

# Modal Analysis, Fatigue Analysis and Optimization of Drop ARM using FEM

Raviraj Inamke

PG Student, Department of Mechanical Engineering  
JSPM's Rajarshi Shahu College of Engineering, Tathawade,  
Pune, Maharashtra, India.

Dr. N. K. Nath

Professor, Department of Mechanical Engineering  
JSPM's Rajarshi Shahu College of Engineering,  
Tathawade, Pune, Maharashtra, India.

Dr. R.R. Arakerimath

HOD, Department of Mechanical Engineering  
JSPM's Rajarshi Shahu College of Engineering,  
Tathawade, Pune, Maharashtra, India

**Abstract**— The Drop Arm is part of the steering component in a Tractor. It is connected to the sector shaft and moves in angular motion with the help of the sector shaft. This motion causes the wheels to move left or right, depending on which way the steering wheel is moved. It is important you have your drop arm in good working condition because poor steering can be hazardous to you and those around you. A performance study will be carried to perform Failure, Fatigue & Modal Analysis of pitman arm using Ansys. The structural optimization will be done on the drop arm by changing the structure of pitman arm by modifying the geometry where stress values are critical. The meshing and boundary conditions will be applied and analysis will be carried out using Ansys 16.0.

**Keywords**— Finite element analysis, Fatigue analysis, Modal analysis, Drop arm, FEM.

## I. INTRODUCTION

The Drop arm is a steering component that is used in an automobile or Tractor. It is a linkage between sector shaft of the steering box and drag link. It transmits the angular motion to the linear motion that is required to steer the wheels in desired direction.

The arm is attached to the sector shaft and supports the drag link or center link. It transmits the motion it receives from the steering box into the drag link, causing it to move Steering arm to turn the wheels in the appropriate direction. The track rod is attached between the opposite sides of the steering arms. A damaged or loose drop arm can cause inability to steer, wandering to the left or right while on the road, poor steering.

## II. OBJECTIVES

- To perform 3D Scanning of Drop Arm used in Tractor.
- To perform Failure analysis of Drop Arm.
- To analyze the fatigue life of the component.
- To perform Modal analysis of the component.
- Structural optimization for better design and increased efficiency.

## III. METHOD

OLGY Phase I- Literature Survey

Phase II- 3D Scanning & CAD

Modelling

Phase III- Failure, Fatigue & Modal Analysis of Drop Arm

Phase IV- Optimization of Drop Arm

Phase V- Failure, Fatigue and Modal Analysis of Optimized

Drop Arm

Phase VI- Validation and Report

## IV. LITERATURE SURVEY

**Pradeep B Patil et al. [1]** Static and modal analysis results of existing pitman arm proved that the model is more stable and there is scope for optimization. The comparison, between modal analysis results of existing and optimized pitman arm has been performed and it is observed that the pitman arm is vibrationally stable.

**Sijith PM et al. [2]** Performance study is carried out followed by static structural analysis and optimization to minimize the weight of the pitman arm and thereby reducing the material cost. Optimized model is then verified by physical testing.

**Vimal Rau Aparow et al. [3]** has investigated 2 DOF mathematical models of Pitman arm steering system and derived using Newton's law of motion and modeled in MATLAB/SIMULINK software. The performance of the electronically actuated Pitman arm steering system can be used to develop a firing-on-the-move actuator (FOMA) for an armored vehicle.

**Srilekha Aurulla, G. and Gopala Krishna [4]** has presented the static and modal analysis of steering lever link of a tractor to check its deformation, maximum stress and natural frequencies by using three materials.

**Aniket Kolekar et al. [5]** has designed and fabricated the fixture which is used in the manufacturing of Pitman Arm of steering system. The fixture is designed by using software CATIAV5R21. The purpose of the fixture is to provide strength, holding, accuracy and

interchangeability in the manufacturing of product. The main purpose of a fixture is to locate and, in the cases, hold a work piece during an operation.

**Shatabdee Sonawane et al. [6]** Static analysis results of existing pitman arm proved that the model is more stable and there was scope for optimization. The Pitman arm is optimized. The weight of original model is 974 gm and that of the optimized model is 840 gm. Weight of the component is reduced successfully upto 14% after optimization. The study confirmed that optimized pitman arm is structurally stable with good fatigue life.

**Pradeep B Patil et al. [7]** Based on FEA it can be concluded that the optimized pitman arm has infinite life because it can withstand above 10,00,000 cycles. Weight reduction of 9.04 % is obtained without compromising the strength of pitman arm. Natural frequency of both conventional and optimized pitman arm is extracted.

### V. 3D SCANNING & CAD MODELLING



Fig. 1. 3D Scanning Process



Fig. 2. 3D Scanning Equipment



Fig. 3. 3D Scanned Data

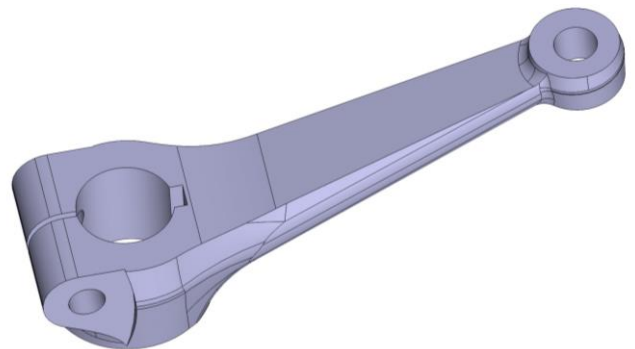


Fig. 4. 3D Model Created from Scanned Data



Fig. 5. Real time Drop Arm

Finite element analysis is a computational technique that is used in engineering to obtain approximate solutions of boundary value problems.

The following are the steps for pre and post processing in FEM.

1. Define the geometry of the problem.
2. Discretize the model by meshing.
3. Define the element type(s) to be used.
4. Define the material properties of the elements.
5. Define the element connectivity.
6. Define the physical constraints (boundary conditions).
7. Define the loadings.
8. Solve the analytical problem.
9. Result evaluation.

Property	Value
Young's modulus (E)	2.06 x 10 <sup>11</sup> Mpa
Poisson's ratio (ν)	0.29
Density (ρ)	7.87 x 10 <sup>-6</sup> kg/mm <sup>3</sup>
Yield strength	450 Mpa

TABLE I. Material properties of Alloy Steel

VI. FORCE CALCULATIONS

Total Mass of the vehicle,  
 M1=Curb weight + Driver weight + Tractor Implement Weight

$$M1 = 1713 + 80 + 1000 = 2793 \text{ kg}$$

This weight is divided into front axle weight and rear axle weight.

35% of the total weight is taken by front axle and 65% is by rear axle.

Therefore, Mass on the front axle,

$$M2 = 977.55 \text{ kg}$$

Mass on one of the front wheels, M = 488.775 kg

Width of tire, B = 132.08 mm

Centre of rotation (king pin) to wheel, E = 145 mm

Coefficient of friction, μ = 0.7

Distance from king pin center to tie rod pin, L1 = 195 mm.

T=Torque required to rotate one wheel (torque at king pin),

$$T = M * g * \mu * (B^2/8) + E^2 \quad (1)$$

$$T = 511296.4938 \text{ N}$$

$$F = T/L1 \quad (2)$$

$$F = 2622.0333 \text{ N}$$

Since single steering arm will be handling two wheels so the force on steering arm will be doubled.

$$F = 5244.0666 \text{ N}$$

**Stress calculation:**

$$\sigma = My/I \quad (3)$$

σ = Maximum bending stress

M = Bending moment

y = Vertical distance away from the neutral axis

I = Moment of inertia

$$y = b/2 \quad (4)$$

$$y = 17 \text{ mm.}$$

$$I = (w * b^3)/12 \quad (5)$$

$$I = 63869 \text{ mm}^4.$$

$$M = F * L \quad (6)$$

$$M = 776121.8668 \text{ N-mm.}$$

The maximum bending stress,

$$\sigma = My/I \quad (7)$$

$$\sigma = 206.58021 \text{ Mpa.}$$

**Vibration analysis (frequency calculation):**

For natural frequency,

$$\omega_n = k^2 - [EI/(ApL^4)]^{1/2} * (1/2\pi) \quad (8)$$

Where,

$$k = (2n-1) * (\pi/2) \quad (9)$$

Mode	Frequency
1 <sup>st</sup> Mode	862.4
2 <sup>nd</sup> Mode	1629.8
3 <sup>rd</sup> Mode	3561.6
4 <sup>th</sup> Mode	5018.2
5 <sup>th</sup> Mode	5962.7
6 <sup>th</sup> Mode	8393.6

TABLE II. Vibration analysis (frequency calculation)

**Fatigue life calculation:**

$$N = 10^{(-c/b)} * S_a^{(1/b)} \quad (10)$$

$$b = (-1/3) * \log [(0.8*S_{ut})/S_e] \quad (11)$$

$$c = \log [(0.8*S_{ut})^2/S_e] \quad (12)$$

N = Number of life cycles before failure

S<sub>ut</sub> = Ultimate tensile strength

S<sub>a</sub> = Stress amplitude

S<sub>e</sub> = Endurance

$$S_{ut} = 450 \text{ Mpa} = 45.887 \text{ kgf/mm}^2$$

$$S_a = 0.8S_{ut} = 360 \text{ Mpa} = 36.709 \text{ kgf/mm}^2$$

$$S_e = 0.5S_{ut} = 225 \text{ Mpa} = 22.943 \text{ kgf/mm}^2$$

$$b = -0.067989$$

$$c = 1.768587$$

$$N = 0.994846 \times 10^6$$

The existing pitman arm will fail after 0.994846 × 10<sup>6</sup> cycles. We say that component is having infinite life if it exceeds one lakh cycles.

### VII. FINITE ELEMENT ANALYSIS OF DROP ARM

For analysis, one end of the pitman arm (larger side connected to sector shaft) is rigidly fixed and on another end, load is applied i.e., of 5244.0666 N.

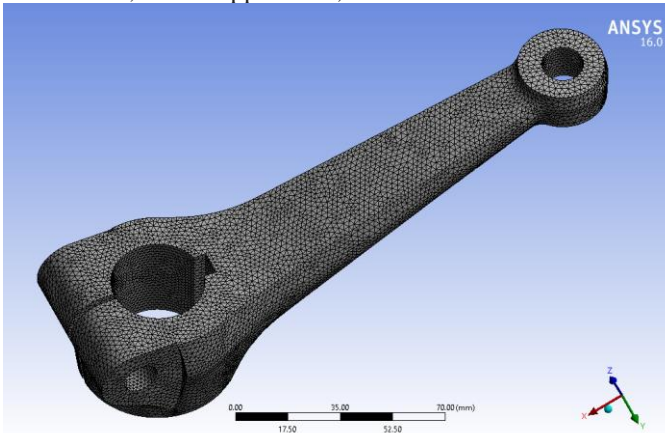


Fig. 6. Meshed Model

#### Mesh Details:

Nodes: 215655

Elements: 143218

#### Deformation Plot:

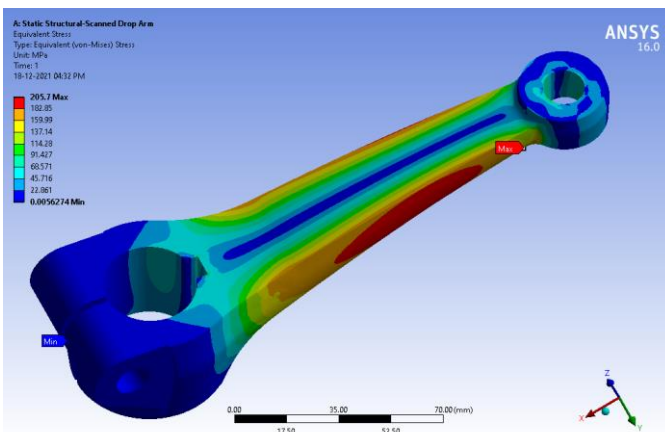


Fig. 7. Deformation Plot  
 Maximum Deformation is 0.63854 mm.

#### Stress plot:

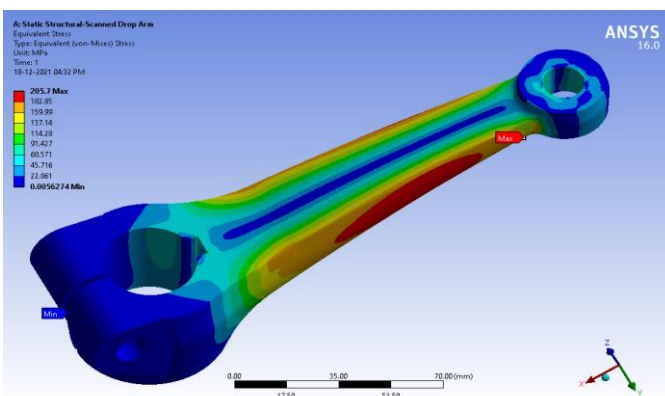


Fig. 8. Equivalent (von-Mises) Stress

Maximum Stress: 205.7 MPa  
 Minimum Stress: 0.0056274 MPa  
 Ultimate Strength: 450 MPa  
 Maximum Force component can withstand: 11472.026 N

As stress is well within the limit and deformation is less hence there is scope for optimization.

### VIII. FATIGUE ANALYSIS OF DROP ARM

#### Results for fatigue analysis:

Force Applied: 5244.0666 N

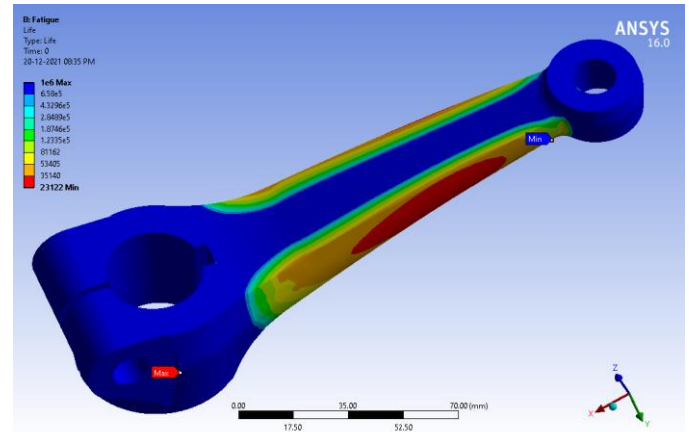


Fig. 9. Fatigue Life of Drop Arm  
 Minimum Fatigue Life (Cycles): 23122  
 Maximum Fatigue Life (Cycles):  $1 \times 10^6$

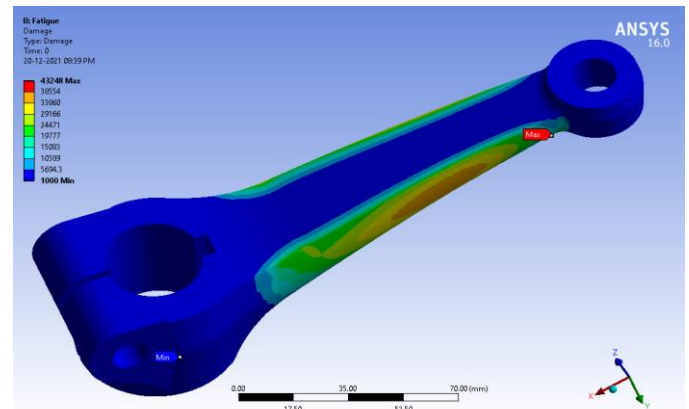


Fig. 10. Damage of Drop Arm  
 Minimum Damage: 1000  
 Maximum Damage: 43248

### IX. MODAL ANALYSIS OF DROP ARM

Modal frequency results of 6 modes of drop arm calculated in Ansys 16.0 are as below.

Modal Frequency	Drop Arm
1 <sup>st</sup> Mode	896.86
2 <sup>nd</sup> Mode	1560
3 <sup>rd</sup> Mode	3617.4
4 <sup>th</sup> Mode	5047.1
5 <sup>th</sup> Mode	6004.2
6 <sup>th</sup> Mode	8284.4

TABLE III. Modal Analysis of Drop Arm

### X. OPTIMIZATION OF DROP ARM

The optimization of drop arm is done by modifying the geometry of drop arm where stress concentration is highest and lowest. Drop arm is optimized by modifying stress concentration areas and improving geometry for better stress distribution. Extra material is added on top side of drop arm to provide better stress distribution in z direction and extreme edges are smoothened.

A slot is also added in low stress areas to compensate for increased weight and netter stiffness in Y direction.

The optimized geometry as below.

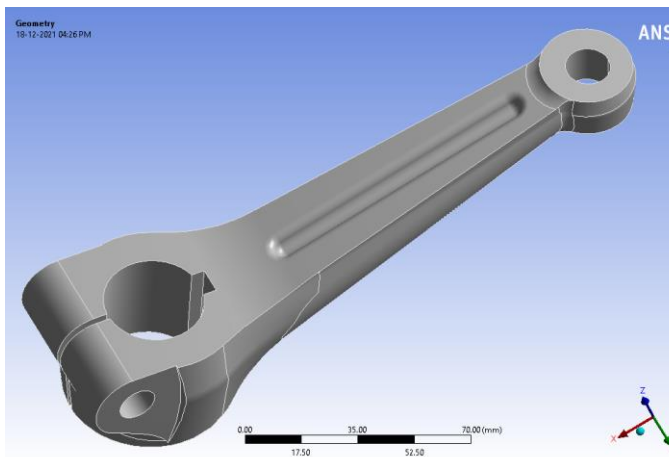


Fig. 11. Optimized Drop Arm

#### Deformation Plot:

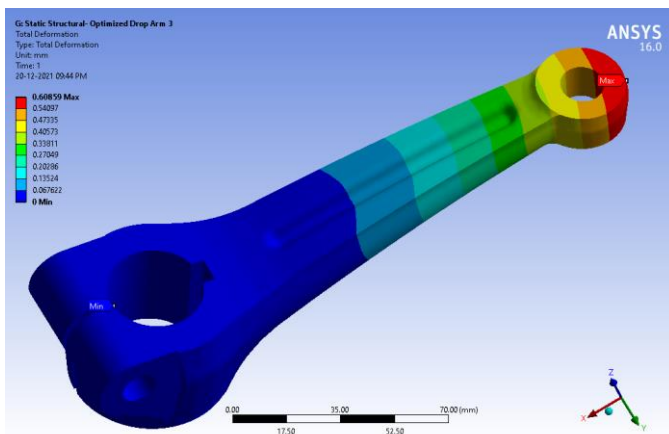


Fig. 12. Deformation Plot of Optimized Drop Arm

Maximum Deformation is 0.60859 mm.

#### Stress plot:

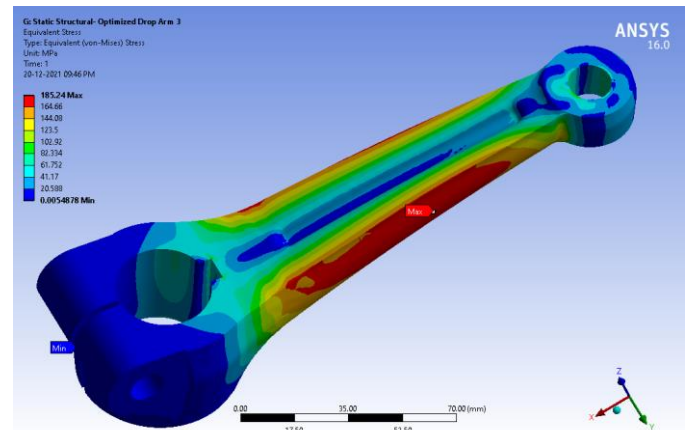


Fig. 13. Equivalent (von-Mises) Stress

Maximum Stress: 185.24 MPa

Minimum Stress: 0.00054878 MPa

Ultimate Strength: 450 MPa

Maximum Force component can withstand: 12738.886 N

### XI. FATIGUE ANALYSIS OF OPTIMIZED DROP ARM

#### Results for fatigue analysis:

Force Applied: 5244.0666 N

Minimum Fatigue Life (Cycles): 33957

Maximum Fatigue Life (Cycles):  $1 \times 10^6$

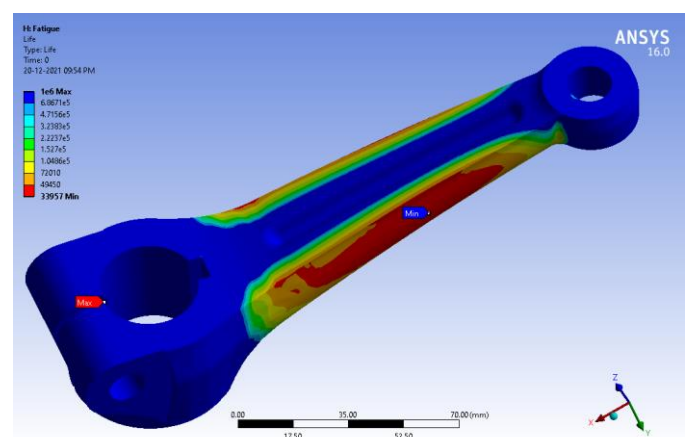


Fig. 14. Fatigue Life of Optimized Drop Arm

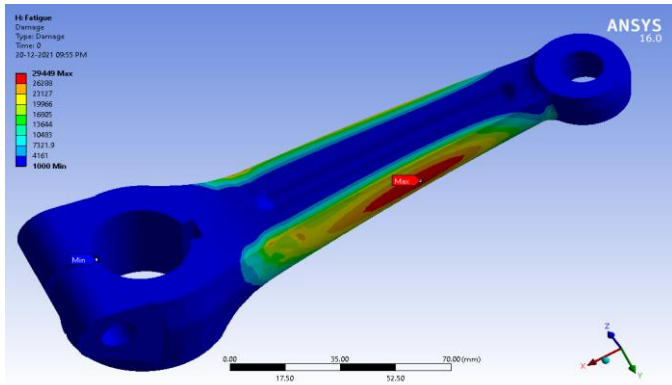


Fig. 15. Damage of Optimized Drop Arm

Minimum Damage: 1000

Maximum Damage: 29449

**XII. MODAL ANALYSIS OF OPTIMIZED DROP ARM**

The Modal frequency results of 6 modes of Optimized drop arm calculated in Ansys 16.0 are as below.

Modal Frequency	Optimized Drop Arm
1 <sup>st</sup> Mode	902.39
2 <sup>nd</sup> Mode	1574.9
3 <sup>rd</sup> Mode	3761.5
4 <sup>th</sup> Mode	4497.9
5 <sup>th</sup> Mode	6230.7
6 <sup>th</sup> Mode	8561.1

TABLE IV. Modal Analysis of Optimized Drop Arm

**XIII. RESULTS AND DISCUSSIONS**

**Fatigue Analysis:**

Parameter	Drop Arm		Optimized Drop Arm	
	Min	Max	Min	Max
Fatigue Life (Cycles)	23122	1×10 <sup>6</sup>	33957	1×10 <sup>6</sup>
Damage	1000	43248	1000	29449

TABLE V. Comparison of Fatigue life

**Structural Analysis:**

Parameter	Drop Arm		Optimized Drop Arm	
	Min	Max	Min	Max
Equivalent (von-Mises) Stress (Mpa)	0.0056274	205.7	0.0054878	185.24
Equivalent Elastic Strain (mm/mm)	4.0917×10 <sup>-8</sup>	0.0011	4.1071×10 <sup>-8</sup>	0.0008992
Ultimate Strength (Mpa)	-	450	-	450
Maximum Force component can withstand(N)	-	11472.03	-	12738.886
Maximum Deformation (mm)	0	0.63854	0	0.60859

TABLE VI. Comparison of structural analysis results

**Modal Analysis:**

Modal Frequency	Drop Arm	Optimized Drop Arm
1 <sup>st</sup> Mode	896.86	902.39
2 <sup>nd</sup> Mode	1560	1574.9
3 <sup>rd</sup> Mode	3617.4	3761.5
4 <sup>th</sup> Mode	5047.1	4497.9
5 <sup>th</sup> Mode	6004.2	6230.7
6 <sup>th</sup> Mode	8284.4	8561.1

TABLE VII. Comparison of Modal Analysis Results

**XIV. CONCLUSION**

- Static and modal analysis results of existing pitman arm proved that there is scope for optimization.
- Von-Mises stress in optimized drop arm is reduced by 10%, Maximum force drop arm can withstand is increased by 11% and deformation is reduced by 5% under same loading conditions.
- The comparison, between fatigue life results of existing and optimized pitman arm has been performed and it is observed that the pitman arm is having infinite life.
- The comparison, between modal analysis results of existing and optimized pitman arm has been performed and it is observed that the pitman arm is vibrationally stable.

The above steady confirmed the optimized pitman arm is vibrationally and structurally stable with good fatigue life.

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