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MODELLING AND ANALYSIS OF DAMPING EFFECT IN EXHAUST SYSTEM USING ANSYS

R RENUGADEVI
Mechanical Engineering
CIET
Coimbatore, TN
renugaa1991@gmail.com

V. RAJKUMAR
Mechanical Engineering
CIET
Coimbatore, TN
rajkmech42@gmail.com

RAJESH KANNAN A
Mechanical Engineering
Adithya Institute of Technology
Coimbatore, TN
rajeshmechtech@gmail.com

ABSTRACT

The vibrations created in car engines transfer to the silencer exhaust manifold, these frequent vibrations cause breakage in silencer exhaust manifold. Two types of vibration can affect the exhaust: the sonic pressure waves coming from the exhaust ports, and the vibration of the engine itself because of torquing. Pressure wave vibrations are usually transparent, travelling through the exhaust system to either absorb into or cancel out in the muffler. These waves are harmonic, like the vibration of a speaker, but they are usually too minute to cause noise through component movement. Engine vibrations, on the other hand, can easily shake your exhaust pipes enough to cause component rattling or impact.

This project deals with the damping of such later mentioned vibration problems with a concept of CAE (Computer Aided Engineering). In this project we are using vibration absorption materials as dampers and analysing the system under various conditions for modal (natural vibrations) and harmonic (forced vibrations) response. The modelling of the system is to be done with Uni-Graphics / Solid Works package and analysis using ANSYS.

In this paper, we describe the formatting guidelines for IJAME Journal Submission.

General Terms

Vibrations exhaust system exhaust manifold, turbocharger, catalytic converter, muffler and silencer, vibration dampers et. al.

Keywords

Damping, deformation, exhaust manifold harmonic, modal analysis.

1. INTRODUCTION

Vibrations in automobile are the major causes for failure of most of the automobile components. These vibrations have to be minimized to their extent so that, the each components can perform to their maximum extent. Such vibration in an automobile system occurs during idle and running conditions. Most running condition vibrations are because of the ups and downs on the roads and also because of the reason that the engine is running below its rated speed. Whereas the idle running vibrations are considered, the cause for the vibrations is observed as the frequency that is produced by the engine and its parts. The out coming frequency is transferred through the drive line axis and damped to the road, but not all the frequency is damped. Some are observed by the sub-assemblies of the chassis/frame through linkages. When considered in case of exhaust system, two types of vibration can affect the exhaust.

The sonic pressure waves coming from the exhaust ports, and the vibration of the engine itself because of torquing. Pressure wave vibrations are usually transparent, travelling through the exhaust system to either absorb into or cancel out in the muffler. These waves are harmonic, like the vibration of a speaker, but they are usually too minute to cause noise through component movement. Engine vibrations, on the other hand, can easily shake the exhaust pipes enough to cause component rattling or impact which leads to the improper functioning of the exhaust components. These vibrations are to be controlled to ensure the proper working of interior parts of the system.

2. EXHAUST SYSTEM

An automobile exhaust system comprises of various devices or parts of an automotive engine, which are used for discharging burned gases or steam. Exhaust systems consists of tubing, which are usually used for emitting out waste exhaust gases with the help of a controlled combustion taking place inside an automobile engine. All the burnt gases are exhaled from an engine using one or more exhaust pipes. These gases are expelled out through several devices like cylinder head, exhaust manifold, turbocharger, catalytic converter, muffler and silencer.

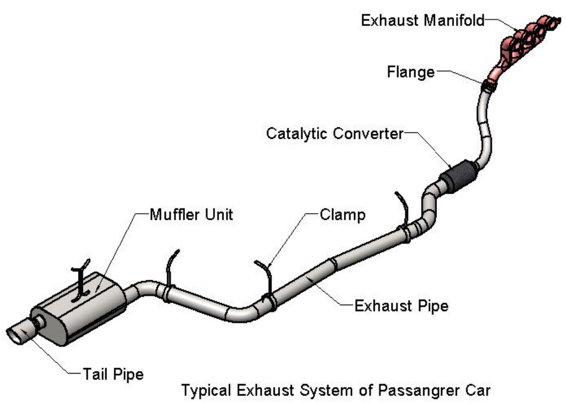

Fig 1. Typical Exhaust System model used in passenger cars and its components

The diagram illustrated above explains the working of all the key components of an exhaust system used in automobile. The major components used in a typical automobile exhaust system are exhaust manifold, resonator, catalytic converter, exhaust pipe, muffler, tail pipe, ‘Y’ pipe, ball flanges. All of these components are especially designed for providing suitable and effective exhaust flow, silencing, and emission levels.

2.1 Exhaust Pipes

Exhaust Pipes are explicitly engineered to carry or transmit various toxic and noxious gases away from the users of the machine. Usually, exhaust gases are very hot, that is why exhaust pipes must be durable and heat resistant so that it does not get spoiled by heat. These double walled pipes are manufactured using different types of metals namely aluminized steel, stainless steel or zinc plated heavy-gauge steel. The exhaust pipes joins exhaust manifold, muffler and catalytic converters together.

2.2 Catalytic Converters

Catalytic Converters are the devices used for converting toxic and harmful hydrocarbons, carbon monoxide, and nitrogen oxides into harmless compounds. Converters transform hydrocarbons and carbon monoxide into carbon dioxide and water while separate nitrogen oxide into nitrogen and oxygen respectively. The converter make use of various catalysts like platinum, palladium, and rhodium coated on a ceramic honeycomb structure which turns the dangerous gases into non toxic gases.

2.3 Exhaust Flange

Exhaust Flange is a type of projecting rim used for attaching, joining or fastening tightly various exhaust pipes with the help of nuts and bolts. These flanges are mostly made of stainless steel, iron, aluminum, steel, carbon steel, alloy steel, and hardened steel.

2.4 Exhaust Manifold

The exhaust manifold is a pipe that conducts the exhaust gases from the combustion chambers to the exhaust pipe. Many exhaust manifolds are made from cast iron or nodular iron.

Some are made from stainless steel or heavy-gauge steel. The exhaust manifold contains an exhaust port for each exhaust port in the cylinder head, and a flat machined surface on this manifold fits against a matching surface on the exhaust port area in the cylinder head.

2.5 The Resonator, Muffler, and Tailpipe

Since the resonator and muffler perform basically the same functions, I decided to write about them under one heading. Firstly, the main function of the muffler is to reduce the sound of the engines out coming exhaust gases through the exhaust pipes to a minimal level. Since the muffler cannot reduce the noise of the engine by itself, some (if not most) exhaust systems also have a resonator between the catalytic converter and the muffler. Resonators are basically the second muffler, and are usually the "straight through" type.

The muffler quiets the noise of the exhaust by "muffling" the sound waves created by the opening and closing of the exhaust valves. When an exhaust valve opens, it discharges the burned gases at high pressures into the exhaust pipe, which is at low pressure.

The tail pipe basically carries the flow of exhaust from the muffler to the rear of the vehicle. In some exhaust systems, the resonator is clamped into the tail pipe. Tail pipes have many different bends to fit around the chassis and driveline components.

3. ANALYSIS AND NUMERICAL SIMULATION

Most of the exhaust system of passenger vehicles fails to give their desired output. This is not because of insufficient performance design, but because of the road conditions that prevail. The vibrations observed during the vehicle movement makes the exhaust components to perform lower that their actual performance level over a period of time.

To overcome these issues, in this project, vibration dampers are adopted to minimize the vibration and safeguard the exhaust pipeline. The main objective of this project is to reduce the amplitude produced by frequencies, i.e., the vibration is arrested using dampers and reduces the stress produced in the exhaust pipe clamps.

3.1 SPECIFICATION OF GEOMETRY

A schematic model of exhaust pipeline from exhaust manifold is modelled using Solid Works. Two types of models are done, one with existing clamps, another one is using counter weights. The following images show the schematic model and parts of the exhaust system used for the project.

3.1.1 Type 1 – Existing model

The image shows the model of existing assembly used in cars. Clamps are used for supporting the pipe along with chassis/frame. Clamps are welded on both the ends.

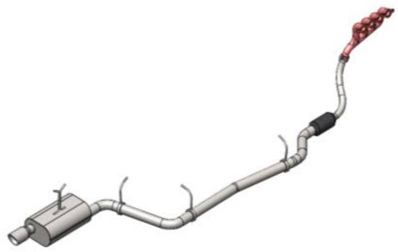

Fig 2. Isometric view of Exhaust pipe line – Type 1

3.1.2 Type 2 – Using counter weights

This is the fundamental approach to reduce vibration. The image shows the exhaust pipe line with rubber bushes which is accomplished by counter weights. These weights are added to absorb the vibrations as their mass is heavy. These weights are welded on a plate and then the plate is welded / fastened to the pipe. The image shows the application if weights near the critical components.

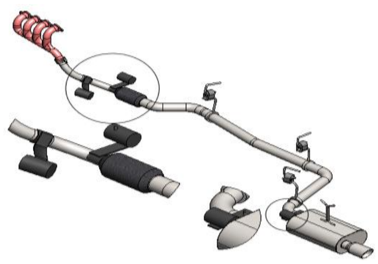

Fig 3. Isometric view of exhaust pipe line - model 2

3.2 SPECIFICATION OF MATERIALS

The following materials are used in the assembly of exhaust system.

Grey cast iron – Manifold

Carbon steel – Exhaust pipe

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The following are the material specifications of the above mentioned materials.

3.2.1 GRAY CAST IRON

Cast iron Properties

Density	7.2e-006 kg mm^-3
Coefficient of Thermal Expansion	1.1e-005 C^-1
Specific Heat	4.47e+005 mJ kg^-1 C^-1
Thermal Conductivity	5.2e-002 W mm^-1 C^-1
Resistivity	9.6e-005 ohm mm

3.2.2 STRUCTURAL STEEL

Steel properties

Density	7.85e-006 kg mm^-3
Coefficient of Thermal Expansion	1.2e-005 C^-1
Specific Heat	4.34e+005 mJ kg^-1 C^-1
Thermal Conductivity	6.05e-002 W mm^-1 C^-1
Resistivity	1.7e-004 ohm mm
Compressive Yield Strength MPa	250
Tensile Yield Strength MPa	250
Tensile Ultimate Strength MPa	460

3.3 MESHING

Meshing is the process of dividing / splitting the model into number of divisions to obtain the result in desired location in the model. If the mesh size is less, more elements will be created, which results in accurate results. The following image is an example of meshed model.

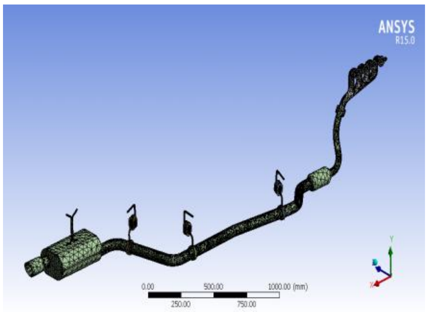

Fig 4. Model meshed in ANSYS

3.3.1 Applying loads and supports

For natural frequency analysis, supports are applied and loads are not applied, as it is free vibrational analysis. The following are the images for supports that are applied various analyses.

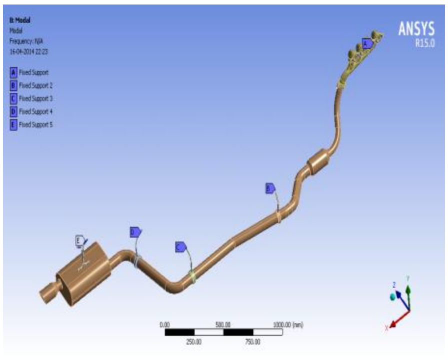

Fig 5. Supports for model 1

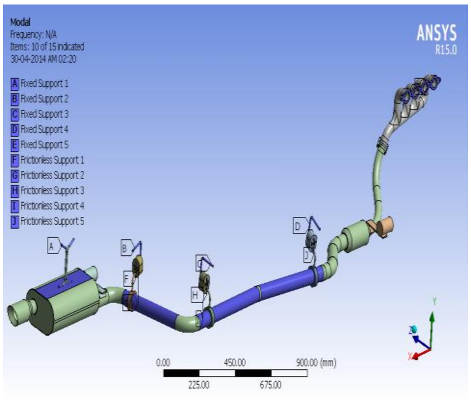

Fig 6. Supports for model 2

In the case of static analysis, natural gravity is to be applied along with the above displayed supports. The following image is an example for this. The arrow in yellow color is the indication of gravity acting downwards.

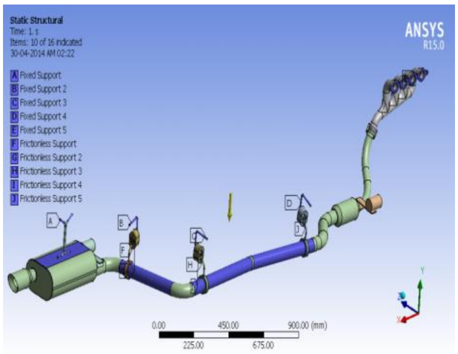

Fig 7. Applying Gravity as load condition

For forced analysis, the nodal forces are applied along with the supports that are used in free vibrational analysis. Gravity is omitted as we have the nodal forces. The following image is an example for loads and supports used in forced vibration analysis.

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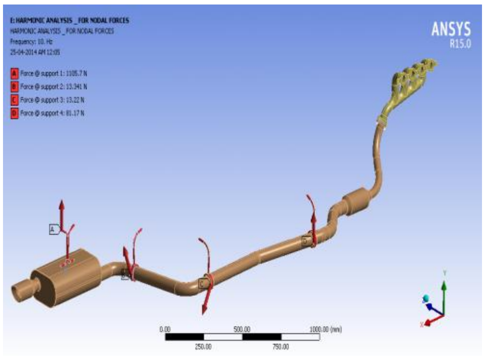

Fig 8. Forces applied on nodes as loads –forced vibration analysis – model 1

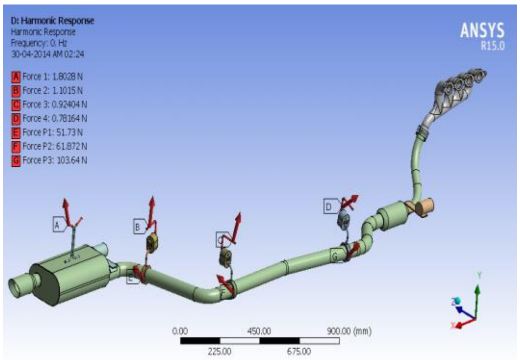

Fig 9. Forces applied on nodes as loads –forced vibration analysis - model 2

4. RESULTS AND DISCUSSION

The following images and tables are the output of the above mentioned problem. The following are the results of free vibration analysis, structural analysis and forced vibration analysis. The output is concentrated on the following results.

Free vibration analysis – natural frequencies nearer to 133.33 Hz, as informed earlier.

Structural analysis – stress in clamps and total deformation of the pipe line.

Forced vibration analysis –Amplitude for given input loads.

Free vibration analysis – for two models – value for first 15 nodes

4.1 Vibration analysis

Total deformation results – existing model

Mode	Frequency [Hz] – desired value = 133.33 Hz	
	Existing model	With counter weights
1.	10.354	41.125
2.	25.844	44.973
3.	31.477	55.295
4.	34.952	100.50
5.	47.640	104.29
6.	55.794	109.36
7.	88.849	193.36
8.	109.64	222.33
9.	116.77	224.77
10.	186.28	244.57
11.	191.82	285.85
12.	215.76	304.08
13.	259.05	378.34
14.	293.19	381.09
15.	311.45	410.10

4.1.1 Total deformation and equivalent stress images for the two models

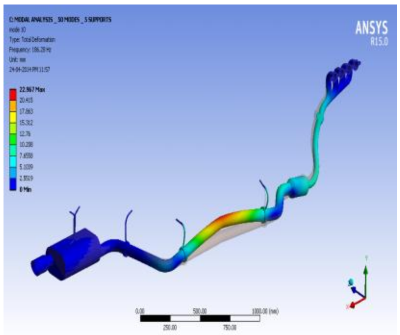

Fig 10. Total deformations - model 1

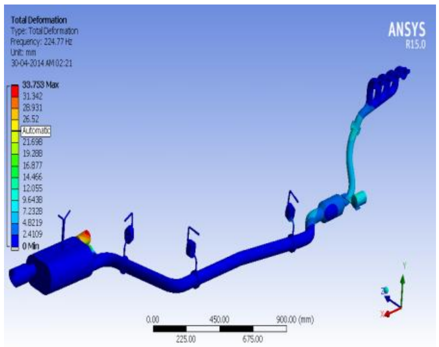

Fig 11. Total deformations - model 2

4.2 Static structural analysis results

4.2.1 Model 1 - Results

Object Name	Total Deformation (mm)	Equivalent Stress on clamps Mpa	Equivalent Stress on pipe line Mpa
Minimum	0	6.7468e-005	3.4749e-005
Maximum	6.7674e-002	28.37	4.3035

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4.2.2 Model 2 – Results

Model 2-Results

Object Name	Total Deformation(mm)	Equivalent Stress on clamp (Mpa)	Equivalent Stress on pipe line (Mpa)
Minimum	0	7.3889e-006	2.4308e-005
Maximum	0.20178	7.0369	3.8545

4.3 Harmonic analysis results

4.3.1 Model 1 – Results

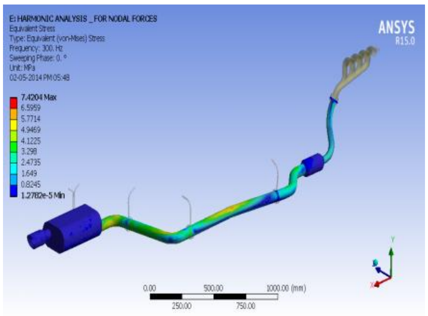

Fig 12. Harmonic analysis - equivalent stress in pipe - model 1

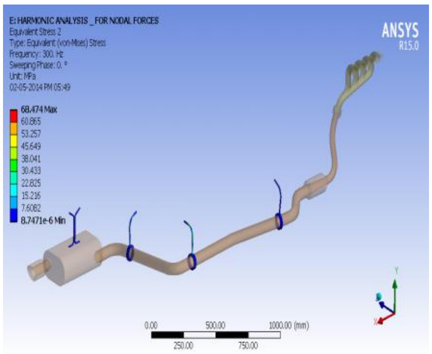

Fig 13. Harmonic analysis - equivalent stress in clamps - model 1

4.3.2 Charts for Frequency response in X directions

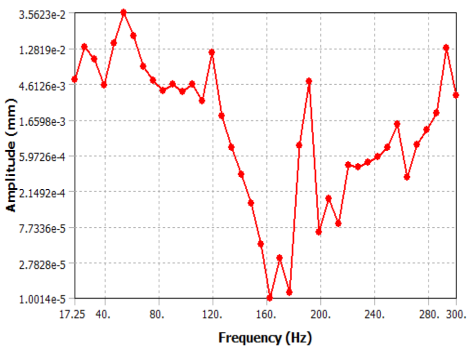

Fig 14. Harmonic analysis X direction

4.3.3 Charts for Frequency response in Y directions

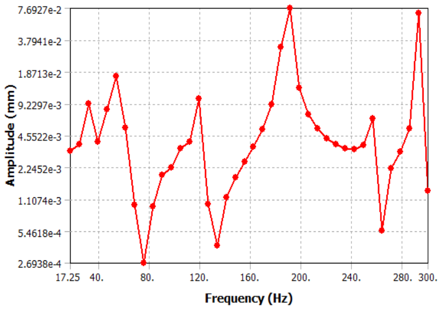

Fig 15. Harmonic analysis Y directions

4.3.4 Charts for Frequency response in Z directions

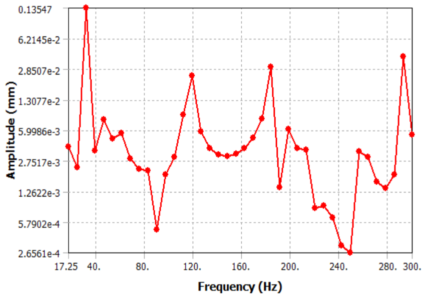

Fig 16. Harmonic analysis model 1 – Z direction

4.4 Model 2 - Results

4.4.1 Model 2-results

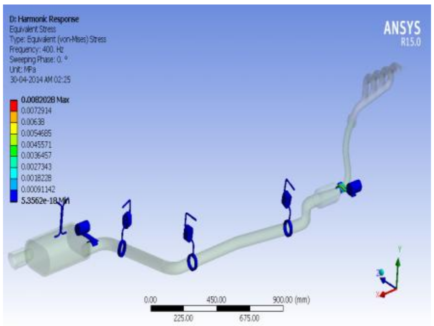

Fig 17. Harmonic analysis - equivalent stress in clamps – model 2

4.4.2 Charts for Frequency response in X directions

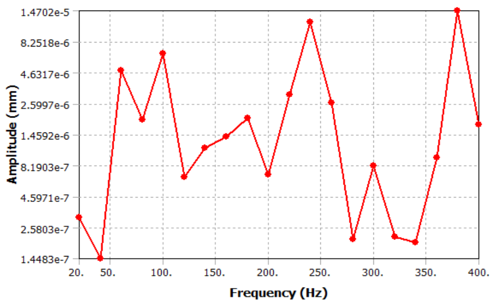

Fig 18. Harmonic analysis model 2 – X direction

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4.4.3 Charts for Frequency response in Y directions

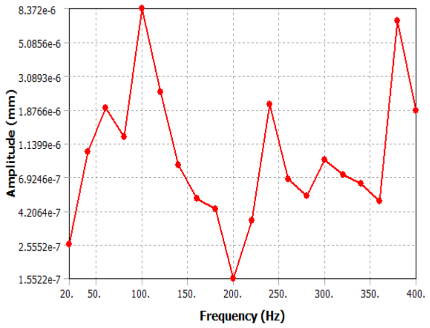

Fig 19. Harmonic analysis model 2 – Y direction

Amplitude - model 2 – Y direction

4.4.4 Charts for Frequency response in Z directions

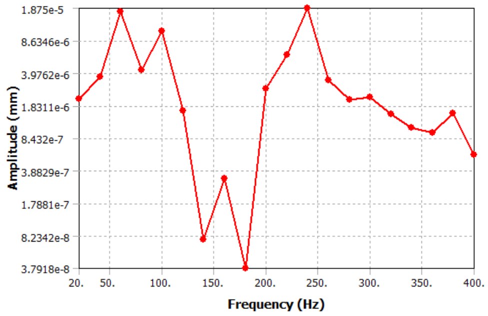

Fig 20. Harmonic analysis model 2 – Z direction

5. CONCLUSION

The defined problem was analysed accordingly and the corresponding outputs were taken and compared. It is clear that, the usage of counter weight is beneficiary as it has good vibration absorption prosperity. The following table gives the maximum amplitude and its corresponding frequency for two models.

5.1 Model 1

Table 1. Model 1 - Result

Object Name	Frequency Response in X	Frequency Response in Y	Frequency Response in Z
Maximum Amplitude	3.5623e-002 mm	7.6927e-002 mm	0.13547 mm
Frequency	53.5 Hz	191.25 Hz	31.75 Hz
Phase Angle	0. °		
Real	3.5623e-002 mm	7.6927e-002 mm	0.13547 mm

5.2 Model 2

Table 2. Model 2- Result

Object Name	Frequency Response in X(mm)	Frequency Response in Y(mm)	Frequency Response in Z(mm)
Maximum Amplitude	1.4702e-005 mm	8.372e-006 mm	1.875e-005 mm
Frequency	380. Hz	100. Hz	240. Hz
Phase Angle	0. °	180. °	
Real	1.4702e-005 mm	-8.372e-006 mm	-1.875e-005 mm

Even though the modern vehicles have the advance damping controls, for existing vehicles, the above analysed two methods can be implemented to reduce the risks of failure of exhaust system which leads to collapse in green environment by emitting more carbon content smokes.

6. ACKNOWLEDGMENT

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