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Modal Analysis, Fatigue Analysis and Optimization of Tractor Drop Arm Using FEM

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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

This 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 centre 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

1) To perform 3D Scanning of Drop Arm used in Tractor.
2) To perform Failure analysis of Drop Arm.
3) To analyse the fatigue life of the component.
4) To perform Modal analysis of the component.
5) Structural optimization for better design and increased efficiency.

III. METHODOLGY

1) Phase I- Literature Survey
2) Phase II- 3D Scanning & CAD Modelling
3) Phase III- Failure, Fatigue & Modal Analysis of Drop Arm
4) Phase IV- Optimization of Drop Arm
5) Phase V- Failure, Fatigue and Modal Analysis of Optimized Drop Arm
6) 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 modelled 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 armoured vehicle.

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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 up to 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 Scanned Data

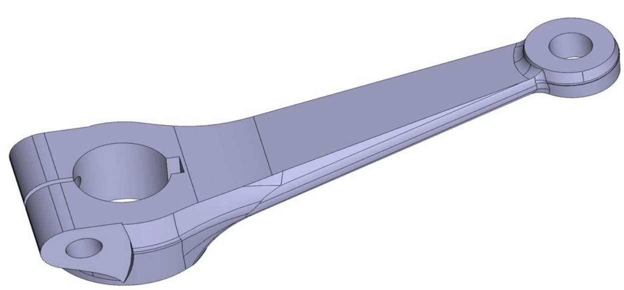

Fig. 3 3D Model Created from Scanned Data

Fig. 4 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) Discretise 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.

TABLE I
MATERIAL PROPERTIES OF ALLOY STEEL

Property	Value
Young's modulus (E)	2.06×10^{11} Mpa
Poisson's ratio (v)	0.29
Density (ρ)	7.87×10^{-6} kg/mm^3
Yield strength	450 Mpa

VI. FORCE CALCULATIONS

Total Mass of the vehicle,
M1=Curb weight + Driver weight + Tractor Implement Weight = 1713 + 80 + 1000 = 2793 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 rare axle.
Therefore, Mass on the front axle, M2 = 977.55 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 centre to tie rod pin, L1 = 195 mm.
T=Torque required to rotate one wheel (torque at king pin),
$T = M * g * \mu * (B^2/8) + E^2$ $\quad$ T = 511296.4938 N
$F = T/L1$ $\quad$ F = 2622.0333 N
Since single steering arm will be handling two wheels so the force on steering arm will be doubled.
F = 5244.0666 N

A. Stress Calculation

$\sigma = My/I$
σ = Maximum bending stress
M = Bending moment
y = Vertical distance away from the neutral axis
I = Moment of inertia

y = b/2	y = 17 mm.
I = (w * b3)/12	I = 63869 mm4.
M = F * L	M = 776121.8668 N-mm.

TABLE III
VIBRATION ANALYSIS (FREQUENCY CALCULATION)

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

B. Fatigue Life Calculation

S_{ut} = Ultimate tensile strength	S_{ut} = 450 Mpa = 45.887 kgf/mm^2
S_a = Stress amplitude	$S_a = 0.8S_{ut}$ = 360 Mpa = 36.709 kgf/mm^2
S_e = Endurance	$S_e = 0.5S_{ut}$ = 225 Mpa = 22.943 kgf/mm^2
$b = (-1/3) * \log [(0.8*S_{ut})/S_e]$	b = -0.067989
$c = \log [(0.8*S_{ut})^2/S_e]$	c = 1.768587
N = Number of life cycles before failure	$N = 10^{(-c/b)} * S_a^{(1/b)} = 0.994846 \times 10^6$

The existing pitman arm will fail after 0.994846×10^6cycles. 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.

1) *Mesh Details:* Nodes: 215655, Elements: 143218

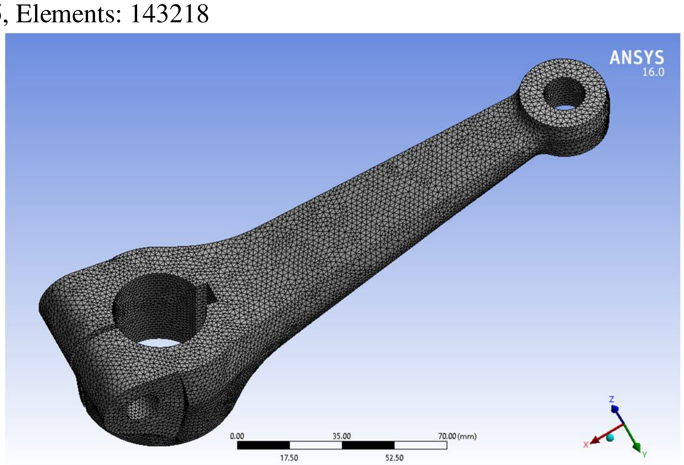

Fig. 5 Meshed Model

2) *Deformation Plot:* Maximum Deformation is 0.63854 mm.

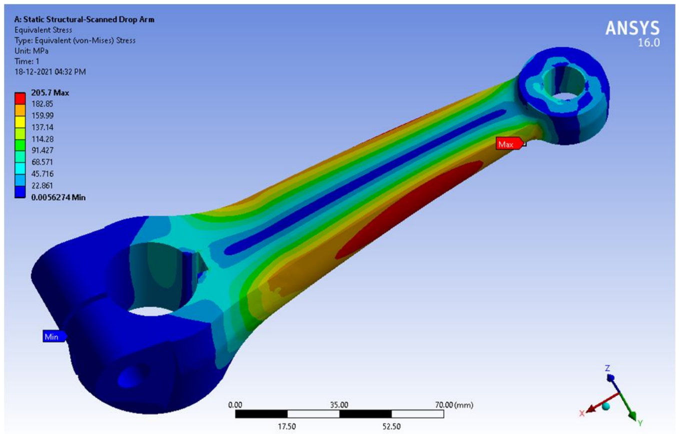

Fig. 6 Deformation Plot

3) *Stress Plot*

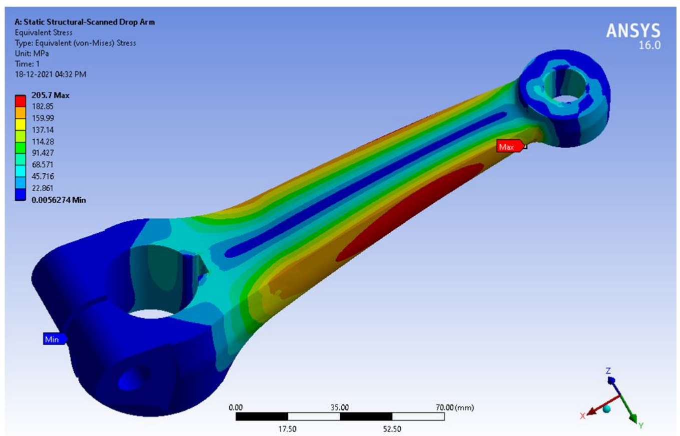

Fig. 7 Equivalent (von-Mises) Stress

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

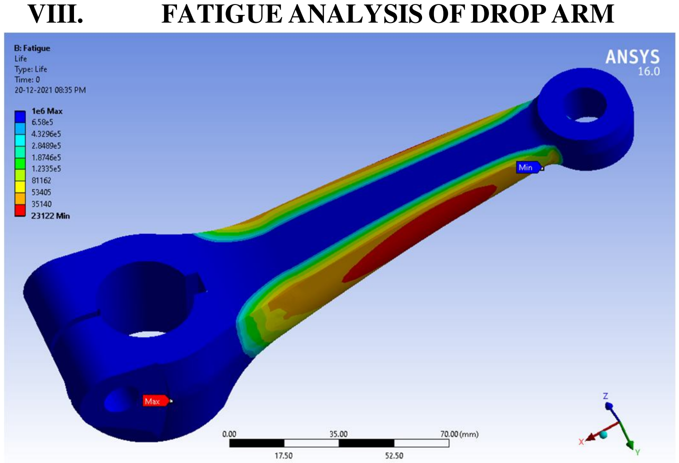

Fig. 8 Fatigue Life of Drop Arm

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Volume 10 Issue IV Apr 2022- Available at www.ijraset.com

Minimum Fatigue Life (Cycles): 23122, Maximum Fatigue Life (Cycles): 1×10^6

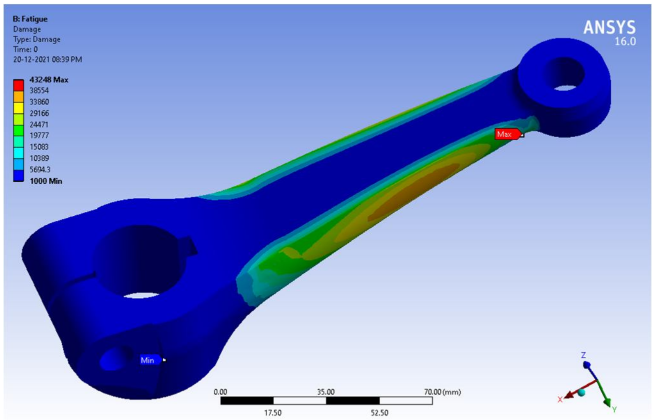

Fig. 9 Damage of Drop Arm

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.

TABLE IIIII
MODAL ANALYSIS OF DROP ARM

Modal Frequency	Drop Arm
1^{st} Mode	896.86
2nd Mode	1560
3rd Mode	3617.4
4th Mode	5047.1
5th Mode	6004.2
6th Mode	8284.4

X. OPTIMIZATION OF DROP ARM

A. *Structural Optimization*

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.

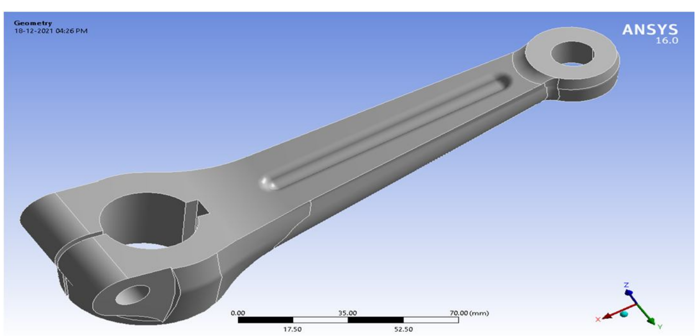

Fig. 10 Optimized Drop Arm

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B. Material Optimization

New Material selected for optimization of Drop arm is AISI 4304 - EN24T. Material properties of EN24T are as below-

TABLE IVV
MATERIAL PROPERTIES OF EN24T

Properties	Metric	English
Density	7.85 g/cc	0.284 lb/in³
Hardness, Brinell	363	363
Hardness, Knoop	392	392
Hardness, Rockwell B	100	100
Hardness, Rockwell C	40	40
Hardness, Vickers	384	384
Tensile Strength, Ultimate	1282 MPa	185900 psi
Tensile Strength, Yield	862 MPa	125000 psi
Modulus of Elasticity	200 GPa	29000 ksi
Bulk Modulus	159 GPa	23100 ksi
Poissons Ratio	0.29	0.29
Shear Modulus	78.0 GPa	11300 ksi

C. Deformation Plot

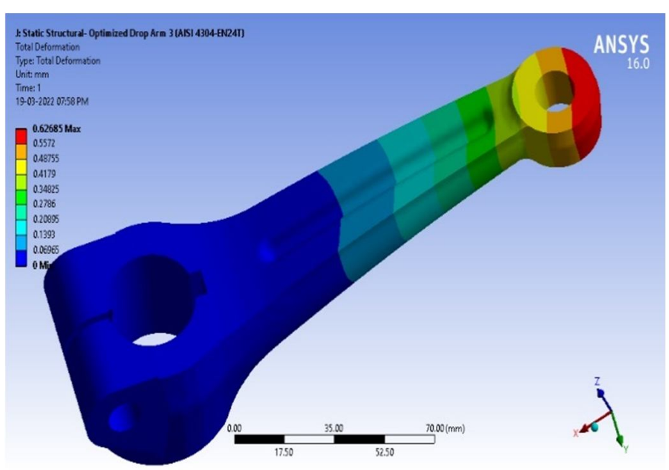

Fig. 11 Deformation Plot of Optimized Drop Arm

Maximum Deformation is 0.62685 mm.

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D. Stress Plot

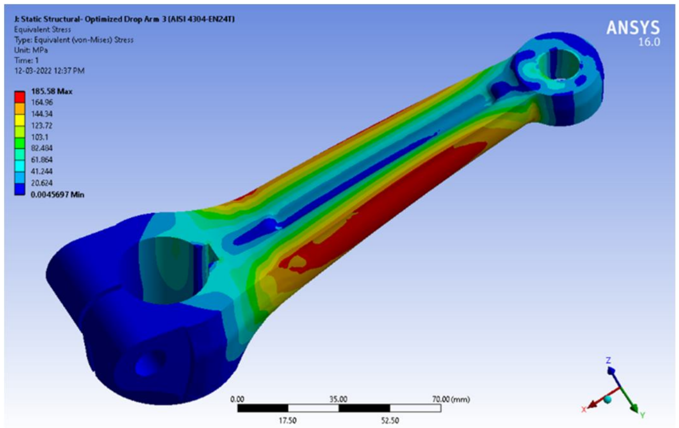

Fig. 12 Equivalent (von-Mises) Stress

Maximum Stress: 185.58 MPa
Minimum Stress: 0.0045697 MPa
Ultimate Strength: 862 MPa
Maximum Force component can withstand: 24357.64 N

XI. FATIGUE ANALYSIS OF OPTIMIZED DROP ARM

A. Results for Fatigue Analysis

Force Applied: 5244.0666 N
Minimum Fatigue Life (Cycles): 33730
Maximum Fatigue Life (Cycles): 1×10^6

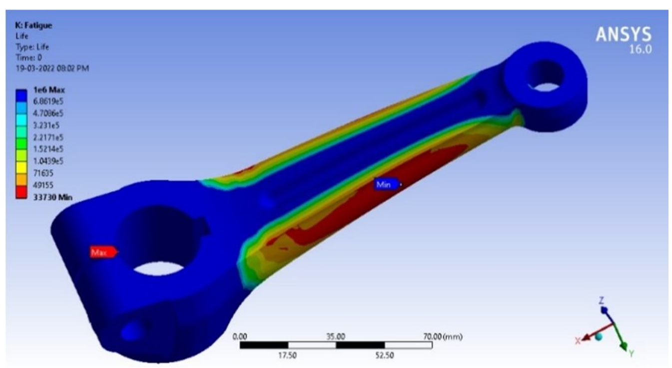

Fig. 13 Fatigue Life of Optimized Drop Arm

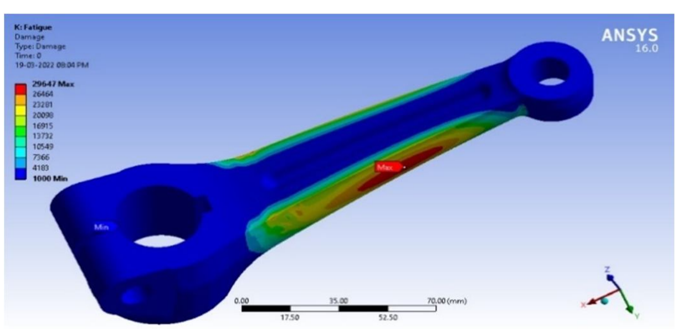

Fig. 14 Damage of Optimized Drop Arm

Minimum Damage: 1000, Maximum Damage: 29647

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Volume 10 Issue IV Apr 2022- Available at www.ijraset.com

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.

TABLE V
MODAL ANALYSIS OF OPTIMIZED DROP ARM

Modal Frequency	Optimized Drop Arm
1st Mode	890.3
2nd Mode	1553.8
3rd Mode	3711
4th Mode	4437.4
5th Mode	6147.1
6th Mode	8446.3

XIII. RESULTS AND DISCUSSIONS

A. *Fatigue Analysis*

TABLE VI
COMPARISON OF FATIGUE LIFE

Parameter	Drop Arm		Optimized Drop Arm	
	Min	Max	Min	Max
Fatigue Life (Cycles)	23122	1×10^6	33730	1×10^6
Damage	1000	43248	1000	29647

B. *Structural Analysis*

TABLE VII
COMPARISON OF STRUCTURAL ANALYSIS RESULTS

Parameter	Drop Arm		Optimized Drop Arm	
	Min	Max	Min	Max
Equivalent (von Mises) Stress (Mpa)	0.0056274	205.7	0.0045697	185.58
Equivalent Elastic Strain (mm/mm)	4.0917×10^{-8}	0.0011	3.5763×10^{-8}	0.0009279
Ultimate Strength (Mpa)	-	450	-	862
Maximum Force component can withstand(N)	-	11472.03	-	24357.64
Maximum Deformation (mm)	0	0.63854	0	0.62685

C. Modal Analysis

TABLE VIII
COMPARISON OF MODAL ANALYSIS RESULTS

Modal Frequency	Drop Arm	Optimized Drop Arm
1st Mode	896.86	890.3
2nd Mode	1560	1553.8
3rd Mode	3617.4	3711
4th Mode	5047.1	4437.4
5th Mode	6004.2	6147.1
6th Mode	8284.4	8446.3

XIV. CONCLUSION

1) Static and modal analysis results of existing pitman arm proved that there is scope for optimization.
2) Von Mises stress in optimized drop arm is reduced by 9.78%, Maximum force drop arm can withstand is increased by 112% and deformation is reduced by 2% under same loading conditions.
3) 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.
4) 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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