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# Experimental Stress Analysis and Topology Optimization of Steering Arm (Pit-Man's Arm) of Heavy-Duty Vehicle

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***Abstract:*** *Today's advancement in the industrialization for manufacturing automotive parts has become much easier and allied. Decrease in vehicle mass is a solution for the optimization strategy to increase the performance by reducing in its mass constraints in the part. This paper helps in investigating the Pit-Man Arm which is also known as steering link, this link impacts large force on it, so it is important to check its strength under the vehicle mass loading condition, also to optimize the link for its mass reduction using topology optimization in ANSYS workbench. This study also emphases transient mode of structural formation followed by static structural and topology-based optimization.*

***Key Word**: Pit-Man Arm, Impact load, Transient structural, Static Structural, Topology optimization*

## I. Introduction

Optimization is the strategy to solve the complex problems in finite mode, in this paper structural analysis of the Pit-Man arm will be solved using FEA ANSYS Workbench R1 2020. Steering system is an important aspect for vehicle, to turn in the direction required steering is used. In most of the heavy-duty vehicles and other preliminary vehicles Pitman arm is used, it is a link which converts rotary or angular movement into the linear motion which in turn helps vehicle wheels to move in the desired direction to travel. Steering system plays a vital role in handling vehicle characteristics. During vehicle drift which is deviation(turn) of vehicle way from straight line during braking is relates to various terminologies of steering system, suspension, tires frictions, wheel alignment and many others. Pitman arm is a linkage usually attached to steering box sector shaft, which converts rotary or angular of sector shaft to linear motion the wheels

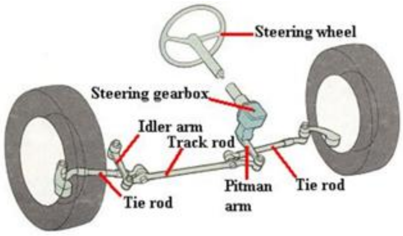



Figure 1 (a,b) Pitman arm application

### 1.1 Applications, Working

As mentioned earlier pitman linkage converts motion of the steering shaft to linear motion required to move the wheels in desired direction in order to move the vehicle to a considerable turn. One side of the arm will be fixed or supported to the sector shaft of the steering mechanism & also supports the center link from ball joints, Invading wheels to move in the direction right and left. The idler arm supports the center link from the pitman arm and the vehicle frame holds the drag link to a proper height, while taking a turn worn ball joint implies serious damage in the steering mechanism, sometimes it may get more worse than ever so failure conduction is important.

### 1.2 Problem Statement

1. Now a day's most of the industries are concentrating on optimization in order to bring down the mass production cost to its minimum.
2. Hence To achieve cost effective product topology optimization of certain products comes in to affect
3. The Pitman arm is one of the most Complex part in the steering system, and actually it is connected the steering gear to the steering linkage, and then to the wheels for Turing. Pitman arm impacts vehicle load, whenever a steering is turned.

4. When a power steering is used sudden boundary is applied to linkage then there may be chance of braking.
5. Weighted part, needs more cost for manufacturing and increases the manufacturing cost for mass production.
6. Improper design can cause the Pitman arm for failure tendency so, it is important to conduct the FEA solution for the defined part.

## 1.3 Objective

1. To study and perform static structural analysis of a pitman arm under actual steering load.
2. To propose an optimized design model, which will have enhanced or equal performance with reduced weight or mass constraint or to enhance the efficiency of arm with minimal weight, cost & strength.
3. Analysis of Pitman Arm.
4. Experimental Testing on Pitman Arm using UTM machine.
5. Comparative Analysis between Experimental & Analysis results.
6. Conclusion & Future scope.

## 1.4 Methodology

Step 1: **-** This project aims to minimize the manufacturing cost for mass production in industrialization using Ansys optimization strategy, many research papers have been investigated and understood the required of software modeling to minimize the testing and fabrication cost for testing models.
Step2: **-** In this stage different materials are selected according to the standard and considering manufacturing process
Step 3: **-** in 3rd stage 3D CAD model will be prepared using Catia v5 software
Step 4: - Fem solution for the define geometry to its actual steering load will be solved. And followed by
Step 5: **-** vibrational analysis or Model Analysis.
Step 6: - Topology Optimization for the sake of material constraint reduction and weight optimization.
Step 7: **-** comparing among the different Material can direct towards the strength propagation but cost varies over grades and its mechanical properties.
Step 8: - fabrication & experimental validation
Step 9: **-** Thesis writing.

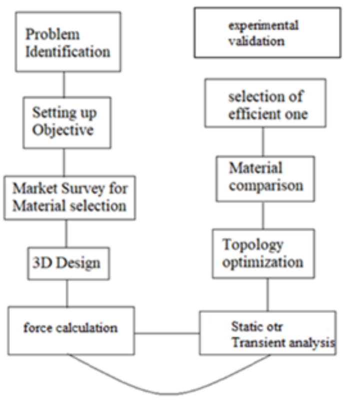



Figure 2 Methodology

## 1.5 Scope

1. CAD Modelling of existing Pitman Arm using CATIA
2. Finite Element Discretization using Hyper mesh/Ansys
3. FEA of Pitman Arm to obtain stress & strain
4. Using Optistruct solver to achieve topological optimization
5. Experimental stress analysis of existing Arm using Strain gauging & Bending load applied through UTM
6. Comparative analysis between FEA & Experimental results
7. Conclusion & Future scope.

## II. PROPOSED SYSTEM

### 2.1 Existing material used in pitman's arm in vehicles is

For parent section standard mechanical properties have been listed out.

**Forged Steel material** – most common material for making solid components in automobile is forged steel less cost, high strength & most commonly available.

- Young's modulus or modulus of elastic : 200GPa
- Poisson's ratio material : 0.30
- Density of the material for the forged steel : 7.85e-6 kg/mm3
- Maximum Yield Strength of the material : 520 Mpa

### 2.2 Materials for choice or optimization or compare during working

- **Property** — **Value**
- Young's Modulus (E) of the material — 210 GPa
- Poisson's Ratio (υ) of the material — 0.3
- Density (ρ) of the material — 7.9 x 10-6 kg/mm3
- Maximum Yield Strength of the material — 740 MPa

### 2.3 AISI 1045 steel

### 2.4 Aluminum 5052

- **Physical Property** — **Value**
- Density — 2.68 g/cm³
- Melting Point — 605 °C
- Thermal Expansion — 23.7 x10^-6/K
- Modulus of Elasticity — 70 GPa
- Thermal Conductivity — 138 W/m.K
- Electrical Resistivity — 0.0495 x10^-6 Ω .m
- **Mechanical Property** — **Value**
- Tensile Strength — 210 - 260 MPa
- Proof Stress — 130 MPa
- Hardness Brinell — 61 HB

### 2.5 Force Calculations

- Total Mass of the vehicle, is considered as
- M1= Curb weight + Passengers weight + other weight
- Toyota Glanza/Curb weight 890 to 935 kg = 935 kg
- Consider 5 people are sitting inside the car =5*100 = 500 kg
- Other weight = 100 kg
- M1= 935 + 500 + 100 = 1535Kg
- The total load of the car is divided into 4 wheels front two wheels and back two wheels according to standard wight distribution in 4-wheeler, 52% front axle and remaining 48% rear.
- Total Mass on the front axle, M2 = 736.8 kg
- Total on one of the front wheels, M = 368. kg
- Coefficient of friction, μ = 0.7

F = u * m
= 0.7 * 368 = 257.6kg = 257.6*9.81
= 2625.15N

But, two front wheels are handled by single steering arm, therefore the force on it will be doubled,

**Application**: -
**Pitman Arm for Toyota Glanza**

**Parent section dimensions**

- Length of the arm = 6.3/8” = 162 mm center distance
- Height of the arm = 2.1” = 53.34mm
- Diameter max = 1.2” = 38.1mm
- Diameter min = 0.590” = 15
- D max outer = - = 58.1 mm
- D min outer = - = 25mm

## III. DESIGN & ANALYSIS

### 3.1 Design procedure

1. CATIA v5 Software is used to generate the CAD model of the Muffler
2. In CATIA v5 software, generative shape design with plane-based sketch has been prepared and converted to 3D using sketch-based tools.
3. The dimensions of 3D Pitman arm for the designed model have been taken from the research paper.
4. Then the final 3D model is converted to IGS or STP for ANSYS importation.
5. Finally drafting of the of the 3D product is extracted from the drafting option using the conversion method.

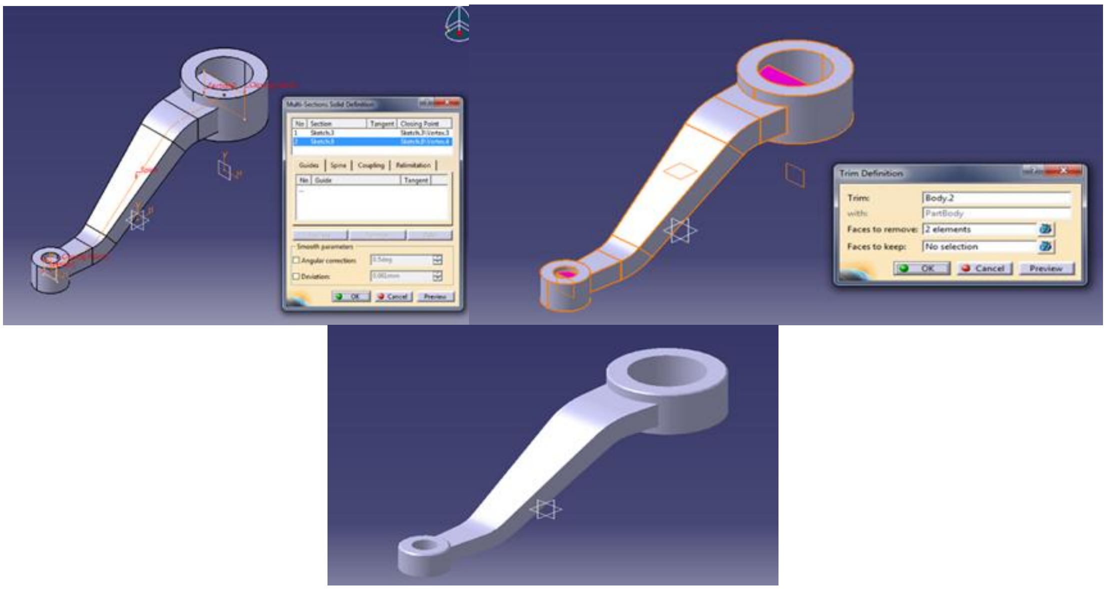


Figure 3 (a, b &c) multi solid section operation
Boolean operation union trim + extra surface remove procedure

### 3.2 Analysis

#### 3.2.1 Requirement

- Transient Structural Analysis of Steering Arm.
- Optimization of Steering Arm.
- Stress plots.
- Deformation plots.

#### 3.2.3 Technology

- CATIA V5 R20 for Solid Modeling.
- Ansys R1 20.0 for Finite element modeling and Analysis.

- Summary - To carry out Static Structural Analysis and Optimization of Steering Arm.
- Situation - To verify stress generated in the Steering Arm for load case.

- Loadings - Force is applied on the Steering Arm as per its application.
- BC's - Fully Constrained at large hole.

### 3.2.4 Work Order

- Modeling the Steering Arm.
  - Performing Finite Element Modeling.
  - Applying Boundary and Loading conditions.
  - Solving the FE Model for results.

### 3.2.5 Working or methodology of the project

1. 3D model design has been made using CATIA v5 software with the help of part designing or surface wireframe modelling.
2. Software version - CATIA v5 r20.00
3. Transient structural analysis
4. Transient means solving with the help of time consideration
5. Ex: - if I apply only angular velocity, force with fixed support on the pitman's arm then ANSYS will solve for default 1 sec time in static. In transient we can add the time consumption-based on boundary condition with nonlinear varied formation.

## 3.3`FEA (FINITE ELEMENT ANALYSIS)

ANSYS TRANSIENT STRUCTURAL ANALYSIS

**Iteration 1**

**Units system**

- Unit System Metric (mm, kg, N, s, mV, mA) Degrees rad/s Celsius
- Angle Degrees
- Rotational Velocity rad/s
- Temperature Celsius

**Model**

**Table No. 1** Geometry properties

| | |
|---|---|
| **Material** | |
| Assignment | Structural Steel |
| Nonlinear Effects | Yes |
| Thermal Strain Effects | Yes |
| **Bounding Box** | |
| Length in X direction | 203.5 mm |
| Length in Y direction | 58. mm |
| Length in Z direction | 88.34 mm |
| **Properties** | |
| Volume of part | 1.6318e+005 $mm^3$ |
| Mass of the part | 1.281 kg |
| Centroidal X | -26.244 mm |
| Centroidal Y | -1.5786e-008 mm |
| Centroidal Z | 43.795 mm |
| Moment of Inertia Ip1 | 380.48 kg·$mm^2$ |
| Moment of Inertia Ip2 | 3852.4 kg·$mm^2$ |
| Moment of Inertia Ip3 | 3897.2 kg·$mm^2$ |

**Mesh Generation**

**Table No.2** Mesh scope

| Object Name | Patch Conforming Method | Body Sizing |
|---|---|---|
| State | Fully Defined | |
| **Scope** | | |
| Scoping Method | Geometry Selection | |
| Geometry | 1 Body | |
| **Definition** | | |
| Suppressed | No | |
| Method | Tetrahedrons | |

| | | |
|---|---|---|
| Algorithm | Patch Conforming | |
| Element Order | Use Global Setting | |
| Type | | Element Size |
| Element Size | | 2.0 mm |
| **Advanced** | | |
| Defeature Size | | Default |
| Behavior | | Soft |

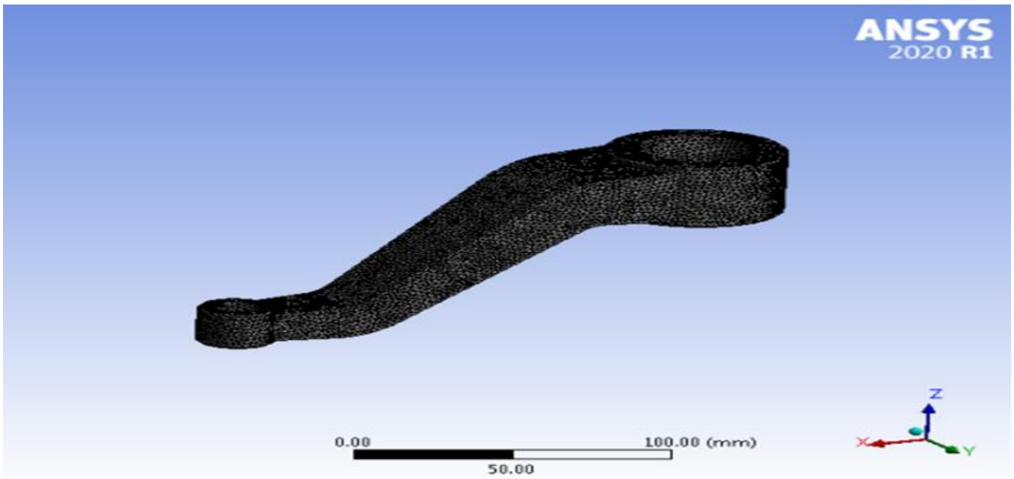
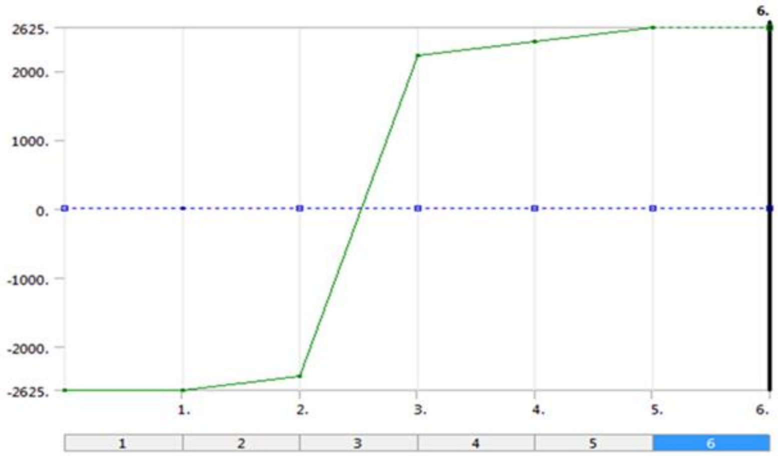



Figure 4 Mesh Geometry

**Boundary condition**

**Table No. 3**. loading condition Loading condition NON-linear types

| Steps | Time [s] | X [N] | Y [N] | Z [N] |
|---|---|---|---|---|
| 1 | 0. | = 0. | -2625. | = 0. |
| | 1. | 0. | | 0. |
| 2 | 2. | = 0. | -2425. | = 0. |
| 3 | 3. | | 2225. | |
| 4 | 4. | | 2425. | |
| 5 | 5. | | 2625. | |
| 6 | 6. | | = 2625. | |




Graph 1 Graph loading condition in RHS & LHS Y Axis in positive & negative direction

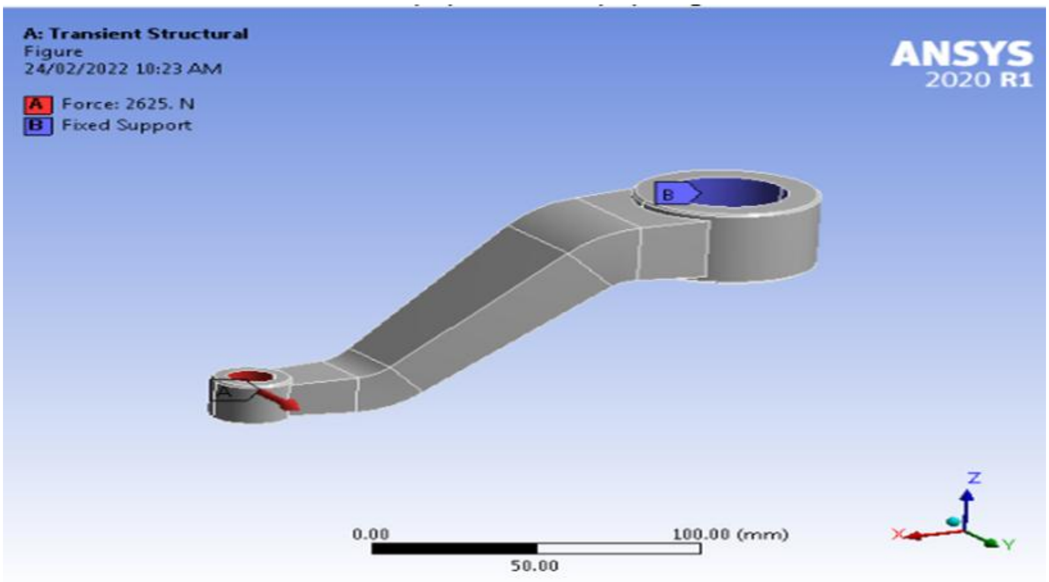
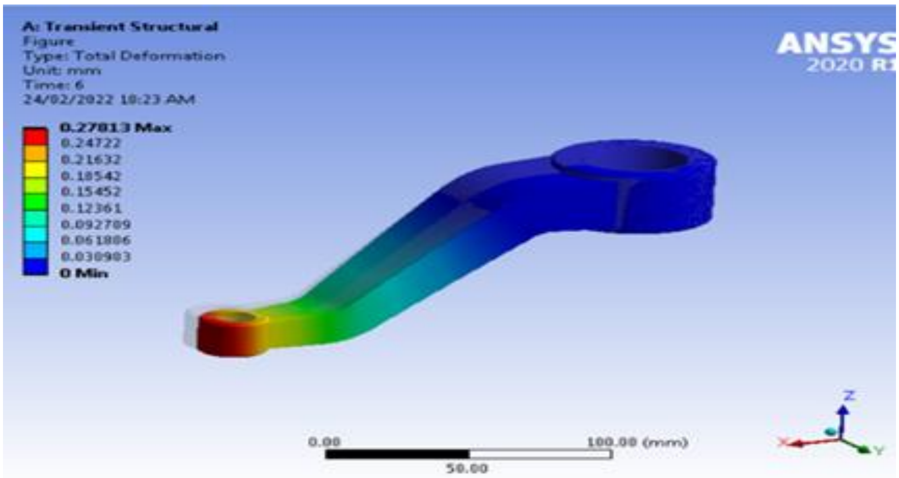
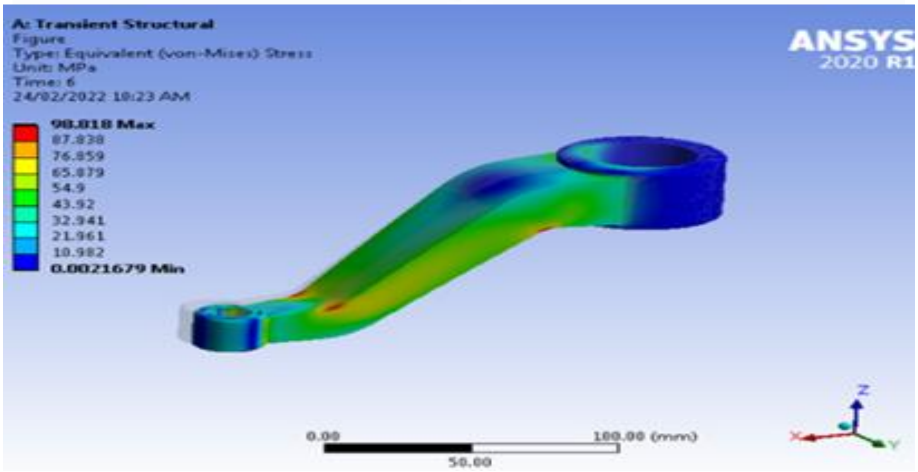



Figure 5. Boundary application Fixed support & load

**Results**



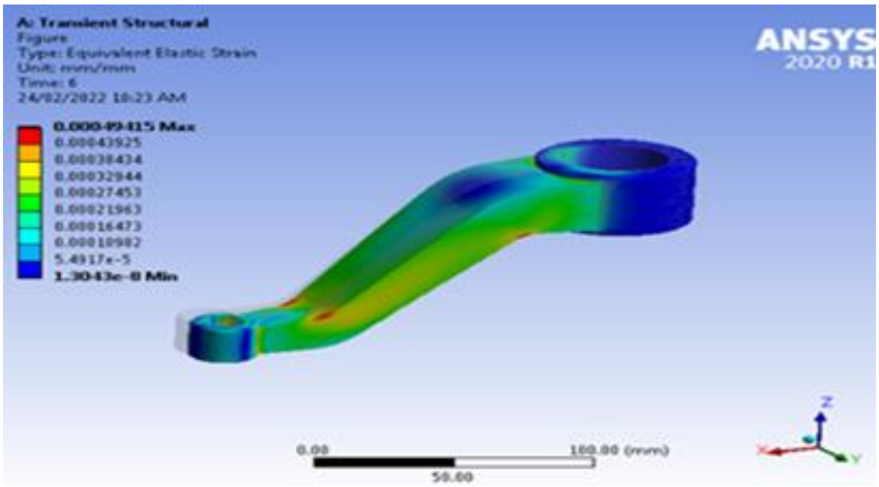
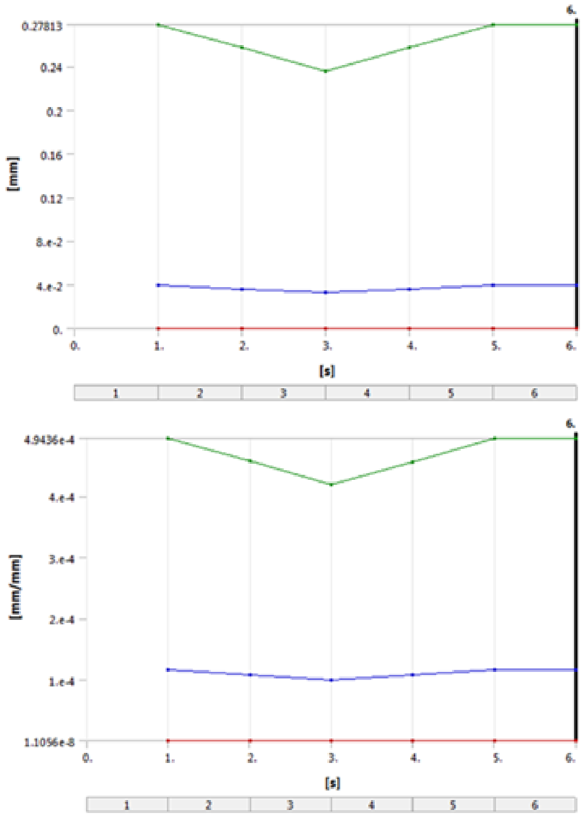



Figure 6. (a, b &c) total deformation, Von-Misses stress & Von Misses Strain




Graph 2 (a & b) Stress & strain curves

**Table No. 4 (a, b & c**) Von-Misses stress, Deformation & Strain

<table>
<tr><th>Time [s]</th><th>Minimum [MPa]</th><th>Maximum [MPa]</th><th>Average [MPa]</th></tr>
<tr><td>1.</td><td>2.1682e-003</td><td>98.86</td><td>23.101</td></tr>
<tr><td>2.</td><td>2.003e-003</td><td>91.327</td><td>21.341</td></tr>
<tr><td>3.</td><td>1.8376e-003</td><td>83.763</td><td>19.581</td></tr>
<tr><td>4.</td><td>2.0027e-003</td><td>91.291</td><td>21.341</td></tr>
<tr><td>5.</td><td rowspan="2">2.1679e-003</td><td>98.819</td><td rowspan="2">23.101</td></tr>
<tr><td>6.</td><td>98.818</td></tr>
</table>

| Time [s] | Minimum [mm] | Maximum [mm] | Average [mm] |
|---|---|---|---|
| 1. | 0. | 0.27813 | 3.9423e-002 |
| 2. | | 0.25694 | 3.642e-002 |
| 3. | | 0.23575 | 3.3416e-002 |
| 4. | | 0.25694 | 3.642e-002 |
| 5. | | 0.27813 | 3.9423e-002 |
| 6. | | | |

| Time [s] | Minimum [mm/mm] | Maximum [mm/mm] | Average [mm/mm] |
|---|---|---|---|
| 1. | 1.3044e-008 | 4.9436e-004 | 1.1615e-004 |
| 2. | 1.205e-008 | 4.5669e-004 | 1.073e-004 |
| 3. | 1.1056e-008 | 4.1886e-004 | 9.845e-005 |
| 4. | 1.205e-008 | 4.5651e-004 | 1.073e-004 |
| 5. | 1.3043e-008 | 4.9415e-004 | 1.1615e-004 |
| 6. | | | |

## IV. Discussion

In this paper only 1st iteration of analysis work has been done topology optimization, comparison on different material and followed by model analysis will be evaluated in next paper.

## V. Conclusion

- In this Paper simulation of the pitman arm using Transient structural analysis with non-linear boundary condition has been done and results are recorded. As we can in the loading variation in the above strategy.
- Hence, force is applied on the smaller end of the pitman arm, deformation, stress & strain Plotting have been done.
- As we can see the results section the maximum stress evaluated in the system is 98.818 Mpa. which is lesser then the ultimate yield strength of the forged material which is 240 Mpa.
- Hence the solution has been satisfactorily safe from the boundary condition applied to it, hence the stress is low and material used has a much higher density, so inversely the weight is also more, so let's try to optimize an arm for topology optimization in the next strategy. And I' ill take off as, much as unwanted material from the arm or linkage.
- After optimization vibrational analysis will be carried out followed by material comparison.

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