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Optimization of Steering Knuckle for All Terrain Vehicle

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Abstract **-** Steering Knuckle is a non-standard component linking the suspension, steering & braking systems and the wheel hub to the chassis of a vehicle. This study aims to redesign the steering knuckle in order to reduce the weight while retaining a satisfactory safety factor for better performance of the vehicle. A two step process has been used for the same. First step is modeling the knuckle as per the structural considerations and design constraints set by suspension, steering and brake assemblies & determination of loads acting on the knuckle. The second step is stress analysis using finite element software and design adjustments for reducing weight without compromising on the structural strength. According to the analysis results, material can be added to parts that are subjected to higher stress than the safety factor permits. Material can also be removed from low stress areas, thus, helping to reduce the component weight.

***Keywords: -* :** *Steering Knuckle, Finite Element Analysis (FEA).*

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I. INTRODUCTION

In case of racing competition such as SAE BAJA, teams are concern about weight of vehicle. As lighter vehicles generally accelerate quicker and require shorter stopping distances than heavier vehicles. A reduction in the weight of suspension components also improves the vehicle handling performance.

Among the off-road vehicle structural components, the steering knuckle is one of important & non-standard component which is connected to steering, suspension and brake to chassis of vehicle. It plays a crucial role in minimizing the vertical and roll motion of the vehicle body, which implies a poor passenger experience, when a vehicle is driven on a rough road. The steering knuckle accounts for maximum amount of weight of all suspension components, which requires high necessity of weight reduction. Under operating condition, it is subjected to dynamic forces transmitted from strut and wheel. The weight reduction of steering knuckle is done such that the strength, stiffness and life cycle performance of the steering knuckle are satisfied.

Fuel consumption and vehicle speed are directly dependent on engine specification and car weight. Engines specification is decided by SAE organising committee and cannot be altered. Concerning the weight reduction, the improvement field is by far wider. There are two ways of meeting these goals:

- Optimising the component design employing the same material.
- Replacing traditional materials with lighter ones.

Types of Optimization

1) Topology optimization: It provides the optimum material layout according to design space and loading case in which design variables are defined as a fictitious density for each element, and these values are varied from 0 to 1 to optimize the material distribution.

2) Geometry optimization: The purpose of a geometry optimization is to find the best use of material for a body.

3) Size optimization: It provides optimum thickness of the component

4) Topography: This optimization being an advanced form of geometry optimization which generates reinforcements

From all this type, in this project geometry optimization is selected for optimization of steering knuckle.

Geometry Optimization

The purpose of a geometry optimization analysis is to find the best use of material for a body. Typically this involves optimizing the distribution of material so that a structure will have the maximum stiffness for a set of loads.The output of this analysis is a contour plot that shows the portions of the geometry that least contributes to the stiffness of the structure for a given load depending upon pattern of geometry variable and design region. Objective of this investigation is reduction of mass of the steering knuckle of off-road buggy. Material selection, shape optimization & finite element analysis has been used to implement optimization and maintaining stress and deformation levels and achieving high stiffness. Shape optimization is done by using analysis software Ansys 14.5.

II. LITERATURE REVIEW

AmeyaBhusari et al. (2015) considered steering knuckle for optimization. Weight reduction of steering knuckle is the objective of this exercise for optimization. Typically, the finite element software solidTHINK INSPIRE V9 (Solidworks) is utilized to achieve this purpose. For optimization, Nastran/Ansys/Abaqus could also be utilized.

The targeted weight or mass reduction for this exercise is about 62% without compromising on the structural strength.

Kamlesh Lalsaheb Chavan et al.(2014) in this paper, author studied the failure during sudden severe loading caused due to abuse or due to continual and repetitive usage while driving for extended timeline over the life of the component. The challenge posed for the Design Engineer is to recreate the actual conditions during the analysis phase and determine the best material or the specifications of the component that would be most suited to the given application. The current Design challenge for the Steering Knuckle Arm is to generate the most optimal configuration of the component Design for the given input conditions of loading. The Sponsoring Company is working on the soon-to-belaunchedautomotive model and is expected to take this task to completion through the use of CAD (CATIA or UG) for creating the geometry and further use the CAE tools (HyperWorks/Optistruct/ or suitable) for conducting analysis for the component. The Test Report/s for the component would form a basis for verifying the results with the Analytical method of analysis. For validating the Design of the component, a good match of the corresponding readings is desired. Typically, depending on the type of Test and the application, an error margin or about 5 to 20% could be considered close towards validating the proposed Design.

Mahendra L. Shelar and H. P. Khairnar (2014) in this paper author had identified the problem of process optimizing the design using a methodology based on durability and design optimization through probabilistic models of design variables (DOE). Their study deals with creation of geometric model of steering knuckle (LUV) in solid works after that that model will be imported to NFX Nastran for finite element modeling where the meshing properties, element properties will be generated. Loads and model conditions applied to model there by generating file that file will be submitted to solver (Nastran) and linear static structural analysis will be performed. To conduct model analysis to understand the dynamic behavior of the structure and thereby followed by transient structural response analysis. When optimized model is compared with initial model, 9.195% Reduction in weight has been achieved with stress and deflection change within range and not exceeding above the Project target limits.

Razak I. H. A. et al. (2013) in this paper, authors aimed to a light weight and optimized design of steering knuckle is proposed to be used for an EIMARace car; a small high-performance formula-style car, with suitable material selection as well as valid finite element analysis and optimization studies. First part of this study involves modeling of steering knuckles and analysis of the stresses and displacement under actual load conditions. A CAD and FEA software; SolidWorks, is applied for modeling as well as for static analysis studies. Shape optimization is the second part of this study, utilizing solid Thinking software from Altair Engineering packages. As the ultimate aim of this study is to reduce mass of the existing knuckle with target to achieve low fuel consumption, selection of the best material and simple geometry are crucial. Aluminum 6061-T651 alloy (yield strength 276 MPa) was found to be the best material for the component due to the good physical and mechanical properties as well as light weight. Obtain the best use of material for the component was justified in reducing the weight of existing knuckle to 45.8% while meeting the strength requirement. The minimal weight of the steering knuckle component may contribute to the reduction of the overall weight of the race car thus may improve the fuel efficiency as well as the overall performance.

Wan Mansor Wan Muhammad et al. (2012) in this paper finite element software, HyperWorks which contains several modules is used to achieve this objective. HyperMesh was used to prepare the finite element model while HyperMorph was utilized for defining shape variables. For optimization purpose, OptiStruct was utilized. The improved design achieves 8.4% reduction of mass. Even though there are volume reduction and shape changes, maximum stress has not change significantly. This result is satisfactory considering using optimization in shape only, with limited design space given and no change in material properties.Optimization method used in this study succeeded in reducing the mass of existing knuckle component to 8.4%. Even though there are volume reduction and shape changes, maximum stress has not change significantly. This result is satisfactory considering using optimization in shape only, with limited design space given and no change in material properties. Other vehicle components, similarly, have the potential to be reduced with respect to mass using shape optimization. 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.

III. DESIGN OF STEERING KNUCKLE

In this study, to observe maximum stress produce into steering knuckle, model is subjected to extreme conditions and static analysis is carried out in AnsysWorkbench. “Table 3.1”depict data collected from off-road design team for the forces calculation on knuckle.

Table 3.1 Off-Road Vehicle Design Data

Mass of vehicle	m	360 kg
Weight Distribution	W.D.	40:60
Turning Radius	R	8 m
Wheel Track	C	1422 mm
Wheel Base	B	1524 mm
Height of C.G.	H	635 mm
Velocity	V	45 km/hr
Suspension Spring Stiffness	K	25 N/mm
Suspension Max. Travel on Bump	X	101.6 mm
Steering Wheel Input Force	Fsi	48 N
Steering Gearbox Ratio	G	13.24
Lateral Acceleration During Turning	at	19.53 m/s2
Pedal Force	P	294.3 N
Area of TMC Piston (Dia = 19.05 mm)	Am	284.2 mm2
Area of Caliper Piston (Dia = 24.5 mm)	Aw	506.7 mm2
Pedal Leverage Ratio	Rp	7
No. of Caliper Piston	n	2
Coefficient of Friction Between Pad & Disc	μ	0.45
Deceleration on Braking	ad	7 m/s2

Forces on Steering Knuckle

Lateral Force due to Turning: Lateral force or side force is the cornering force produced by a vehicle tire during cornering. It is equivalent to the centrifugal force generated due to cornering.

Brake Force due to Torque Required for Braking: Brake force is generated on the knuckle at the points of brake caliper mountings when brake is applied to retard the motion of the vehicle. It is calculated as the product of the pressure generated in fluid line with net area of caliper piston and the coefficient of friction between the brake pads and the brake disc.

Force due to Steering Gearbox During Turning: This is the force exerted by the steering gearbox on the steering arm mounting of the knuckle through the tie rod while turning.

Weight Transfer During Breaking or Turning: During acceleration and braking, inertia of the vehicle chassis causes a load transfer in longitudinal direction on the vehicle; i.e. the load form the rear is transferred to the front while braking and the opposite effect takes place while accelerating. This load transfer (or weight transfer) exerts a force on the knuckle. A similar effect takes place while negotiating a corner. Inertia causes load transfer in lateral direction; i.e. the load form the right side is transferred to the left side while taking a right turn and vice versa.

Bump Force: When the vehicle undergoes a ground disturbance in the form of a bump or a hole a force is exerted on the knuckle. For design considerations, it is assumed that the suspension spring has attained full travel which is 4 inches.

Force on Impact: When the vehicle is subjected to a front, rear or side impact an impulse force is exerted on the knuckle. For this study purpose, this force has been neglected as it is ambiguous to predict the nature of such impact force.

Table 3.2Loading Condition

Moment Due To Braking Force	159025 Nmm
Moment Due To Steering Force	50682.72 Nmm
Longitudinal Force	2118.96 N
Lateral Force	2812.50 N
Vertical Force Due To Weight	706.32 N
Vertical Force Due To Longitudinal Weight Transfer	1032.38 N
Vertical Force Due To Lateral Weight Transfer	3195.80 N
Vertical force Due To Bump	2540.00 N

IV. METHODOLOGY

Solid Modeling, Meshing and FEA

A knuckle was designed for the calculated loads, taking all the mounting points and bearing surfaces as critical points. The material was considered to be Cast Iron. The solid modeling was done in CATIA V5. The weight of the knuckle was **4.212 kg.** Stress and Displacement Analysis is performed on the knuckle by applying the various loads calculated in the previous section. Loads are applied in singular as well as in combination to simulate real-time road conditions. The analysis was done using ANSYS

14.5. Maximum Stress was found out to be **123.56 MPa**. Hence the factor of safety (FOS) is **1.95**. The displacement analysis shows that maximum displacement in the component is **0.61184mm** which is well within limits. The Boundary conditions for a FEA problem are basically the points of application of the constraints as well as the forces on the knuckle. The boundary conditions depend mostly on the geometry of the knuckle. Generally the suspension mountings are constrained as they are in direct contact with the chassis of the vehicle. The lateral forces for the FEA model are applied to the bearing support step provided in the knuckle. The forces due to braking are applied at the brake mounting points and forces due to steering gearbox are applied on the steering arm bolting points. The bump force is applied on the top half of the bearing surface. Accurate application of loads, moments and constraints is important for proper analysis results.

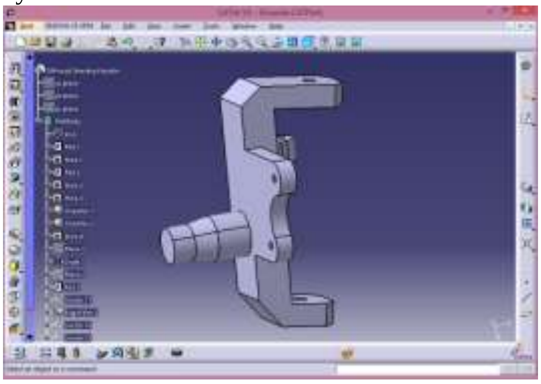

Fig. 4.1 Solid Model of Steering Knuckle

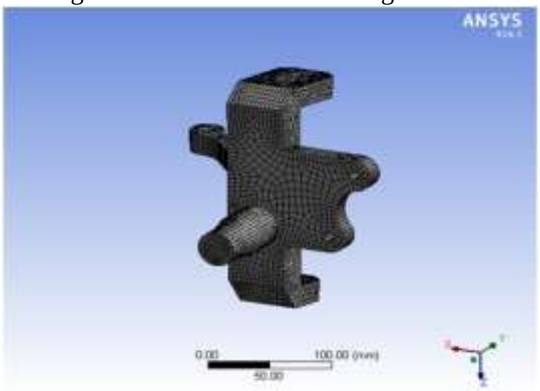

Fig. 4.2 Meshed Model of Knuckle

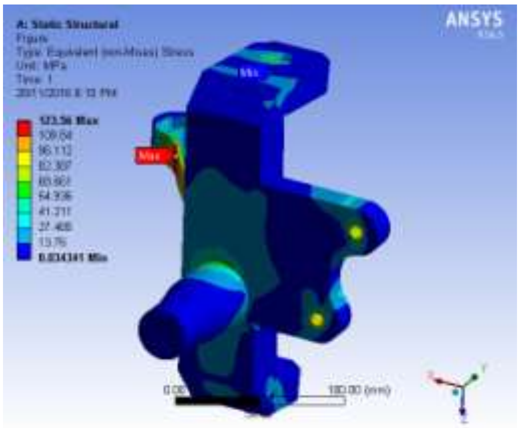

Fig. 4.3 Stress Analysis of Knuckle in ANSYS 14.5

Optimization for Weight Reduction

For reducing the weight the Geometry Optimization study was done. The software used for geometry optimization is ANSYS 14.5 (Shape optimization). Keeping the same magnitude of loads and identical loading conditions the result obtained shows the parts of the knuckle from where the material can be removed without disturbance of internal stress flow patterns within the material. This result was taken as reference and a new revised design of the knuckle was created. The material was Cast iron and the solid modeling was done in CATIA V5. The weight of the new revised knuckle was found out to be 3.481kg. This design was once again meshed and analysis was performed in ANSYS 14.5. Hence the Max Stress was 137.21 MPa which gives a factor of safety of 1.75. Hence even though there is significant weight reduction the design is safe. The maximum displacement was 0.61106 mm.

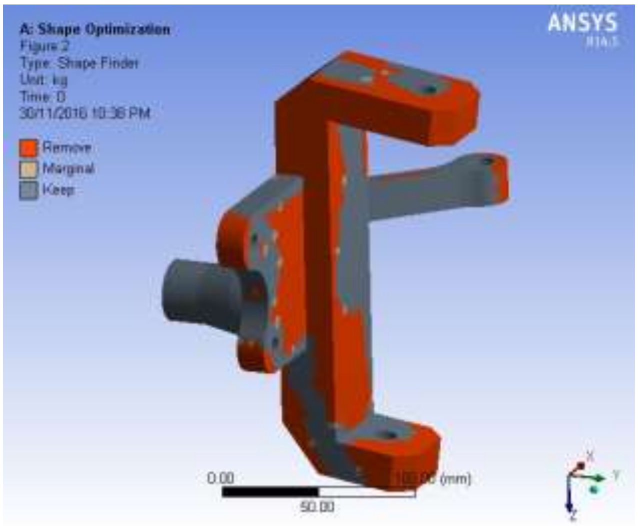

Fig. 4.4 Optimization Analysis Result Done in ANSYS.

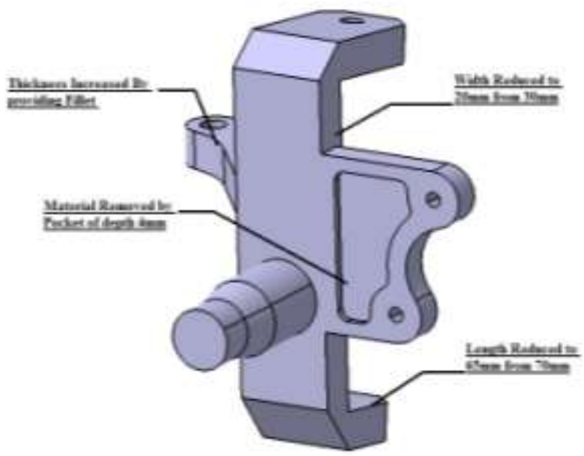

Fig. 4.5 Revised Solid Model of Steering Knuckle.

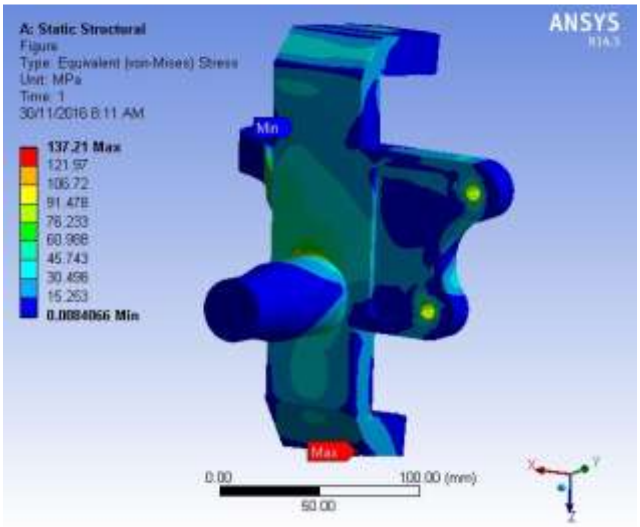

Fig. 4.6 Stress Analysis of Knuckle in ANSYS.

V CONCLUSION

Shape optimization method is used in this study for reducing the mass of knuckle by 17.53%. Maximum stress and deformation are within control. Due to shape optimization gives small change in the deformation. It means that change of volume and shapes doesn't influence significantly to 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, better handling and reduce carbon emissions to sustain the environment.

IV. ACKNOLEDGEMENT

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