Structural and Thermal Analysis of an Exhaust Manifold of A Multi Cylinder Engine

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Abstract--**The paper is used to the structural and thermal analysis of a multi cylinder engine exhaust manifold, for the given dimensions. The dimensions of the exhaust manifold are taken from the drawing. By performing Modal analysis Critical frequencies in the operating range are obtained . Harmonic analysis is performed and the deflections and stresses at the nearest natural frequencies are plotted. The exhaust manifold design's acceptance is done from the results obtained in different analysis. This is an effort to automate design optimization which would reduce schedule, technical, and cost risks for new engine developments.**

Keywords:* *Kadenacy Effect , Mass Participation Factor, Critical Mode, TMF Crack Shapes, dof, Yield Strength.

I. INTRODUCTION

It is placed on the Cylinder head of the ENGIN . On other end the Catalyst converter is connect to Exhaust manifold. At temperature of nearly 8000 C ,the exhaust gases emitted from the cylinder.High Pressures range 100 to 500 Kpa and temperature is used to exhaust manifold which will lead the thermo mechanical failure.. A back pressure is created due to not completely vacating the exhaust system before the gases from the other cylinder is released. These Pressure waves from gas restrict the engine's true performance possibilities.

The pipe must be heat resistant because the exhaust gases are very hot, The deffrent Exhaust pipe are used for different type of engine . chimney serving as an exhaust pipe is use in stationary type engine . in case motor cycle the exhaust pipes depends on the type of the engine .Horizontal pipe are used in case trucks In case of trucks, but some time Vertical exhaust pipe may be used Some trucks are provided with flexible ducting between the engine and silencer. , the exhaust pipe is provided with a bulge in two stoke engine . This is Known as expansion chamber. This improves the power and fuel efficiency cylinder and assisting more air and fuel to enter into the cylinder is called Kadenacy effect.

Cast Iron is mostly used as manifold's material. Thermal analysis has to be done initially to calculate the temperature distribution, heat transfer, thermal gradients and thermal flux. This is followed by stress analysis, to know the thermal stresses.

Maximum deflections and the Von Mises stress Check by Coupled field analysis of Thermal-Structural type .

Modal Analysis is used to found Vibration characteristics like mode shapes of the exhaust manifold and natural frequencies . These frequencies are calculated.

A. Mass participation .

when forced frequency matches the natural frequency then Resonance occurs . if the

participation factor is 0, then no energy will get into that mode.

B. Harmonic Response

Analysis is used to check the dynamic behaviour of the exhaust manifold Frequency Vs Displacement graphs are plotted at the "Peak" responses. These Peaks are used to calculate Stress and deflections.

If stress values do not exceed the allowed limitsthen Design is safe .

The performance and efficiencies of the engine depend upon the exhaust manifold. Also, proper design of the exhaust manifold will result in lower fuel consumption.

II. PROBLEM FORMULATION

A. Input for the project:

The exhaust manifold collects the exhaust gases coming from number of cylinders into oneexhaust pipe. The exhaust pipe is connected to the catalyst converter.

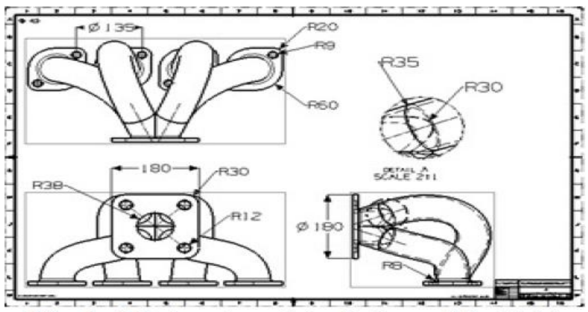


Fig. 1: 2D drawing of the Exhaust Manifold

B. Properties of Material of Cast Iron:

Poisson's ratio, v -0.3

Coefficient of friction, μ -0.2

Thermal conductivity, K (w/m k) -50

Specific heat, c (J/Kg k) -1.88

Density, (kg/m3) -7200

Thermal expansion, á (10ı6 / k) -0.3

Elastic modulus, E (GPa) -105

Yield strength (MPa) -130

C. Exhaust gas:

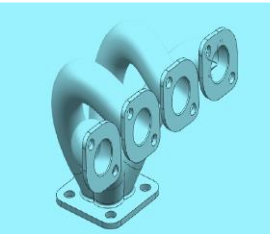
Temperature – 8000 C

Pressure range – 100 to 500 kPa.

D. Methodology followed:

- Perform coupled field analysis on the exhaust manifold for pressure load and thermal load to find stree and defection
- Perform thermal analysis on the exhaust manifold for thermal load
- Form the modal analysis results the natural frequencies mode shape and there mass participations are plotted
- Perform modal analysis to find natural frequencies on existing modal of exhaust manifold
- Maximum Deflection and stress are calculated at Peak response .

E. 3D Model generation



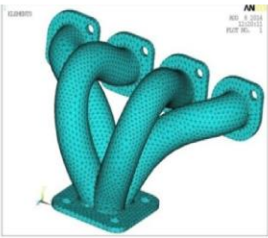


Fig. 2 :3d Model of the Exhaust Exterior

Fig 3:3d Model of manifold

III. BOUNDARY CONDITIONS:

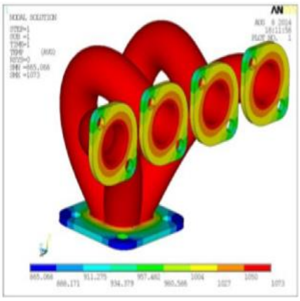
A. Thermal analysis

1) Inside of the pipes – 10730 K

External condition of the pipes – Convection

Fig. 4: Exhaust Manifold – Temperature applied

Fig. 5: Manifold – Convection applied externally



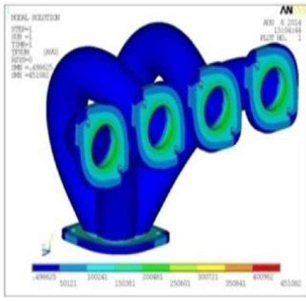


Fig. 6: Manifold – Temperature distribution

Fig 7: Manifold – Thermal gradient

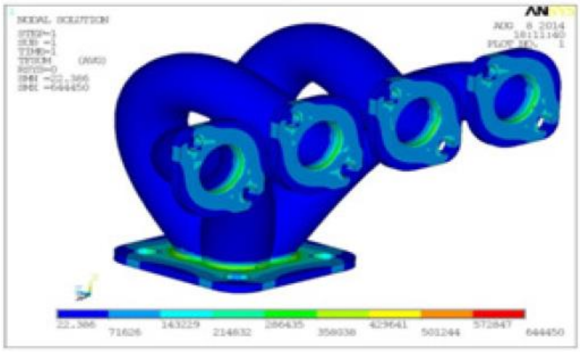


Fig. 8: Manifold – Thermal flux

2) Results:

The temperature distribution is found on the exhaust manifold . These temperatures are applied as the body loads in the structure analysis.

IV. STRUCTURAL ANALYSIS

A. Coupled Field Analysis

1) Boundary conditions :

- Pressure of 500 kPa inside pipes, as Structural loads
- Bolts arrested in all Dof and
- Temperature distribution applied as thermal loads.

2) Results obtained:

- Maximum Von Mises stress is 115 MPa
- Maximum deflection of 0.1 mm and

As the Von Mises stress is less than yield strength of Cast Iron (130 MPa). Hence the design is considered to be safe as per the Maximum Yield Stress theory.

B. Modal Analysis

Modal analysis is carried out on exhaust manifold to determine the natural frequencies and mode shapes of a structure in the frequency range of 0 -1500 Hz.

1) Boundary conditions :

- Bolts arrested in all Dof and
- Mass of the exhaust manifold is 15.5 Kg.

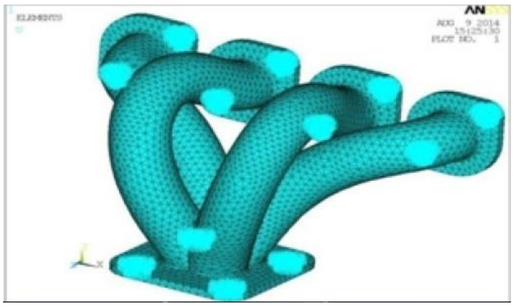


Fig. 9: Manifold – Boundary conditions for Modal analysis

2) Results:

A total of 6 natural frequencies are observed in the frequency range of 0-1500 Hz. The mass participation of each of these 6 frequencies are listed in the below table. The mode shapes of these frequencies are also plotted.

It is observed that the maximum mass participation is

- 2.5kgs and 2.66kgs in X-dir for the frequency of 617 and 700Hz.
- 3.4kgs and 3.7kgs is observed in Y-dir for the frequency of 1321 and 1486Hz.
- 2.2kgs and 3.7kgs is observed in Z-dir for the frequency of 1082 and 1237Hz.

C. Harmonic Analysis

1) Boundary conditions:

- Loads : Pressure = 500000 Pa
- Bolts arrested in all Dof.

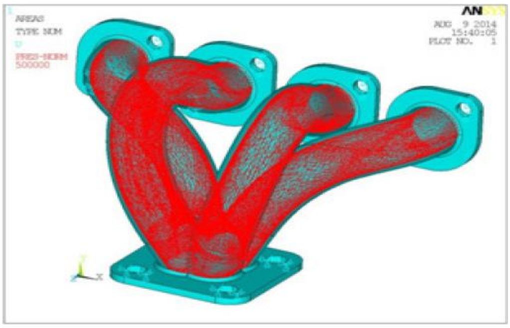


Fig. 10: Manifold–Boundary conditions for Harmonic analysis

2) Results:

- At Base of Exhaust manifold - Amplitude of 1e-5 m (0.001mm) - at a frequency of 1237 Hz.
- At Exhaust pipe1 of exhaust manifold - Amplitude of 1.1e-4 m (0.01mm) - at a frequency of 1237 Hz.
- At Exhaust pipe2 of exhaust manifold - Amplitude of 2.25 e-6 m (0.0025mm) - at a frequency of 1486 Hz.
- At Exhaust pipe3 of exhaust manifold - Amplitude of 2.1e-4 m (0.02mm) - at a frequency of 617 Hz.
- At Exhaust pipe4 of exhaust manifold - Amplitude of 0.8e-5 m (0.008mm) - at a frequency of 1486 Hz.

The deflections and stresses nearest natural frequencies to the above frequencies in the operating range of 0 – 1500 Hz are obtained.

V. CONCLUSIONS

- Thermal analysis provides the thermal loads for Structural analysis.
- Coupled Field analysis results show maximum deflection of 0.1 mm and Von Mises Stress as 115 MPa.
- As per Maximum Yield Stress theory, the design is accepted and further analyses are carried out.
- From Modal analysis, 6 natural frequencies for the structure is identified. Maximum Mass participation factor in the different directions are obtained.
- Harmonic Response analysis is done and the amplitudes at the forcing frequency for each pipe is obtained.
- Deflections and stresses at these critical frequencies are obtained.
- The given design of the exhaust manifold is safe.

VI. FUTURE SCOPE

- Flow behaviour and velocity of the exhaust gases inside the pipe can be analysed by conducting Computational fluid dynamics which will help to optimize the design of exhaust manifold.
- Use of Stainless steel increases the corrosion and Thermal Mechanical Fatigue (TMF) resistance
- of the exhaust manifolds. Hence thermal and structural analysis with Stainless steel can be done.
- Life prediction of the exhaust manifold design can be done for the same operating conditions.
- The exhaust manifolds can be either cast or fabricated. Thermal and structural analysis can be
- done to predict the failure of the exhaust manifold manufactured by different methods.

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