WEIGHT OPTIMIZATION OF STEERING KNUCKLE JOINT USING FEA

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Abstract - *This project focuses on optimization of steering knuckle targeting reducing weight as objective function with required strength and stiffness. In automotive suspension, a steering knuckle is that part which contains the wheel hub or spindle, and attaches to the suspension components. It is variously called a steering knuckle, spindle, upright or hub, as well. The wheel and tire assembly attach to the hub or spindle of the knuckle where the wheel rotates while being held in a stable plane of motion by the knuckle/suspension assembly.*

The modeling of this project is done in modeling software, Creo Parametric 2.0 and the optimisation analysis is carried out in Ansys Workbench 15.0. The optimisation is carried out for different material addition and material removal cases.

Keywords: Creo Parametric 2.0, steering knuckle, stiffness, suspension components, shape finder.

1.INTRODUCTION

The steering knuckle is the connection between the tie rod, stub axle and axle housing. Steering knuckle is connected to the axle housing by using king pin. Another end is connected to the tie rod. Then the wheel hub is fixed over the knuckle using a bearing. The function of the steering knuckle is to convert linear motion of the tie rod into angular motion of the stub axle. The lighter steering knuckle resulting greater power and less the vibration because of the inertia is less.

Weight reduction is becoming important issue in car manufacturing industry. Weight reduction will give substantial impact to fuel efficiency, efforts to reduce emissions and therefore, save environment. Weight can be reduced through several types of technological improvements, such as advances in materials, design and analysis methods, fabrication processes and optimization techniques, etc.

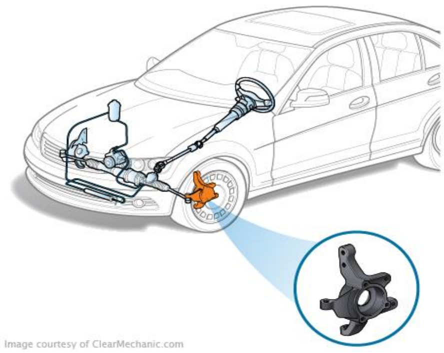

Fig-1: Location of steering knuckle in an automobile.

2.EASE OF USE

There are four disciplines for optimization process:

Topology optimization: It is an optimization process which gives the optimum material layout according to the design space and loading case.

Shape optimization: This optimization gives the optimum fillets and the optimum outer dimensions.

Size optimization: The aim of applying this optimization process is to obtain the optimum thickness of the component.

Topography: It is an advanced form of shape optimization, in which a design region is defined and a pattern of shape variable will generate reinforcements.

Shape optimization was developed using optimization techniques such as Genetic Algorithms (GAs). Shape optimization is applied to many fields such as Computational Fluid Dynamics (CFD) especially aerodynamics and electrical engineering field as well as mechanical engineering, for example : strain gauge load cell, a cantilever beam and cam . Finite element method used for many type of analysis, such as linear analysis, nonlinear analysis, fatigue analysis and another types. FE analysis was developed to solve the optimization process such as Shape finder tool to identify the areas of low stress.

3. MATERIAL SELECTION

There are several materials used for manufacturing of steering knuckle such as S.G. iron (ductile iron), white cast iron and grey cast iron. But grey cast iron mostly used. Forged steel are most demanding material for this application. Now a day's automobile industry has put effort to use aluminium alloy as an alternative. Due to low weight of this material, it can reduce fuel consumption and CO2 emission. So as per survey best suited material was aluminium alloy. It has low density and compatible yield strength. This material was chosen for designing knuckle by comparing its result with other material.

4. DESIGN MODELING

CAD model of steering knuckle component was made in 3-D modeling software Creo (Pro-E) 2.0. It consists of Stubhole, Brake Caliper mounting points, Steering tie-rod mounting, Suspension upper arm mounting and Suspension lower arm mounting. Steering knuckle component design mainly depends on suspension system geometry and steering geometry. The design also needs to follow the criteria and regulations, which the size would mainly depends on suspension system. The previous steering knuckle was made with Grey Cast Iron and the mass is about 2.4 *kg*.

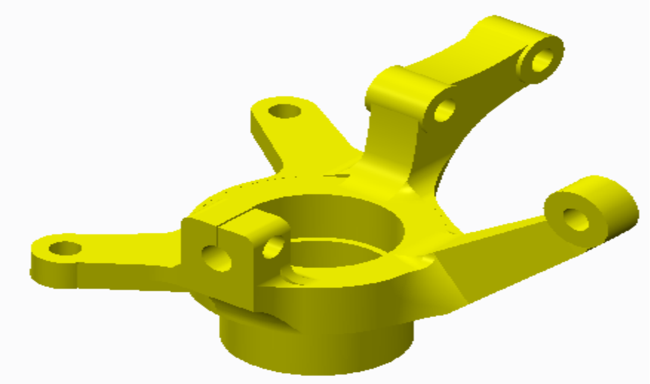

Fig-2: Steering knuckle model.

5.MESHING

CAD model of knuckle converted into STEP file. This model is imported into Ansys Workbench simulation. Geometry cleanup was performed prior to meshing of model. For better quality of mesh fine element size is selected.

Table-1: Nodes and Elements of the meshed model.

No. of Element	14376
Nodes	26359

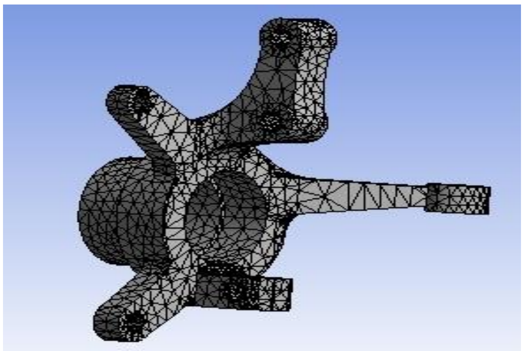

Fig-3: Meshing applied to model.

6. CALCULATION OF LOAD

Loading Condition on Knuckle.
For the calculation of load acting on steering knuckle component, the required loading conditions are considered as mentioned in the table-1.

Table-2: Loading conditions.

LOADING CONDITION	
Braking Force	1.5*mg*
Lateral Force	1.5*mg*
Steering Force	45-50*N*
Force on knuckle hub in X-axis	3*mg*
Force on knuckle hub in Y-axis	3*mg*
Force on knuckle hub in Z-axis	1*mg*

There are two types of load acting on knuckle i.e. force and moment. This knuckle is designed for vehicle of 400 kg weight so braking force acting on it produces a moment.

For calculating breaking force acting on one wheel we have to distribute weight of vehicle for four wheels so that we get vehicle weight acting on one wheel. i. e. 400/4 = 100 kg for one wheel

Breaking force = 1.5g*W (g = 9.81m^2/s)
=1.5*9.81 *100 = 14.715 m/s^2
=1471.5 kg-m/s^2

Moment = breaking force * perpendicular distance
= 1.5*100*10*48.5
=72750 N-mm

This moment is acting on steering knuckle where brake caliper is mounted. Brake calliper is mounted at two location therefore distributing moment at two point,
Moment on the brake caliper = 72750/2

= 36375 N-mm

This moment is acting on steering knuckle where Brake caliper is mounted .Since all loads act in X, Y and Z direction are perpendicular to each other as shown in fig 5.

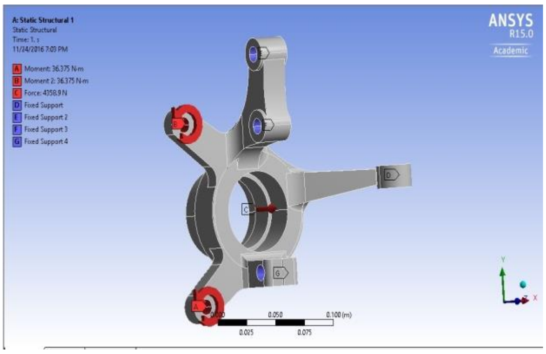

Fig-4: Loading conditions

Since all load in X, Y, and Z direction are perpendicular to each other, the resultant of all the forces is given by,

$$F = \sqrt{X^2 + Y^2 + Z^2}$$

$$X = Y = 3g = 3*9.81*100 = 2943 \text{ kgm/s}^2 \text{ ie N}$$

$$Z = 1g = 1*9.81*100 = 981 \text{ N}$$

$$F = 4358.9 \text{ N}$$

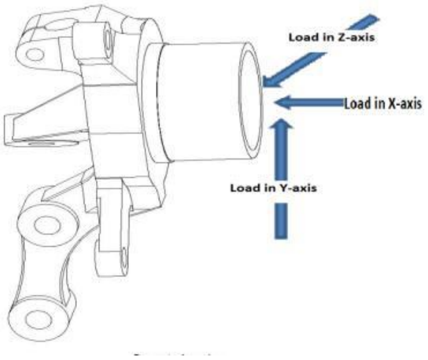

Fig 4: Load direction.

7. ANALYSIS

The analysis of steering knuckle component is done in ANSYS Workbench 15.0. The required load of steering knuckle component was determined from various research papers. A single seater ATV of weight 400 kg is considered. The weight is directly acting on all the four wheels and the weight distributed on one wheel is 100 *kg*. The loads acting on the steering knuckle is stated in the loading conditions section, Table-2.

The base model or the original cast iron steering knuckle properties are given in the table-3.

The geometry is imported to Ansys workbench. Meshing is applied to the model. Loading conditions are applied respectively.

The base model analysis results are shown in figures which are given below:

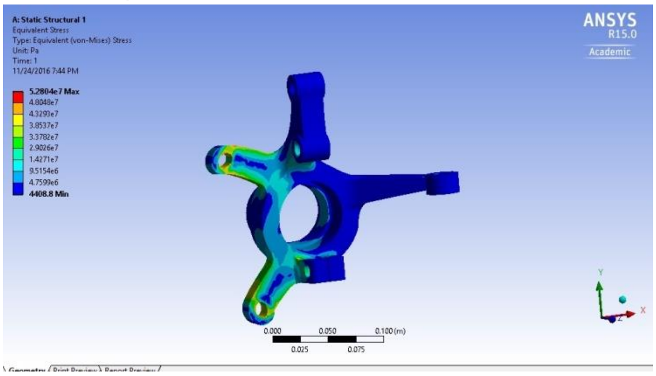

Fig-6: Total Stress (Base model)

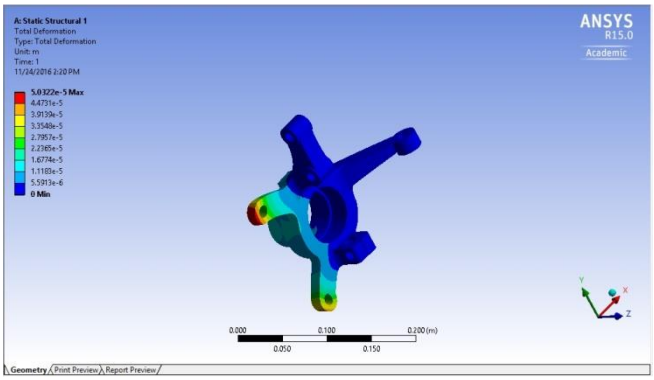

Fig-7: Total Deformation (Base model)

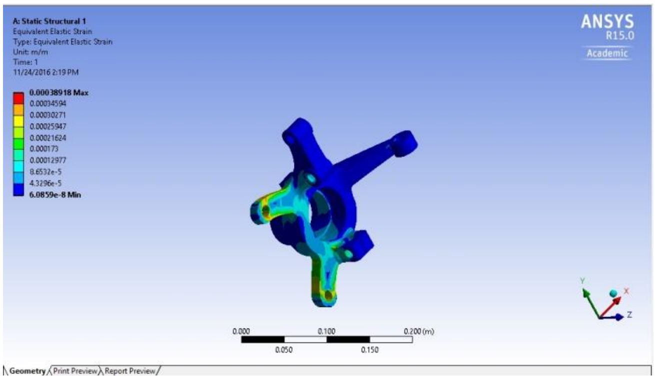

Fig-8: Total Strain (Base model)

8. SHAPE OPTIMISATION

Shape optimization is a technique to modify the structural shape based on predefined shape variables to obtain optimal shape. Size optimization defines ideal component parameters, such as material values, cross-section dimensions and thicknesses. Shape finder tool

Ansys has been used to identify the low stress areas. The 3D model is modified using modelling software Creo-parametric 3.0. Fig-10, fig11, fig-12 shows the modified areas.

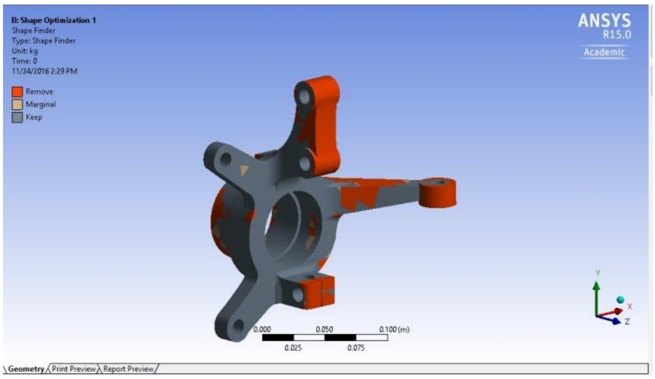

Fig-9: Shape finder tool in workbench showing removable areas.

The orange area represents removable material in fig-9.

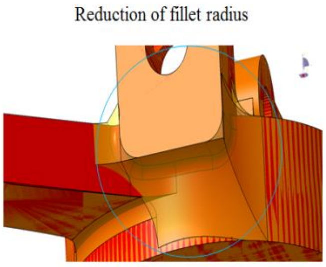

Fig-10: Removing material near support.

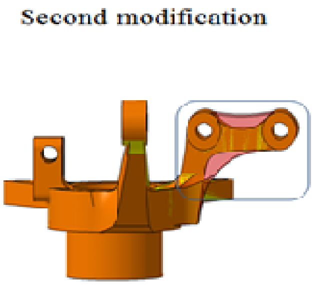

Fig-11: Reducing the thickness of suspension mount.

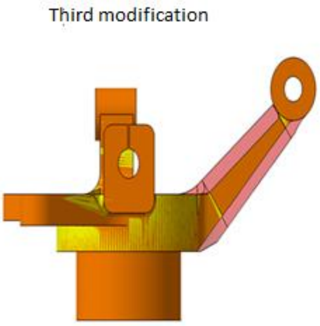

Fig-12: Reducing thickness of steering rod support.

9. MATERIAL PROPERTIES.

The steering knuckle which I modelled is made up of cast iron. Now a day's automobile industry has put effort to use aluminium alloy as an alternative. Due to low weight of this material, it can reduce fuel consumption and CO2 emission. So as per literature survey I found the material which can be used for manufacturing of steering knuckle which is Aluminium 6061 T6 Alloy.

Physical and Mechanical properties of Cast Iron.

Table-3: Properties of Cast Iron.

Young's Modulus	1.1e+005 Mpa
Poisson's Ratio	0.28
Density	7200 kg/m3
Ultimate tensile strength	240Mpa

Physical and Mechanical Properties of Aluminium 6061-T6 alloy.

Table-4: Properties of Alumunium alloy.

Young's Modulus	7.0e+4-8.0e+4 Mpa
Poisson's Ratio	0.33
Density	2700 kg/m^3
Yield Strength	230 MPa

10. RESULTS and DISCUSSIOIN.

The below figures shows the various results of the modified knuckle made with Cast Iron.

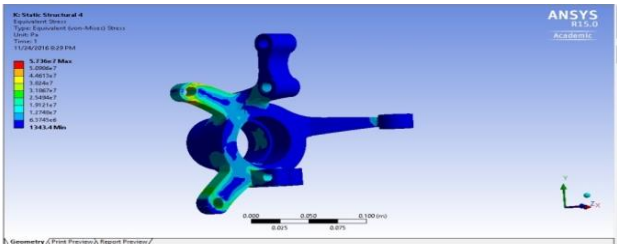

Fig-13: Total Stress (Modified model-Cast Iron)

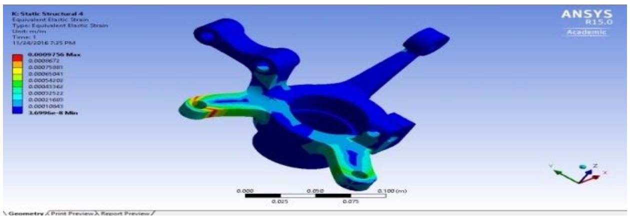

Fig-14: Total Strain (Modified model-Cast Iron)

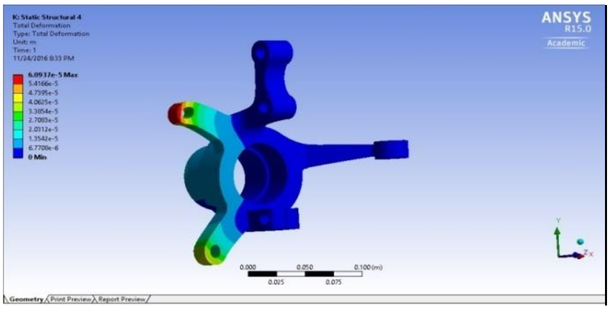

Fig-15: Total Deformation
(Modified model-Cast Iron)

Below figure shows the various results of the modified model when aluminum alloy is used as the steering knuckle material.

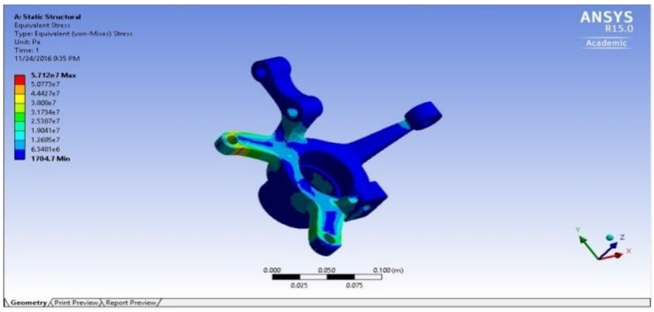

Fig-16: Total Stress (Modified model-Al alloy)

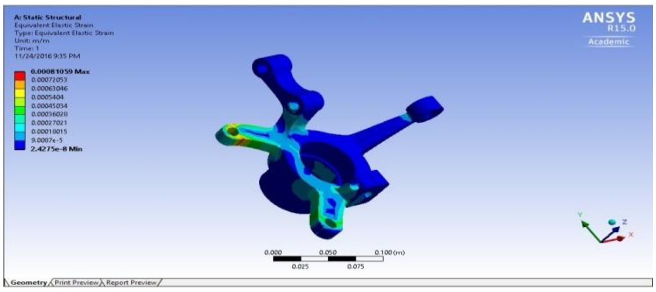

Fig-17: Total Strain (Modified model-Al alloy)

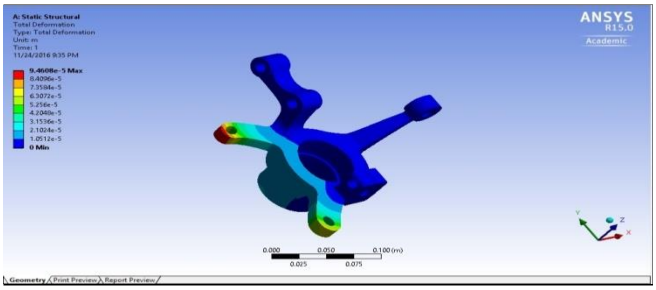

Fig-18: Total Deformation
(Modified model-Al alloy)

The following table represents the various results obtained in the base model, modified model of Cast Iron and the modified model of Aluminium alloy,

Table-5: Results of the initial, modified model.

Optimisation	**Stress (MPa)**	**Strain**	**Deformation (mm)**
Base model	52.80	0.0003891	0.0503
Modified model(Cast Iron)	57.36	0.0009756	0.0609
Aluminium alloy	57.12	0.00081	0.094

Initial model of knuckle is shown in Fig.4. It has maximum Stress 52.8 MPa. After applying load and design constraints shape optimization was performed. Fig. 9 shows material which can be removed from model (shown in orange) after optimization. The objective of the research is to reduce the mass (represented by reduction volume) using shape optimization. The mass reduction for the front knuckle was found to be 11.7%, compared to the currently used model.

Original weight of steering knuckle is 2.4 kg
Final optimized mass of steering knuckle using aluminium 6061 T6 alloy replacing cast iron material is 0.8755kg i.e, 63.9% weight is reduced.
From original weight 2.4 kg, weight is reduced to get 0.8755kg wt. The equivalent stress obtained for modified Aluminium alloy is slightly less than that of cast iron. From these entire results aluminum alloy can be selected as a replacement material for steering knuckle.

11. CONCLUSION

Shape optimization method used in this study in reducing the mass of knuckle by 63.9% and factory of safety is 4 is maintained. Maximum stress and displacement are within control and below the safe limit. This optimization process gives small change on the displacement which means that change of volume and shape doesn't influence significantly to the stiffness of the structure. Therefore, the overall weight of the vehicle can be reduced to achieve savings in costs and materials, as well as, improve fuel efficiency and reduce carbon emissions to sustain the environment.

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