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Topology Optimization of Lower Control Arm for LMV

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***Abstract*—Lower control arm is an important part in the suspension system. It is connected between subframe and knuckle. It holds the vehicle wheels in alignment. High unsprung weight complicates steering control and traction control issues. This paper deals with the reduction of unsprung mass of vehicle by topology optimization of lower control arm. For analysis existing lower control arm of Mac- Pherson suspension system is selected. CATIA software is used for CAD modelling. Ansys software is used for static structural analysis of existing model to find out Von- mises stress and deformation by applying required boundary conditions and loading. On the basis of stress developed, topology optimization is carried out by removing excess material from CAD model. Lower control arm is redesigned and is analysed for stress distribution and deformation. It is observed that total reduction of weight in existing model is found to be 13.46 %.**

Key Words*—Lower control arm, Static structural analysis, Topology optimization, Unsprung mass.

I. INTRODUCTION

Suspension system is an integral part of automobile. It is used to prevent the road shocks being transmitted to vehicle frame and other components of vehicle. Its main function is to provide stability, safety and comfort. It maintains traction between the tyre and road surface. Lower control arm is an important component in the suspension system. It is present in both Mac- Pherson suspension and Double wishbone suspension system [2]. Control arm connect the cars suspension to the actual vehicle frame. One end of lower control arm is connected to knuckle through a ball joint and other end is attached to vehicle subframe. Lower control arm forms the unsprung weight of vehicle. High unsprung weight complicates wheel control issues under hard acceleration or braking. It may cause severe wheel hop, compromising traction and steering control. Unsprung weight increases the overall weight of suspension system and finally of vehicle. The main objective of paper is to reduce the unsprung weight of vehicle; by reducing weight of lower control arm using topology optimization. The cost of manufacturing is also reduced. Topology optimization include removing unnecessary material from the base model to reduce weight using given sets of objectives and constraints.

Excess material is removed from the low stressed region of lower control arm. The existing design of left lower control arm from one of the light motor vehicle having Mac-Pherson suspension system is selected for the study (Maruti Suzuki Swift Dzire). It is essential to focus on the stress and deformation study to develop the changes in existing design. FEA approach is used for static structural analysis and topology optimization.

Balasaheb Gadade et. al. [1] The paper aims at Design and analysis of A-type front lower control arm in commercial vehicle. Objective of the study is to calculate working life of the component under static loading. M.Sridharan et. al. [2] Objective of the paper is to model and perform structural analysis of a LCA in front suspension system, which is a sheet metal component. LCA is modelled in Pro-E software while for analysis, CAE software is used. Bharatesh M Goudra1 et. al. [3] The paper deals with structural analysis of lower control arm using Kevlar and SAE J2340. CAD model is generated in CATIA and finite element analysis is done using ANSYS. Bhushan Kumar [4] The research work involves the development of sheet metal lower control arm, that has many advantages over forged metal. The model is translated into IGES file, which is used for analysis. M. Viqaruddina [5] The paper focuses the static analysis and torsion analysis of the LCA using Radioss software and improve the stiffness and weight reduction of component by changing structural properties and the geometrical dimension as well. The design is given by topology optimization to compare analysis of existing and optimized model. Sagar Darge [6] The paper aims to perform FEA of control arm which consist the stress optimization under static loadings.

II. METHODOLOGY

In order to carry out analysis, left lower control arm from one of the LCV is selected having Mac- Pherson suspension system. Reverse engineering of existing lower control arm is done using Coordinate Measuring Machine (CMM). With the help of the coordinates obtained CAD model is generated in CATIA software. In Ansys static structural analysis of control arm is carried out by applying required loading and boundary conditions. Excess material is removed from low stressed region by Topology optimization and the model redesigned and optimized. Static structural analysis of optimized CAD model is done to evaluate stresses and total deformation.

A. Analytical Calculation

For research work Left lower control arm of Maruti Suzuki Swift Dzire is selected. Gross weight (m) is 1505 Kg.

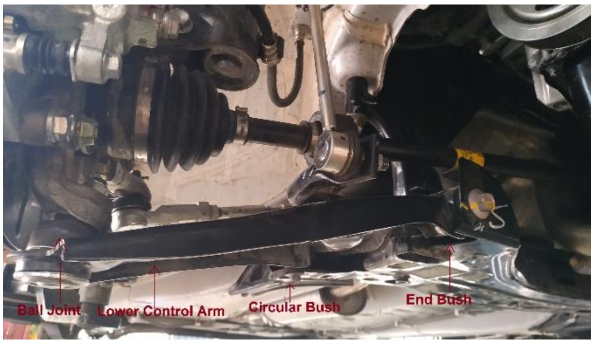

Fig. 1 Position of Lower Control Arm

Load calculation for a given vehicle model is as follows:

Weight of vehicle acting at its centre of gravity is given by,

W= m.g ----- (1)

As we know that approximately 52% of weight of the whole car is carried by front wheels and 48% weight carried by rear wheels [7].

Weight on front axle is,

$F_f = 0.52*m*g$ N

Reaction at each front wheel is,

R_{fw} = Weight on front axle /2

From above calculation load acting on front wheel is 3838.65 N.

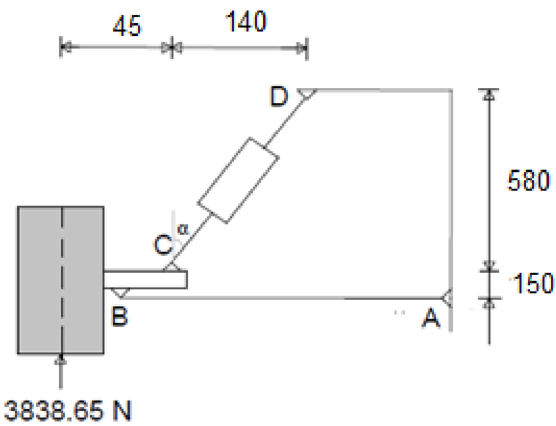

Fig. 2 Front Mac- Pherson Suspension schematic

From Fig. 2,

$$\alpha = \tan^{-1}\left(\frac{140}{580}\right) = 13.57° \quad \text{----- (2)}$$

$\Sigma M_B = 0$

CD = 1204.09 N

$\Sigma F_x = 0$

B_x = -1170.37 N

$\Sigma F_y = 0$

B_y = - 4120.40 N

Resultant force is given by,

B_{xy} = 4283.39 N ----- (3)

B. Reverse Engineering of Lower Control Arm

Coordinate measuring machine (CMM) is used to measure all the dimensions of lower control arm. A coordinate measuring machine (CMM) measures the geometry of physical objects by sensing discrete points on the surface of the object with a probe. CMM allows probe movement along X, Y and Z axes which are orthogonal to each other in a three-dimensional Cartesian coordinate system. Each axis has a sensor that monitors the position of the probe on that axis. When the probe contacts .a particular location on the object, the machine samples the three position sensors, thus measuring the location of one point on the object's surface. As the probe touched the surface of the component the stylus deflected and simultaneously sent the X, Y and Z coordinate information to the computer.

Lower control arm is fixed by clamping and a reference is selected for datum. 449 coordinates are obtained by moving the probe over the lower control arm. These coordinates are plotted for creating a sketch. Tangram software is used for CMM.

Fig. 3 CMM of Lower Control Arm

C. CAD Modelling

CAD model of the front lower control arm is generated using CATIA V5 software. CATIA has a special tool of generative surface design to construct typical surfaces, which is then converted into solid model. CAD model is exported to meshing software in igs format.

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Fig. 4 CAD Model of LCA

D. Finite Element Analysis

Ansys software is used for meshing of CAD model. Solid tetrahedron elements are used for generating mesh to lower control arm. No. of nodes is 42549 and no. of elements is 42885 with an element size of 3 mm.

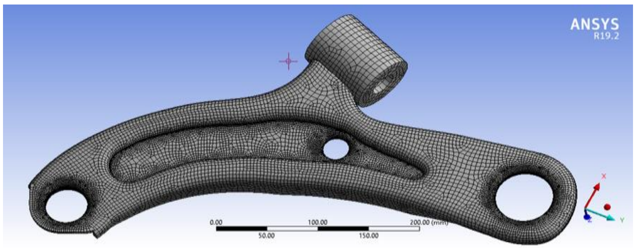

Fig. 5 Meshing of CAD Model

Boundary conditions are applied after carrying out meshing on CAD model. Circular bush is free in rotational Z direction and its other DOFs are fixed. End is free in Y direction and its other DOFs are given fixed constraints [3]. The force of 4283.39 N is applied on a ball joint in downward direction.

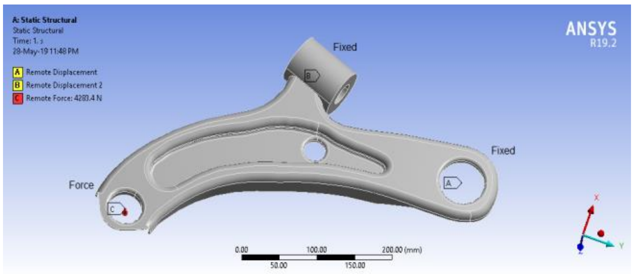

Fig. 6 Boundary Conditions to CAD Model

Table I- Material Properties

Material	AISI 1040
Young's modulus	2.1e5 MPa
Poisson's ratio	0.3
Density	7850 Kg/m3
Yield strength	415 MPa
Tensile strength	620 MPa

E. Static Structural Analysis

Static structural analysis is used to determine the forces stresses, strains and displacements in the component caused by loads that do not induce significant inertia and damping effects [1]. Steady conditions of loading and response are assumed; this means that the loads and response of the structures vary slowly with time.

1. Von- Mises stress in Existing Model

The curvature near the end bush and the circular bushing regions are subjected to a high level of stress as indicated by the red zone. Whereas the remaining portion undergoes a lower level of stress and is indicated by blue zone. Maximum stress is found to be 384.75 MPa.

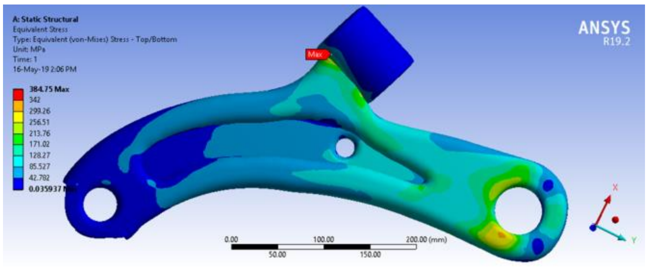

Fig. 7 Von- Mises Stress in Existing LCA

2. Deformation in Existing Model

Maximum deformation occurs at the ball joint portion since load is applied at the ball joint. It is indicated by red zone. Maximum deformation is found to be 6.45 mm.

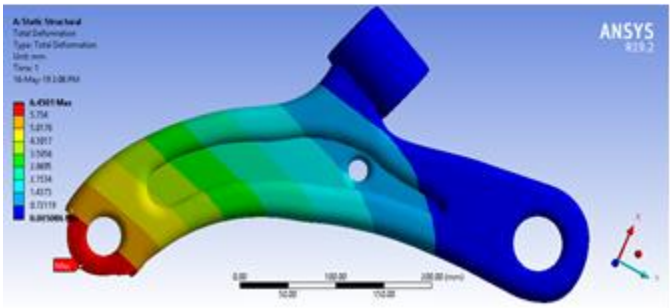

Fig. 8 Deformation in Existing LCA

III. TOPOLOGY OPTIMIZATION

The Topology optimization gives the optimum material layout according to the design space and loading condition using given sets of objectives and constraints. The main aim of topology optimization is to reduce weight by removing excess material from low stressed region. To solve any topology optimization problem, three parameters must be specified, namely design variables (material density), design objective (weight reduction) and design constraints (volume) Topology optimization is used to generate optimal shape of mechanical
structure[5].

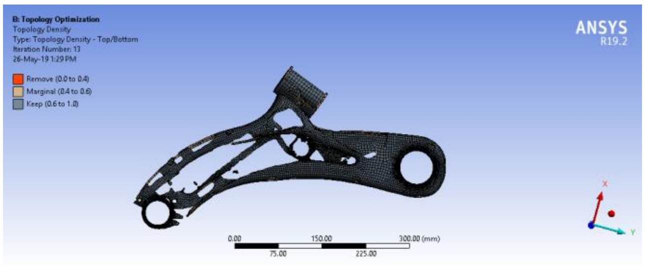

Fig. 9 Topology Optimization

A. Optimized CAD Model

After topology optimization the existing model is re-design and optimized. Re-design of the optimized model is done in CATIA V5 and the model is imported in Ansys for further static structural analysis by applying necessary boundary condition and loading.

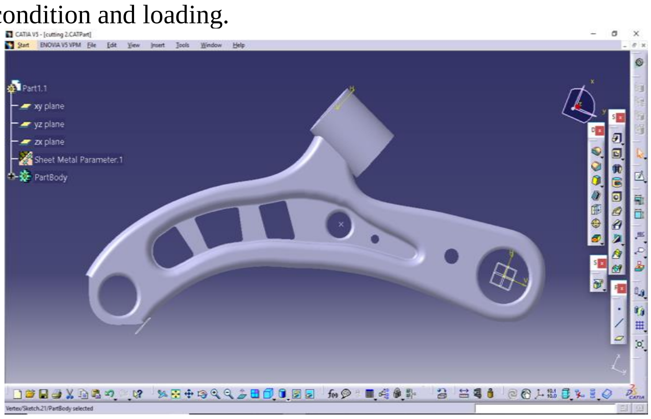

Fig. 10 CAD Model after Optimization

B. Meshing of Optimized Model

Solid tetrahedron elements are used for generating the mesh to lower control arm. Node population count is 41339 and element population count is 41732 with an element size of 3 mm.

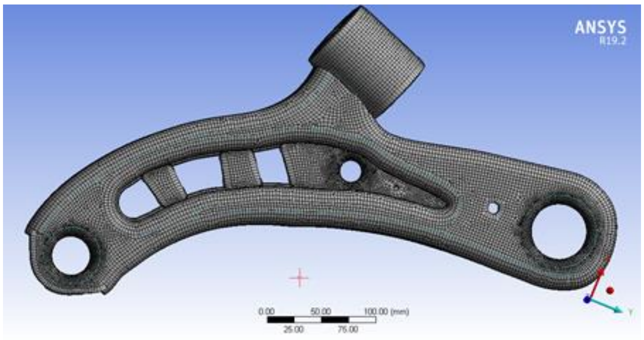

Fig. 11 Meshing of Optimized CAD Model

C. Static Structural Analysis of Optimized Model

Structural analysis is done to determine the stress distribution and deformation by applying mechanical load. Critical areas of location predicted where the stress distribution is high. The yield strength of material is 415 MPa and generated von-Mises stress in lower control arm should be less than yield strength of material.

1. Von- Mises stress in Optimized Model

Stress induced in lower control arm is 398.86 MPa. It is well below the critical limit of the material.

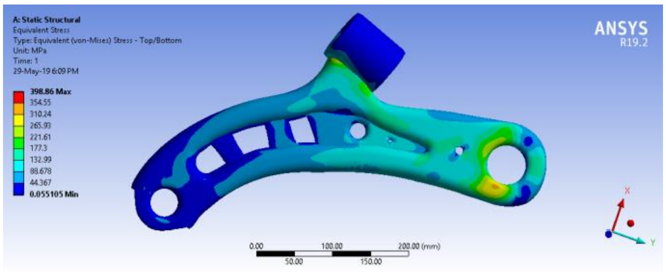

Fig. 12 Von- Mises Stress in Optimized Model

2. Deformation in Optimized Model

Deformation in optimized model is found to be 8.84 mm. The maximum deformation of optimized design and existing design are not varying by considerable amount.

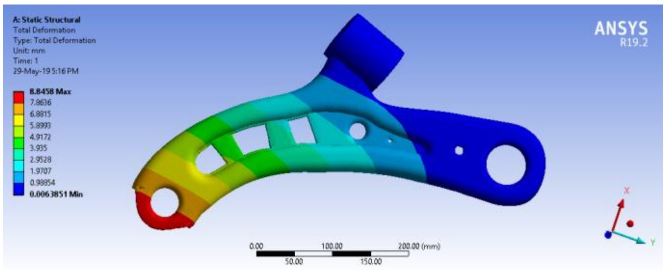

Fig.13 Deformation in Optimized model

IV. EXPERIMENTAL VALIDATION

The actual lower control arm is designed by analyzing CAD model. Pockets are made on the surface of control arm according to the CAD model.

Fig. 14 Optimized Lower Control Arm

For testing the tensile strength and compressive strength of materials, Universal Testing Machine (UTM), also known as a universal tester, is used. The loading conditions are applied on the lower control arm for testing purpose using load cells of universal testing machine. Loading is increased gradually from 1N to 4298 N and the displacement in the control arm seen on the desktop of a computer. The graph increases slowly with deflection. Deformation in optimized LCA from testing is found to be 10 mm. From FEA deformation is found to be 8.84 mm. Therefore, the percentage of error is 11.6%.

Fig. 15 Testing of LCA under UTM

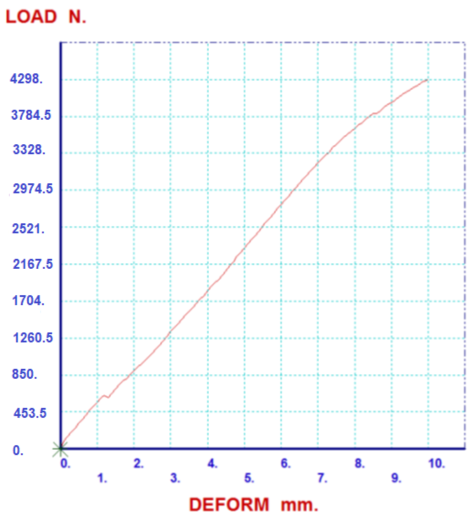

Fig. 14 Variation of Deforamation with respect to Load from UTM

V. RESULT AND DISCUSSION

The existing model of lower control arm is analysed in Ansys to find out stresses and deformation. In existing model maximum stress is 384.75 MPa and maximum deformation is 6.45 mm. Then existing model is optimized by making pockets on the surface of model. The maximum stress value for optimized upper control arm is 398.86 MPa and maximum deformation is 8.84 mm. Since the material's permissible stress is 415 MPa, this means that the design under the given load is safe. It is observed that there is an increase in stress occur in optimized model due to reduction in mass but this increased stress is below the yield limit of the material.

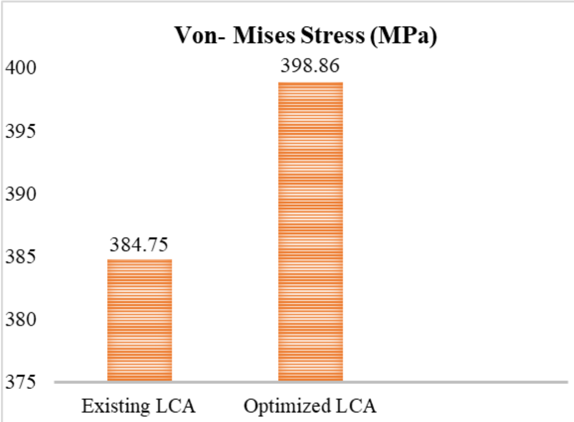

Fig. 17 Comparison of Von- Mises Stress in Existing and optimized LCA

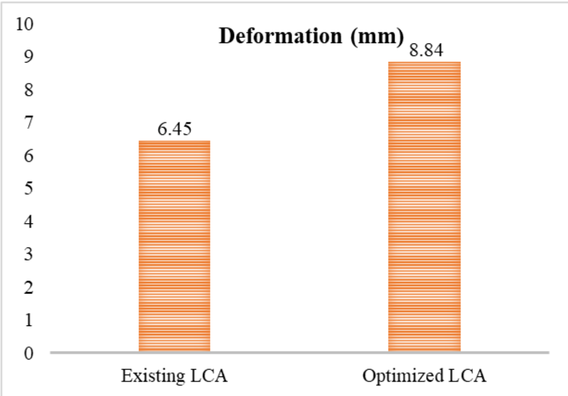

Fig. 18 Comparison of Deformation in Existing and Optimized LCA

Table II- Mass Comparison of Existing and Optimized Model

Existing Model	2.70 Kg
Optimized Model	2.25 Kg
% Mass Reduction	16.66 %

It is observed that mass reduction of 450 gm which is 16.66 % leads to large amount of material saving. It also saves time as well as cost of manufacturing control arm.

The cost of AISI 1040 material is Rs. 65 per Kg. Existing lower control arm weighs 2.60 Kg. Hence the raw material cost for existing lower control arm is Rs. 175. The optimized lower control arm weighs 2.25 Kg. Raw material cost for optimized lower control arm is Rs. 146.

Cost saving in material of one control arm

= Cost of material for existing LCA – Cost of material for optimized LCA

=Rs. 175 – Rs. 146

=Rs. 29

For a given vehicle having Mac-Pherson suspension system there are two lower control arm. Hence, the total cost saving in material for two LCA is Rs. 58. The percentage of cost saving in material for optimized lower control arm over existing is 16.57 %.

A comparative study of FEA and Experimental results is made. From the results it can be concluded that the validation of results shows resemblance with an error of 11.6%.

VI. CONCLUSION

The stresses in optimized lower control arm is within the allowable limit. Hence, design is safe according to yield strength criteria. The deflection dose not vary by considerable amount. Weight reduction of lower control arm is done without varying the performance. By topology optimization of lower control arm weight reduction of 16.66 % is observed over existing model. The cost saving in material for two lower control arm is Rs. 58 which is very high. Thus, the objective of weight reduction of unsprung mass and the cost reduction has been achieved.

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