DESIGN AND OPTIMIZATION OF EXHAUST MUZZLER IN AUTOMOBILES

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ABSTRACT

The present work aims at improve the Frequency of NSD (Nash Shell Damper) muffler by controlling the noise level of a diesel engine by developing an exhaust muffler for the same, since exhaust noise is the single largest contributor to the overall noise from the engine. The TATA INDICA TURBOMAX TDI BSIV four-cylinder diesel engine car was considered for test purposes. In this study Muffler dimensions are measured through the Benchmarking, to create CAD models. The CAD models are created in CATIA V5 R19, later these CAD models of muffler are exported to HYPER MESH for pre-processing work. Free Free analysis is carried out on this muffler by FEA Method using NASTRAN Software. The stress and stiffness of the model is studied from the results obtained from analysis to verify the success of the design.

KEYWORDS: Automobile Exhaust System, Exhaust NSD Rear Muffler, Free Stress Analysis, Optimization, Catia V5 And Nastran Softwares

INTRODUCTION

The engine is like an air pump; the more air that is allowed to flow through it, the more Horsepower that you get out of it. In other words, if you have a free-flowing air intake and exhaust system in your average vehicle, you’ll get more horsepower because of the efficient flow of air into and out of the engine. Fuel requires air to burn and thus to produce energy. The more air that is available for combustion will also improve efficiency otherwise known as gas mileage.

COMPONENTS THAT INFLUENCE AIRFLOW OUT OF THE ENGINE ARE AS FOLLOWS

1. Exhaust valve and exhaust ports of the cylinder heads
2. Exhaust manifolds or EKE and Tubing
3. Catalytic converters
4. Muffler
5. Resonator
CATALYTIC CONVERTERS

TWO-WAY

A two-way (or "oxidation") catalytic converter has two simultaneous tasks:

1. Oxidation of carbon monoxide to carbon dioxide:
   \[ 2\text{CO} + \text{O}_2 \rightarrow 2\text{CO}_2 \]

2. Oxidation of hydrocarbons (unburnt and partially-burnt fuel) to carbon dioxide and water:
   \[ \text{CxH}_{2x+2} + [(3x+1)/2] \text{O}_2 \rightarrow x\text{CO}_2 + (x+1) \text{H}_2\text{O} \] (a combustion reaction)

   This type of catalytic converter is widely used on diesel engines to reduce hydrocarbon and carbon monoxide emissions.

   They were also used on gasoline engines in American- and Canadian-market automobiles until 1981. Because of their inability to control oxides of nitrogen, they were superseded by three-way converters.

THREE-WAY

Since 1981, "three-way" (oxidation-reduction) catalytic converters have been used in vehicle emission control systems in the United States and Canada; many other countries have also adopted stringent vehicle emission regulations that in effect require three-way converters on gasoline-powered vehicles.

The reduction and oxidation catalysts are typically contained in a common housing, however in some instances they may be housed separately. A three-way catalytic converter has three simultaneous tasks:
1. Reduction of nitrogen oxides to nitrogen and oxygen: \(2\text{NOx} \rightarrow x\text{O}_2 + \text{N}_2\)
2. Oxidation of carbon monoxide to carbon dioxide: \(2\text{CO} + \text{O}_2 \rightarrow 2\text{CO}_2\)
3. Oxidation of unburnt hydrocarbons (HC) to carbon dioxide and water: \(\text{CxH}_{2x+2} + [(3x+1)/2]\text{O}_2 \rightarrow x\text{CO}_2 + (x+1)\text{H}_2\text{O}\)

**Fig 2: Three Way Catalytic Converter**

**MUFFLERS**

The term muffler is defined as a device for reducing the amount of noise emitted by a machine. To reduce the exhaust noise, the engine exhaust is connected via exhaust pipe to silencer called muffler.

The various types of mufflers used in automobiles are

1. Baffle type
2. Resonance type
3. Wave cancellation type
4. Combined resonance and absorber type
5. Absorber type mufflers.

**Fig 3: Exhaust Muffler**
PURPOSE OF MUFFLER

• An automotive requires a muffler to reduce the amount of noise emitted by a vehicle.
• Mufflers are installed along the exhaust pipe as a part of the exhaust system of an I.C. engine to reduce its exhaust noise.
• Mufflers use neat technology to cancel out the noise.
• The muffler reduces exhaust noise by dampening the pulsations in the exhaust gases and allowing them to expand slowly.
• It was usually made of sheet steel, coated with aluminum to reduce corrosion. Some are made of stainless steel.
• A muffler contains perforated pipes, baffles and resonance chambers.
• Many also contain sound-absorbing material such as fiberglass or wire wool.
• The muffler slows down the gases and breaks up the pulsating sound waves, and so reduces the noise.
• It must cause as little restriction as possible. Poor design can cause excessive back-pressure that will slow down the escape of the exhaust gases and reduce engine performance.
• Some mufflers combine baffles and pipes to change the flow of gases without restricting them. Gases enter through the inlet and must reverse their direction of flow before they exit through the outlet. This is called a reverse-flow muffler.
• Some mufflers use double outer-skins to minimize heat and noise transmission.
• Some exhaust systems use a resonator as well as a muffler. It looks like a muffler but it usually has a straight-through design and it contains sound absorbing material. It’s designed to remove types of sound that mufflers can’t remove.
• Silencers and mufflers cover a wide range of noise reduction devices and must be considered one of the most powerful weapons available to reduce noise emitted from cars, trucks, motor cycles, boats, vacuum pumps, compressors,…etc.

CATIA V5 WORKBENCHES

CATIA V5 serves the basic design tasks by providing different workbenches. A workbench is defined as a specified environment consisting of a set of tools that allows the user to perform specific design tasks. The basic workbenches in CATIA V5 are

1. Part Design,
2. Wireframe and Surface Design,
3. Assembly Design, Drafting.

4. Generative Sheet metal Design, and

5. DMU Kinematics.

Fig 4: Design Of Exhaust Muffler Using Catia V5
Fig 5: Design And Detail Views Of Exhaust Muffler
OPTIMIZATION TECHQUES

The integration of optimization techniques with Finite Element Analysis (FEA) and CAD is having pronounced effects on the product design process. This integration as the power to reduce design costs by shifting the burden from the engineer to the computer. Furthermore, the mathematical rigor of a properly implemented optimization tool can add confidence to the design process. Consider a three-step process:

1. Generation of geometry of part or assembly in CAD,
2. Creation of FEA model of part or assembly, and
3. Evaluation of results of FEA models.

STEPS TO BE FOLLOWED IN OPTIMIZATION

- The user simply selects which dimension in the CAD model needs to be optimized and the design criterion, which may include maximum stresses, temperatures or frequencies.
- The analysis process appropriate for the design criteria is then performed.
- The results of the analysis are compared with the design criterion, and if necessary without any human intervention, the CAD geometry is updated.
- Care is taken such that FEA model is also updated using the principle of associatively, which implies that constraints and loads are preserved from the prior analysis.
- The new FEA model, including a new high-quality solid mesh, is now analyzed, and the results are again compared with the design criterion.

FINITE ELEMENT ANALYSIS

The finite element method has become a powerful tool for the numerical solution of a wide range of engineering problems. It has developed simultaneously with the increase in use of the high speed electronic digital computers and with the growing emphasis on numerical methods for engineering analysis.

- Matrix algebra
- Solid mechanics
- Variation methods
- Computer skills

STEPS in FEM as follows

**Step 1**: Descritization of structure (Domain)

**Step 2**: Selection of proper interpolation model

**Step 3**: Derivation of element stiffness matrices (characteristics matrices) and load vectors:
Step 4: Assemblage of element to obtain the equilibrium equations:

Step 5: Solution of system equation to find nodal values of displacement (field variable)

Step 6: Computation of element strains and stress.

- Pre-processor
- Solver
- Post-processor

PROCEDURE FOR NASTRAN ANALYSIS:

A static analysis can be either linear or non linear. In our present work we are going to consider linear static analysis. The procedure for static analysis consists of these main steps:

1. Building the model.
2. Obtaining the solution.
3. Reviewing the results.

**TABLE 1: Units and Mesh information**

<table>
<thead>
<tr>
<th>Study name</th>
<th>Alloy_Steel</th>
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</thead>
<tbody>
<tr>
<td>Pressure/Stress</td>
<td>N/m^2</td>
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<tr>
<td>Frequency</td>
<td>HZ</td>
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<tr>
<td>Unit system:</td>
<td>SI (MKS)</td>
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<tr>
<td>Length/Displacement</td>
<td>Mm</td>
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<tr>
<td>Temperature</td>
<td>Kelvin</td>
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<tr>
<td>Angular velocity</td>
<td>rad / sec</td>
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<tr>
<td>Mesh type</td>
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<td>Analysis type</td>
<td>Free free analysis</td>
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<td>Total Nod</td>
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<tr>
<td>Total Elements</td>
<td>19442</td>
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<tr>
<td>Maximum Aspect Ratio</td>
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<td>% of elements with Aspect Ratio &lt; 3</td>
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TABLE 2: Material Properties

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<th>Model Reference</th>
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<th>Components</th>
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<td></td>
<td>Name: Alloy Steel</td>
<td>SolidBody1(Imported1)(Muffler)</td>
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<td></td>
<td>Model type: Linear Elastic</td>
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<td></td>
<td>Default failure criterion: Max von Mises</td>
<td>Stress</td>
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<tr>
<td></td>
<td>Yield strength: 6.20422e+008 N/m²</td>
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<td></td>
<td>Tensile strength: 7.23826e+008 N/m²</td>
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<td></td>
<td>Elastic modulus: 2.1e+011 N/m²</td>
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<td></td>
<td>Poisson's ratio: 0.28</td>
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<td>Mass density: 7700 kg/m³</td>
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<td>Shear modulus: 7.9e+010 N/m²</td>
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<tr>
<td></td>
<td>Thermal expansion coefficient: 1.3e-005 /Kelvin</td>
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</table>

RESULTS

The existing muffler having the Frequency of 281Hz. The new muffler was found to be superior to the existing one in terms of both acoustic performance and engine performance. With the new muffler, thickness of baffles modified 2mm into 3mm the maximum Frequency obtained was 381 Hz. The present work has thus experimentally shown that results from Finite Element Analysis can be modified and applied to an alternative design.

Analysis type : Free free analysis
Software    : Nastran
CONCLUSIONS AND FUTURE WORKS

The purpose of this experiment was to conduct design and free free analysis of muffler system in order to determine the resonant frequencies of the system and suggest changes in the system design. For this analysis, Nastran software was used. In order to determine the resonance frequencies, were then compiled to determine which peaks were the most significant for the system. From the data, side baffels were selected as weak parts of the muffler. In order to minimize the effects of these resonance frequencies, the suggested design improvement is to add thickness and also add damping to the system.

In terms of future research, a good deal more analysis could be done on this system. If a similar experiment would be done in hopes of eliminating some of the noise, the analyst could attempt to isolate the system better, perhaps using the bungee chord technique. If more accurate data could be obtained, then the analyst could observe the analysis results of the system to help in determining appropriate locations for damping. Finally, a Catia model of the system could be constructed that would allow the user to change the dimensional properties of the system in order to see the result which the changes have on the system without actually altering the mufflers physical properties in person. Although it would be difficult to obtain an accurate virtual model, having one would be extremely valuable in judging the value of design improvement suggestions.
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