Design and Optimisation of a Slat Conveyor for Airport Application

Vatsal Singh, Sanskar Joshi, Sahil Shaikh, Siddheshwar Wakude, Dilip Panchal

Abstract: ***This manuscript deals with the design, analysis and optimization of a Slat Conveyor for bag handling at the Airports. The requirement here is to transport the bags from loading station to the unloading station which covers the distance of 28 metres. The specification provided are the approximate weight of each bag, the total weight to be transported between the stations and the height upto which it is transported. The Input parameters are reference to the design calculations. Proper material selection is done using appropriate standards like the ASME , CEMA and Ashby standard. With the proposed conveyor system the weight of the base frame will be reduced and the fatigue strength/cycle of drive shaft will be increased using the appropriate materials.***

Keywords **:** ***Factor of Safey, Load, Shaft, Slat Conveyor.***

I. INTRODUCTION

A conveyor is a mechanical device which helps in transporting heavy and bulky materials from one place to another. It has several components like slat, chain, bearings etc. Conveyors are usually driven using the motor. The type of conveyor system depends on the type of requirement of the industry. Some of its types are - Chain conveyor, roller conveyor, slat conveyor, gravity conveyor, belt conveyor. They are in so much use because of the various advantages that they provide The project is design and development of slat conveyor for the application of transporting bags at the airport. Conveyor mainly consists of components like sprocket, chain, drive assembly, take up assembly, electric motor, etc. Number of factors are included in the design and development of the conveyor like load calculation, conveyor chain selection, design of the various component, layout design, drafting, modelling, Finite element analysis, iterations on the design, etc.

The essential requirements of a good material handling system may be summarized as:

1) Efficient and safe movement of materials to the desired place.

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2) Timely movement of material when needed.

3) Supply of material at desired rate.

4) Storage of materials using minimum space.

Problem statement

Most of the times the materials used for making the shaft for various applications are either low carbon steel or medium carbon steel. The disadvantage with these materials is that they tend to undergo torsion and break whenever they are overloaded. So our purpose is to find the right material for the shaft.

SHAFT

Itcan undergo failure due to various factors. These include corrosion, wear, fatigue and overloading. The machine shafts rarely fail because of the wear and corrosion. The reasons are mainly fatigue or overloading and fatigue is most common between the two. The shafts undergo the fatigue failure if the same load is applied to it over a cycle of period, whereas in overloading the shaft breaks just after the high load is applied. Our objective here is to increase the fatigue strength per cycle of the shaft.

BASE FRAME

The slat conveyor has to carry the load of 12 Metric tonnes per hour at a height of 94 inches (approx.) inclined at an angle of 20°.Here we have tried to optimize the critical parts (shaft, baseframe) . By doing so a considerate amount of material is also saved.

Literature Survey

Makoto Kanehira gave us the idea about how different variety of chains can be used for power transmission, depending the type of application.

H.G Rachner tells us about the design of chains and its lubrication and also the factor of safety mostly preferred.

Ashveer Singh's paper tells us about the comparative outcomes after designing different components of conveyor based on different requirements

Huanyu Zhao discovered that the tension in the chain link of an excavator was measured by assessing the values of horizontal straight, pivot steering and differential steering .

Design of Conveyor chain link:- Chain manufactures specify the chain in their product range by breaking load. Some have quoted average breaking loads, some have quoted minimum breaking loads depending upon their level of confidence in their product. To obtain a design working load is necessary to apply a "factor of safety" to the braking load and this is an area where confusion has arisen.

Daniel J Fonseca, Gopal Uppal, Timothy J Greene explained how complex it becomes to select the components of the equipment. CEMA standards if followed in a right way makes it easier for human experts to take an unbiased decision .

Suitability score matters the most for fulfilling the need of the material handling conveyor.

II. METHODOLOGY

A. Layout

The layout of the Slat Conveyor gave us a brief idea about the components and their positions inside the conveyor.

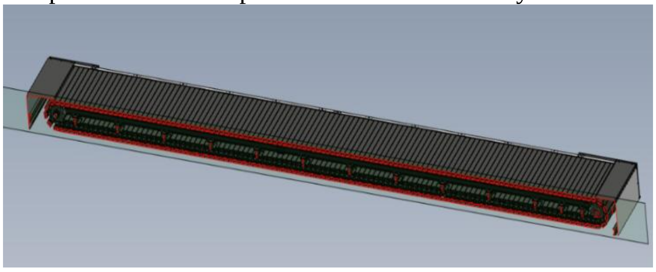


Fig 1: Isometric layout

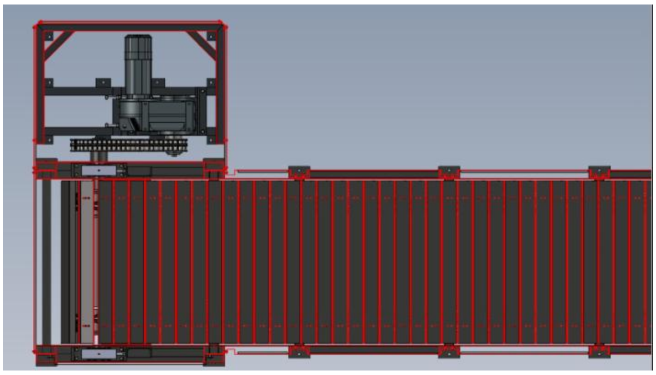
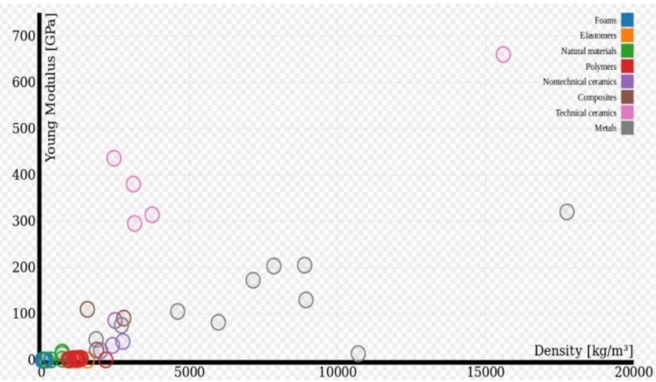


Fig 2: Top View

B. Standards for Material Selection

ASHBY STANDARD: Named after Michael Ashby, Ashby charts or Ashby plots are used for material selection. They are used to compare the ratio of properties of different materials. This graph helps us to recognize the material with the highest stiffness as well as the lowest density by using a log scale.



Cema Standard: Cema Or **Conveyor Equipment Manufacturing Association Standard**: CEMA is the standards that the companies usually follow while designing and manufacturing conveyors.

Calculations

Approach/Techniques applied:

Customer inputs

Material to be handled : Fertiliser Bags

Bag Size : 240mm*320mm*210 mm.

Bag Weight : Max.= 50 kg , Min.= 28 kg

Bag arrangement in cartons : Min.: 16 bags (4*4) or Max.: 25 bags(5*5).

Conveyor Length = 28m.

Conveyor Angle = 20° (Inclined)

No. of Bags transported in 1 hour = 240.

Bag handling rate (in mtph): (240*50)/1000 = 12mtph.

Suggested Conveyor Speed according to CEMA Standards : 0.25m/s.

Speed in m/h = 900m/h.

Slat Calculation

For Slat selection various section sizes are provided by the customer.

75*40*3	100*75*5	125*75*6
75*40*5	100*75*6	125*75*8
75*40*8	100*75*8	

Considering the Section Size 75*40*3.

Material Used : IS2062. (E = 210000MPa , Syt= 490MPa).

Given Data:

Length = 800mm.

Weight of Each Carton (Considering Maximum Load) = 50*25 = 1250 kg = 12262.5 N

Desired FOS = 2

Allowable Stress = Syt/2 = 490/2 = 245MPa.

Max. Bending Moment = (w*l)/4= (12252.5*0.8)/4= 2452.6N-m

Calculating the Moment of Inertia along X axis i.e.

$I_{XX} = 39.29 * 10^{-8}\ m^4$.

Max. Bending Stress = (Maximum Bending Moment* y)/ I (Moment of Inertia)

$= (2452.5*0.0375)/(39.29*10^{-8})$

$= 234076737.1 N/m^2 = 234.076 N/mm^2$.

Now the actual FOS = Allowable Stress / Max. Bending Stress

FOS = 245/234.076 = 1.046.

$(FOS)_{Actual} < (FOS)_{Desired}$, Hence the Design fails.

Similarly for Different Sections , by following the same above procedure, the FOS values found out below:

Section Size	I_{XX} (m^4)	$FOS_{(Actual)}$
75*40*5	$60.5*10^{-8}$	1.6
75*40*6	$69.8*10^{-8}$	1.85
75*40*8	$86.2*10^{-8}$	**2.29**

Since the section 75*40*8 gives us the value of **2.29** as FOS which is greater than the Desired FOS.

Hence **75*40*8** can be selected for the slat design.

Development of Slat for section 75*40*8 = 34+34+18.84+9.42+63 =161mm.

Mass of one slat = $(161*800*8*7.8)/10^6$ = 8.03 kg/m.

Chain Calculations:

Chain selected : SS911.

Pitch: 9 inches (225mm).

Allowable Pull Force = 4600 lbs (2090 kgf).

Breaking Load = 29000 lbs (13181 kgf).

Weight of single Strand of chain = 12.7 lbs/ft.

Weight of strand in S.I. unit = 12.7*1.5 = 19.05 kg/m.

Pin Diameter = 5/8 inches (16 mm).

Roller Size = 3 inches (75 mm).

Roller rolling friction coefficient = (0.6*Pin diameter)/ Roller Diameter

= (0.6* 16)/ 75 = 0.128.

Double Strand weight = 19.05*2 = 38.1 kg/m.

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Slat weight with double strand weight = 38.1+ 8.03 = 46.13 kg/m.
Weight of one slat = 8.03 kg/m.
No. of slats per metre = 1000/75 = 13.33 = 14 slats
No. of slats for 28 m = 28*14 = 392 slats.
Weight carried by the conveyor for 1 metre = 1250*14 = 17500 kg/m.
Total weight carried per metre = 17500 + (8.03*14) + 38.1 = 17650.52 kg/m
Carrying Run Resistance = length of Conveyor*Total weight*cosØ*0.15
= 28*17650.52*cos20*0.15 = 69661.46 kgf
Lifting resistance = Length of conveyor * Total Weight * sinØ = 28*17650.52*sin20 = 169031.33 kgf
Considering 5% extra resistance = 0.05
Terminal Resistance = 0.05 (69659.41 + 169031.33) = 16934.53 kgf
Return Run Resistance = 28*46.13*cos 20 * 0.15 = 182.06 kgf
Lift Resistance = -28*46.13* sin20 = -441.76 kgf
Return Run Total = 182.06-441.76 = -259.7* 0.1 =-25.97 kgf
Total Resistance = Carrying Run side Resistance + Terminal Resistance + Total Return side Resistance
= 86570.09 kgf.
Power at Head Shaft = (Total Resistance * Speed)/102 = 212.18 kW.
Drive Efficiency = 80%.
Minimum power for drive = 0.8*212.18 = 169.74 kW

C. Material Selection

When developing new products, it is necessary to consider a few mechanical attributes of the materials we wish to utilize. The fact is, material selection is very important because engineers have to plan for any potential consequences that certain materials may present.

Candidate Material Selection :- A group of materials is selected for the comparison of their properties and cost, feasible for the product. These materials selected are known as candidate materials. These candidate materials are selected using Ashby Chart.

Ashby Chart:- Almost all the properties of the materials can be known from this graph. This graph is very useful in comparing the properties of materials by finding the appropriate ratio between the respective materials.

There is a generic step-wise procedure for the selection of materials. These are also called the Quantitative methods for material selection. They are mainly categorized as :-

1. Cost per unit property method
2. Weighted properties method
3. Digital Logic method

Material Selection Part :- Drive Shaft

Function :-To support in combined loading.
Objective:-To increase fatigue strength.
Variables :-Density, Cross-sectional area.
Constraints :- Length, Force
Candidate materials selected for the drive shaft of slat conveyor :-
1) 4340 steel
2) Aluminum Alloy (2024-T6)
3) Titanium Alloy (Ti-6Al-4V)
Properties considered for material selection of slat conveyor

i) Elastic modulus
ii) Density
iii) Tensile stress
iv) Yield stress
v) Working stress
vi) Factor of safety

Scaled Property Chart

Property	Positive decision	Weighing ratio	Property	Positive decision
Elastic modulus	2	0.11	Elastic modulus	2
Density	8	0.44	Density	8
Tensile stress	5	0.277	Tensile stress	5
Yield stress	3	0.166	Yield stress	3

Numerical Values of the properties considered

Materials	Elastic modulus (N/mm^2)	Density (Kg/m^3)	Tensile stress (N/mm^2)	Yield stress (N/mm^2)	Working stress (N/mm^2)	FOS
4340 Steel	210	7850	745	470	149	5
Aluminum alloy (2024-T6)	72.4	2780	427	345	85.4	5
Titanium Alloy Ti-6Al-4V	113	4430	950	880	190	5

Relative Cost and Performance Index

Material	Relative cost	Performance index	Final material
4340 steel	9.2	85.26	784.39
Aluminum alloy (2024-t6)	6.2	38.24	237.10
Titanium alloy (Ti-6Al-4V)	6.8	74.51	509.67

Final selection of material by comparison of their respective performance index .For the final selection of the material the performance indices of the candidate material are compared. Performance index is given by ***C***.

Materials	Elastic Modulus	Density	Tensile stress	Yield stress
4340 steel	100	97.79	78.42	53.4
Aluminum alloy (2024-t6)	34.47	34.63	44.94	39.2
Titanium alloy (Ti-6Al-4V)	53.8	55.18	100	100

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The material with **greater** *performance index is selected*.

5.2 Material Selection Part:- Slat

Function :- To support in combined loading.
Objective :- To increase fatigue strength.
Variables :- Density, Cross sectional area.
Constraints :- Length, Force.
Candidate materials selected for the slat :-
1) AISI 1010
2) AISI 1020
3) AISI A36
4) AISI A516
5) IS 2062

Properties considered for material selection of slat conveyor :-

i. Elastic modulus
ii. Density
iii. Tensile stress
iv. Yield stress

Numerical values of the properties

Material	Elastic modulus	Density	Tensile stress	Yeild strength
AISI 1010	95.23	99.36	63.72	31.57
AISI 1020	95.2	100	82.35	61.55
AISI A36	95.23	99.36	78.43	43.85
AISI A516	100	99.36	100	58.77
IS 2062	100	99.36	82.325	100

Scaled Property Chart

Material	Elastic modulus	Density	Tensile stress	Yield strength
AISI 1010	200	7850	325	180
AISI 1020	200	7900	420	351
AISI A36	200	7850	400	250
AISI A516	210	7800	510	335
IS 2062	210	7850	420	570

Digital Logic Method and Weighing Ratio

Property	Positive decision	Weighing ratio
Elastic modulus	2	0.11
Density	8	0.44
Tensile stress	5	0.27
Yield strength	3	0.16

Final selection of material by comparison of their respective performance index.

Material	Relative cost	Performance index	Final material
AISI 1010	9.2	77.70	714.9
AISI 1020	6.2	88.16	546.62
AISI A36	6.8	83.84	570.12
AISI A516	6.4	92.56	592.42
IS 2062	**1.9**	**94.81**	**180.15**

Thus in this case **IS 2062** is selected as it is having the highest performance index i.e**94.81.**

5.3 Material Selection Part:- Baseframe

Material Used: - Plain Carbon Steel
Properties of Plain Carbon Steel

Properties	Values
Density (kg/m^3)	7850
Yield strength (N/mm^2)	275
Young's modulus	210000

D. *CAD Modelling*

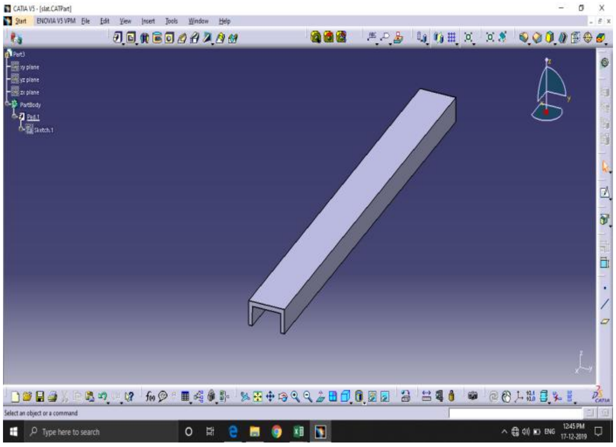

Fig 5.1: Slat Design

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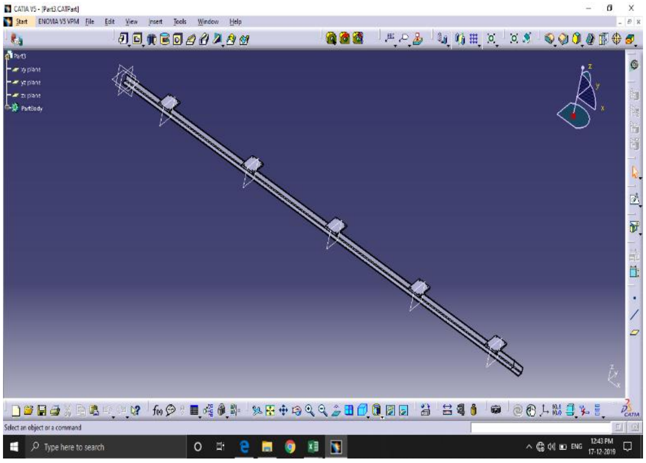


Fig 5.2: Conveyor Support

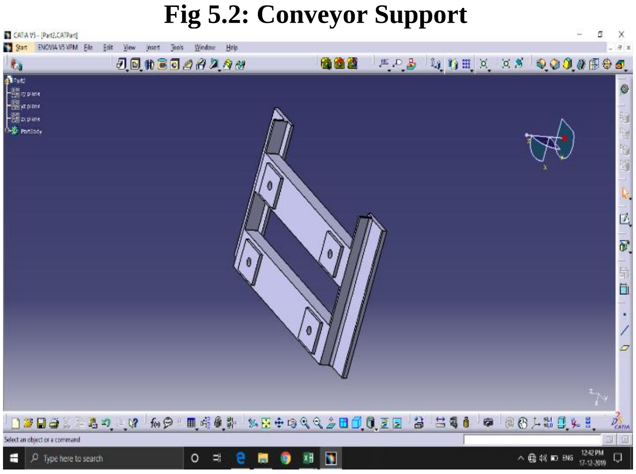
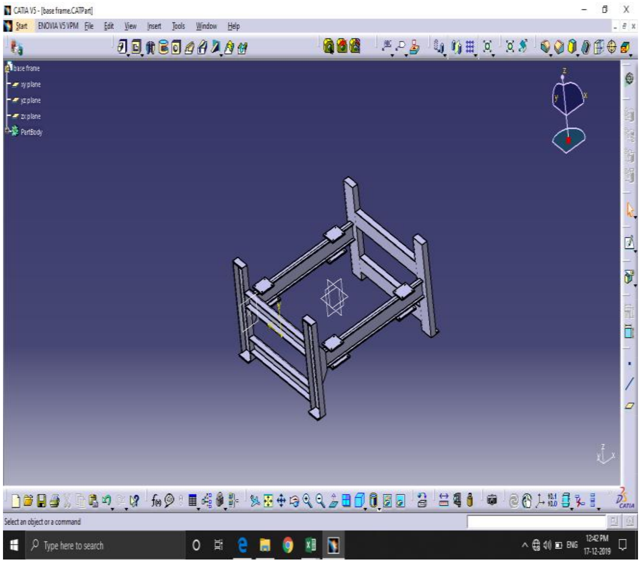


Fig 5.3: Fixed Support



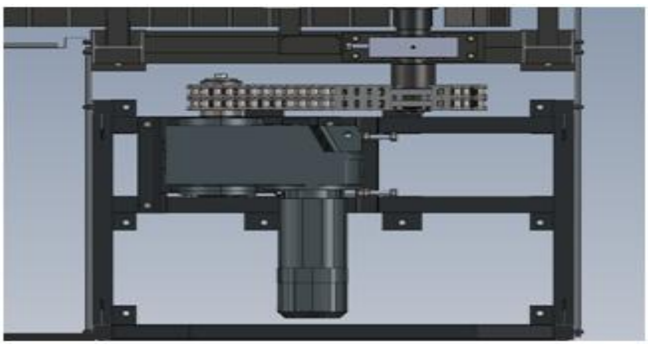


Fig 5.4: Chain Assembly (Top View)

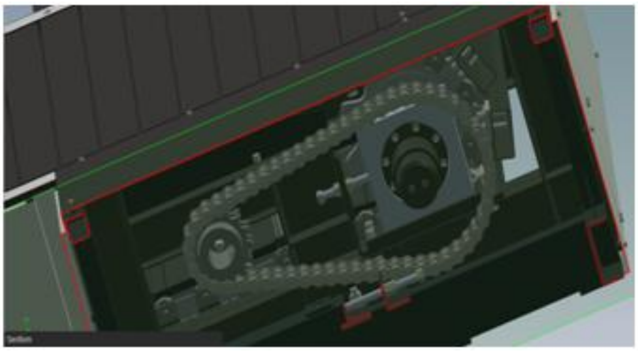


Fig 5.5: Chain Assembly (Top View)

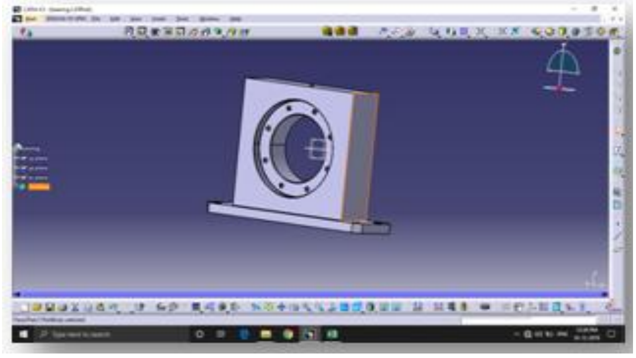


Fig 5.6: Bearing Support

III. FINITE ELEMENT ANALYSIS

SHAFT

Model type:	Linear Elastic Isotropic
Default failure criterion:	Max von Mises Stress
Yield strength:	4.7e+08 N/m^2
Tensile strength:	7.45e+08 N/ m^2
Elastic modulus:	2.1e+11 N/ m^2
Poisson's ratio:	0.28
Mass density:	7850 kg/ m^3
Shear modulus:	7.9e+10 N/ m^2
.Thermal expansion coefficient:	1.3e-05 /Kelvin

Mesh Information

Mesh Type	Solid Mesh
Mesher Used	Blended Curvature based Mesh
Jacobian Points	4 points
Maximum element Size	45.8564mm
Minimum element size	9.37128mm
Mesh Quality Plot	High

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Mesh Details

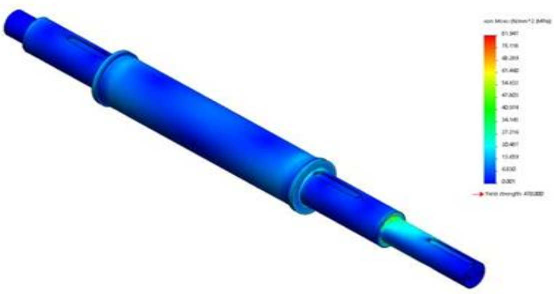
Total Nodes	37099
Total elements	23519
Max. Aspect ratio	33.389

Resultant Forces

Components	x	y	z	$F_{Resultant}$
Reaction Force(N)	1.38951	236628	-1603.66	236633
Reaction moment(N-m)	0	0	0	0

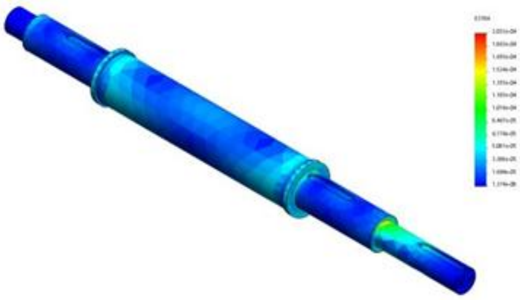
Results

1) *Stress*



Max. Stress = 81.947 N/mm^2

2) *Strain*



Max. Strain = 2.032e-04mm

3) *Factor of Safety* = ***4.65e+05***

Material 2 **:2024-T3**

Model type:	Linear Elastic Isotropic
Default failure criterion:	Max von Mises Stress
Yield strength	3.45e+08 N/ m^2
Tensile strength	4.85e+08 N/ m^2
Elastic modulus	7.24e+10 N/ m^2
Poisson's ratio	0.33
Mass density	2780 kg/ m^3
Shear modulus	2.8e+10 N/ m^2
Thermal expansion coefficient	2.32e-05 /Kelvin

Mesh Information

Mesh Type	Solid Mesh
Mesher Used	Blended Curvature based Mesh
Jacobian Points	4 points
Maximum element Size	45.8564mm
Minimum element size	9.37128mm
Mesh Quality Plot	High

Mesh Details

Total Nodes	37099
Total elements	23519
Max. Aspect ratio	33.389

Loads Applied

Force	-22,000 N (Z-axis)
Torque	-396 N-m

Forces(Resultant)

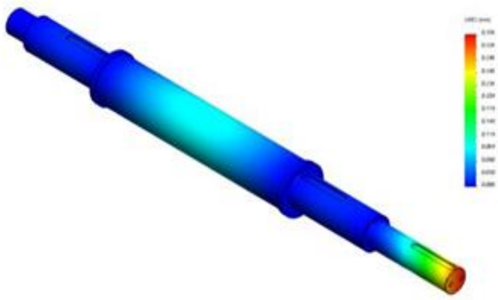
Components	x	y	z	$F_{Resultant}$
$F_{Reaction}$(N)	-3.071	236625	-1603.55	236631
Reaction moment(N-m)	0	0	0	0

Results

1) *Stress*

Max. Stress = 80.585 N/mm^2

2) *Displacement*



Max. Deformation = 0.358mm

3) *Strain*

Max. Strain = 6.120e-04

4) *Factor of Safety = 3.51e+05.*

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Material 3 : Ti-6Al-4VSolution treated and aged (SS)

Model type	Linear Elastic Isotropic
Default failure criterion	Max von Mises Stress
Yield strength	8.27371e+08 N/ m^2
Tensile strength	1.05e+09 N/ m^2
Elastic modulus	1.048e+11 N/ m^2
Poisson's ratio	0.31
Mass density	4428.78 kg/ m^3
Shear modulus	4.10238e+10 N/ m^2

Mesh Information

Mesh Type	Solid Mesh
Mesher Used	Blended Curvature based Mesh
Jacobian Points	4 points
Maximum element Size	45.8564mm
Minimum element size	9.37128mm
Mesh Quality Plot	High

Mesh Details

Total Nodes	37099
Total elements	23519
Max. Aspect ratio	33.389

Loads Applied

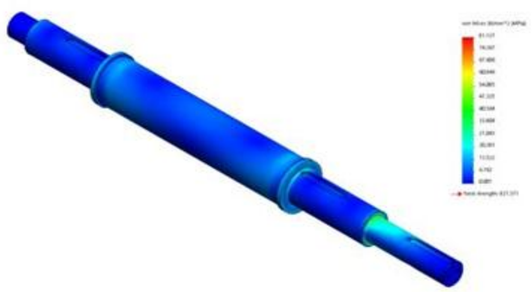
Force	-22,000 N (Z-axis)
Torque	-396 N-m

Forces(Resultant)

Components	x	y	z	$F_{Resultant}$
$F_{Reaction}$(N)	4.782	236626	-1601.48	236631
Reaction moment(N-m)	0	0	0	0

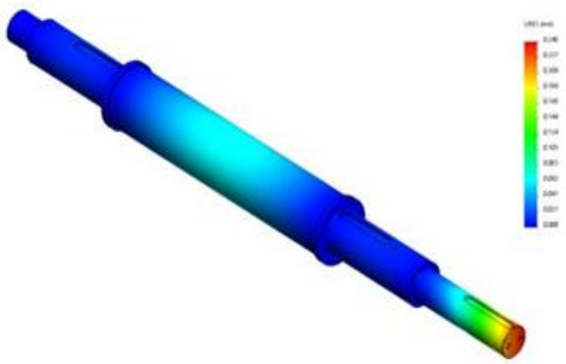
Results

1) *Stress*



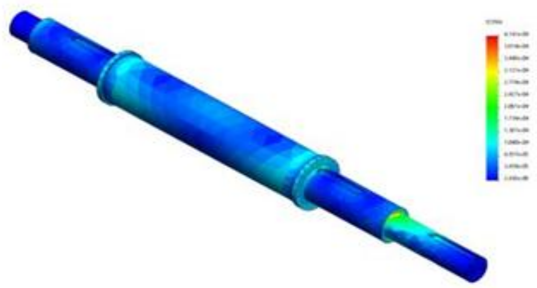
Max. Stress = 81.127 N/mm^2

2) *Displacement*



Max. Displacement = 0.248 mm.

3) *Strain*



Max. Strain = 4.161e-04

4) *Factor of Safety = **8.34e+05.***

SLAT

Dimension 1 : **75*40*3**

Material Used: - Plain Carbon Steel

Model type	Linear Elastic Isotropic
Default failure criterion	Unknown
Yield strength	2.20594e+08 N/ m^2
Tensile strength	3.99826e+08 N/ m^2
Elastic modulus	2.1e+11 N/ m^2
Poisson's ratio	0.28
Mass density	7800 kg/ m^3
Shear modulus	7.9e+10 N/ m^2
Thermal expansion coefficient	1.3e-05 /Kelvin

Mesh Information

Mesh Type	Solid Mesh
Mesher Used	Standard Mesh
Jacobian Points	4 points
Element Size	18.8261mm
Tolerance	0.941303mm
Mesh Quality Plot	High

Mesh Details

Total Nodes	27159
Total elements	15209
Max. Aspect ratio	41.263

Loads Applied

Force	5400 N(Normal)
Torque	0 N-m

Forces(Resultant)

Components	x	y	z	$F_{Resultant}$
$F_{Reaction}$(N)	-1.6 856	5397.34	1.73	5937.34
Reaction moment(N-m)	0	0	0	0

Results

1) Stress

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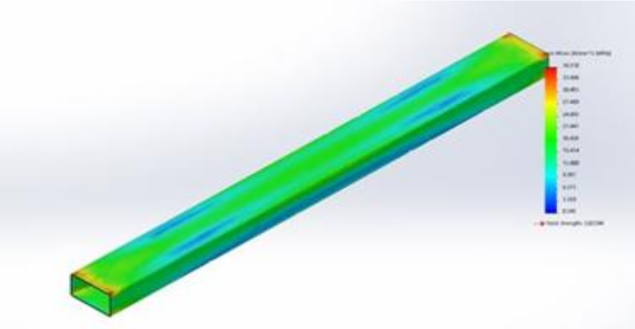
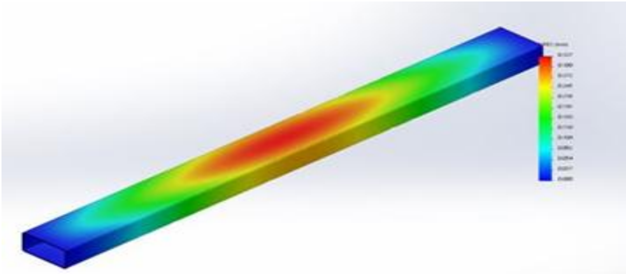


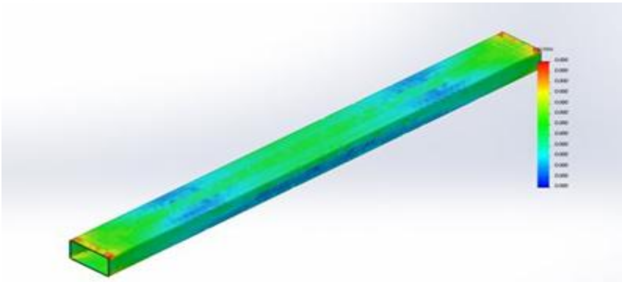
Max. Stress = 36.510 N/mm^2

2) Displacement



Max. Displacement = 0.327mm

3) Strain



Max. Srain: 0.

Dimension 2 : **75*40*5**

Material Used: - Plain Carbon Steel

Model type	Linear Elastic Isotropic
Default failure criterion	Unknown
Yield strength	2.20594e+08 N/ m^2
Tensile strength	3.99826e+08 N/ m^2
Elastic modulus	2.1e+11 N/ m^2
Poisson's ratio	0.28
Mass density	7800 kg/ m^3
Shear modulus	7.9e+10 N/ m^2
Thermal expansion coefficient	1.3e-05 /Kelvin

Mesh Information

Mesh Type	Solid Mesh
Mesher Used	Standard Mesh
Jacobian Points	4 points
Element Size	18.8261mm
Tolerance	0.941303mm
Mesh Quality Plot	High

Mesh Details

Total Nodes	27159
Total elements	15209
Max. Aspect ratio	41.263

Loads Applied

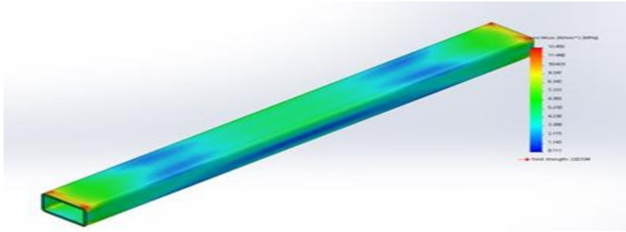
Force	5400 N(Normal)
Torque	0 N-m

Forces(Resultant)

Components	x	y	z	$F_{Resultant}$
Reaction Force(N)	-0.1206	5399.65	0.066	5399.64
Reaction moment(N-m)	0	0	0	0

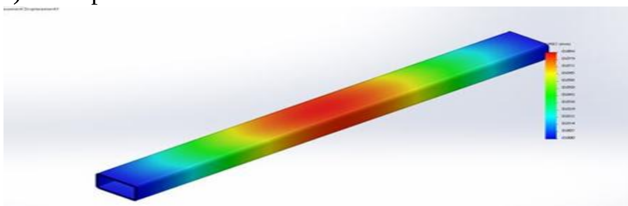
Results

1) Stress



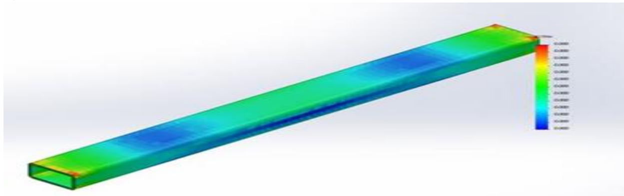
Max. Stress = 12.492 N/mm^2

2) Displacement



Max. Displacement = 0.086mm

3) Strain



Max. Strain = 0.

BASE FRAME

Material Used :- **Plain Carbon Steel**

Material Properties

Model type	Linear Elastic Isotropic
Default failure criterion	Unknown
Yield strength	2.20594e+08 N/ m^2
Tensile strength	3.99826e+08 N/ m^2
Elastic modulus	2.1e+11 N/ m^2
Poisson's ratio	0.28
Mass density	7800 kg/ m^3
Shear modulus	7.9e+10 N/ m^2
Thermal expansion coefficient	1.3e-05 /Kelvin

Mesh Information

Mesh Type	Solid Mesh
Mesher Used	Standard Mesh
Jacobian Points	4 points
Element Size	47.9735 mm
Tolerance	0.5 mm
Mesh Quality Plot	Draft Quality Mesh

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Mesh Details

Total Nodes	7314
Total elements	21813
Max. Aspect ratio	99.719

Loads Applied

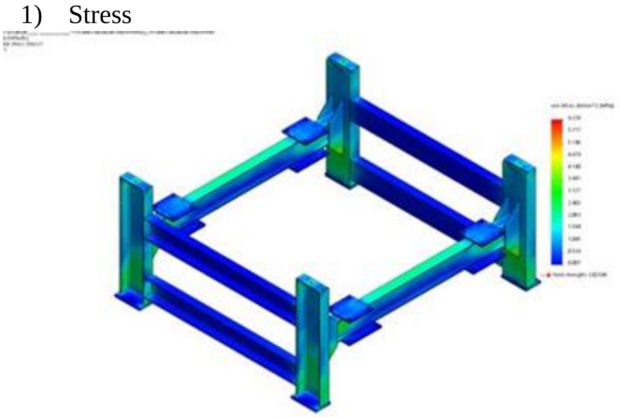
Force	2156 N(Normal)
Torque	0 N-m

Forces(Resultant)

Components	x	y	z	$F_{Resultant}$
Reaction Force(N)	-4.7024	17246.7	-0.74	17246.77
Reaction moment(N-m)	0	0	0	0

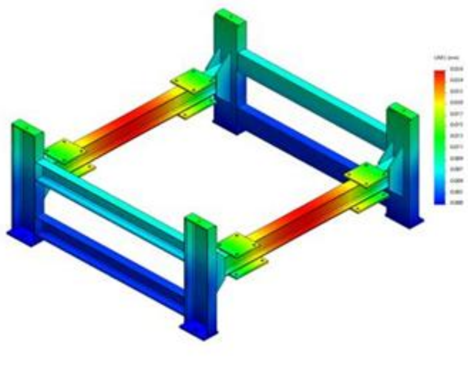
Results

1) Stress



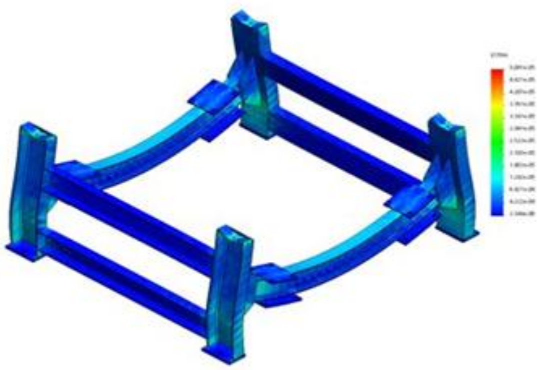
Max. Stress = 6.236 N/mm^2

2) Displacement



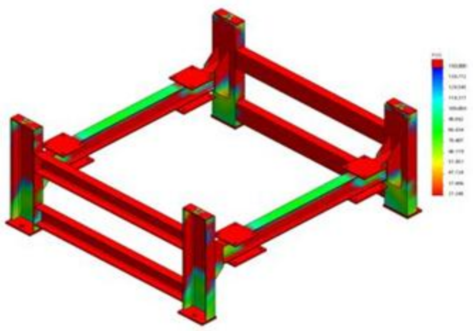
Max. Displacement = 0.026mm

3) Strain



Max. Strain = 5.041e-05

4) Factor of Safety



Max. Value = 31565.008

IV. CONCLUSION

After observing the analysis of the above components the objective of the research has been fulfilled. The material for the components is selected according to the Industrial standards like Ashby and CEMA. The analysis was done for each iteration to optimize the design and also the cost as well as the weight of the components. Through this research we have designed the shaft that will work efficiently with improved life cycle.

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