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Design and Analysis of Hangers for Exhaust System

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***Abstract*— Vibration caused in any vibrating structure has a vital role in determining the performance of the structure. Thus, the critical objective in an automobile exhaust system design is lowering the vibration level. It is therefore necessary for a design engineer to predict, describe and assess the dynamics of various system design proposals during product development. The objective of the project is to design and analyse the hangers, Optimise the best hanger locations for minimum damage and to determine the number of hangers required for the entire system. Finite element modelling is carried out for the exhaust system using Altair's pre-processing tool HYPER MESH. Modal analysis is performed by using MSC NASTRAN for exhaust components to determine the natural frequency along with mode shapes. The frequency range considered is between 1 Hz to 200 Hz. Further, a method called ADDOFD (average driving degree of freedom displacement) is carried out to determine the hanger locations. The hangers are located where the displacements are lower. This is then validated analytically.**

Index Terms*— Exhaust System; Hanger Location; ADDOFD; MSC.Nastran; Normal Modal Analysis; Static Analysis.

1. INTRODUCTION

Lowering the fuel consumption of the vehicle is one of the important criteria that an automotive industry is challenged with. Reducing the vibrations that are induced in the vehicle when they are running can be one way to increase the fuel efficiency of the vehicle. Vibration causes wear and worsens the comfort and the comfort is an important quality characteristic which can influence the customers purchase decision and hence designing an exhaust system of a vehicle has become difficult. An Automotive exhaust system consists of a series of pipes that run under the car, connected with the muffler and the catalytic converter. A modern exhaust system generally consists of a manifold, flexible joint, flex coupling, a catalytic converter, exhaust pipe, mufflers, tail pipes and heat shields.[1] The aim of this work is to perform a modal analysis of an exhaust system. Information's from the literature survey and from the past experiences of studying the specific exhaust system will help to gain conclusions that may be generally useful for performing modal analyses during the product development process.

2. SIMULATION OF FE MODEL

A vehicle exhaust system is composed of many parts like the catalytic converter, flexible joint, muffler, exhaust pipes and the tail pipe. The Finite Element Model of the entire exhaust system is obtained using HYPERMESH software. Since the structure of the exhaust system is a little complex, some simplifications are required to be done before FE modeling.

In this paper, the flange which connects the manifold is subjected to solid meshing, the muffler is regarded as a mass element, the flexible joint, as a connection part of the exhaust pipes (RBE2 elements), is simplified as a zero-length spring element. The exhaust pipe is subjected to shell meshing. The material considered is steel having the density and elastic modulus 7800 kg/m3 and 2.1×105 MPa, respectively and the Poisson's ratio is 0.3.[2]

2.1. GEOMETRIC MODEL DETAILS

Table 1 Details of Geometric Model

Length of the system	2860mm
Thickness	2mm
Outer diameter of the pipe	64mm
Inner diameter of the pipe	60mm
Mass of the system	15.57kg
Area	959379mm^2
Volume	1.933E6mm

3. SYSTEMIC MODAL ANALYSIS

Modal analysis is performed in MSC NASTRAN. The FE model is solved by the SOL103 module in the MSC NASTRAN. The SPC is applied at the circumference of the two holes provided on the flange which is used for clamping the exhaust pipe to the manifold.

A sample vehicle engine speed ranges between 800rpm to 6000rpm and the corresponding engine ignition frequency ranges from 27 to 200 Hz. The engine excitation starts after 200 Hz. Hence the cut off frequency of the modal analysis is set to 200 Hz.[3] The engine excitation starts after 200 Hz. Hence the cut off frequency of the modal analysis is set to 200 Hz.

The result file is in the form of .f06 and the natural frequency and the corresponding mode shapes are recorded. The relative displacements and the corresponding nodes are also obtained.

Table 2 Frequencies for 15 modes.

Modal number	Frequency (Hz)	Modal number	Frequency (Hz)
1	9.05	9	94.50
2	11.00	10	115.00
3	19.14	11	121.10
4	24.03	12	128.50
5	25.34	13	138.60
6	34.51	14	157.50
7	42.81	15	174.00
8	75.97		

Mode shape

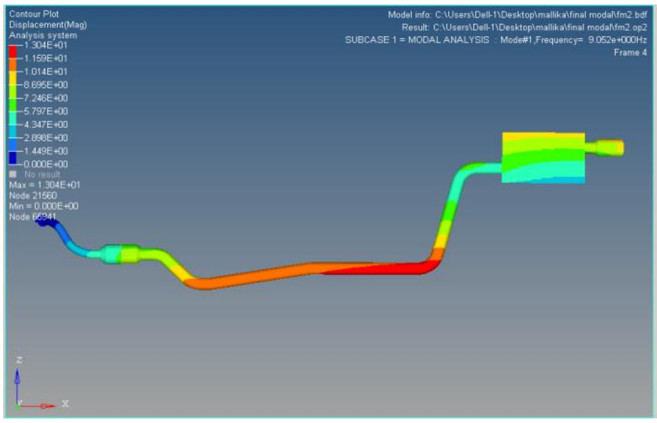

Fig.1 Mode Shape for First Mode

Similarly mode shapes for all 15 modes were obtained and the corresponding relative displacements were recorded.

4. DETERMINATION OF EXHAUST SYSTEM HANGER POSITION

The length from the flex end to the tail pipe is considered (i.e the length of the cold end of the exhaust system). It is measured to be 2365mm. This length is then divided into 19 equal parts, each parts having a length of 125mm. 19 nodes which are at a distance of 125mm from each other are considered.

Based on the results of modal analysis, for each modes, the X,Y,Z displacements at 19 considered nodes is calculated using MSC NASTRAN software. Graph with distance in X-axis and displacement in Y axis is plotted for all the 15 modes.

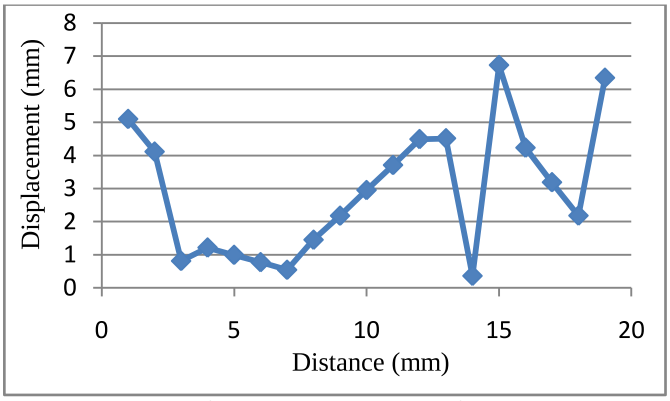

Fig.2 Plot of Displacement V/s Distance for Mode 1

Then at each point (i.e considered nodes), the displacements of all 15 modes is tabulated and Graph with X axis the mode number and Y axis the displacement is plotted for all 19 considered nodes (positions).

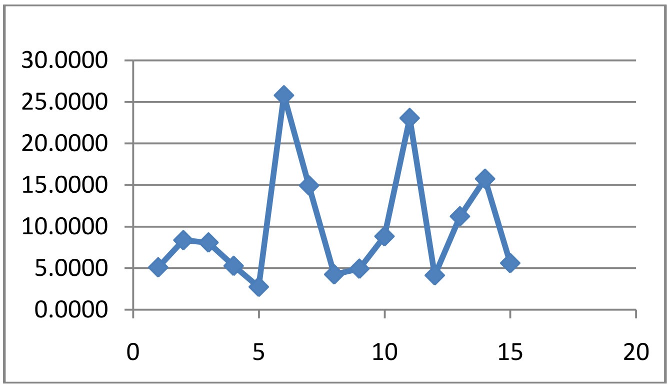

Fig.3 Plot of Mode Num V/s Displacement for position 1

The lower displacement values and the corresponding nodes (positions) are obtained from these graphs. From the above details, a final graph with distance in X axis and displacements in Y axis is plotted.

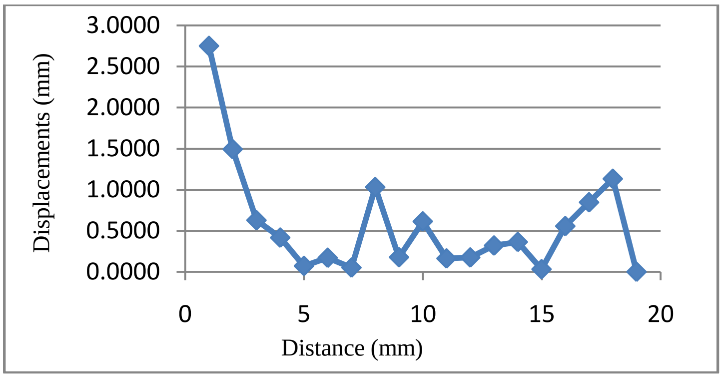

Fig.4 The ADDOFD results for selection of the hanger positions

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From the above graph, the positions where the displacements are lower are obtained. In this analysis the positions where the displacements are lower are 5, 7, 9, 11, 12, 15, and 19. Position 5 and 7 are close by and hence any one position among the two is considered. Similarly 11 and 12 are close by and one position among the two is considered.

4.1. CASE 1

Assuming positions 5,9, 12 and 15.Rigid is created at these positions. The model is then subjected to linear static analysis by applying 1G load and SPC at the rigid. The reaction force is obtained at these assumed positions.

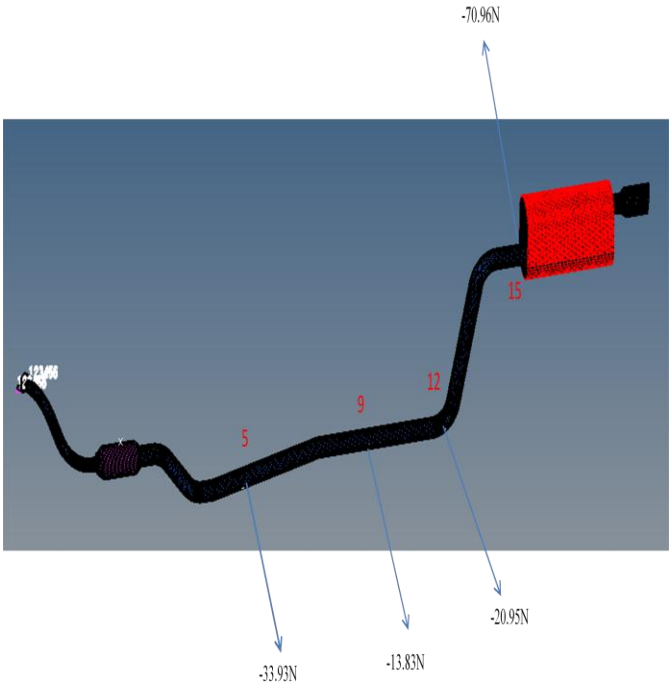

Fig 5 Reaction forces at position 5,9,12,15

From the results it is seen that, the reaction force at 15th position has a value of 70.96N which is more than the considered limit of 55N.[4] Hence the analysis is again done assuming different positions.

4.2. CASE 2

Assuming positions 5, 12, 15 and 19.Rigid is created at these positions. The model is then subjected to linear static analysis by applying 1G load and SPC at the rigid. The reaction force is obtained at these assumed positions.

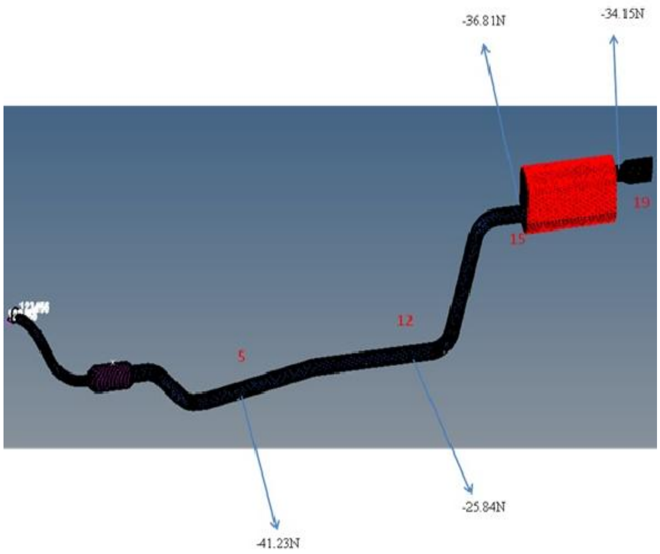

Fig 6 Reaction forces at position 5,12,15,19

From the results it is seen that, the reaction force at all assumed position have values less than the considered limit of 55N. Hence the hangers can be positioned at positions 5, 12, 15, and 19.

5. ANALYTICAL VALIDATION

A part of the exhaust pipe is considered and solved analytically.
Consider a hollow steel pipe of length 0.3m with inner diameter 0.06m and outer diameter 0.062m fixed at one end as shown.

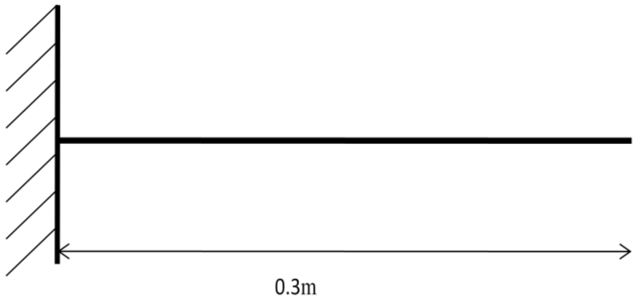

Fig.7 Hollow pipe

$E = 2.1e11\ N/m^2$
$L = 0.3m$
$D_i = 0.06m$
$D_o = 0.064m$
$\mu = 0.3$
$\rho = 7800\ kg/m^3$

$Area = (\pi/4)\ (D_o^2 - Di2)$
$= 3.8955e\text{-}4\ m$

$Volume = A*L$
$= 1.1685e\text{-}4m^3$

$I = (\pi/64)\ (D_o^4 - Di4)$
$= 1.873e\text{-}7\ m^4$

Mass = Density* volume
= 0.9115 kg

We have the frequency equation for the first mode
$f_n = (3.52/2\pi)\, SQRT[(EI)/(ML^3)]$ [5]
= 707.74 Hz

5.1. SOFTWARE SOLUTION

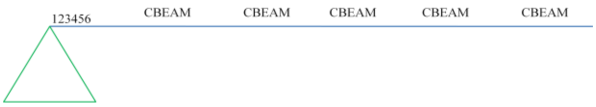

Fig.8 FE representation of Hollow Pipe

Table 3 Tabulation of mode number and frequency

Mode Number	Frequency (Hz)
1	6.85e2
2	6.85e2
3	2.682e3
4	3.678e3
5	3.678e3
6	4.324e3
7	8.043e3
8	8.671e3
9	8.671e3
10	1.297e4

Mode shape

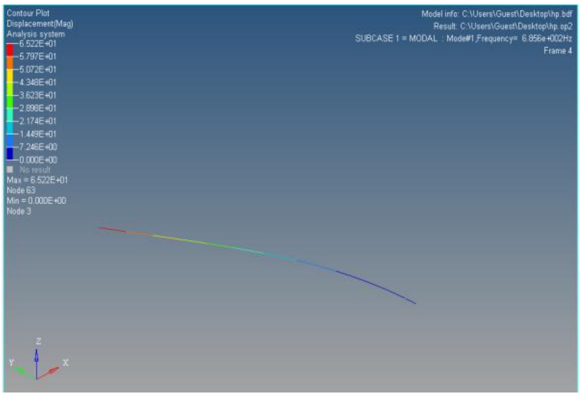

Fig.9 First mode shape for the Hollow Pipe

The comparison of the results obtained analytically with those obtained by the software resulted in an error of 3% .

CONCLUSION

This project is involved in studying the dynamic characteristics of the vehicle exhaust system and carrying out various analysis and finding the best hanger location. Once the hanger locations are found, the optimization of number of position for the entire exhaust system is done. From the geometric model, a finite element model is developed using hyper mesh software. The type of elements and quality of the mesh is maintained. Finite element model is then subjected to boundary conditions and modal analysis is carried out by keeping the frequency range between 1 to 200 Hz. Modal analysis is carried out using MSC NASTRAN software. From modal analysis, the displacements for the corresponding modes are obtained. Then a method called ADDOFD is carried out. In this method the displacements of all the modes are analysed and then lower displacement value and their corresponding positions are obtained. Decisions are made to locate the hanger positions at places where the displacements are low. Static analysis is carried out by applying SPC's at the assumed positions and 1g (gravity) load. The reaction forces are noted. The final hanger positions are located where the reaction forces are minimum. This is then validated analytically.

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