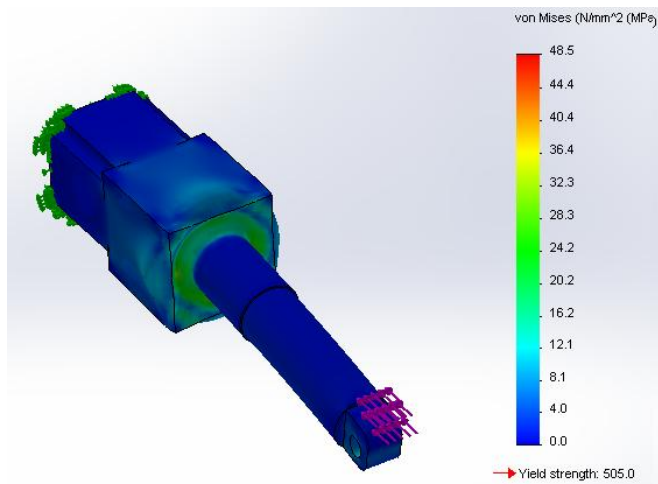


Fig 16 Stress induced on assembly

#### 4.3.5 Results- Values are achieved from analysis

'Maximum stress' build up on the assembly= 48.5 MPa

'Maximum deformation' induced = 0.1785 mm

The maximum stress (48.5 MPa) induced in the assembly is less than the yield stress of 7075 aluminium alloy that is 505 MPa.

### 4.4 Optimization

Optimization is defined as minimizing or maximizing the function by selecting input principles from known set and calculates value of the function. It is mainly depends on designers and it also defined as maximize or minimize the manufactured goods, reduce the manufacture cost, improve the excellence. Minimizing the manufactured goods size or introducing the fewer cost material it should not be alter the presentation of the replica. It includes obtaining the great quality of the manufactured goods at minimum manufacture cost and introducing the new properties in there manufactured goods. The purchaser required getting very well quality of material or manufactured goods at most spirited cost accessible in market.

In this project we optimize the electro mechanical actuator of the diameter of the ball screw and the thickness of the gear.

### 4.5 Analysis of the ball screw after optimization

#### 4.5.1 Create the model

. In the optimization process reducing the diameter of the ball screw, the model is created in the solid work simulation is 3D by using software therefore the geometry of the model is as shown below

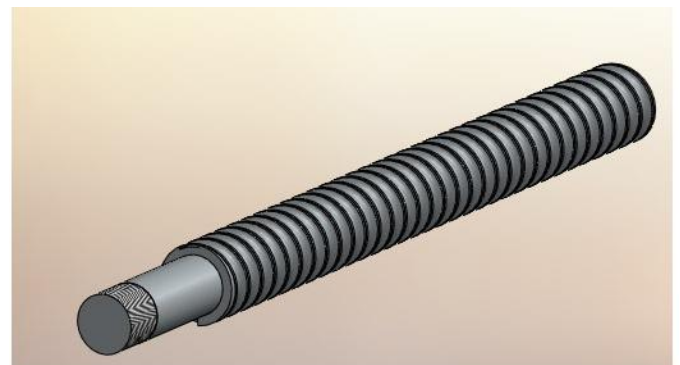


Fig 17 Geometry of the ball screw

#### 4.5.2 Meshing

The mesh is solid type mesh. The total nodes and elements are 19567 and 9457 respectively.

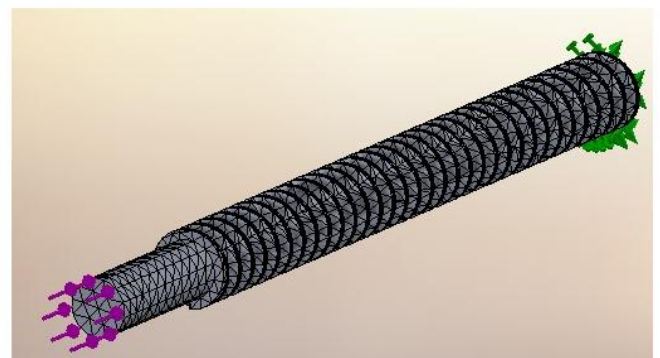


Fig 18 Meshing of the ball screw

#### 4.5.3 Force applied

20468.8 N compression force is applied on the ball screw, as shown in below figure

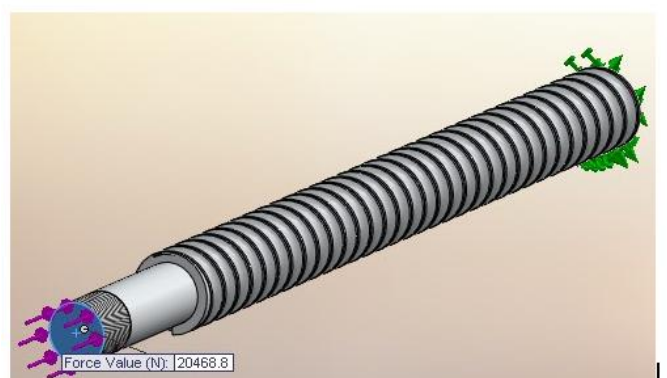
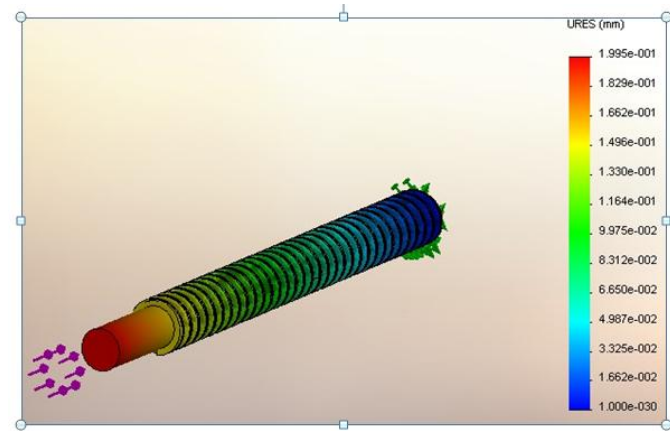


Fig 19 Force applied on the ball screw

#### 4.5.4 Stress and deformation

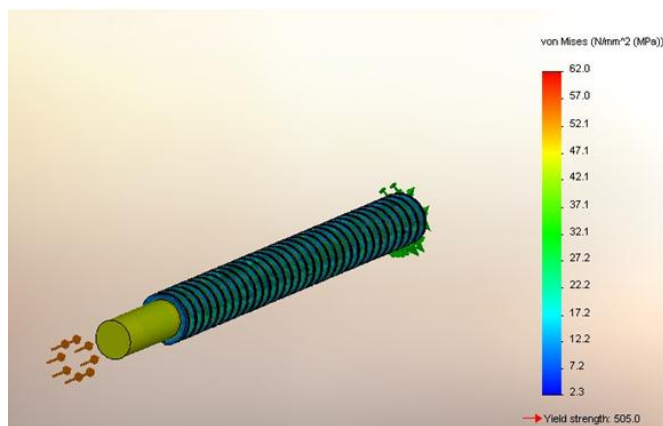
After applying the loads the stresses and deformations are induced. The loads are applied on the lines, nodes, key

points or model. If the load is applied on the model it is transmitted to the nodes of the body.



**Fig 20** Deformation of the ball screw

After the optimization process, from the solid works simulation analysis we have got the maximum deflection is 0.1995 mm.



**Fig 21** Stress induced on the ball screw

After the optimization process, from the solid works simulation analysis we have got the maximum stress is 62 MPa.

**4.5.5 results-** Values are achieved from analysis after optimization.

'Maximum stress, build up on the assembly= 62 MPa

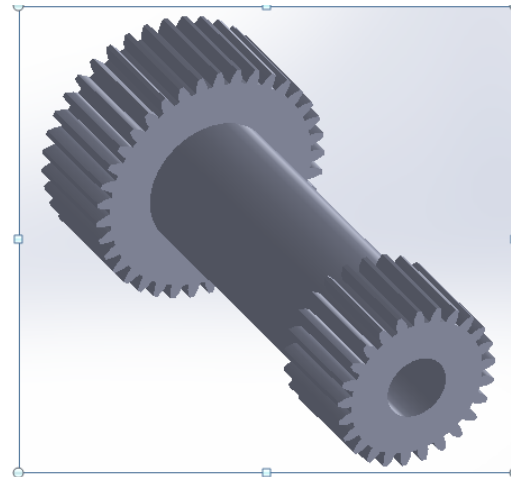
'Maximum deformation, induced = 0.1995 mm

The maximum stress (62 MPa) induced in the ball screw is less than the yield stress of 7075 aluminium alloy that is 505 MPa.

#### 4.6 Analysis of the Gear after optimization

##### 4.6.1 Create the model

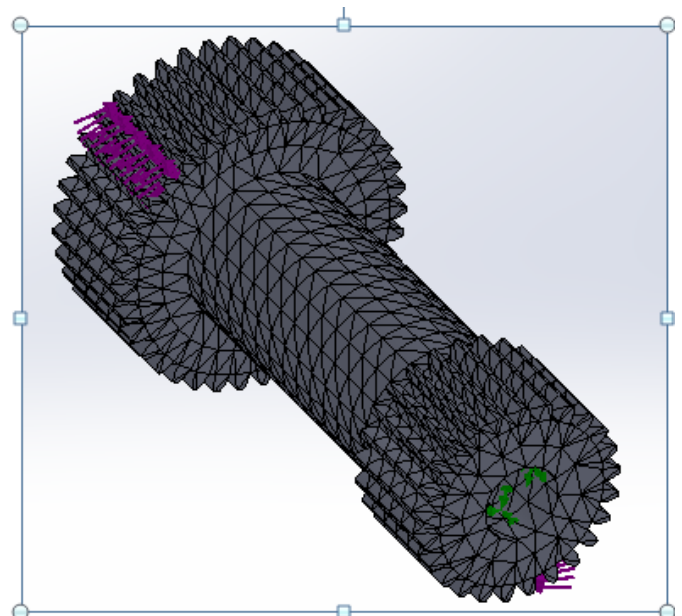
. In the optimization process reducing the thickness of the gear, the model is created in the solid work simulation is 3D by using software therefore the geometry of the model is as shown below



**Fig 22** Geometry of the gear

##### 4.6.2 Meshing

The mesh is solid type mesh. The total nodes and elements are 21459 and 11367 respectively.



**Fig 23** Meshing of the gear



#### 4.6.3 Force applied

850 N transmission forces are applied on the gear, as shown in below figure

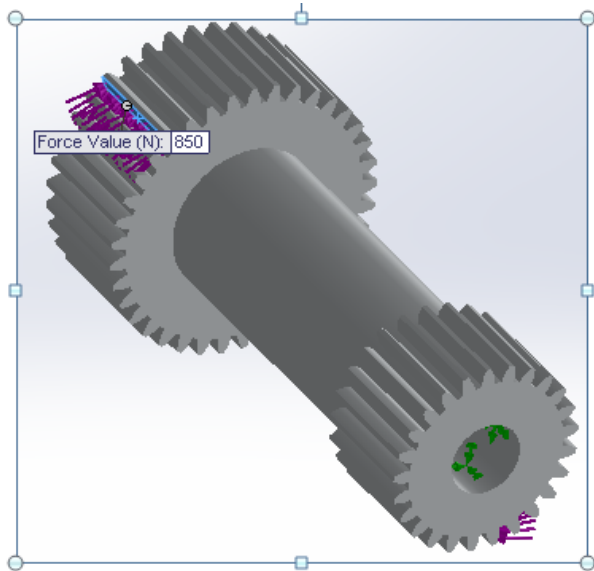


Fig 24 Force applied on the gear

#### 4.6.4 Stress and deformation

After applying the loads the stresses and deformations are induced. The loads are applied on the lines, nodes, key points or model. If the load is applied on the model it is transmitted to the nodes of the body.

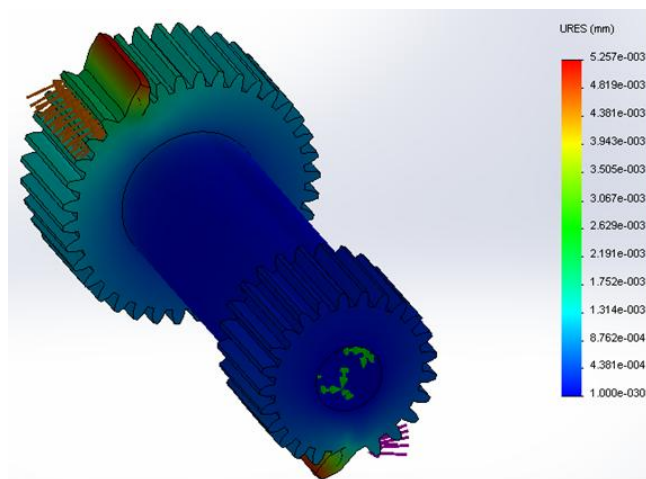


Fig 25 Deformation of the gear

After the optimization process, from the solid works simulation analysis we have got the maximum deflection is 0.005257 mm.

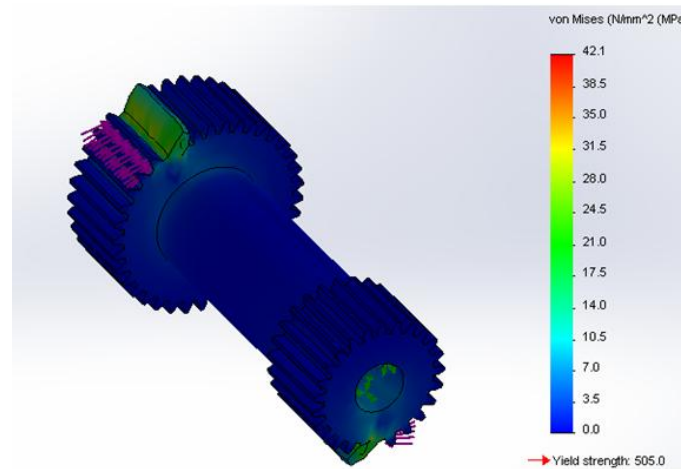


Fig 26 stress induced on the gear

After the optimization process, from the solid works simulation analysis we have got the maximum stress is 42.1 MPa.

**4.6.5 Results-** Values are achieved from analysis after optimization.

'Maximum stress, build up on the assembly= 42 MPa

'Maximum deformation, induced = 0.005257 mm

The maximum stress (42 MPa) induced in the gear is less than the yield stress of 7075 aluminium alloy that is 505 MPa.

#### 4.7 Analysis the assembly after optimization

##### 4.7.1 Create the model

. In the optimization process reducing the size of the assembly, the model is created in the solid work simulation is 3D by using software therefore the geometry of the model is as shown below

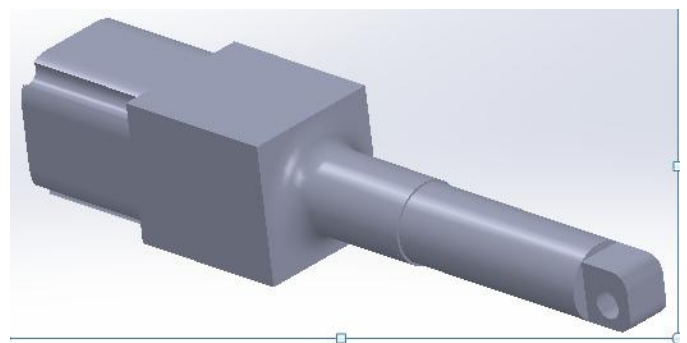


Fig 27 Geometry of the assembly

#### 4.7.2 Meshing

Once the geometric model is created then the program subdivides the model into small pieces of simple shapes called elements which are connected at common points called as nodes and the process of subdividing the model into small pieces is called meshing. In this COSMOS Works creates a mesh of solid elements that is tetrahedron and which is appropriate for bulky or complex 3D models and the accuracy of the solution is depends on the quality of mesh, finer the mesh better the accuracy and the meshed model was shown below.

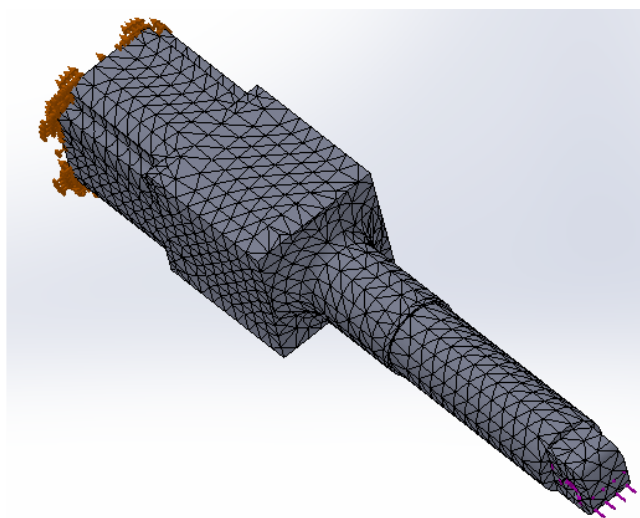


Fig 28 Meshing of the assembly

#### 4.7.3 Force applied

20468.6 N compression force is applied on the gear, as shown in below figure.

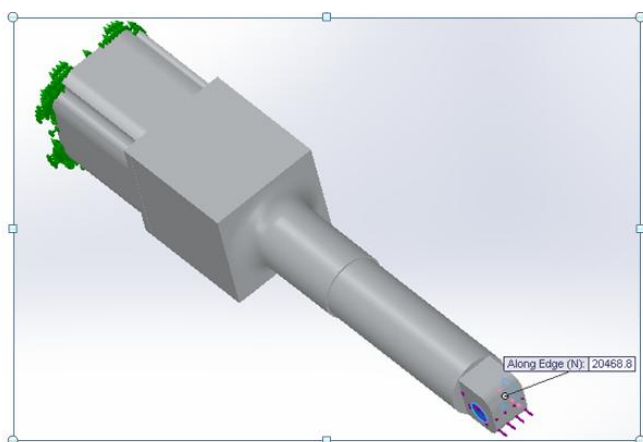


Fig 29 Force applied on the assembly

#### 4.7.4 Stress and deformation

After applying the loads the stresses and deformations are induced. The loads are applied on the lines, nodes, key points or model. If the load is applied on the model it is transmitted to the nodes of the body.

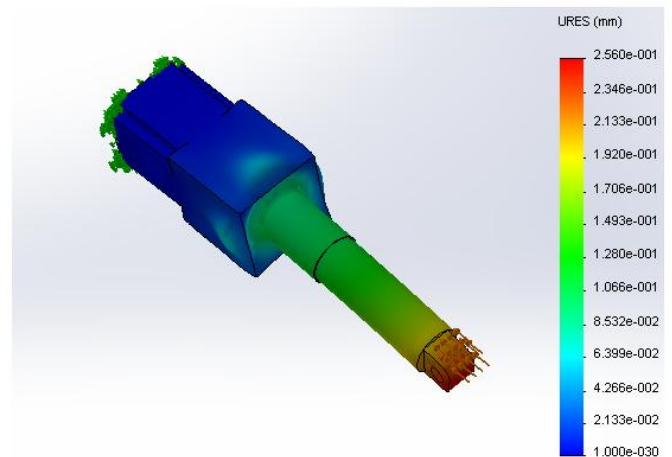


Fig 30 Deformation of the assembly

After the optimization process, from the solid works simulation analysis we have got the maximum deflection is 0.2560 mm.

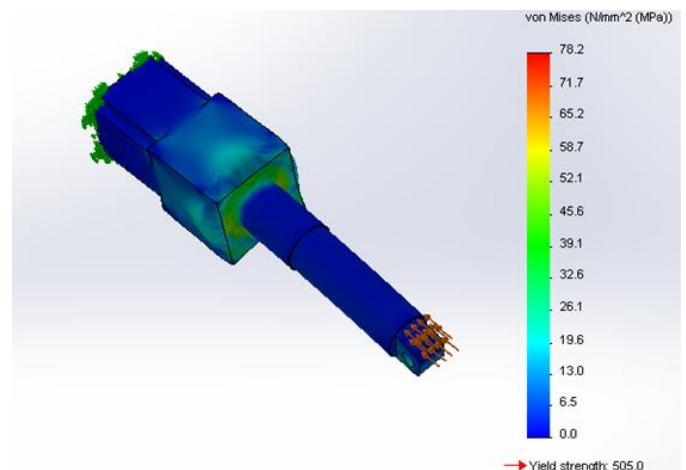


Fig 31 Stress induced on the assembly

After the optimization process, from the solid works simulation analysis we have got the maximum stress is 78.2 MPa.

**4.7.5 Results-** Values are achieved from analysis after optimization.

'Maximum stress' build up on the assembly= 78.2MPa

'Maximum deformation' induced = 0.2560 mm

The maximum stress (78.2 MPa) induced in the assembly is less than the yield stress of 7075 aluminium alloy that is 505 MPa.

## 5. RESULTS AND DISCUSSION

### 5.1 Comparison of results

Comparison of the weight before and after optimization of the ball screw and the gear, the values are shown in below table.

Table 6.1 Comparison of values of weight

Serial number	part	Weight before optimization (gm)	Weight after Optimization (gm)	Saving Weight (gm)
1	Ball screw	817.66	242.17	575.49
2	Gear	205.26	60.18	145.08

Comparison of the stress before and after optimization of the ball screw and the gear, the values are shown in below table.

Table 6.2 comparison of values for stresses

Serial number	part	Stress before optimization (MPa)	Stress after optimization (MPa)
1	Ball screw	33.8	62
2	Gear	18.8	42.1

The above comparison results illustrate that the weight of the ball screw and the gear are reduced by reducing the diameter of ball screw and reducing the thickness of gear. The weight of the ball screw before optimization is 817.66 gm and weight of the ball screw after optimization is 242.17 gm. Hence the total material reduced in the ball screw is  $817.66 - 242.17 = 575.49$  gm = 0.57549 kg

The total material reduced in the gear is  $205.26 - 60.81 = 145.08$  gm = 0.14508kg

The total amount of 'Cost reduction', in the ball screw is =  $0.57549 \times 1200 = 690.588$  Rs

Expected monthly production rate is 500 quantities,

Total cost saved per month for ball screw =  $500 \times 690.588 = 345,294$  Rs

Total cost saved per year for ball screw =  $345,294 \times 12 = 4,143,528$  Rs

The total amount of 'Cost reduction', in the gear is =  $0.14508 \times 1200 = 174.096$  Rs

Expected monthly production rate is 500 quantities,

Total cost saved for month for the gear =  $500 \times 174.09 = 87048$  Rs

Total cost saved per year for the gear =  $87048 \times 12 = 1,044,576$  Rs

The total weight of reducing in EMA is =  $0.57549 + 0.14508 = 0.72057$  gm

The total cost saved per year for the EMA is =  $4,143,528 + 1,044,576 = 5,188,104$  Rs

## 6 Conclusions

An attempt was made to analysis the Electro Mechanical Actuator and is done using Solid works simulation software.

The project work carried out is successfully analyzed to meet the requirements as per the constraints. The Electro Mechanical Actuator is carefully analyzed and cross checked where it does meet the requirements. The maximum stress induced in the Electro Mechanical Actuator in 78.2 MPa which is less than the allowable stress of the material giving Factor of Safety 8. Further reduction in Size causes unsafe and gives higher deformations and stresses which are not allowable to Electro Mechanical Actuator. As the maximum stress is around 78.2 MPa which is far less than Yield stress 505 Mpa. The total weight reduced is 0.72057 gm. Hence we save the cost that is 5,188,104 Rs per year.

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