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Shape and Material Optimization of the Steering Knuckle Component

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Abstract - **The steering knuckle is a most critical component in automotive vehicle. It experiences the continuous application of the loads and also the deflections. As the need of people with respect to high comfort increases, the weight of the vehicle will also increase, ultimately performance of the vehicle reduces and fuel consumption increases accordingly. Keeping this concept in mind an effort has been made to improve the performance by reducing the weight of the steering knuckle, as it is a known fact that by reducing the weight of both smaller and bigger components only the overall weight can be reduced. This has been done using numerical method. The 3D cad model is created by using the software CATIA V5. Then the component is discredited in Hyper Mesh pre-processor. For steering knuckle, the static and modal analysis is carried out to understand its behaviour under operating conditions. Using the results of analysis the low stress regions are marked and the shape optimization has been done.All the above procedure to be done for the different aluminium alloys like 2011-T3Al, 2024-T3Al and 6061-T6Al. The best design among above mentioned materials is proposed by comparing the structural strength with that of existing cast iron component in material optimization stage for weight reduction with optimum efficiency.**

I. INTRODUCTION

Steering knuckle is one of the main components of the vehicle which facilitates to turn the front wheel for steering and also acts as a load carrying member.The steering knuckle is a most critical component in automotive vehicle. It experiences the continuous application of the loads and also the deflections. These dynamic effects are majorly caused due to the irregularities on the roads, sudden application of the break and the self-weight of the vehicle. The steering knuckle behaves like a connection of hub because it connects with multiple components like suspension system, braking system and steering mechanism. Steering knuckle provides the connection between suspension, steering tie rod and braking system.

A. Hub type steering knuckle

The hub type steering knuckle is most widely used in passenger vehicles and small Goods vehicles. This kind of steering knuckle comes with the drive type suspension system example- MARUTI ESTEEM, TATA ACE, TATA INDICA.

The hub-steering knuckle consisting of central circular hub in which the rotating shaft is fitted, in this type of knuckle there is no any horizontal projection. The central circular hub consisting of the bearing arrangement at inside radius, this make easy for the free rotation of the shaft about its axes. The end of the rotating shaft is provided with the mounting stud arrangement to facilitate for fixing the breaking system and wheel assembly. When shaft is on rotation the wheel assembly also rotates but the wheel assembly not move freely when there is an engagement with the shaft , it will rotate freely when it disengage with the rotating shaft.

B. Spindle type steering knuckle

The spindle type steering knucklemost commonly used in the high speed application vehicles like racing cars. The spindle type steering knuckle having different design compared with the hub type steering knuckle, this type of knuckle most commonly used for the non-drive suspension system and example- sports cars and high speed cars

Spindle type steering knuckle consisting of a circular shaft instead of circular hub. The shaft is extended enough to get the proper attachment with the brake drum and wheel assembly. The inside diametrical surface of the rotating drum is placed rigidly on the steering shaft with the help of tooth provided on the steering shaft. The brake disc is attached to the brake calliper and tyre assembly is attached to it respectively. When the vehicle is running the entire wheel assembly is rotating independently upon the spindle of the steering shaft.

C. Introduction to Design

A study on the existing design of steering knuckle is conducted, for this steering knuckle maruthi esteem passenger car is selected. After extracting the dimensions from the design, cad model of steering knuckle was created using CATIA V5 software. Then analysis on the component for static and modal conditions was carried out using HyperMesh as preprocessor and NASTRAN as the structural solver. After this shape optimization was carried out using Ansys shape optimization software. Again redesigning the steering knuckle with shape optimization results analysis for static and modal conditions was carried out. A comparison between the results of both before and after shape optimization analysis for different materials like Grey cast Iron, Aluminium alloy 2011-T3, Aluminium alloy 2024-T3 and Aluminium alloy 6061-T6.

D. Design Of Steering Knuckle [Existing Design]

Steering knuckle model is taken and all the dimensions were measured by drafting with the help of measuring instruments and drawings are created on the paper for further study. Using this drawings 3D CAD model were created using CATIA V5.

E. Material Selection

Previously several kind of materials are used for the steering knuckle component like grey cast iron, white cast iron, S G iron. These materials have high yield strength but the weight of the material also more hence searching for the alternate material with nearest yield strength and lesser in weight. Taking in to consideration of these factor chosen a different aluminium alloys like Aluminium alloy 2011-T3, Aluminium alloy 2024-T3 and Aluminium alloy 6061-T6 for the study.

II. Load Calculations

The gross weight of the of the vehicle is M= 1315 kg. Hence the vehicle is in equilibrium condition therefore the total weight is equally distributed on the each wheel. The weight on the each wheel is m= 328.75 kg.

1) Break force can be calculated as shown below.
   F = 4837 N
   Load on left side arm F_L = 2481.7 N
   Load on right side arm F_R = 2481.7 N
2) Break moment at the hub.
   Breaking moment = 4837.5*94
   Breaking moment (M_b) = 454725 N-mm
3) During the cornering of the vehicle the lateral force is acting on the hub and it can be calculated as calculated in breaking case
   $F_{lateral}$= m*(1+0.5)a
   $F_{lateral}$= 4837.5 N

TABLE I
MESH QUALITY PARAMETER

Mesh type	Solid Mesh
Element Type	3d Tetrahedral [tetra4]
Average Element Length	1.5mm
Warpage	$< 15^0$
Jacobian	< 0.65
Aspect Ratio	5
Skewness	$< 60^0$
Tria Angles	20^0<tria< 120^0
Total Number of 3d Elements	312721

Cad Model of steering knuckle generated in CATIA V5 is imported into the HyperMesh user interface for pre-processing. The Model was checked for any geometrical errors and corrected using geometry cleanup options. Tetrahedral meshing is done using the mesh quality parameters defined.

III. FINITE ELEMENT ANALYSIS

TABLE II
STATIC AND MODAL ANALYSIS TEST RESULT FOR DIFFERENT MATERIAL.

Material	Stress(MPa)	Displacement in mm
Gray Cast Iron	4.43E+01	3.21E-02
2011-T3 AL	4.40E+01	3.10E-02
2024-T3 AL	4.74E+01	2.98E-02
6061-T6 AL	4.40E+01	3.15E-02

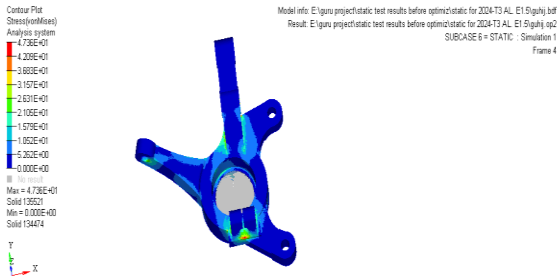

Figure 1. static stress test result for 2024-T3 AL

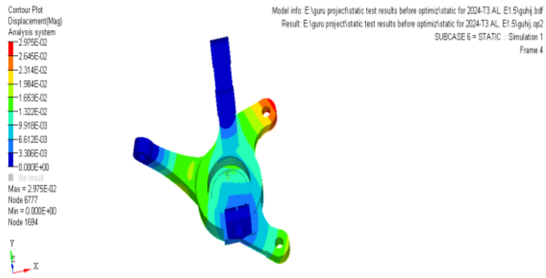

Figure 2. static displacement test result for 2024-T3 AL

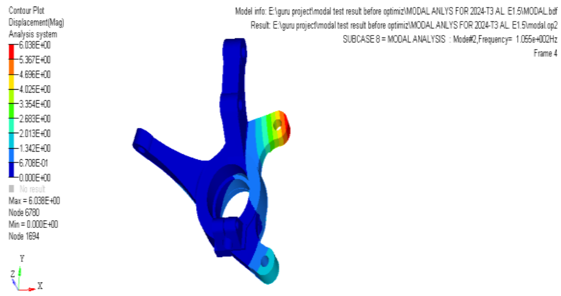

Figure 3. modal test displacement result for 2024-T3 AL

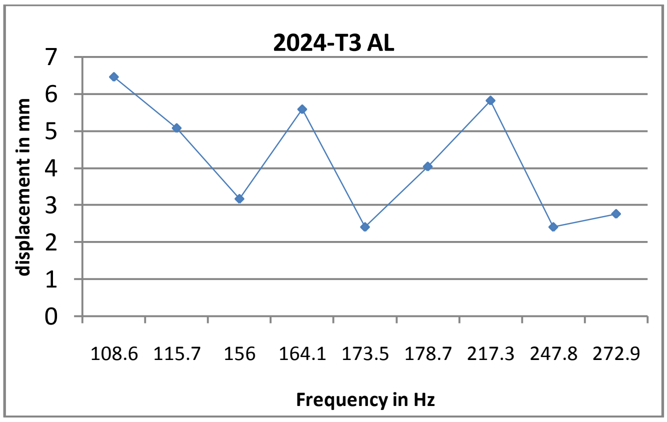

Figure 4. Displacement-frequency curve for 2024-T3 AL

IV. Shape Optimization

Shape optimization is a process in which optimizing the design of the component by removing the material from original shape by varying in the external features of the design without effecting in its performance and its life. The main objective to perform the shape optimization is to reduce the weight of the existing component and also to facilitate the space available.

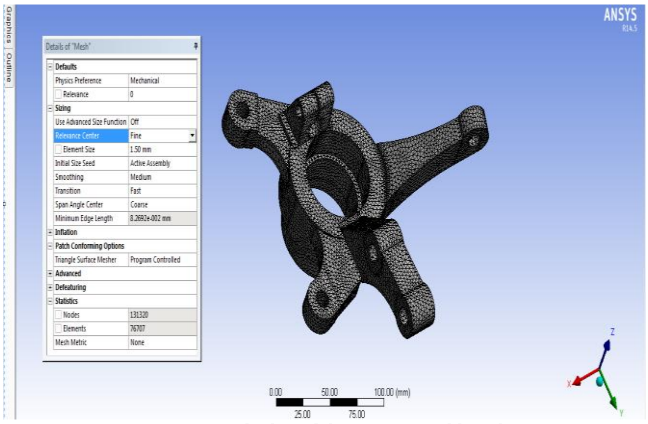

Figure 5. Meshed model in ansys workbench

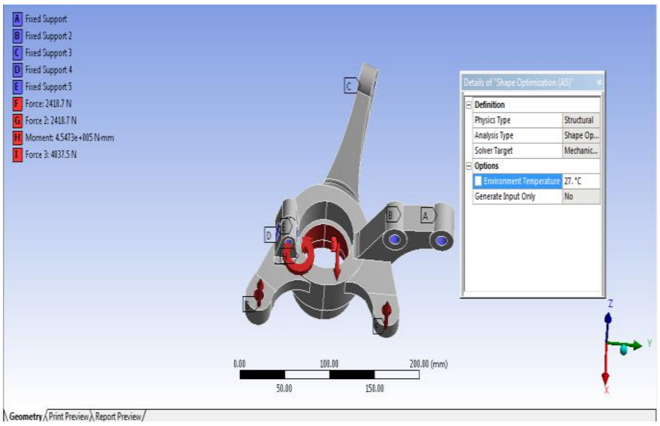

Figure 6. Loads and boundary are applied to the meshed model

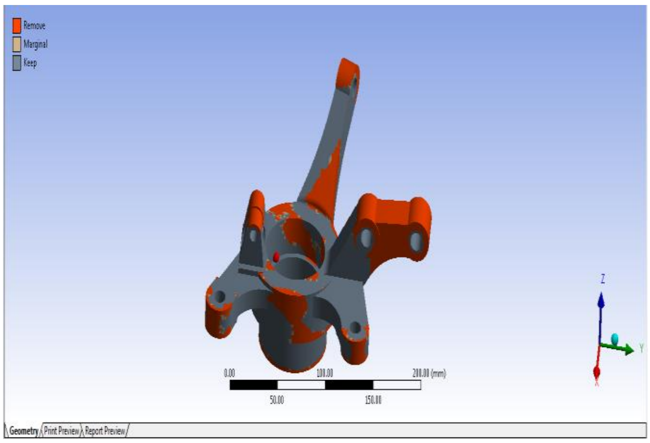

Figure 8. Result obtained by shape optimization in ansys workbench

V. Static And Modal Analysis Of Optimized Design For 2024-T3 Al

Static analysis for the optimized design was carried out using MSC NASTRAN solver for which HyperMesh was used and pre-processor and Hyperview was used as postprocessor. It was carried out for material Aluminum alloy 2024-T3

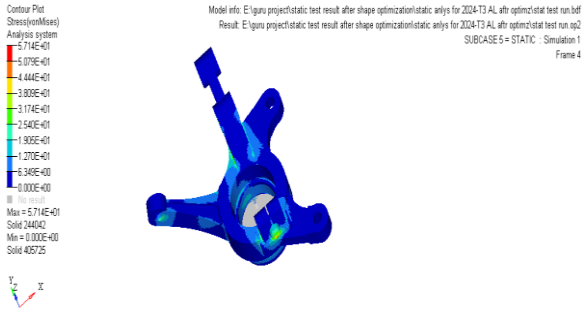

Figure 9. static stress test result for 2024-T3 AL before shape optimization

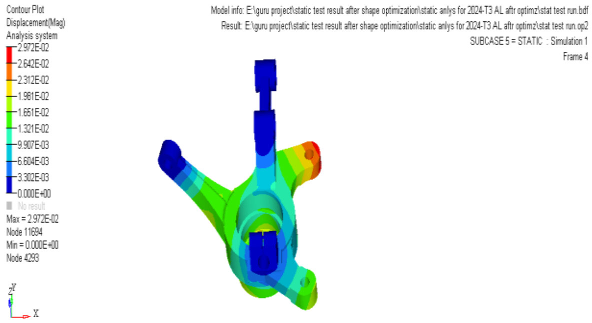

Figure 10. static displacement test result for 2024-T3 AL after shape optimization

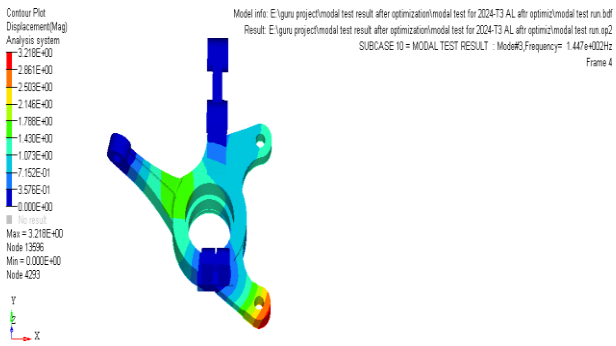

Figure 11. modal test displacement result for 2024-T3 AL after shape optimization

VI. Static And Modal Analysis Test Results After Shape Optimization

The static and model test are conducted for the optimized design for 2024-T3 Al material and get the induced stress value as 57.14 Mpa and this stress value is within the safe limit.

TABLE III
STRESS AND DISPLACEMENT VALUES FOR OPTIMIZED DESIGN

Material	Stress (MPa)	Displacement in mm
GRAY CAST IRON	5.70E+01	3.21E-02
2011-T3 AL	5.72E+01	3.10E-02
2024-T3 AL	5.71E+01	2.97E-02
6061-T6 AL	5.71E+01	3.14E-02

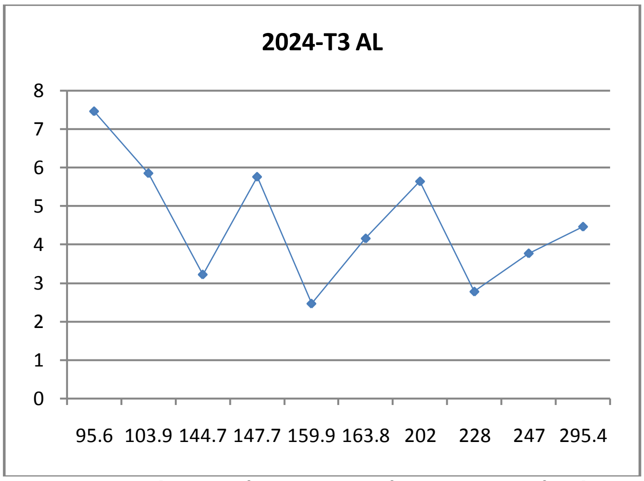

Figure 12. Displacement-frequency curve for 2024-T3 AL after shape optimization

TABLE IV
WEIGHT REDUCTION COMPARISION

Sr. No.	Material used	Mass in kg
1	Gray cast iron	2.710
2	2011-T3 AL	1.0619
3	2024-T3 AL	1.042
4	6061-T6 AL	1.0162
	After shape optimization	
5	Gray cast iron	2.6092
6	2011-T3 AL	1.0219
7	2024-T3 AL	1.00384
8	6061-T6 AL	0.9784

Therefore weight reduction rate

$$= \frac{mass of GCI - mass of optimized\ 2024-T3\ AL}{mass of GCI}$$

Weight reduction rate= $\frac{2.710 - 1.00384}{2.710} \times 100$

Weight reduction rate= 62.95 %

VII. RESULTS AND DISCUSSION

To conduct the numerical analysis of the steering knuckle first conducting the static and modal analysis for the existing model with existing material which is having its yield strength about 289 Mpa and factor of safety value 2, having its allowable stress 144.5 Mpa taking reference allowable stress as 144.5 Mpa and choosing the alternate material for steering knuckle which can fulfil all the necessary requirement. By consideration of allowable stress, density, weight, poissions ratio, Youngs modulus choosing 2011-T3 AL, 2024-T3 AL and 6061-T6 AL as an alternate materials having yield stress 340 Mpa, 350 MPa, 310 Mpa respectively.

VIII. CONCLUSION

1. In static analysis of the existing model the induced stress for all materials used are very less compared it with the allowable stress of the respective material hence it is evident from the result that existing model has over designed.
2. In static analysis the stress induced for 2024-T3Al material is 47Mpa and its allowable stress is 175 Mpa, the displacement induced in static condition for 2024-T3Al is 2.98e-2mm which is comparatively less with gray cast iron material which having displacement 3.21e-2mm.
3. In model condition before shape optimization the maximum displacement induced is 7.535mm at frequency 95.93 Hz which is very high by comparing it with the other material hence 2024-T3Al material can with stand at higher frequency range.
4. Shape optimization is conducted for existing model, after shape optimization we can reduce 62.95 % of weight from the existing model for 2024-T3Al material.
5. After shape optimization the stress induced in the 2024-T3Al material is 57.1Mpa which is within its allowable stress level.

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