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A Study on Thermal Behavior of Exhaust Manifold for Four Wheeler using FEM Approach

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***Abstract-* The exhaust manifold is the first part of the vehicle's exhaust system. It is connected to the engine exhaust and receives the burnt gases. A maximum exhaust gas temperature will be found in the exhaust manifold is of 850^0C. Due to this crack on the exhaust manifold initiates. This is because of the thickness and the material used. Hence in this project, the material selected for the exhaust manifold is cast iron as it can withstand high temperature and study on different thickness were made. The exhaust manifold system is modeled using Solid works software. Then the geometric model is discretized using tetrahedral elements and analyses were performed using Hyper mesh software. Here the Modal, Heat Transfer and Thermal Fatigue analysis is performed. In this project, the focus is on to study the Thermal behavior of exhaust manifold by varying thickness of the material considered.**

***Index Terms-* Exhaust system, Exhaust manifold, Hyper mesh, Material thickness, Modal analysis, Heat transfer analysis, Thermal fatigue analysis.**

I. INTRODUCTION

An Automotive exhaust system consists of an arrangement about pipes that run under those car, Catalytic converter and muffler are joined with it. Relying upon the general framework design, those debilitate gas might stream through quit offering on that one alternately that's only the tip of the iceberg of:

1) Exhaust manifold and Cylinder head
2) A turbocharger on increment motor force
3) To decrease air contamination a catalytic converter

A. *Components of an Exhaust System*

1) *Exhaust manifold* - Its function is to gathering deplete gasses from all the cylinders of engine and discharging it through a solitary opening, which acts as funnel. Some advanced engines will have two manifolds in their design.

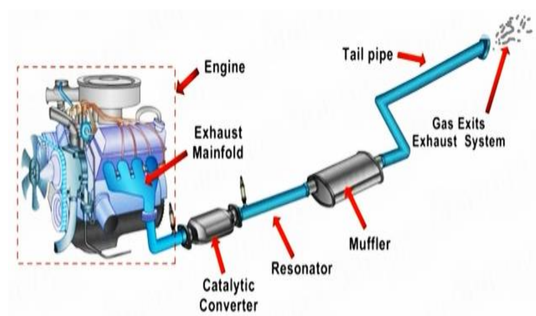

Fig: *Exhaust System Components*

2) *Exhaust channels* - composed particularly for every model of automobile to legitimately course or guide gases to the back of the automobile.
3) *Catalytic converter* - It is a device designed to control emissions; means to diminish the measure of destructive discharges or toxic gases in exhaust gas by converting it to less toxic gases by catalyzing it into water vapor.
4) *Muffler* - it is a metal holder with gaps, confuses and chambers that stifles noise. this is a device to control or reduce noise emitted by engine.
5) *Resonator* – It is with the muffler performs the task to lessen commotion.
6) *Tail pipe* – It is intended to divert exhaust gasses from the automobile, we can observe at the back of automobile.

B. *Exhaust Manifold*

The Exhaust system is the initial segment of the vehicle's fumes framework. It is associated with the automobile's engine and gathers the engine's outflows.

The air/fuel blend from the various chambers in the vehicle's engine is gathers the fuel/air blend from every chamber, regardless of whether it have four, six, or eight barrels. Not exclusively does the ventilation system get the greater part of the consumed engine gasses, additionally utilizing its high temperature it totally consumes any unused or inadequate consumed gasses. to examine the measure of oxygen entering the framework the system additionally houses the primary oxygen sensor. the oxygen sensor will advise the fuel injection process to increment or reduction the measure of oxygen utilized as a part of the fuel/air blend used to control the engine by screening the measure of oxygen.

Fig: *Exhaust Manifold*

C. *Functions of Exhaust Manifold*

In spite of the fact that the motor's moving parts makes burning conceivable, a standout amongst the most essential just stays there moving gasses. The "header" if made of independently welded tubes moves spent burning gasses from the motor's fumes ports to a focal gathering point. From that point, the gasses experience the auto's emanations framework, mufflers and out the tail-pipe. Some functions are,

1) Prevent Reversion

Any automobile can keep running without fumes funnels of any sort, yet without a manifold no engine will keep running for long time. The fumes valve is still somewhat open when the motor's admission valve opens and the cylinder goes down (sucking in outside air and fuel from the admission valve). The greater part of the barrel's burning gasses would surge out in a rush, making the fumes valve (quickly) the easiest course of action for wind stream into the chamber without a manifold. Alongside air and fuel from the admission, the motor would suck cool air in through the fumes valve, exponentially expanding burning chamber temperature and rapidly dissolving the fumes valve, valve seat and cylinder top. This wonder is known as reversion and is a known motor executioner.

2) Promote Exhaust Scavenging

Manifolds hold the high temperature of exhaust gas and heat, which builds pressure inside of the held region. The gas will squirt out through that authority furthermore under the fumes or exhaust pipe by the force of exhaust manifold due to the high pressure. In light those exhaust gases as inertia, as they have mass, the importance is that they will make a vacuum clinched alongside their get Likewise they passageway those pronouncements. This impact will be known as "scavenging” Also acts to suck in those remaining gasses crazy of the engine. Standard cast iron Furthermore "log" kind manifolds regularly show minimal from claiming this power-building scavenging; the impact may be by mossy cup oak maintained Previously, tubular headers, which are intended on upgrade searching.

3) *Speed Exhaust Flow*

Like executing or neglecting your thumb again the outlet of a hose to build those water's range (speed and pressure), along these lines to do headers/manifolds utilize sort of limited "primary" tubes on speed debilitate stream in low rpm. Precise low debilitate gas speed will foundation a significant part of the gasses will stay in the motor toward low RPM, bringing about a misfortune for torque. Exhaust system designers must strike a watchful equalization the middle of making primaries that are in length Furthermore limited sufficient should assistance velocity debilitate gasses through at low volume (low RPM) yet all the would expansive sufficient something like that Similarly as not to confine stream toward secondary rpm. Debilitate gas speed and searching are two sides of the same coin on pronouncement design; one will unavoidably influence the other.

D. *Exhaust Manifold Types*

There is an assortment of exhaust manifold and manifolds plan, each sort influencing the characteristics of engine. the straight forward cast manifolds can be designed which are intended to get the gasses out of the chamber and far from the engine as fast as could be expected under the circumstances, which is used by most of the street vehicles, because they are shabby and simple to produce, however more often than not a limitation to the engine.

There are two types of exhaust manifold:

1) Exhaust Manifold 4-2-1
2) Exhaust Manifold 4-1
3) Exhaust Manifold 4-2-1

At whatever point the active exhaust gasses achieve an adjustment in the framework which causes an extension, for example, a join with another pipe, a negative pressure pulse is reflected back towards the exhaust valve. This will at that point get the gasses following out of the cylinder much snappier and subsequently, additionally enhance advantages of attempting to cover charge the cylinder with the approaching blend.

Fig: *Exhaust Manifold 4-2-1*

1) *Exhaust Manifold 4-1*

In this manner as shown in fig, one pulse at one motor speed and tends to surrender benefits higher in the revolution range has been provided by four-into-one exhaust manifold. Nonetheless, a complex manifold that joins combines to begin with, similar to a four-into-two-into-one will adequately give two pulses back to the fumes valve at various speed, and consequently the inside and out increases won't be as huge as a four-into-one framework, yet will be spread further all through the rev extend, as they will happen at a more extensive scope of motor speeds.

Fig: *Exhaust Manifold 4-1*

E. *Objectives of the project*

1) To study the plastic strains of existing base design of exhaust manifold system.
2) To study the parameters that influences the thermal fatigue life.
3) To improve the strength and durability of exhaust manifold based on the above parameter.
4) To optimize the design using gauge optimization.

II. STATEMENT OF THE PROBLEM

1) The high temperature gas coming out of engine cause expansion and leads to crack formation in the exhaust manifold. Due to crack formation, leakage of gas takes place which leads to failure of exhaust manifold.
2) Also due to thermal fatigue the present exhaust manifold requires design changes frequently.

III. METHODOLOGY

This chapter gives the complete details of the methodology used to solve the stated problem. Mainly this chapter deals about the methods and the software used to solve the problem effectively.

The method of work carried out are represented in the flow chart below,

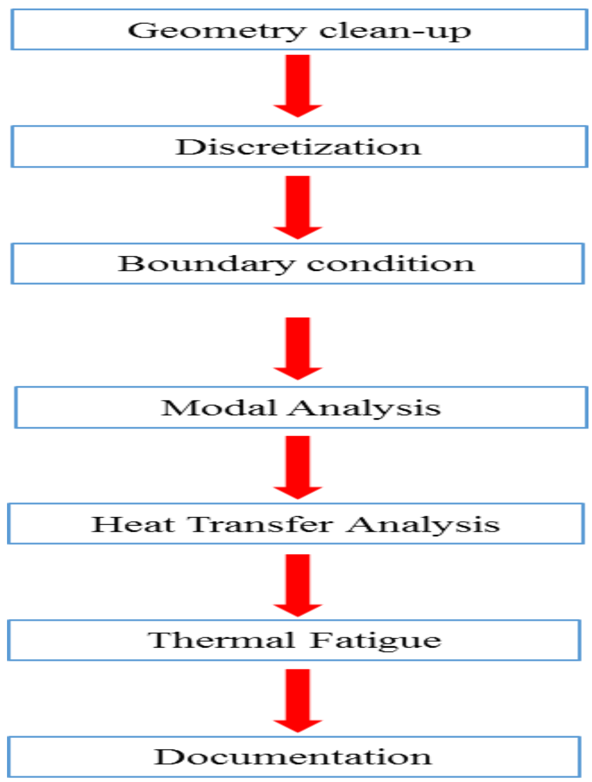

Fig*: Flow chart of the step by step methods followed*

IV. MODELING OF EXHAUST MANIFOLD

Modeling: An Existing model of exhaust manifold selected with a thickness of 1mm.The material selected is cast iron. The model is created using solid works software. The geometric model of exhaust manifold is shown in figure below,

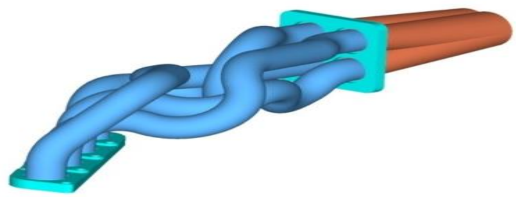

Fig: *Geometric model*

Meshing: The geometric model is imported from Solid Works to Hyper Mesh for meshing the model and analysis. The model is discretized using tetrahedral element with an element size of 10 in the software. The meshed model of exhaust manifold as shown in figure,

Fig: *Meshed model*

V. BOUNDARY CONDITION

The hot gases coming out of the engine is of temperature $\mathbf{850^0}\boldsymbol{C}$. In order to enhance the performance, the boundary conditions are applied to the plate that is attached to the outlet of the engine. The coordinate system is X, Y and Z.

1) The horizontal sides of the plate are kept free in Y coordinate and the remaining X and Z coordinates are constrained.
2) The vertical sides of the plate are kept free in X coordinate and the remaining Y and Z coordinates are constrained.

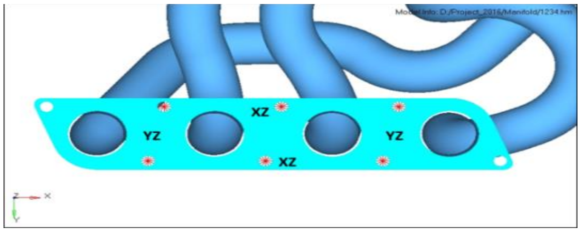

Fig: *Boundary condition*

VI. ANALYSIS

In this project, it will study the Thermal behavior of exhaust manifold. How it responds to the Thermal loads when a high temperature gas is made to flow through it. Thermal fatigue analysis will be carried out on the manifold to study its strain. Analysis is carried out by using Abacus/Nastran software.

A. *Heat transfer analysis*: The gases coming out of the engine are very hot, when these gases pass through exhaust manifold will causes changes in it by heat transfer. So it is necessary to conduct heat transfer analysis for exhaust manifold to observe the temperature distribution throughout the exhaust system, because due to temperature load manifold may lead to initiation of crack. The result is shown in figure.

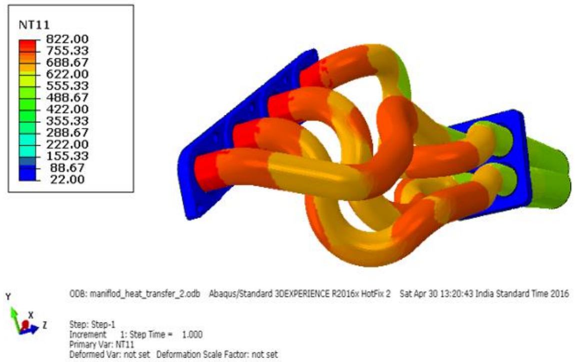

Fig: *Temperature plot*

The gases with high temperature pass through the exhaust manifold will cause Thermal expansion in it, due to heat transfer and about 3.66 mm of Thermal expansion is recorded. The result is shown in figure.

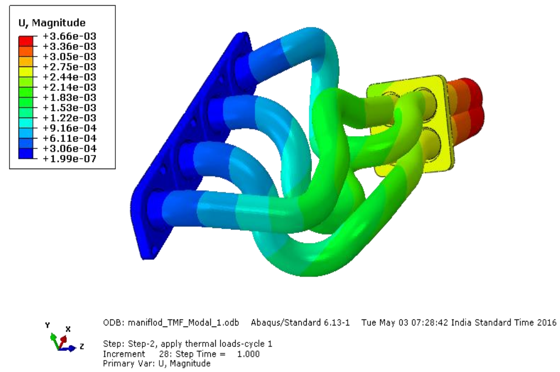

Fig: *Thermal expansion of 3.66mm*

B. *Thermal fatigue analysis:* Thermal fatigue is a cyclical thermal loading, which leads to fatigue of a material. Due to thermal fatigue, failure occurs causing the cracks in exhaust manifold. so it is very necessary to conduct Thermal fatigue analysis. In order to improve strength and durability of exhaust manifold it should get plastic strain value less than 1%. PEEQ refers to equivalent plastic strain. The results are shown below.

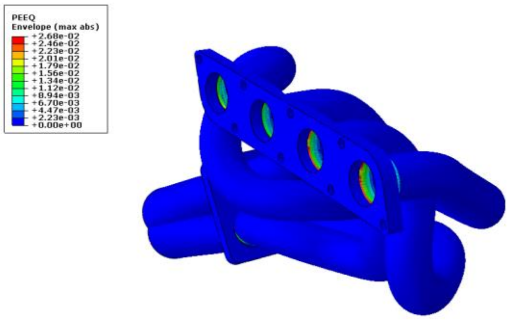

Fig: $\mathbf{1}^{st}$ *Heating PEEQ cycle*

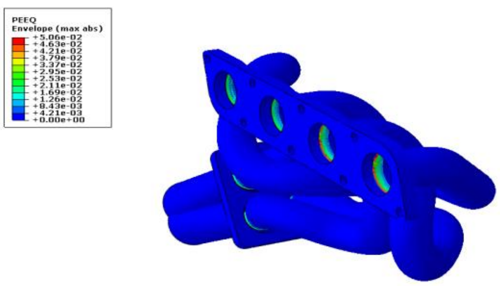

Fig: $\mathbf{1}^{st}$ *Cooling PEEQ cycle*

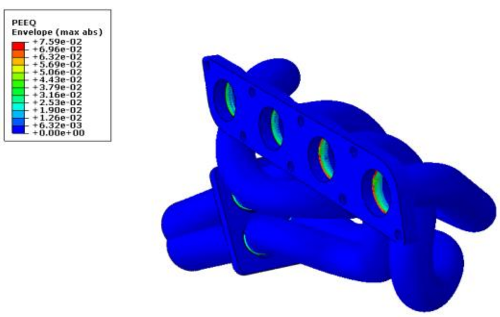

Fig: $\mathbf{2}^{nd}$ Heating PEEQ cycle

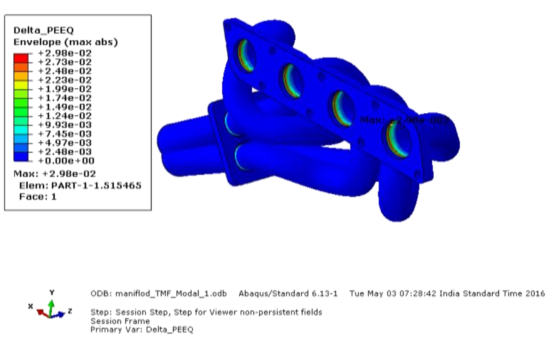

Fig: *Plastic Strain of Exhaust Manifold*

C. *Modal analysis***:** Exhaust manifold is subjected to modal analysis, in which for different mode shapes it shows frequencies with different values. Modal analysis is done for both hot and cold condition.

Modal analysis is done for room temperature of $\mathbf{20^0}\boldsymbol{C}$. It considers two mode shapes and get the frequencies. For mode 1, it shows the frequency of 64.935 Hz. The results of modal analysis at room temperature of $\mathbf{20^0}\boldsymbol{C}$ is shown in figure.

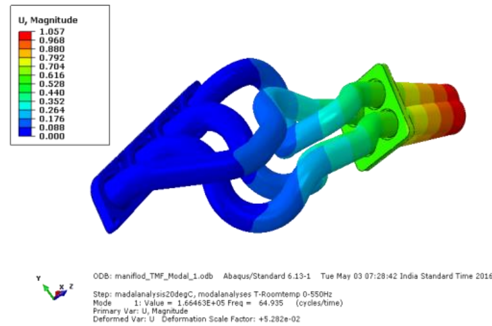

Fig: *Frequency of 64.935Hz for mode 1 at room temp.* $\mathbf{20^0}\boldsymbol{C}$

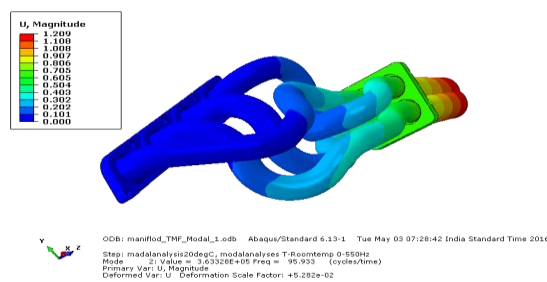

Fig: *Frequency of 95.933Hz for mode 2 at room temp.* $\mathbf{20^0}\boldsymbol{C}$

Modal analysis is also done for hot temperature of $\mathbf{850^0}\boldsymbol{C}$. It considers two mode shapes and shows the frequencies. For mode 1, it shows the frequency of 55.462Hz.The results of model analysis at hot temperature of $\mathbf{850^0}\boldsymbol{C}$ is shown in figure.

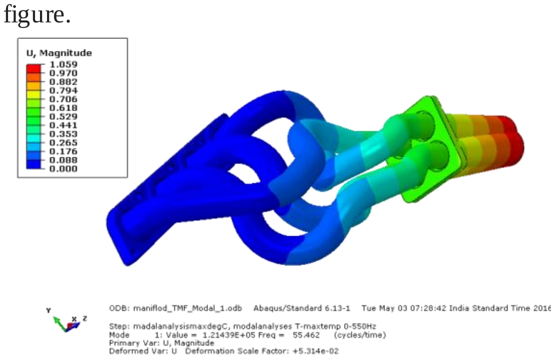

Fig: *Frequency of 55.462Hz for mode 1 at hot temp.* $\mathbf{850^0}\boldsymbol{C}$

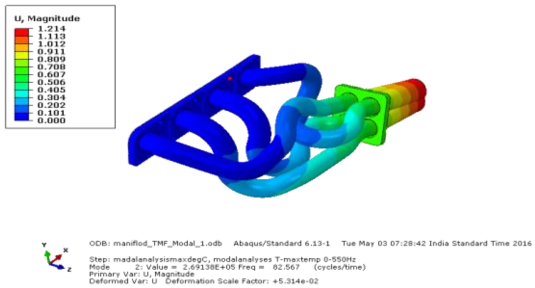

Fig: *Frequency of 82.567Hz for mode 2 at hot temp.* $\mathbf{850^0}\boldsymbol{C}$

VI. DESIGN OPTIMIZATION

Optimize of design is performed using guage optimization.

The base design is of material gauge thickness 1mm; the iteration is done by increasing the gauge thickness by 0.5mm and 0.2mm.

The procedure is repeated with the model of increased thicknesses and optimum one is considered based on result obtained.

VII. RESULTS

The result obtained by Heat transfer analysis is shown in below table:

MODEL THICHNESS(mm)	SURFACE TEMPERATURE (°C)	THERMAL EXPANSION (mm)
1mm	822	3.66
1.5mm	822	3.69
1.2mm	822	3.67

As the temperature is determined on the surface of the manifold there is no much changes in the results obtained.

Thermal fatigue analysis results are tabulated below:

MODEL THICKNESS(mm)	PLASTIC STRAIN (%)
1mm	2.98
1.5mm	0.67
1.2mm	0.77

From the results, it can see the model with thickness 1.5 and 1.2 mm are less than one therefore the design is safe for these two. But considering the lighter one the model with 1.2mm is optimum one.

Modal analysis results are shown in table below:

Model Thickness (mm)	Mode number	Frequency for room Temperature 20°c (HZ)	Frequency for hot Temperature 850°c (HZ)
1mm	1	64.935	55.462
	2	95.933	82.567
1.5mm	1	76.837	65.882
	2	109.74	94.582
1.2mm	1	70.284	60.124
	2	102.21	88.027

VIII. CONCLUSION

From the analysis carried out, the following conclusions are made:

1) Exhaust manifold with material thickness of 1mm is the existing base design with a material thickness of 1mm. This is not so effective for analysis carried out. From thermal fatigue analysis carried out, the plastic strain value should be less than 1% but it got the value is 2.98%. Therefore, failure of component takes place. Strength and durability should be improving in further iteration.
2) The exhaust manifold with material thickness increase by 0.5 mm is effective for the analysis carried out. From thermal fatigue analysis carried out, it got plastic strain value is 0.67%. Strength and durability improved but thickness and mass of model is little bit high.

3) Iteration is done for optimized design and analysis is performed of Exhaust manifold with material thickness of 1.2 mm. From thermal fatigue analysis carried out, it obtained plastic strain value is0.77%. Strength and durability improved and it is optimum one.

Therefore, from the analysis of the above three iterations, the overall conclusion is that the Exhaust manifold with material thickness of 1.2 mm is the optimum design because it requires less material and hence weight of the system reduces and also it reduces the material cost.

IX. SCOPE FOR FUTURE WORK

The following are the extent of future work:

1) Use of stainless steel rather than other material increases the thermo-mechanical fatigue and corrosion resistance of the exhaust manifold.
2) Optimization of Exhaust manifold design can be performed by Computational fluid dynamics analysis by observing the behaviour of flow of exhaust gases through the pipe.

ACKNOWLEDGMENT

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