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Vibration Response Analysis Of Lower Control Arm And Its Maximum Deformation Under Different Mode Shapes

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***Abstract*—All vehicles, machines and building are subjected to dynamic forces which cause vibration. Vibration problems and most practical noise problems are related to the resonance phenomenon where operational force excites one or more modes of vibration.The control arm suspension consists of upper and lower arms. The lower control arm is better shock absorber than upper arm because of its position and load bearing capacity. The main objective of the study is to find frequencies at different mode shapes of optimized model. The project involves CAD model generation of lower control arm in CATIA V5 with reverse engineering, Determination of loading for road bump case, cornering etc when a car is moving, finite element based weight optimization of lower control arm helps in finding the most appropriate design and frequency of optimized model. The frequency of lower control arm before and after optimization is studied at various mode conditions to verify the success of the design. Optimized model is fabricated and experimental results are verified with theoretical analysis.**

I. INTRODUCTION

Lower Control Arm:

Lower Control Arm plays major role in independent suspension system. Lower control arm is better shock absorber than upper arm because of its position and load bearing capacity. It forms the connection between wheel hub and chasis of automobile.

The suspension must be properly designed because of it is crucial subsystem in vehicle in order to:

- Carry the weight of the vehicle and also its weight (unsprung weight).
- Keep the wheels normal to the road for maximum grip resultant which results in good ride and handling performance.
- Take the forces for accelerating or braking the vehicle.
- To ensure that the steering control is maintained during maneuvering.
- Take the forces involved when cornering the vehicle.

Many loads act on the lower control arm which can cause its failure.

The following dynamic conditions are considered for calculations:

1. Road bump
2. Sudden Braking.

Vibration and modal analysis is carried out to find out natural frequency of the component.

Figure 1: Lower Control Arm

Lower control arm has an "A" shape on the bottom known as wishbone shape, it carries the most of the load from the shock received. The lower control arm takes the most of the impact that road has on the wheels of motor vehicle. It either stores that impact or sends it to the coils of the suspension depending on the shape.

The main objective of the study is to find frequencies at different mode shapes of optimized model.

To achieve the objective following steps must be taken:

- CAD model generation in CATIA V5 with reverse engineering(Reverse Engineering will follow a method of hand calculations using blue light scanning)
- Determination of loading for road bump case, cornering etc. when a car is moving.

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- Finite element analysis of discretized model of lower control arm to carry out modal and vibration analysis.
- Optimization of the shape considering maximum deformation analysis at different modes.
- Again modal analysis of optimized model to know its response under various mode shapes.
- Determination of the frequency of lower control arm before and after optimization.
- Fabrication of optimized model and comparison of experimental results with theoretical results to verify the success of design.

II. CAD MODEL GENERATION

Blue Light Scanning:

- A 3D scanning technology has been adopted to get the exact dimensions of the model. The 3D model in most cases should not only look visually similar to the real object, but should also be very accurate from a geometrical point of view.
- The scanner has been designed around two very common electronic devices: a video projector and a digital still camera.
- A video projector is used to project structured light patterns on the object to be scanned.
- The digital still camera is used to capture images of the object under structured lighting.
- Both devices are driven by software tool running on a standard PC, which produces the series of patterns, projected by the emitter and drives the camera.
- Photos are taken to capture images of the object. This generated points are transferred to modeling software, using the points surfaces are made.

Figure 2: Lower control arm during blue light scanning

3D–Model: Points which are generated from blue light scanning is transferred to CATIAV5. Model is created using surfaces. The model looks as below in CATIA V5.

Figure 3: Control arm in CATIA V5

III. FINITE ELEMENT ANALYSIS

Stage-I:

In stage-I igs file is imported to the meshing software like Hypermesh. The CAD data of the lower control arm is imported and the surfaces were created and meshed. Since it is a 3D model the best element for meshing is the tetra element.

A general purpose commercial finite element code, HyperMesh and Radioss is applied to conduct the static simulations, optimization. The FEA model of lower control arm in this study is constructed based on the geometry. A full 3-D solid model is constructed for the static test simulation.

Meshing:

A structure or component consist of infinite number of particles or points hence they must be divided in to some finite number of parts. Dividing helps us to carry out calculations on the meshed part. We divide the component by nodes and elements. We are going to mesh the components using 3D element. Number of nodes and elements formed after meshing are 9217 and 35848 respectively.

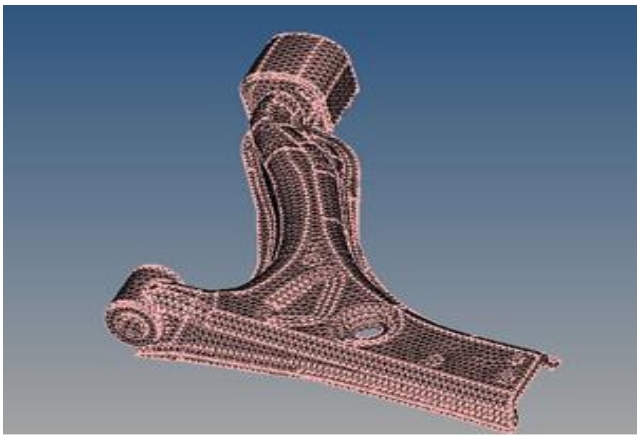

Figure 4: Meshed model of a lower control arm

While meshing mesh size of an element is to be taken into

consideration because all software's have some limits for the number of elements. Less the mesh size more will be the number of elements and coarse the mesh size less will be the number of elements. As the number of elements increases the run time increases, After meshing elements are to be checked for quality i.e. elements have some definite quality criteria which should be met by all elements. A quality criterion consists of minimum and maximum angles of the elements, jacobian, warpage, etc.

Stage-II:
Calculation of load
Loads on transverse link

- Road bump case
- Braking Case

Car wheel designation: Indica
Weight distribution= 54:46(As engine is in front side)
Gross vehicle weight= 1080 kg
Therefore weight on rear side= 496.8 kg
Weight on one side of wheel = 248.4 kg

Road bump case
Let Speed of vehicle = 14 km/hr(3.8 m/s)

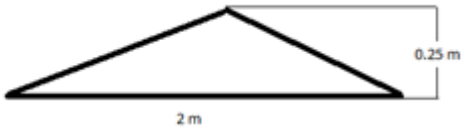

Figure 5: Road Bump

U = x/t (1)
U vertical = x vertical/ time (2)
A vertical = U vertical/time (3)
Inertia Force = mass x acceleration (4)
By using above equations
t= 0.25 m/sec, U vertical = 1m/s, A vertical = 4 m/sec^2
Wheel acceleration force(Inertia force)=993.6~1000 N

Braking Case
Vehicle de accelerates(i.e. braking) at a constant 0.5 G
Braking Force = mass x acceleration x 0.5 G (5)
Braking Force = 1218.4 ~ 1230 N

Loading and boundary conditions:

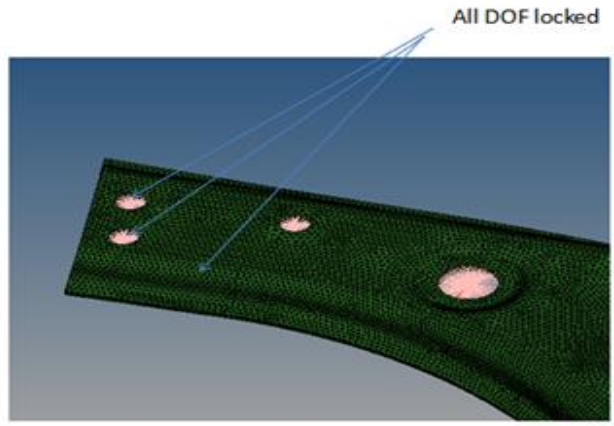

Figure 6: Constraint at the mounting location

Rigids are being formulated for the case of application of boundary conditions. The rigids are concentrated on an independent node on which the forces are to be applied. The boundary conditions include braking, cornering and bump loads. The constraints are put on the mounting areas arresting all degrees of freedom as shown.

Property	Value
Young's Modulus, E	210 GPa
Poisson's Ratio, ν	0.29
Density, ρ	7850 kg/m^3

IV.STATIC ANALYSIS RESULT

Von-mises stress:

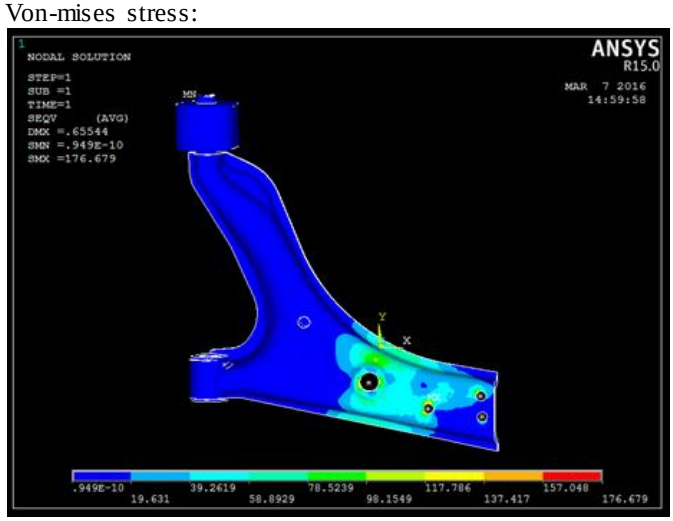

Figure 7: Von-Mises Stress

From above plot the maximum stress value for lower control arm is 176.67 MPa which is less than yield strength, hence the design for lower control arm is safe.

Defomation:

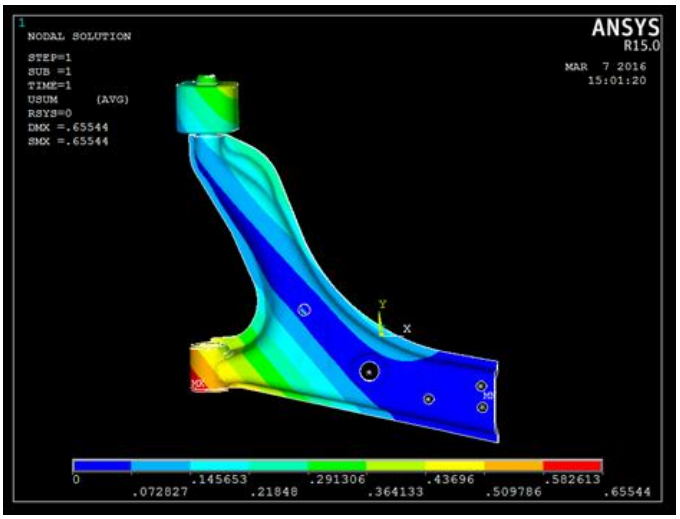

Figure 8: Deformation

From above plot the maximum displacement value for lower control arm is 0.65 mm.

V.MODAL ANALYSIS OF LOWER CONTROL ARM

Modal analysis is the study of the dynamic properties of structures under vibrational excitation. Modal analysis uses the overall stiffness and mass of a structure to find the various periods at which it will naturally resonate. These periods of vibration are most important to note in vibration of any machine, as it is imperative that a components or nearby system's natural frequency does not match the frequency of machine. If a structure's natural frequency matches a component's frequency, the structure may continue to resonate and experience structural damage.

Detailed modal analysis determines the fundamental vibration mode shapes and corresponding frequencies. Modal analysis also related to the response. The response of the structure is different at each of the different natural frequencies. These deformation patterns are called mode shapes. The mode shape is the shape of the deformed structure if it is excited by a dynamic force which has the same frequency as the natural frequency of the structure. The mode shape has no unit.

Result for modal Analysis:

Mode 1:

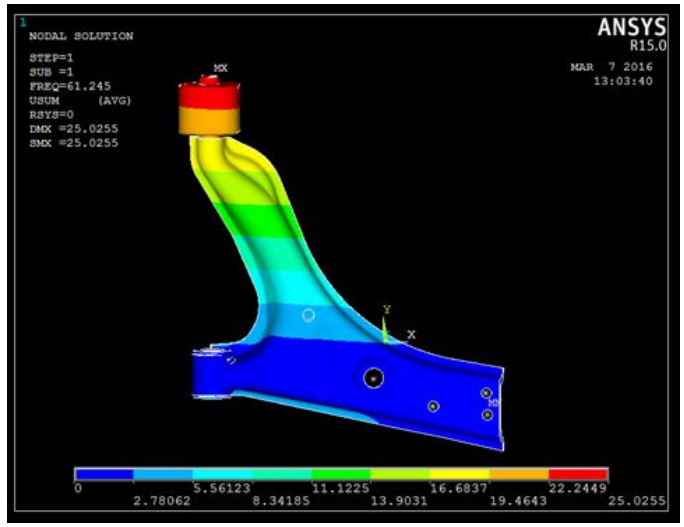

Figure 9: 1st mode frequency of lower control arm

The frequency of 1st mode is 61.24 hz.

Similarly modal analysis for 5 additional modes are carried out. From the results of finite element analysis it is observed that stress value is coming out to be 176.67 N/mm^2 which is within the safety limit which can be done by removing material at the region where the stress concentration is less, thus optimizing its weight without effecting on its structural behavior. The maximum displacement value is also very less.

Modal analysis result for model to mode 6 are 61.24, 173.28, 220.49,760.09,878.38,1393.29 hz respectively.

VI.OPTIMIZATION OF LOWER CONTROL ARM

Topology optimization is aimed at finding the best use of material within a given design space (often referred to as ground space) fulfilling requirements on stiffness, displacement, eigen values, etc. In short the optimization seeks to the optimal load path for a particular load and boundary condition.

Topology may be used to improve not only structural performance but also thermal properties, fluid flow, electric boards(MEMS), electromagnetic applications and bio-mechanic properties.

Optimization of lower control arm is stated as:

Objective Function	Minimize Volume
Constraint	Von mises < 390 MPa
Design Variable	Density of each element in design space

Results for Optimized Model:

Von mises stress:

Iteration 1:
Changes are made for iteration 1as shown in below figures

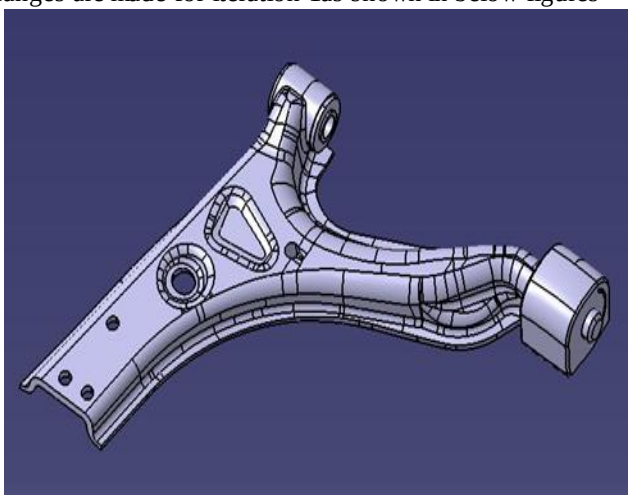

Figure 10: CAD model iteration 1 model of lower control arm

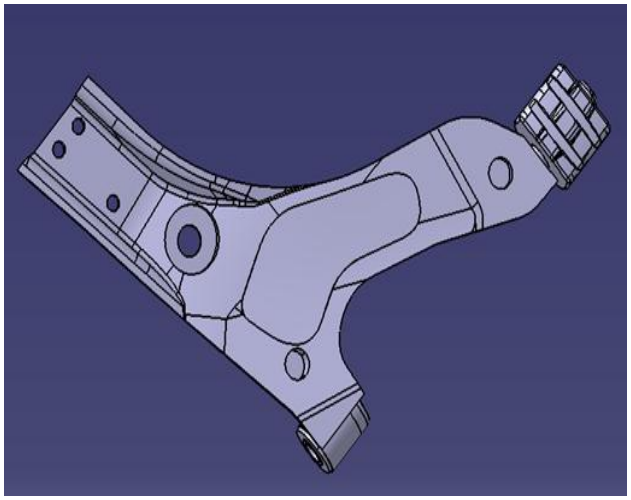

Figure 11: CAD model iteration 1 model of lower control arm

This optimized model is meshed and boundary conditions are applied
No. of nodes: 14664
No. of elements: 62151
Following are the results displayed for stress and deformation(MS):
Stress value for lower control arm is 164.44 N/mm^2 which is well below the critical value. Hence the design is safe. Deformation for lower control arm is 0.66 mm.

Iteration 2:

CAD Model

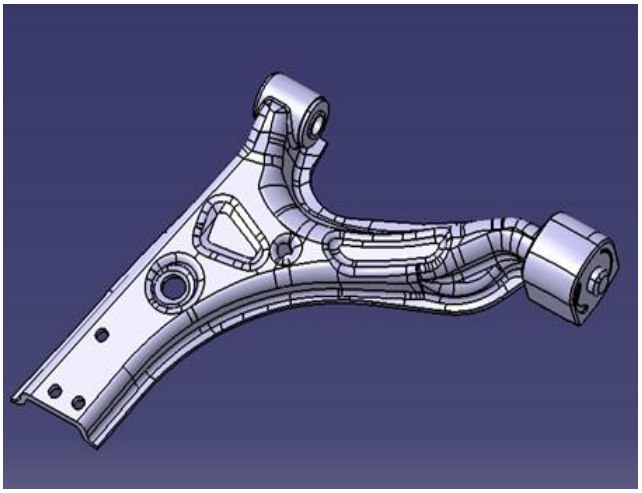

Figure 12: CAD model iteration 2 model of lower control arm

This optimized model is meshed and boundary conditions are applied.
No. of nodes: 74360
No. of elements: 336771
Following are the result displayed for the stress and deformation:
Stress value for lower control arm is 154.5 N/mm^2 which is well below the critical value. Hence the design is safe. Deformation for lower control arm is 0.66 mm.

Modal analysis of optimized model:

Mode 1:

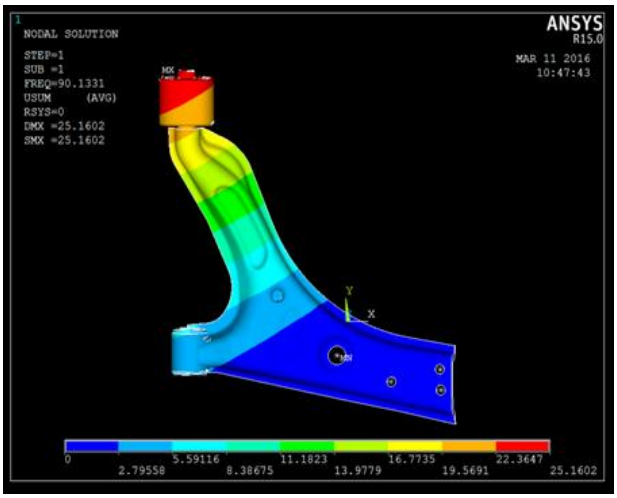

Figure 13: 1st model frequency of lower control arm

The frequency of 1st node is 90.13 Hz.
Similarly modal analysis are carried out for additional 5 modes. Modal analysis result for mode 1 to mode 6 are 90.13, 284.62, 319.42, 814.25, 1042.96, 1230.2 hz respectively.

VII.COMAPRISON OF MODE FREQUENCY

Comparison of the frequency, stress & deformation of lower control arm before and after optimization:

Mode Frequency	Lower Control Arm	Optimized Lower Control Arm
1	61.24	90.13
2	173.28	284.62
3	220.49	319.42
4	760.09	814.25
5	878.38	1042.96
6	1393.29	1230.2

	Lower Control Arm	Optimized Lower Control Arm
Stress	176.67 MPa	154.5 MPa
Deformation	0.65 mm	0.66 mm

Thus from above results we observed that stress value of lower control arm after optimization is less as compared to the value of stress before optimization.

VIII.CONCLUSION

Finite element based weight optimization of lower control arm helped in finding the out the most appropriate design and frequency of the optimized model. This study helps in finding frequencies at different mode shapes of the optimized model.

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