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Research Article

Topology optimization of Automotive Steering Knuckle using Finite Element Analysis

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Abstract

Topology of a structure can be defined as a spatial arrangement of structural members and internal boundaries. Topology optimization means varying the connectivity between structural members of discrete structures or between domains of continuum structures this contributes to the development of structural design and mass reduction of vehicle components. The overall weight of the vehicle can be reduced to achieve savings in raw material costs and consequently processing cost as well as improve fuel efficiency and reduce carbon emissions to help sustain the environment.

Keywords: *Stress Analysis, Optistruct, Hypermesh, Mass Optimization.*

1. Introduction

Topology optimization is an approach that optimizes material area within a design space, for a restricted set of loads and boundary conditions such that the resulting layout meets a prescribed set of workloads. With this we can find the best concept design that meets the user requirements. Topology optimization has been implemented with the help of finite element methods for the analysis and optimization techniques based on the method of moving asymptotes, genetic algorithms, optimality criteria method, level sets and topological derivatives.

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Fig.1 Distribution of Vehicle Weight by System–ICE

Topology optimization is used at the concept level of the design process to arrive at a conceptual design proposal that is then fine-tuned for performance and manufacturability. The knuckle of a vehicle due to uneven ground, braking and side skidding subjected to various loading conditions. The impact road condition is equivalent to the wheels under the impact load conditions, so that the dynamic load factor is maximum. The weight reduction of the vehicle is the real need to increase the fuel efficiency and overall performance. The weight distribution of a vehicle is as shown in fig. 1

2. Boundary Conditions

The steering knuckle is the component which transfers the load of the vehicle to the ground through tyres in every condition of the travel. The load of the vehicle is normally not equally distributed on the front and rear axle. For a typical front wheel drive car the car weight distributed as 60% on front axle and 40% on the rear axle. In Straight driving condition the load usually distributed equally on each tyre. The direction of car changes through braking, accelerating or cornering where each tyre will experience a gain or loss of mechanical down force.

In the case of braking the maximum weight of the vehicle get shifted to the front axle. In the extreme case of the braking 50% of the load can be transferred to the front axle. Same can happen in the driving on the sharp sloping road. This is the maximum value of the parameter to avoid the skidding of the vehicle. Create four load collectors (constraints, Brake arm, suspension and rack and pinion) and assign each collector with a color. Follow these steps for creating each load collector. From model browser create load collector for card image keep the field to none.

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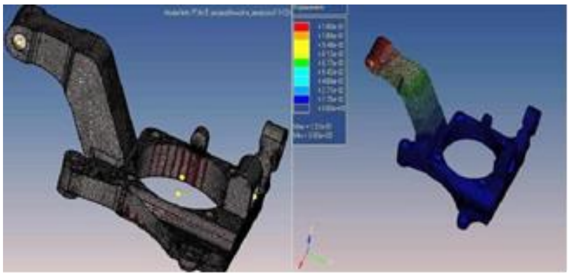

Fig. 2 Constraints Applied to Nodes

3. Load Cases

These forces are mainly due to braking, steering and bumping of vehicle. Therefore while analyzing steering knuckle, three different load cases should be considered. In this load case, the forces considered are wheel load components along X, Y and Z axes. And the moment around the x axis.

Load Case I: - Bumping

In load case, the forces considered are wheel load components along X, Y and Z axes. And the moment around the x axis.

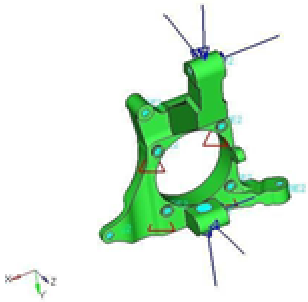

Fig. 3 Load Case I: Bumping

Load Case II: - Braking

Two brake force components along X are applied on the brake caliper, this is due to applied brake force by the driver.

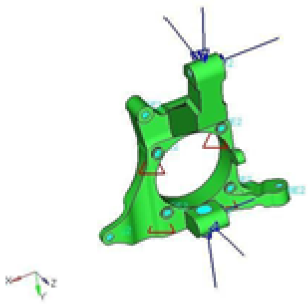

Fig. 4 Load Case II: Braking

Load Case III: - Steering

In this load case steering load components along X, Y and Z axes are applied. These loads are acted on arm of the knuckle due to the steering force introduced by the driver and acting on the small.

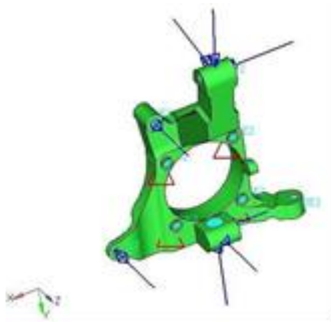

Fig. 5 Load Case III: Steering

Load Case IV: - Combined Loading

In this case, all the three load cases i.e. bumping, braking and steering are considered simultaneously. These loads are common in all three load cases. In the given FE model, the three hub bolt holes are fixed (all degrees of freedom are constraint) to the wheel hub.

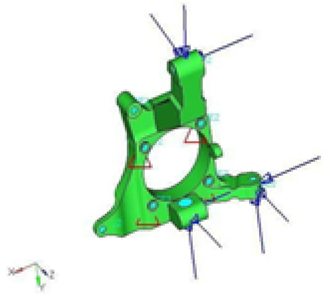

Fig 6 Load Case IV: combined loading

It is not sufficient to say that to minimize stresses or maximize Eigen value the statements must be more specific. For example, to minimize the maximal nodal stresses experienced during two load cases or to maximize the sum of the first five Eigen values.

4. Static Analysis Results

A static analysis can, however, include steady inertia loads such as gravity and rotational velocity, and time – varying loads that can be approximated as static equivalent loads. A static analysis calculates the effects of steady loading conditions on a structure, while ignoring inertia and damping effects such as those caused by time varying loads. On the mesh model of steering knuckle, the forces and constraints were applied as discussed and linear static analysis for each load case was carried out using Optistruct. The following contour plots shows the displacements and stresses induced in the steering knuckle for each load case.

4.1 Result of load case I:- Bumping

The maximum displacement was found to be at the location where upper chassis connects to the steering knuckle and it has magnitude equals to 0.223mm and maximum stress of 171.2 MPa was found to be at shaft corner.

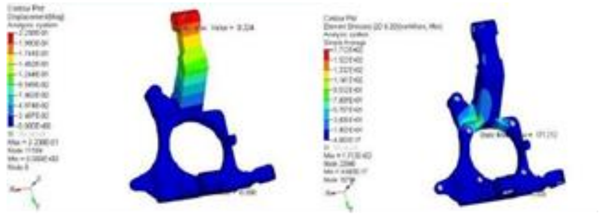

Fig 7 Displacement and Stress contour plot for bumping

4.2 Results of load case II: - Braking

The maximum displacement and stress for the braking condition is found to be 0.209mm and168 MPa.

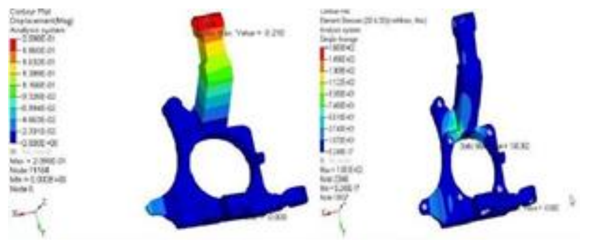

Fig 8 Stress and Displacement contour plot for braking

4.3 Results of load case III: - Steering

In this load case, the displacement has its peak value at the end of steering arm and stress was maximum at the upper hub bolt and steering arm. The peak values for displacement and stress are 0,229 mm and 171MPa.

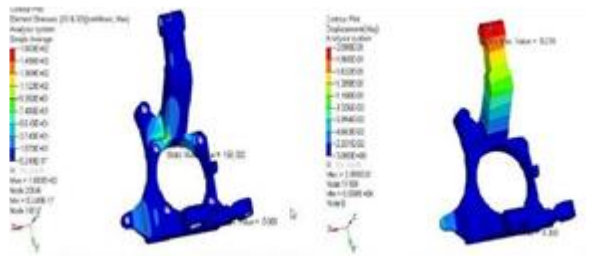

Fig 9: Stress and Displacement contour plot for steering

4.4 Results of load case IV:- Combination of bumping, braking and steering

The peak values for displacement and stress are 0.328 mm and 255.4 MPa.

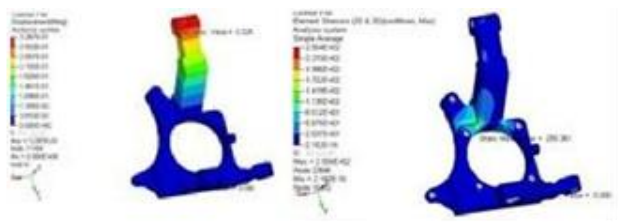

Fig 10 Displacement and Stress contour plot for combine loading

The goal of an optimization is called the objective function. In addition, a certain values can be enforced during the optimization. For example, specify that the displacement of a given node must not exceed a certain value. After removing the weight from the specified area the steering knuckle is again analyzed for the given forces according to the loading conditions. The results obtained from this are as discussed below.

From the above analysis the stress and displacement observed under loading condition in Steering Knuckle and Optimized steering knuckle is as shown in table.

Table1: Comparison of Steering Knuckle and Optimized Steering Knuckle

Material Properties	Steering Knuckle	Optimized Steering Knuckle
Stress	44.33 MPa	44.40 MPa
Displacement	00.10 mm	00.18 mm
Weight	05.30 Kg	04.60 Kg

5. Optimized Knuckle analysis

Further the analytical study carried out on the optimized steering knuckle for the different loading condition as discussed in load cases. The result obtained from this study is as shown in below accordingly in three case loading conditions.

I) Optimized Knuckle in Bumping

The maximum displacement was found to be at the location where upper chassis connects to the steering knuckle and it has magnitude equals to 0.177mm and maximum stress of 150.9 MPa was found to be at shaft corner.

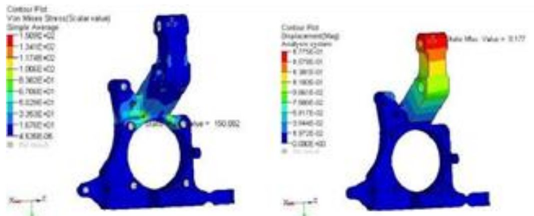

Fig. 11 Stress and Displacement contour plot for Bumping (Optimized Knuckle)

II) Optimized Knuckle in Braking

The maximum displacement and stress for the braking condition is found to be 0.182 mm and 155.6 MPa.

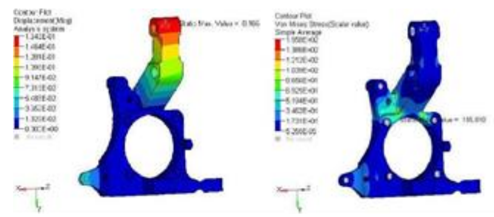

Fig. 12 Stress and Displacement contour plot for Braking (Optimized Knuckle)

III) Optimized Knuckle in Steering

In this load case, the displacement has its peak value at the end of steering arm and stress was maximum at the upper hub bolt and steering arm. The peak values for displacement and stress are 0,177 mm and 150.9 MPa.

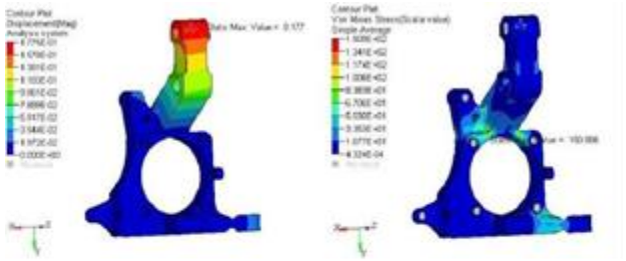

Fig. 13 Stress and Displacement contour plot for Steering (Optimized Knuckle)

IV) Optimized Knuckle in Combined loading

For combined loading the stress and displacement results are 251.7 MPa and 0.289 mm.

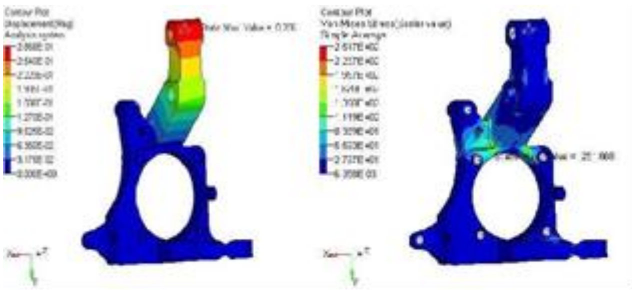

Fig. 14 Stress and Displacement contour plot for Combined Loading (Optimized Knuckle)

6. Results and Discussion

The analysis of the steering knuckle used for project shows that the maximum stress occurs for combined loading condition at the inner side of the suspension arm near the hub.

Table 2 Comparison of FEA result

Loading Conditions	Steering Knuckle		Optimized Steering Knuckle	
	Displacement (mm)	Stress (MPa)	Displacement (mm)	Stress (MPa)
Bumping	0.223	171.2	0.177	150.9
Braking	0.209	168	0.182	155.6
Steering	0.229	171	0.177	150.7
Combined Loading	0.328	255.4	0.296	251.7

From the above results it is clear that the geometry get optimized without compromising the safety features for steering knuckle and material also. The following conclusions can be drawn from the current work presented in this report.

The result of the computational analysis and the experimentation study are varied by 2.90%. The results obtained are satisfactory.

Stress level of the optimized model is correlated with the stress level of the baseline model. That means new proposed geometry is satisfactory.

The mass of the existing knuckle is reduced from 5.320Kg to 4.600 Kg.

By using topology the mass reduction achieved is 13.20% in the exercise.

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