International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 03, March-2016

Evaluation and Optimization of Macpherson Steering Knuckle using Topological Approach

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Abstract **- Automotive Makers Continuously Develop New Vehicles With More Luxury, Convenience, Performance And Safety. A Reduction In The Weight Of Suspension Components Also Improves The Vehicle's Handling Performance. Therefore, Topology Optimization Should Be Implemented To Obtain A Minimum Weight With Maximum Or Feasible Performance. Among The Vehicle Structural Components, The Steering Knuckle Is Prominent Part In The Suspension System Which Plays Major Role In Many Direction Control Of The Vehicle Linked With Other Linkages And Supports The Vertical Weight Of The Car. In This Study Weight Optimization Of Macpherson Steering Knuckle Using Topological Approach Has Been Carried And 12.56 % Weight Reduction Achieved With Meeting Strength Requirements.This Study Has Been Dealt With Generation Of Cad Model In Catiav5, Meshing In Hyper Mesh With Applying Loading & Boundary Conditions, Simulation Of Model & Optimization In Optistruct Solver , Cad Meshing & Re-Analysis Of Optimized Model, Fabrication, Experimentation & Validation.**

Keywords: Optimization, Macpherson Steering knuckle, Topology

INTRODUCTION

A forged or cast joint that usually includes the steering arm and spindle, allowing the wheel to pivot, is known as a Steering knuckle. It is part in automotive suspension contains the wheel hub which is fixed over the knuckle by using a bearing and attaches to the suspension system. It links suspension, steering system, wheel hub and brake to the chassis. There has been a strong trend towards the adoption of optimum materials and components in automotive industry. Automotive designers have a wide range of materials and processes to select from. Steel forgings are in competition with aluminium forgings and castings, cast iron and sintered powder forgings. The lighter steering knuckle resulting greater power and less the vibration because of the inertia is less. Weight reduction will give substantial impact in terms of fuel efficiency and vehicle's overall performance as it directly affected by power to weight ratio. Objective of this investigation is weight reduction of steering knuckle for Macpherson strut geometry of suspension which can be achieved by optimization technique such as topology optimization which gives the optimum material layout according to the design space and loading case.

LITERATURE SURVEY

*Wan Mansor Wan Muhammad et al.(2012)*focus on shape optimization technique for mass reduction in steering knuckle. HyperMesh was used to prepare the finite element model while HyperMorph was utilized for defining shape variables. For optimization purpose, OptiStruct was used. The improved design achieves 8.4% reduction of weight while meeting the strength requirement.

Purushottam Dumbre et al. (2014) Weight reduction of steering knuckle is the objective of exercise for optimization. Typically, the finite element software like OptiStruct (Hyper Works) is utilized to achieve this purpose. Topology optimization used to reduce the weight of existing knuckle component by 11% while meeting the strength requirement, with limited design space given with or without change in material properties.

3. Mahendra L. Shelar et al. (2014) The process of optimizing the design using a methodology based on durability and design optimization through probabilistic models of design variables.Weight reduction of 9.95% has been observed by using topology optimization when optimized model compared with initial model.

Jatin Agrawal (2015) Designing of steering knuckle of an off-road vehicle, using Solid works and performing its shape optimization using ANSYS Workbench in order to meet the required strength parameters at the cost of minimum weight. The study was carried out with suitable material selection as well as valid finite element analysis (FEA) and shape optimization studies.

V. Sivananth et al. (2015) In this study, computer aided design of steering knuckle was developed using modeling package SOLIDWORKS. Finite element analysis was performed on the developed model of knuckle using HYPERMESH. To simulate the effect under operating load conditions OPTISTRUCT AND RADIOSS solver was used. This work discusses the methodology adopted for static, fatigue, and impact analysis of knuckle.

Sneh Hetawal et al. (2014) In this study importance has been given to optimization of suspension geometry and obtaining the optimum locations of the mounting points i.e. hard points of the suspension geometry. Steering knuckle also analyzed in this study and emphasis has been given on alternate material for weight reduction. The knuckle was modeled in Solid Works and analyzed in ANSYS 15.0. The knuckle was optimized for material considerations. Thus, the suspension un-sprung masses can be reduced, improving the response of the suspension.

Mahesh P. Sharma et al. (2014) In this study static analysis of steering knuckle is carried out CAD modal of knuckle was prepared in CREO2.0. Static analysis was done in ANSYS WORKBENCH by constraining the knuckle,

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applying loads of braking torque on caliper mounting, longitudinal reaction due to traction, vertical reaction due to vehicle weight and steering reaction. Also, reducing the weight of vehicle component plays vital role in increasing efficiency of vehicle and reducing fuel consumption.

Viraj Rajendra Kulkarni et al. (2013) The work focuses on optimization of steering knuckle targeting reducing weight as objective function, while not compromising with required strength, frequency and stiffness. Finite element model was developed in Hyper-Works. 10 node tetrahedral elements were used for meshing, providing better results in less time. On constraining the knuckle, combined load of brake torque on the caliper mounting, longitudinal loads due to traction, vertical reactions due to weight and steering reaction, the finite element model was solved using RADIOSS solver. The stress levels and deformation was checked using Hyper-View for static as well as dynamic conditions. FEA results were verified by analytical calculations. Optistruct solver was used for performing topology optimization to minimize the amount of material to be used. Displacement is under 0.08mm and frequency obtained is at higher range thus eliminating cause of resonance.geometric model was modified and iterated until satisfactory results were achieved.

METHODOLOGY

DESIGNING CAD MODEL

CAD model of steering knuckle was developed in 3D modeling software CATIA V5 R19. It consists of stub hole, brake caliper mounting points, steering tie-rod mounting points, suspension upper and lower A-arm mounting points. Knuckle design mainly depends on suspension geometry and steering geometry.For this study steering knuckle of Macpherson front suspension system has been selected. CAD model generated using commands Pad, Pocket, Fillet and geometrical selections in part design module.

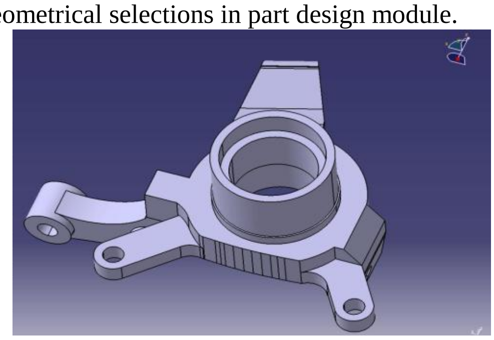
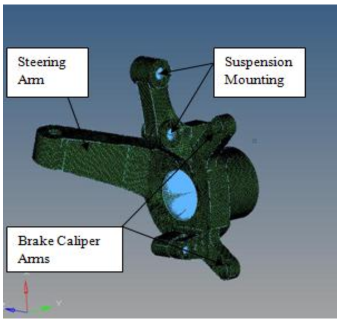


Fig.1 CAD model of Steering Knuckle

MESHING

A structure or component consists of infinite number of particles or points hence they must be divided in to some finite number of parts. In meshing components divide these into finite numbers by nodes and elements. It helps to carry out calculations on the meshed part. Components mesh using 3D elements. As all dimensions of steering knuckle are in proportion and for better quality the tetra-hedral elements used.



Nodes	50055
Elements	224543
Element Size	2 mm

Fig.2 Tetra-hedral Meshing of Steering knuckle

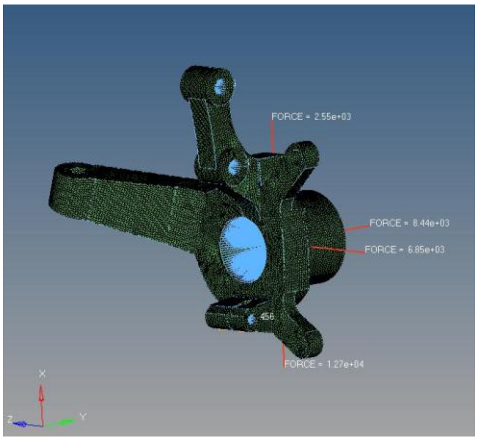


Fig.3 Boundary condition application on steering knuckle

PRELIMINARY ANALYSIS

In order to observe maximum deformation and stresses analysis carried out using HYPERWORKS and RADIOSS solver for conventional model.

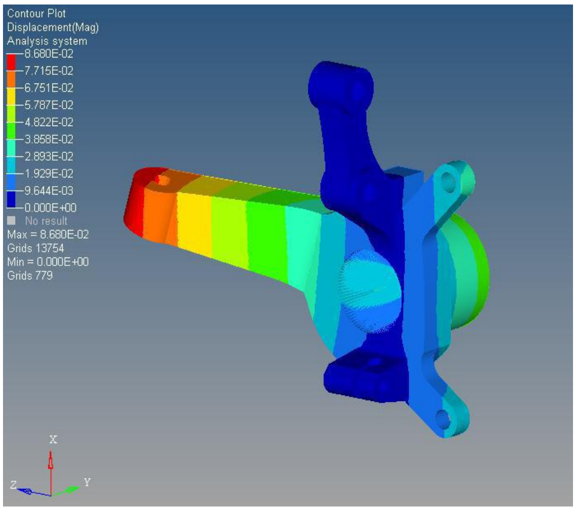


Fig.4 Deformation plot (Max value: 8.68E-02)

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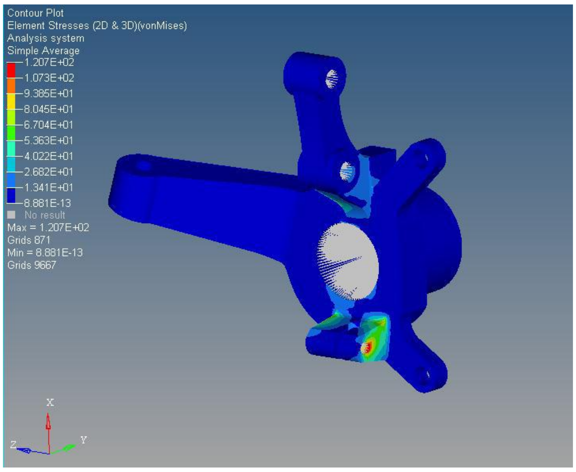

Fig.5 Von misses stress plot (Max Value: 121 MPa)

TOPOLOGY OPTIMIZATION

It uses highly advanced optimization algorithms; Optistruct can solve the most complex optimization problems with thousands of design variables in a short period of time. Optistruct advanced optimization engine allows users to combine topology, topography, size and shape optimization methods to create better and more alternative design proposals leading to structurally sound and lightweight design.

Optistruct Solver

Design Constraint	Von Misses stress < 390 MPa
Objective Function	Volume reduced
Design Variable	Density of the element

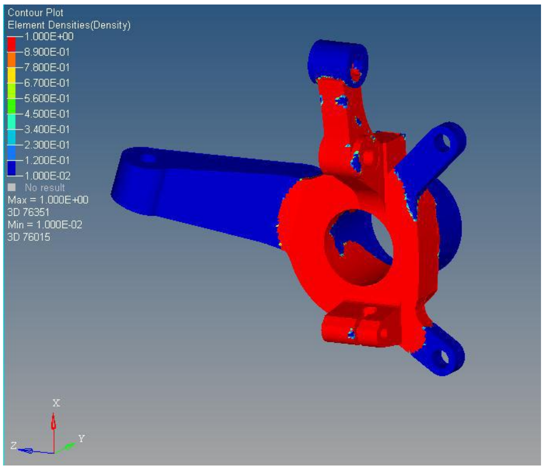

Fig.6 Plotting of results in OPTISTURCT solver

The red plot in the figure defines the area where the stresses are concentrated and the blue region can be optimized as it defines area of low stress or no stress.Material can be removed from low stress region where density is design variable.

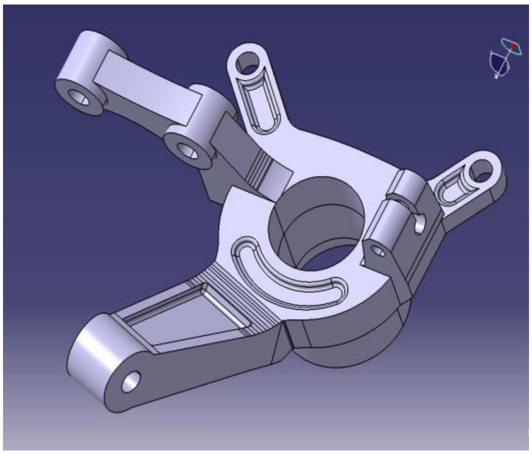

Fig.7 Optimized Steering Knuckle Model

Iteration method carried out to remove material from brake caliper arms,steering arm and circular portion of hub.

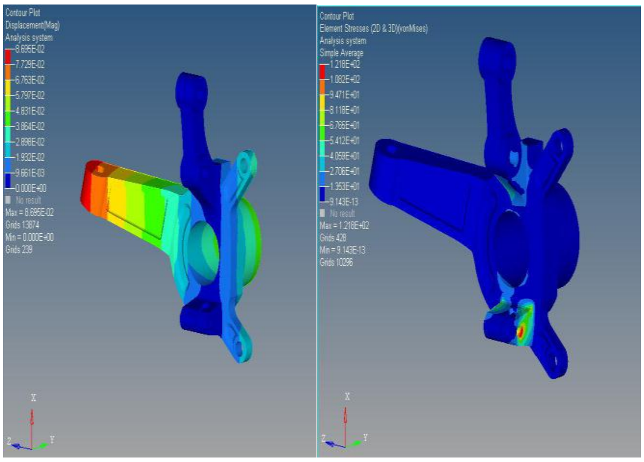

Fig.8 a) Deformation Plot b) Von misses stress plot

Table: 1 Summary of FEA

Iteration	Deformation	Stresses
Iteration 1	8.66E-02	119 MPa
Iteration 2	8.67E-02	118 MPa
Iteration 3	7.28E-02	113 MPa
Iteration 4	8.69E-02	121 MPa

EXPERIMENTAL ANALYSIS

Optimized steering knuckle model fabricated by removing material from existing model with the help of Universal Milling Machine where different mounting and locating positions employed for steering knuckle. Material removed from various regions as obtained in optimized model.

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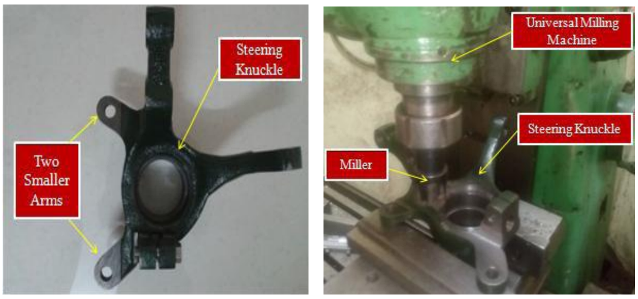


Fig. 9 Material removal from conventional knuckle model

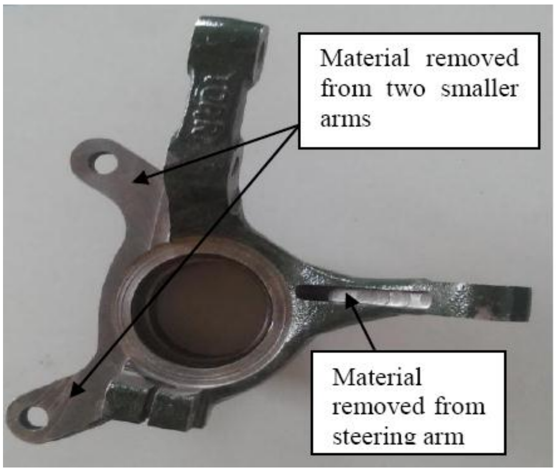


Fig. 10 Fabricated Optimized Model

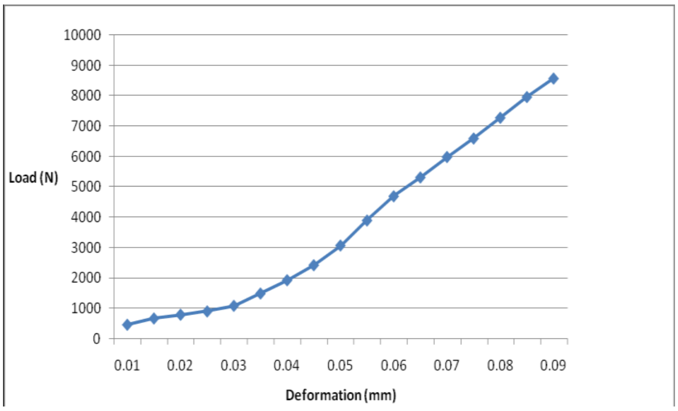
EXPERIMENTAL SET UP AND TESTING

In experimental investigation compression test is performed on fabricated prototype on universal testing machine. Loading conditions of 8.44KN lateral force and 6.85KN longitudinal force are applied on the prototype for testing purpose. For testing the steering knuckle we need to have a holding device which should treat like it is mounted as per the boundary conditions. Therefore a fixture is fabricated so that the steering knuckle is hinged on the fixture for testing purpose.

a) Lateral force(8.44KN) b) Longitudinal force(6.85KN)

Fig.11 Loading conditions for steering knuckle

For the load applied on the prototype of Steering knuckle the deformation is noted down and the graph is plotted on Load vs.Deformation



Plot of load vs. Deformation

It is observed that the maximum deformation is 0.085mm.With increasing load deformation also varies accordingly and it attains the certain value.

RESULTS AND DISCUSSION

Table:2 Results Validation

Sl.no	Results	Deformation	% error
1	FEA results	0.080	5.88
2	Experimental results	0.085	

Weight of actual model = 2.562kg

% weight reduction = $(W_A - W_I)$ X 100

Where,

W_A - Weight of actual model

W_I - Weight obtained in iterative method

Table: 3 Percentage mass reduction of steering knuckle

Iteration	Weight	% difference
Iteration 1	2.48	3.2
Iteration 2	2.39	6.71
Iteration 3	2.31	9.84
Iteration 4	2.24	12.56

CONCLUSION

Critical yield strength of the material is 250MPa, from the table.1 we conclude that steering knuckle with different iterations are below critical limit and hence they are safe in design.The iterations are carried out through the optimization process and the best optimized steering knuckle is chosen for fabrication and testing purpose.Weight of the final optimized model is 2.24 kg. Therefore, percentage weight reuction between original existing model and optimized steering knuckle model is about 12.56 %. Thus the weight reduction objective is achieved. The FEA results are compared with the experimental results with a percentage error of approximately 5.88 in deformation hence, optimization done without affecting stiffness of steering kuckle for applied load. This also shows a closure convergence towards the results is achieved.

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FUTURE SCOPE

The steering knuckle can further be tested for different modes of vibration. The optimized model can be validated for durability with different load conditions. There is a scope to build a complete forged integrated hub or spindle which may further increase performance or steering capabilities. The proposed model can also be further optimized if the fatigue parameters fulfill the durability of the steering knuckle. Sticking with the same objective we can optimize steering knuckle as per the suspension system in different vehicle models in order to improve its performance and efficiency. Also there is scope for weight reduction of steering knuckle using different optimization techniques like shape optimization, size optimization and topography. Results obtained from these techniques can be compare and validate simultaneously.

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