Weight reduction of Steering Knuckle by Optimization Method

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Abstract — *Recent trends in automobile industry is to increase vehicle performance by reducing weight of various component which in turn reduce overall weight of vehicle. Steering knuckle is critical components of vehicle which connects suspension, steering system, brake and wheel hub to the chassis. It undergoes alternating loads subjected to different conditions, without affecting vehicle steering performance and other desired vehicle characteristics. In this paper, structural analysis is carried out by considering static and dynamic load conditions to study the nature and magnitude of stresses. The objective is to reduce weight through optimization without affecting its strength, frequency and stiffness. In this study, CAD Model is generated by Catia v5, Hypermesh is used for pre-processing and for post processing Ansys is used. Shape optimization is performed by using optistruct.The total weight or mass reduction of about 4% is achieved without comprising its structural strength.*

Keywords — *Integrated steering Knuckle, Stress analysis, FEA, shape optimization*.

I. Introduction

Various loads from the wheels act on steering knuckle and transfers forces to the suspension system. It is essential part in the vehicle because it requires proper attention in selection because once it is damaged then it needs to be replace by new one. Steering knuckle is capable of resisting a single applied load but may fail when subjected to a fatigue load. Power thrust is carried from tie rod to the stub axle and hence it must be very tough, rigid and also as light as possible. During steering and turning, compressive and tension loads are induced on steering knuckle and due to wheel rotation it is also subjected to torsional load. This result in stress concentration and deformation at critical area. Conventional steering knuckles comprise an assembly of two or more forged components which includes a hub, a spindle, a tie-rod arm, and a steering arm. In one-piece steering knuckle assembly, the tie rod arm, hydraulic brake caliper bracket and the steering arm extend from the flanged body in a one-piece forged manner. They are all formed from a single steel billet as a one-piece heavy duty forging. Such a design eliminates the brake caliper/knuckle joint and the tie rod arm/knuckle joint, and thus, it results in savings in assembly time and weight. Nowadays, mass or weight reduction is becoming important topic in vehicle industry. Weight reduction will give significant impact to fuel efficiency, attempts to reduce emissions and therefore, save environment. Various recent developed technologies, such as advances in materials, design and analysis approach, fabrication methods and optimization tools etc. are used to reduce weight. Optimization methods are used to have lighter, less cost and to have better strength. Many optimization types, methods and tools are available today due to the dramatic change of the high speed computing and software development, from which shape optimization gives the best use of material for a body. This involves optimizing the distribution of material so that a structure will have the maximum stiffness for given set of loads.

II. Literature Review

Mehrdad Zoroufi and Ali Fatemi [1], Jhala and Kothari et al. [4]&[5] and Sharad Kumar Chandrakar et al. [8] estimated fatigue life of steering knuckle for three different materials i.e. forged steel, cast aluminium and cast iron produced by different manufacturing processes and carried out Geometric optimization of knuckle through finite element analysis to reduce the weight in their research. S. Vijayarangan, N. Rajamanickam et al.[7] carried out structural analysis of steering knuckle made of alternate material Al-10 wt.% Tic and compared it with that of aluminium alloy and SG iron steering knuckles for its performance and results encourage using particulate reinforced metal matrix composites for critical component steering knuckle with a weight saving about 55%. Wan Mansor Wan Muhammad et al. [2] and Purushottam Dumbre et al. [6] achieved mass or weight reduction of steering knuckle of 8.4% and 5% respectively that of existing, subjected to various loads at different conditions using FEA Software. Fuganti, Cupito[10], describes the development of a suspension steering knuckle through the application of thixoforming technology of an aluminium alloy and described the methodology which was used for material/technology choice and component optimization. A component weight saving of about 30% was obtained, compared to the solution made of cast iron. Kulkarni and Tambe [11] focuses on optimization of steering knuckle targeting reducing weight as objective function, while not compromising with required strength, frequency and stiffness.

III. PROBLEM STATEMENT

Various time varying load acts on steering knuckle during its service lifetime. Various forces and loads acts on steering knuckle and also stresses are induced, due to which there is risk of failure. This will have effect on wheel arrangement and lead to high maintenance cost. To overcome this problem an efficient solution is proposed. This problem can be solved by redesigning the steering knuckle. The steering knuckle can be made compact by integrating with spindle which helps in good steering capabilities, overall performance and by using shape optimization weight of component can be reduced which will contribute towards mass reduction, lower its energy consumption and will improve its fuel efficiency.

A. Objective

The main objective of this project is development of structural design and mass reduction of vehicle components using shape optimization which will reduce the cost and to avoid complex steering assembly which will enhance it performance.

- Structural analysis is carried out using finite element analysis.
- To study areas of concern for advancement.

To suggest appropriate alternatives to design for improvement of strength or mass reduction.

IV. METHODOLOGY

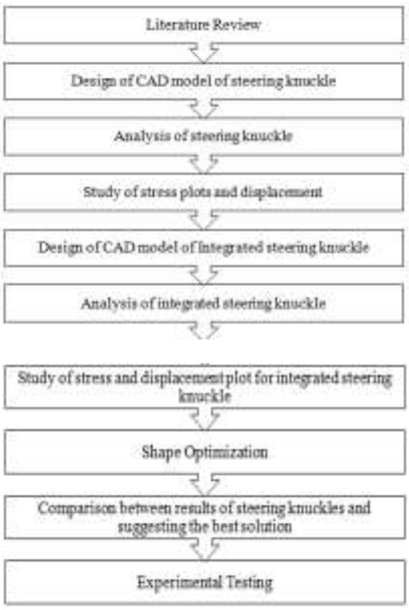

Fig.1 Methodology Flowchart

A. Material Selection

Mechanical, chemical and physical properties are studied before proper selection of material. There are several materials used for manufacturing of steering knuckle such as S.G. iron (ductile iron), aluminium, and mild steel. We selected mild steel as per its properties and availability.

Table 1: Physical and mechanical properties of Mild Steel

Young's Modulus	210 Gpa
Density	7850 kg/m^3
Poisson's Ratio	0.3
Yield Strength	340Mpa

B. Designing a CAD model

3D modelling software CATIA V5 was used for generating CAD model of steering knuckle. It includes of stub hole, brake calliper mounting points, steering tie-rod mounting points, suspension upper and lower A-arm mounting points. Suspension geometry and steering geometry plays important role in knuckle design.

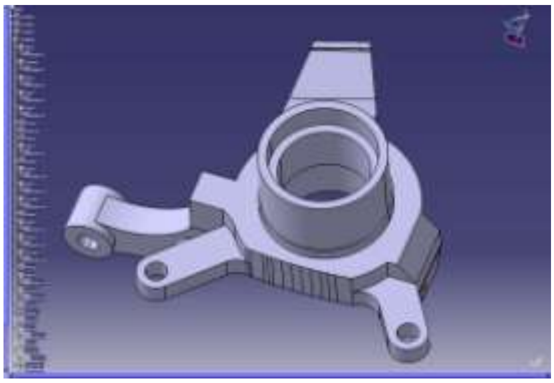

Fig.2. CAD Model of Steering Knuckle

C. Meshing

For meshing, CAD model of knuckle was converted into STEP file. This model was imported into Altair Hyperworks and hypermesh was used for meshing. Before meshing of model, geometry cleanup was performed. Finite element model was developed using Altair Hyperworks. For better quality of mesh fine element size is selected.

Table 2: Nodes and Elements of model

Number of nodes	50055
Number of elements	224543
Element size	2 mm

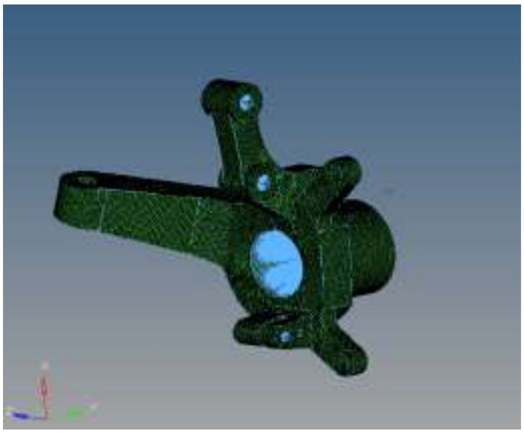

Fig.3. Meshing of Steering Knuckle

D. *Load and Boundary Conditions*

i. *Calculations for Steering Knuckle*

The forces acting on a stationary car are as shown in figure 4.The earth's gravitational pull (mg) acts through the centre of gravity and the reaction acts through the contact patches between the tyres and the road. The vectors shown represent the combined reactions at both front wheels (R_1) and both rear wheels (R_2).

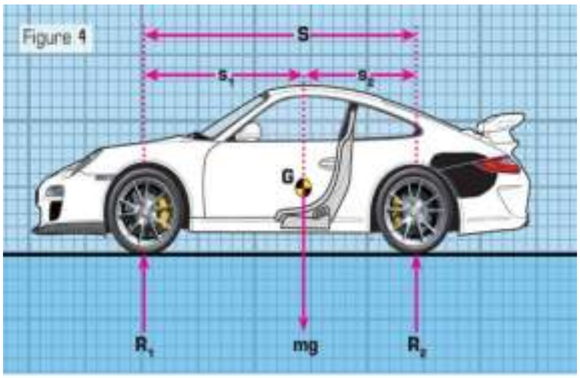

Fig.4. Forces acting on a stationary car

Total weight of the car = 2200kg = 21582 N
This weight must be divided into front axle weight and rear axle weight. 52% of total weight is taken by front
Axle and 48% of total weight is taken by rear axle.
Front axle weight = 1144kg = 11222 N
Reaction at one wheel = 1144/2= 572 kg = 5611 N
Rear axle weight = 1055kg = 10359 N

Table 3: Input for Load Calculation

Sr No.	Description	Symbol	Value
1	Total weight of vehicle	W	21582 N
2	Front axle weight	F1	11222 N
3	Rear axle weight	F2	10359 N
4	Tire road coefficient	M	1.5
5	Wheel base	L	2680
6	Avg. acceleration	Ā	3.3m/s^2
7	Centre of gravity height	Hcg	940 mm

For the given input, various loads and forces acting on wheel which are transferred integrated steering knuckle are calculated. Various Forces are as follows:

a. Breaking force (FB) = 10.4KN
b. Vertical force (FV) = 20.68KN
c. Lateral force (FL) = 13.78KN

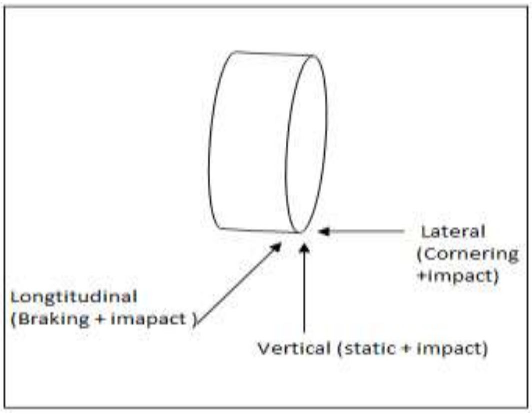

Fig.5: Wheel loads and directions

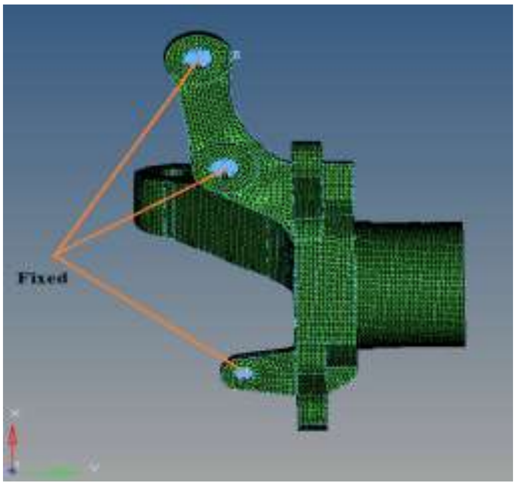

Fig.6 Design Constraints in steering knuckle

E. *Stress Analysis*

Stress analysis is carried to determine the stresses and strains in materials and structures subjected to forces. In existing model, stress analysis of knuckle is subjected to high stress shown in figure 12. According to the methodology to safer the design, stress induced in component must be less than the yield stress of the material. The maximum Von-misses stress and maximum deformation found from the analysis are 163Mpa and 0.157mm respectively.

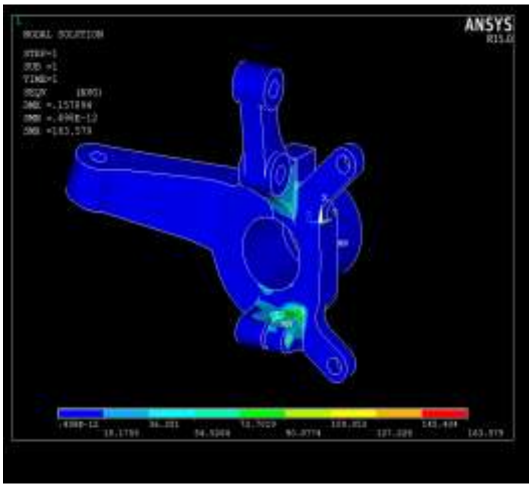

Fig.7: Deformation & von-mises Stress in steering knuckle

V. NEW PROPOSED DESIGN

In Conventional steering knuckle, a hub, a spindle, and one or more arms are manufactured separately and then joined together to form a steering knuckle.

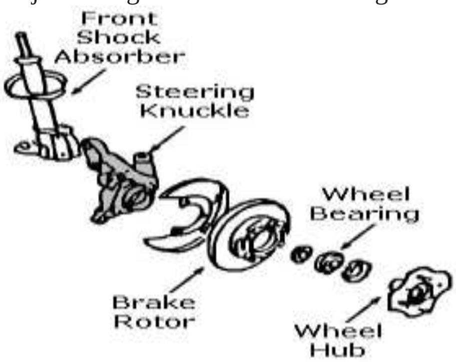

Fig.8 Dissembled knuckle with spindle

In new proposed model, modification in existing steering knuckle is done and spindle is assembled to it which together constitutes as a single piece of component that eliminates complex assembly of wheel hub and steering, thus reducing complexity and weight of steering system.

Wheel specification is taken in consideration while designing integrated knuckle, as knuckle will be attached to wheel hub.

A. *New Proposed Design 1*

In new proposed model, improvement in existing steering knuckle is done and spindle is integrated to knuckle through bolting consideration which together constitutes as a single piece of forged component. Hub and spindle are assembled together by bolt tightening them by bolt M8 to form integrated steering knuckle. Bolts exert pretensioners stress on component due to bolt tightening. So pretension load of 20KN is applied on bolts

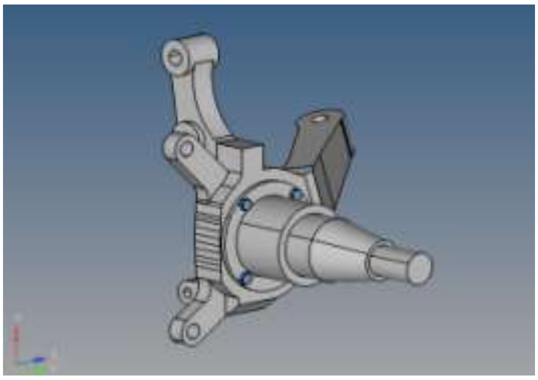
Fig.9: Cad Model of Steering Knuckle bolted with spindle

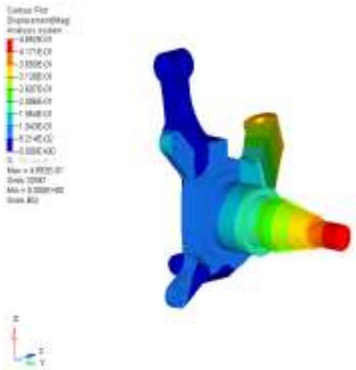
Fig.10: Deformation of new proposed design 1

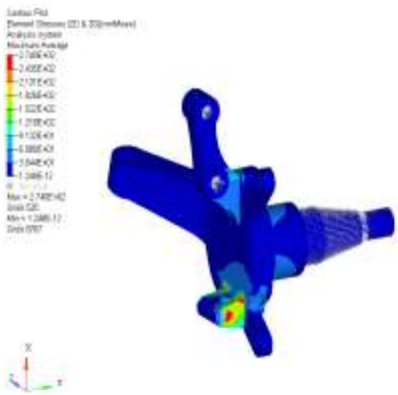
Fig. 11: Von-mises stress in new proposed design 2

After applying boundary conditions to proposed design 1, maximum von-mises stresses were found to be 274 Mpa and maximum deformation was 0.46mm respectively.

B. *New Proposed Design 2*

In this new proposed design, a single piece forged component is developed which constitutes of hub body, wheel spindle, tie rod arm and brake calliper bracket.

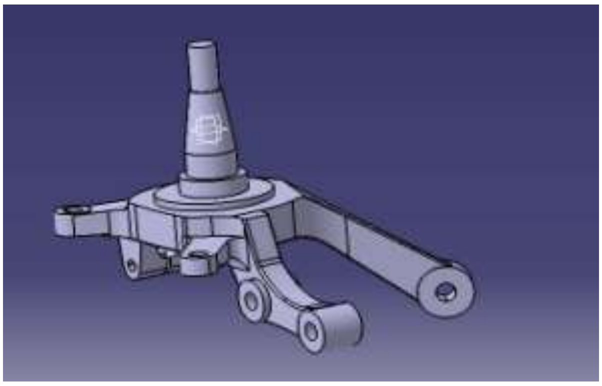

Fig 12: New Proposed Cad Model of Steering Knuckle

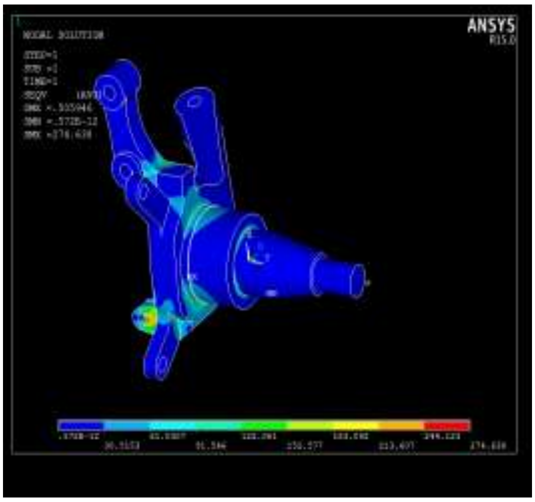

Fig.13: Deformation & von-mises Stress in new proposed design 2

To observe maximum stress produce into steering knuckle, model is subjected to extreme conditions and stress analysis is carried out. Maximum von-mises was found to be 274Mpa and maximum deformation of 0.505mm was found.

As stresses are less than yield stress (340MPa) and deformation is much less, so design is safe.

VI. OPTIMIZATION

Optimization methods were developed to have lighter, less cost and may have better strength too. Shape optimization is approach to redesign the structural shape based on predefined shape variables to obtain optimal shape. Size optimization defines ultimate component parameters, such as material values, cross-section dimensions and thicknesses. In shape optimization, the outer boundary of the structure is reshaped and best use of material for a body is estimated to solve the optimization problem. This involves upgrading the distribution of material so that a structure will have the maximum stiffness for given loads.

In this paper, shape optimization of knuckle was done by using Optistruct. Here objective function is to reduce weight of knuckle. Design constraints are applied as in static analysis.

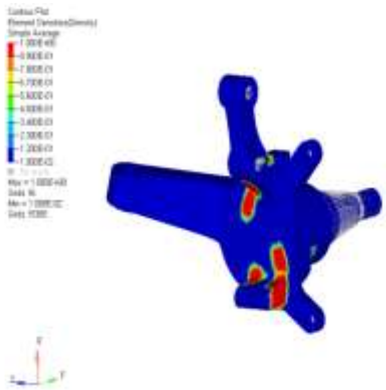

Fig.14: Material stress density distribution

The material density distribution is evaluated for finding the low stress area where we can reshape the geometry. Fig.9 shows the low stress area where we can remove material that bears no load. For removal of material, we have to consider the manufacturing detail and some functional constraint.

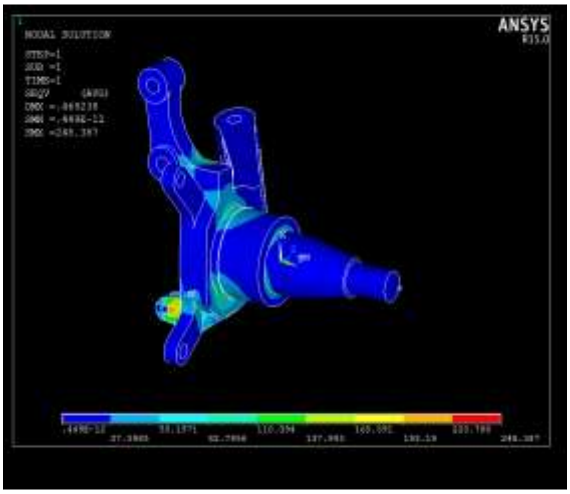

Fig. 15: Deformation & von-mises Stress in Optimized model

After material removal, optimized is analysed and observed for displacement and stress pattern. It was observed that maximum von-mises stress is 248Mpa while maximum deformation was found to be 0.469mm. The result obtained from analysis is studied and interpreted. It is observed that steering knuckle is safe and stresses are below limits and the stresses are observed in local areas.

A. Optimization Result

CAD Model	Deformation	Von-mises stress	Weight
Integrated	0.505mm	274Mpa	23.6
Optimized	0.469mm	248Mpa	22.7

Weight reduction % = (existing-optimized/existing)
= (23.6-22.7/23.6)
= 3.97 % $\simeq$ 4.00 % (Appox).

Original Mass was 23.6 Kg, after modification it was reduce to 22.7 Kg. Total weight reductions of 4 % of total weight was achieved

VII. CONCLUSION

- Under given loading condition, part is safe as working stresses are less than the yield stress
- Decrease in Stress Level from 274Mpa to 248Mpa.
- After optimization mass is reducing from 23.6Kg to 22.7Kg.
- Total weight reduction of 4 % of total weight is achieved.

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