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Application of CAE in Durability Assessment of Automotive Exhaust System under Static Loads and Comparison of Natural Frequency between Coupled and Lumped Mass

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***Abstract* - The exhaust system is to route the exhaust gases from the engine and keep the gases away from the passenger compartment, vibration is transferred from engine to the exhaust system and then transfer to the body structure. The flex is used to reduce the vibration transferring from the engine to exhaust system and the hanger isolators is used to reduce the vibration transferred from exhaust system to body.The CAD modelling is done using CATIA V5 R20 and Finite element modelling is carried out for the automotive exhaust system using Altair's pre-processing tool HYPERMESH tool. The analysis is executed by the MSC NASTRAN tool and the results are observed in the Altair's post-processing tool HYPERVIEW.**

Static and Dynamic Analysis are carried out to the exhaust system components to determine the high stress region at different loading condition one is for self-weight of the exhaust system, and another one for the bad road condition observing that that how the structure of exhaust system behaves and also the maximum displacement and the reaction are observed at the hanger locations. Modal analyses are carried out to determine the structural behavior of the exhaust system.

Comparing the natural frequency with the lumped and the coupled mass it is found that there will be slight variation in the assembly level. While comparing in component vise there will be more of variation than assembly level.

Key Words: Exhaust System, CATIA V5 R20, HYPERMESH, HYPERVIEW , MSC NASTRAN, Natural Frequency,etc..

1. INTRODUCTION

Increasing mandate for stability, design of motorized products have led to more regular usage of Statistical methods for resolving structural problems. The finding of structural failure in automotive industry has habitually relied on verifying ground road load checks. Developing design it is commonly predictable through testing and retesting using a number of prototypes is helping in quickening the product development. Structural Calculation of automotive components has become an essential part for vehicle manufacturers. Structural examination is exceedingly important for designing the automotive exhaust system. Manual test offer durability assessment of all the automotive exhaust components. A numerous altered tests for authenticating the automotive exhaust component design below changed loading conditions.

1.1 AN OVERVIEW OF EXHAUST SYSTEM

Automotive Exhaust system shows an main part in the presentation of the vehicle. There is a trend to use extra computer simulation to find out the structural actions and declines the time to market and coasts. A complex real world seeing that an automotive exhaust system in the vehicle can be shortened and exhibited using statistical simulation. In the experience of the engineering and time-tested traditions, important information can be saved in relative cost and time.

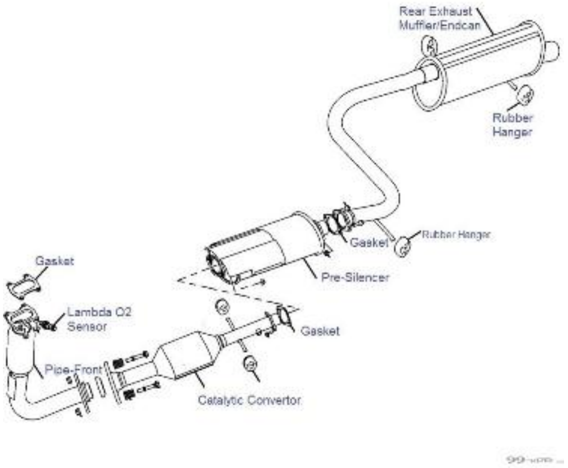

Fig 1.1 Typical exhaust system design.

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1.2 Lumped mass and coupled mass:

Mass is formulated as either lumped mass or coupled mass .Lumped mass matrix contain uncoupled, translation component of mass. Coupled mass matrix contain translation component of mass with coupling among the components. Coupled mass can be more exact than lumped mass. However, lumped mass is more efficient and is preferred for its computational speed in dynamic analysis.

The MSC.NASTRAN coupled to mass formulation is modified approach to the classical consistent mass formulation found in most finite element text. The lumped mass is identical to the classical lumped mass approach. The various formulation of mass matrix can be compared using the CROD element.

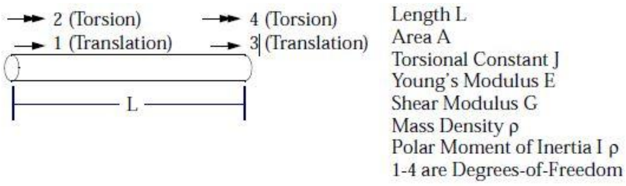

Fig 1.2 Example of lumped & coupled mass

2. LITERATURE REVIEW

Bhadule A.A et al., [1] this paper deals with static analysis is done for the weldless exhaust system fitting by FEA. The objective is to present research, modeling and analysis of the exhaust system suitable weldless by using FEA. Modeling is done by the CATIA. Analysis is done by using ANSYS. The optimization of cast and fabricated manifolds needs different techniques, due to the making restrictions. The positions where failures happen, on both the exhaust manifolds and exhaust gaskets, are expected with high degree of accuracy.

Sanjay S.Patilet al., [02] deal with dynamic analysis of a modular automotive exhaust system where it is directly mounted on power train pack. Selection of dynamic loads, processing of the test data, and effect of assembly loads along with material property variation due to temperature are explained. It also includes validation of the CAE model, prediction of probable failure locations and improving the design based on analysis outcome. He gives a conclusion as it is probable to recognize the failure locations and find out Result for the problematic. The results found assure the structural integrity of the changed automotive exhaust system when applied on the vehicle. This methodology also donates to a better understanding of system performance and its structural strength, for future project applications. The same approach can also be extended to analysis of exhaust system with hanger mountings.

3. OBJECTIVES

The main Objectives of the Projects are:

1. To generate a CAD model and Finite Element model an automotive Exhaust system.
2. To determine the Natural frequency of the Exhaust system [Normal mode analysis] by carrying Dynamic analysis.
3. Linear static analysis is carried to know the stress distribution in the exhaust system mounts and in the system.

Also the displacement in the system is found by linear static analysis.

4. To determine the Max displacement and Reaction forces on hanger location under self-weight and bad road loading.[Static analysis]
5. Comparing the natural frequency with lumped and coupled mass are carried out by dynamic analysis.
6. To determine the Max Displacement, under dynamic loading [Modal Frequency response] at different location in the exhaust system.

4. METHODOLOGY

In this project, Finite Element analyses were used to regulate the characteristics of the Exhaust system. All methodology principles and theories debated were utilized to attain the project's objectives. The arrangement of all the analysis results were used to grow virtual model created by FEM tools and the model was modernized based on the correlation process.

The literature evaluation of the Exhaust system was carried out to find basic understanding of the project. Data like classical natural frequency values of Exhaust system, excitation sources and mode shape were examined and reviewed.

For the purpose of this study, the Exhaust system was modeled using CATIA V-5 Software according to the original size of structures. The model was then imported into Finite Element preprocessing software Hyper mesh for the FE modelling.

The model was then imported into Finite Element solver software MSC Nastran to carry the FE analysis like Modal Analysis (SOL103) and Linear static analysis (SOL101). Further results are interpreted using Hyperview tool. Following Fig: 1.4 shows methodology followed to carry the work.

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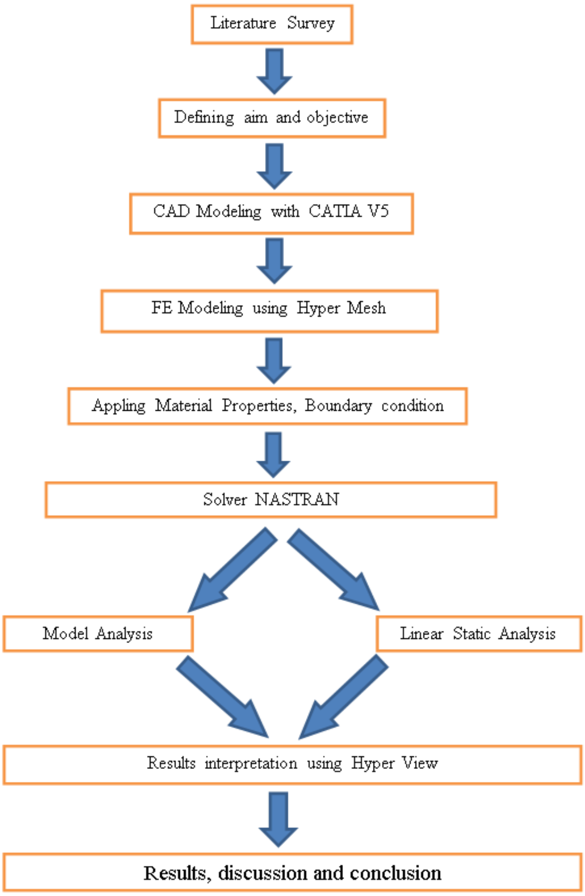

Fig 4.1 Shows methodology followed to carry the work.

4.1 CAD modeling:

The modelling of the system is carried out using CATIA V5 R20 software using the workbench like sketcher, part modelling, assembling of all components and finally the drafting. The CAD model of an full exhaust system is shown in Figure: 4.2

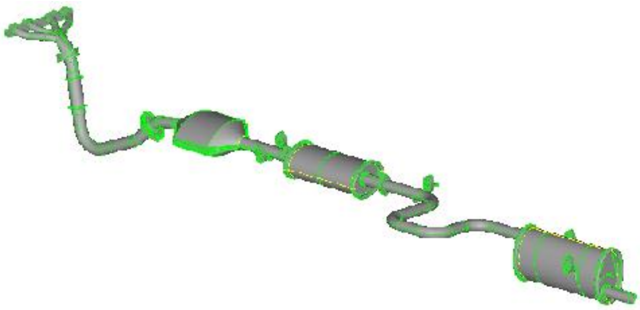

Fig 4.2 The CAD model of an full exhaust system

4.2 FE modeling

Later the CAD step file is imported to FE modelling tool and the meshing of the model is carried out using HEX, Shell (QUAD & TRIA) elements. The welds are represented by using HEX and PENTA elements. In the system components are connected by using RBE2 elements which represent the fasteners. Hanger isolators and the flex are modelled using CBUSH elements. Figure: 4.3 below shows the FE model of complete exhaust system

Fig 4.3: Finite Element Model of the exhaust system

4.3 Mesh convergence study

In finite element modeling, a finer mesh will always result in an accurate solution. But as the refinement increases, the computation time also increases. To get a fine mesh that satisfactorily balances accuracy and computing resources can be obtained by performing a mesh convergence study. The exhaust system model is meshed with QUAD elements. As the mesh is refined, at a particular element size the results shown would remain constant. This element size is used for further analysis.

The results are plotted for the Stress, Displacement, File size, Time taken for the analysis verses different Mesh size from 10mm to 1mm. Stress v/s total degrees of freedom, Displacement v/s total degrees of freedom, Run Time v/s total degrees of freedom plots are shown below.

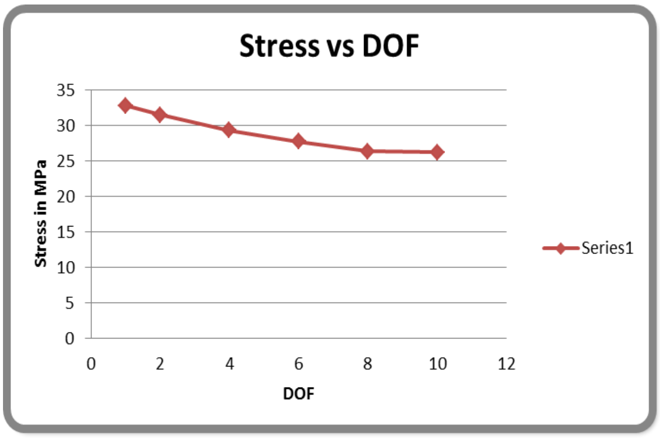

Fig 4.4 Stress vs total DOF

As the mesh size decreases, the curve converges as shown in above graphs. It is seen that the curve starts converging at 5mm mesh size. Further decrease in mesh size may result in complications like larger file sizes and increased computational time. So the mesh size of 5mm is taken for further analysis.

5. RESULTS AND DISCUSSIONS

Modal analysis is carried to know the natural frequency of the system. Reason to find the natural frequency is to avoid the resonance condition that is if the natural frequency of the system equals with the external excitation frequency (Engine frequency) the system starts to vibrate with high amplitude this leads to a failure of a system. For this the

system frequency has to 20% above or below the external excitation frequency.
For the current work different modes shapes are studied to avoid resonance and these modes shapes

Table 5.1: mode shapes and natural frequency

Mode shapes	Natural frequency(Hz)
1st	5.389
2nd	6.568
3rd	6.885
4th	7.651
5th	8.176
6th	8.508
7th	10.038
8th	11.730
9th	13.09
10th	14.73

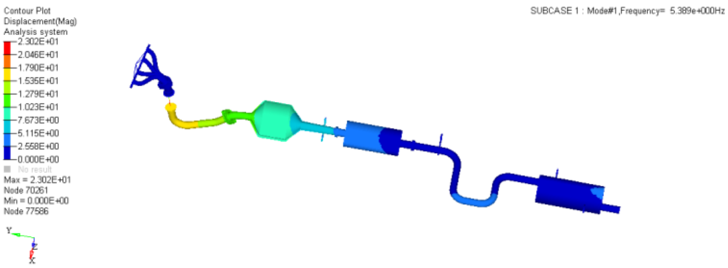

Fig 5.1 first mode of the natural frequency=5.389Hz

Figure shows 5.1 shows first mode of natural frequency of 5.38 Hz in which the value of displacement magnitude varies from zero to 2.302E+01

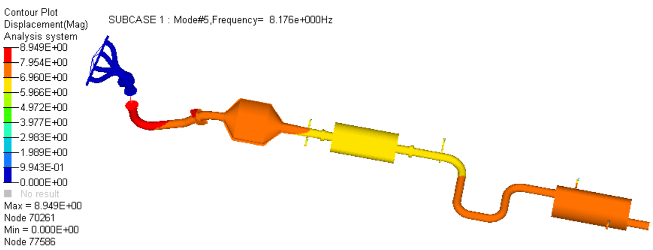

Fig 5.2 Fifth mode of the natural frequency=8.176Hz

Figure shows 5.2 shows fifth mode of natural frequency of 8.176 Hz in which the value of displacement magnitude varies from zero to 8.949E+01.

5.2 Linear Static Analysis

Static analysis was carried to know the stress distribution pattern, to have better understanding on the load path in the system and to find its structural stiffness under operational condition of the exhaust system and also reaction forces and the displacement at the hanger location. The name static means for the exhaust system here the load of the exhaust system is constant, that is load not varying with respect to time.

Static analysis is performed with bad road conditions (1G, 3Gand 5G) as body force in X, Y and Z directions. The boundary conditions are applied and all DOF in the Hanger location are constrained.

5.2.1Static analysis is carried out for two cases:

Due to self- weight:

Self-weight is considered to carry out to know the hanger loads because the exhaust system is mounted on chassis using the hangers. Following figure shows the reaction force at each constraint.

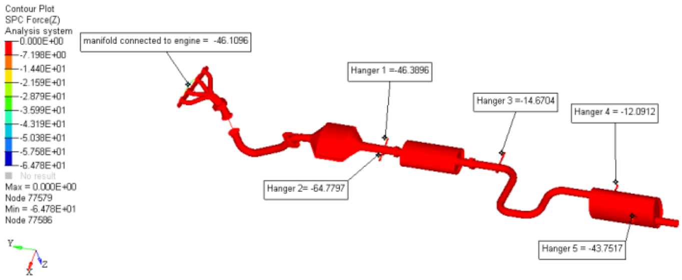

Fig 5.3 Reaction forces of hangers due to self-weight

In the figure 5.3 shows that the total weight of the exhaust system should be balance with the hangers . the weight the exhaust system is distributed equally to all the hangers of the exhaust system.

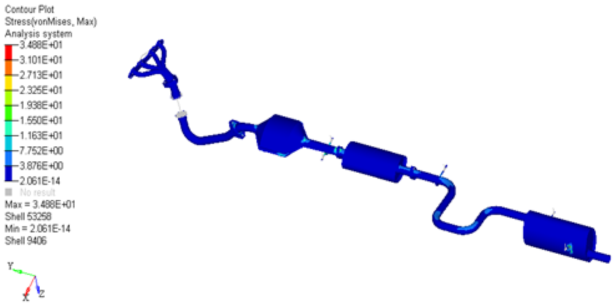

Fig 5.4 Stress Distribution at self-weight condition

Figure shows 5.4 shows Stress Distribution at self-weight condition. The contour plot in von mesis condition Which varies from 2.061E-14 to 3.488E+1

CONCLUSIONS

The present work demonstrates meshed model of exhaust system fulfilled all quality criteria's. Usual road conditions are considered for loading. Static 1g load is chosen for smooth road, whereas for rough road which involved with pot holes, bumps etc., Loads and boundary condition are exactly simulated to obtain the accurate loading conditions. From the normal mode analysis we are gaining the natural frequency and mode shapes. The found natural frequencies are related with lumped and coupled mass. By the percentage error in the evaluation is well below the 10% in component vise, in assembly level there will be slight variation hence the results obtained is acceptable. By the mode shapes hanger positions are measured, where the deflection is generally less.

1. Modal analysis is carried to know the natural frequency and it is found that the natural frequency is 20% below the external excitation frequency
2. For the self-weight linear static analysis is carried out to check the forces acting in the hangers. The reaction forces in the hangers is found that the hanger 2 is having more reaction and the hangers 4and 5 is having less reaction hence the mass is not distributing equally.
3. For bad road condition the linear static analysis is carried out and it is found that the rear muffler shell hanger is having maximum stress of 251.6 Mpa and it is less than the yield strength of the material.
4. In the same analysis the displacement of the system is found to be 33mm.

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