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"Experimental Modal Analysis of Automotive Exhaust Muffler Using Fem and FFT Analyzer"

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Abstract— Experimental modal analysis, also known as modal analysis or modal testing, deals with the determination of natural frequencies, damping ratios, and mode shapes through vibration testing. The exhaust muffler in an automobile plays an integral role in reducing the sound of the automobile, as well as the ride itself. In order to maintain a desired noise and comfortable ride, the modes of a muffler need to be analyzed. Modal analysis is done both experimentally through FFT analyzer and finite element analysis. The natural frequencies obtained by both the methods agree with each other. This is useful while designing of exhaust muffler to avoid the resonance.

Keywords— **Experimental Modal Analysis, Exhaust Muffler, FEM, FFT**

I. INTRODUCTION

A vibrating object normally produces sound, and that sound may be an annoying noise. Sound in a physical sense, is the vibration of gas or air particles that causes pressure variations within our eardrums. These pressure variations are translated by our hearing senses into what we call "Sound'. In an automotive engine, pressure waves are generated when the exhaust valve repeatedly opens and lets high-pressure gas into the exhaust system. These pressure pulses are the sound we hear. As the engine rpm increases so do the pressure fluctuations and therefore the sound emitted is of a higher frequency. All noise emitted by an automobile does not come from exhaust system. Other contributors to vehicle noise emission include intake noise, mechanical noise and vibration, induced noise from the engine body and transmission [1].

A muffler is a device for reducing the amount of noise emitted by the exhaust of an internal combustion engine. Mufflers are installed within the exhaust system of most internal combustion engines, although the muffler is not designed to serve any primary exhaust function. The muffler is engineered as an acoustic sound proofing device designed to reduce the loudness of the sound pressure created by the engine by way of Acoustic quieting.

The majority of the sound pressure produced by the engine is emanated out of the vehicle using the same piping used by the silent exhaust gases absorbed by a series of passages and chambers. Both are lined with roving fibre glass insulation and/or resonating chambers harmonically tuned to cause destructive where in opposite sound waves cancel each other out.

Finite element analysis was used to find out the Eigen values and Eigen vectors of an exhaust muffler. Among power-train components exhaust muffler is the major noise contributing structure. From the literature survey and fundamental finite element techniques, the HYUNDAI i10 exhaust muffler was post processed to understand the structure and dynamic behavior, and to compare finite element analysis results with experimental test data. The task included preparing the geometric model, FE-model, the boundary conditions and evaluating the mode shapes and natural frequencies of an exhaust muffler.

The literature related to the analysis of exhaust muffler reveal the following facts. **Brian J. Schwarz et al. [2]** "EXPERIMENTAL MODAL ANALYSIS" explained the different FRF measurement testing. Obtaining of modal parameters by different ways. **Wang jie et al. [3]** has investigated on the modal analysis of an automobile exhaust muffler to determine the natural frequencies and mode shapes during the design of the muffler. Also to distinguish working frequency from natural frequency so as to avoid the resonance occurring in exhaust muffler.

M Rajasekhar Reedy et al. [4] explain design and optimization of exhaust muffler in automobiles, to determine the resonance frequencies, and then compiled to determine which peaks were the most significant for the system. From the data, side baffles were selected as weak parts of the muffler. In order to minimize the effects of these resonance frequencies, then increase of baffle thickness & damping.

II. MODELING AND FEM ANALYSIS OF EXHAUST MUFFLER

MODELING: The modelling of exhaust muffler was done using CATIA V5 R17. The Fig 1 shows the CATIA model of exhaust muffler.

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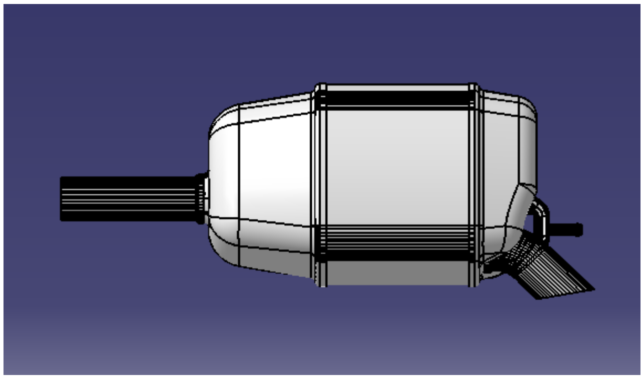


Fig.1 CATIA Model of Muffler

FINITE ELEMENT METHOD: The finite element method is a powerful tool for the numerical solution of a wide range of engineering problems. With the advances in computer technology and CAD systems, complex problems can be modelled with relative ease. Several alternative configurations can be tested on a computer before the first prototype is built.

In this method of analysis, a complex region defining a continuum is discretized into simple geometric shapes called finite elements. The material properties and the governing relationships are considered over these elements and expressed in terms of unknown values at element corners. An assembly process, duly considering the loading and constraints, results in a set of equations. Solution of these equations gives the approximate behaviour of the continuum [5].

FE model of exhaust muffler meshed by using linear first-order (3-or 4-noded) shell elements at the part mid surface and meshing is done using Altair HYPERWORKS v12 pre-processor. Meshed model consists of 19957 Quad4 & 38 trai3 elements. TABLE I shows material Properties of an exhaust muffler**.**

TABLE I
Material Properties of an exhaust muffler.

PROPERTIES	**VALUE**
YOUNG'S MODULUS [E]	2.1E5 N/MM^2
POISSON'S RATIO	0.3
DENSITY [RHO]	7.9E-09 TONNE/MM^3
MASS [M]	1.721E-3 TONNE

The Fig 2 shows the meshed model of exhaust muffler.

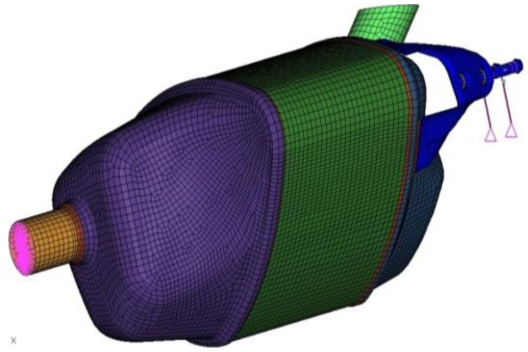


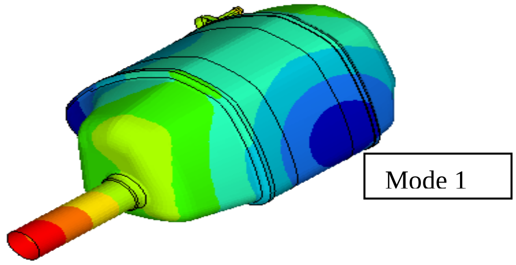
Fig.2 Meshed Model of Muffler

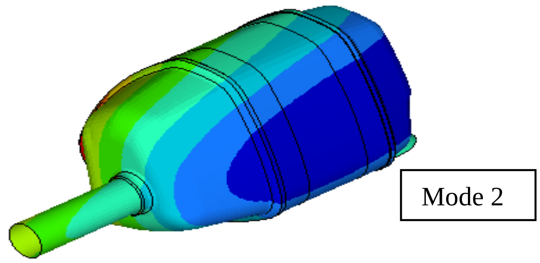
Analysis of exhaust muffler is done by using MSC NASTRAN. The result obtained by modal analysis for first six natural frequencies are tabulated in TABLE II.

TABLE II
First six natural frequency of vibration

Mode. No	1	2	3	4	5	6
Frequency (HZ)	313	428	510	587	638	701

The various mode shapes of an exhaust muffler are shown in Fig. 3.





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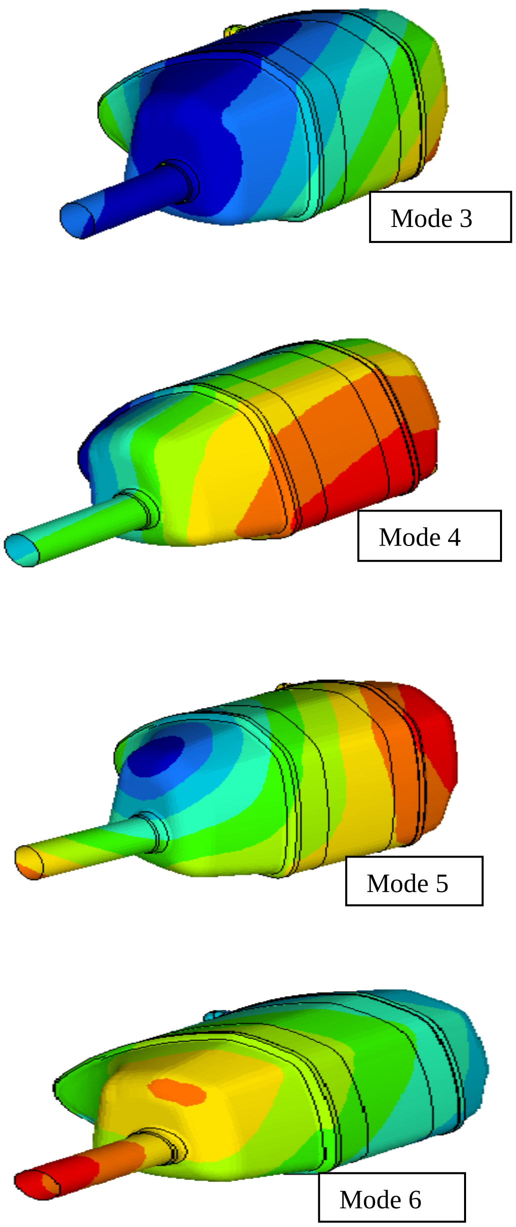


Fig.3 Various mode shapes of exhaust muffler under free-free condition.

III. Experimental Validation

The experimental validation is done by using FFT (Fast Fourier Transform) analyzer. The FFT spectrum analyzer samples the input signal, computes the magnitude of its sine and cosine components, and displays the spectrum of these measured frequency components. The advantage of this technique is its speed. Because FFT spectrum analyzers measure all frequency components at the same time, the technique offers the possibility of being hundreds of times faster than traditional analog spectrum analyzers.

The exhaust muffler has been suspended on elastic cords trying to minimize the stress in the structure and to allow the rigid body modes movement. Experimental modal analysis by using impact testing has become largely known as a fast and economical mean of finding modal parameters of a structure. In this approach, the impact hammer was connected to the first channel of an MESCOPE test lab acquisition system and was used to excite the structure at 60 locations (roving hammer), a mini-accelerometer of 1.5 grams is placed into the proper reference point for the set of FRFs measurement. The accelerometer is connected to the second channel of the acquisition system in order to record the response of the structure. The impact force and the acceleration have been recorded simultaneously for each pair of measuring points. A column of FRFs of the transfer matrix has been built for the EMA by using ME'SCOPE test lab software.[6]

A schematic overview of the experimental test set-up for modal analysis of exhaust muffler using FFT analyser is shown in Fig 4.

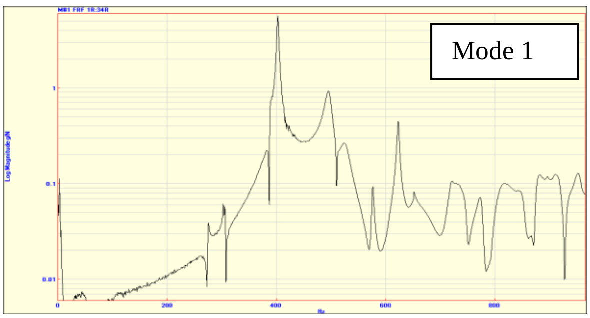
Fig.4 Experimental set up for modal analysis

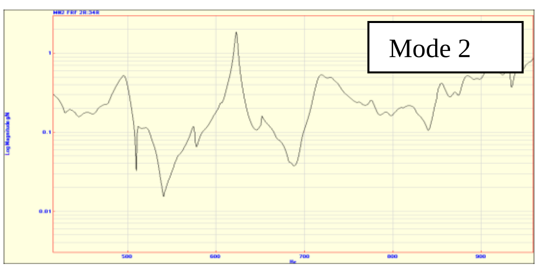
The first six natural frequency obtained is tabulated in TABLE III.

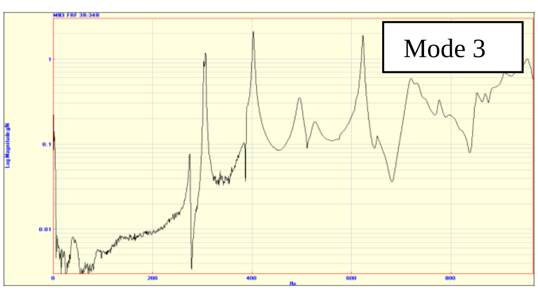
TABLE III
First six modal frequency of vibration by FFT analyzer.

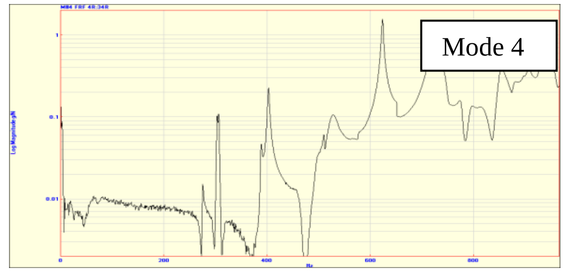
Modes	1	2	3	4	5	6
Frequency(HZ)	306	402	495	576	623	674

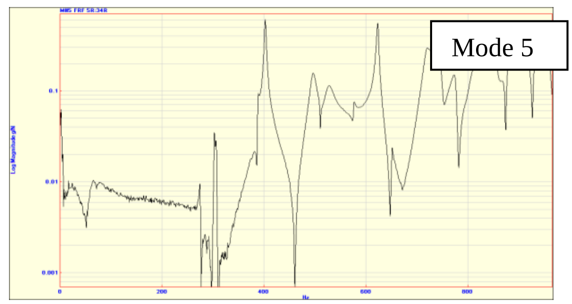
Fig.5 shows Frequency response function of various modes of exhaust muffler.











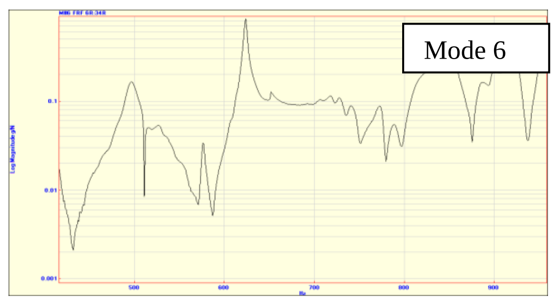


Fig.5 Frequency response functions of exhaust muffler using FFT analyzer.

IV. RESULT AND DISCUSSION

The TABLE IV shows the comparison for the first six natural frequencies of vibration of exhaust muffler by FEM package and FFT analyzer. The comparison shows that the natural frequency obtained by both methods agree with each other.

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TABLE IV
Six natural frequency of vibration

Mode. NO.	FEA FREQUENCY(Hz)	EMA FREQUENCY(Hz)
1.	313	306
2.	428	402
3.	510	495
4.	587	576
5.	638	623
6.	701	674

The dynamic characteristic such as the natural frequencies and mode shapes of the exhaust muffler was determined numerically and experimentally. The experimental data was used to validate finite element model representing the real structure. The result indicating that the FE model shows a good correlation with the experimental model for the mode shape.

V. Conclusion

The summaries of modal analysis of exhaust muffler under free condition were carried out using MSC NASTRAN and experimental test was conducted using Impact testing machine.

The first six frequencies were nil frequency which indicates rigid body motion. The next six frequencies ranged from 313 to 701 Hz. These frequencies are the natural frequencies. From experimental modal analysis, the natural frequencies ranged from 306 to 674 Hz. The natural frequencies from both methods agree with each other. Which are useful designing of exhaust muffler to avoid the resonance.

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