Coupled CFD-FE Thermal Stress Analysis on Exhaust Manifold of a Diesel Engine

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***Abstract*:**

Understanding of the structural behavior in the initial phase of design can help to reduce the number of virtual prototypes and the time taken for their evaluation.

The present work deals with the investigation of Exhaust Manifold of a four cylinder Diesel Engine. First, geometry creation and finite element modelling of exhaust manifold was done using appropriate CAD and CAE software. Then, in attempt to simulate the thermal boundary coefficients of exhaust manifold wall under steady state loading conditions, the internal flow fields will be obtained using Computational Fluid Dynamics (CFD) software. The film heat transfer coefficient and the temperature of the boundaries have to be calculated. The thermal boundary conditions will be mapped to structural element surfaces of the exhaust manifold based on commercial FE code ABAQUS. Thermal analysis will be conducted to find out the high thermal stress areas. Design modifications will be done on high stress area and the process has to be repeated. Numerical results and contour plots will be reported out.

I. INTRODUCTION

The exhaust manifold mounted on the cylinder head of an engine collects a gas exhausted from an engine, and sends it to a catalytic converter. The exhaust manifold plays an important role in the performance of an engine system. Particularly, the efficiencies of emission and fuel consumption are closely related to the exhaust manifold. The exhaust manifold is under a thermal fatigue produced by increasing and decreasing temperature, which leads to a crack of the exhaust manifold. Through a great deal of efforts to increase the performance and to reduce the weight, automotive companies have tried to achieve a goal in optimal engine design.

During the combustion process, the air-fuel mixture in the cylinders produces exhaust gases. These by-products need to exit the engine, and the exhaust manifold provides this means of escape. Every time the pistons do the exhaust stroke, they push the exhaust gases into the header. By collecting these gases from the cylinders and moving them into a central pipe, these fumes finally move to the exhaust pipe. Because an exhaust gas leak is dangerous, exhaust gaskets are used to prevent this from happening.

Factory exhaust manifolds are made of cast iron or stainless steel. Each material has its own benefits-ceramic

types are lighter than their stainless steel counterparts. However, stainless steel is not prone to cracking under high temperatures. A modification that you can introduce to your engine's exhaust manifold is by insulating it.

A).Types

There is a variety of exhaust manifolds and manifolds design, each type affecting the engine characteristics.

Most road car engines use simple cast manifolds that are designed to get the gases out of the cylinder and away from the engine as quickly as possible. They are cheap and easy to manufacture but usually a restriction to the engine.

The problem with cast manifolds, especially on an engine that is using valve overlap to overcharge the cylinders, is that they allow interference between the cylinders and hence get in the way of that process.

Tubular manifolds solve this problem. They feature a single pipe per cylinder to make sure that each pot is effectively isolated from its neighbours so gases don't interfere with each other. Tubular manifolds can be formed from steel, stainless steel, titanium or Inconel and the individual pipes will join further downstream, where they meet the exhaust pipe.

There are two main ways in which these individual pipes join. They can either all meet at the same point or they can become pairs that then join together to form a single pipe to the back of the car and atmosphere. Each of these has a different effect on the engine characteristics.

Some of the distinct advantages associated with dual fuel operation are longer engine life, potential cleaner operation and long lubricants with fewer filter changes. However, dual fuel operation also has certain limitations like the requirement of simultaneous availability of two or more fuels which would increase the complexity in controls and additional cost.

Moreover, a serious problem associated with dual fuel engine is the relatively poor light load and idling performance associated with low efficiency and inferior emission characteristics. The principle of injecting a small quantity of DEE fuel is to auto-ignite the diesel fuel, so that flames produced by diesel-air mixture burns the lean homogeneous charge available in the rest of the combustion chamber. This behaviour of the engine affects the performance of dual fuel engines at loads adversely.

The introduction of the fuel with the inlet air, even in very small quantities, can also have a significant effect on the cylinder charge during compression, affecting markedly the process of pre-ignition and subsequent combustion of the pilot and the cylinder charge this deterioration in fumigated fuel being used, operating conditions and the engine employed. In some cases even idling or light load operation becomes totally impaired, with certain fuels and engines.

Exhaust manifolds are classified as cast and fabricated. Cast manifolds can be designed as a separate part but can also be integrated in the cylinder head structure. Fabricated manifolds are known in single and dual wall design, where an interior and exterior sheet metal is separated by an isolating air gap.

B).Materials

Exhaust manifold design has to reflect the individual material characteristics and loading conditions by appropriate stiffness and low operating temperatures in addition to satisfying main drivers of engine development; namely emissions, power and fuel consumption.

In earlier design stages, when the main parameters like mean exhaust gas temperature is known, a proper material choice is initially driven by benchmarking. Chemical composition and microstructure of the materials define the thermal strength, resistance to creep, oxidation and microstructural changes, which are of utmost importance for exhaust manifold applications. Higher strength materials are continuously searched for accompanying timely and costly testing programs.

II. ANALYSIS METHODOLOGY AND DATA MAPPING

A. *Analysis Methodology*

The flow and temperature field is solved using FLUENT (a CFD system) and resulting film heat transfer coefficient of fluid boundaries between solid and fluid and the ambient flow temperature is interpolated to the corresponding surface of a mesh generated for thermal-stress analysis. Then applies a boundary condition that consists of a constant ambient temperature and a constant film coefficient on the outer surface of the solid part of the pipe. The temperature distribution of the solid part is re-calculated and the thermal-stress analysis is done using ABAQUS.

B. *Data Mapping:*

One important issue here is how to convert the temperature field obtained in the CFD analysis to the input data for the thermal stress analysis. The first consideration to be made is whether the same mesh should be used in both analyses. If the same mesh is used, the temperature values at the nodes of the mesh be interpolated to the nodes of the mesh for thermal stress analysis. Thus some introduction of error is expected in the interpolation process. On the other hand, because the mesh can be different for CFD and structural analysis, a suitable mesh can be chosen for each analysis stage without affecting the other stage.

In the paper same mesh is used and hence there are no errors in the mapping process.

C. *Practical exhaust manifold model*

The computational model to solve for flow field and associated thermal stress field Fig. 1 shows the model of the exhaust manifold. The mesh is created using Hyper mesh pre-processor.

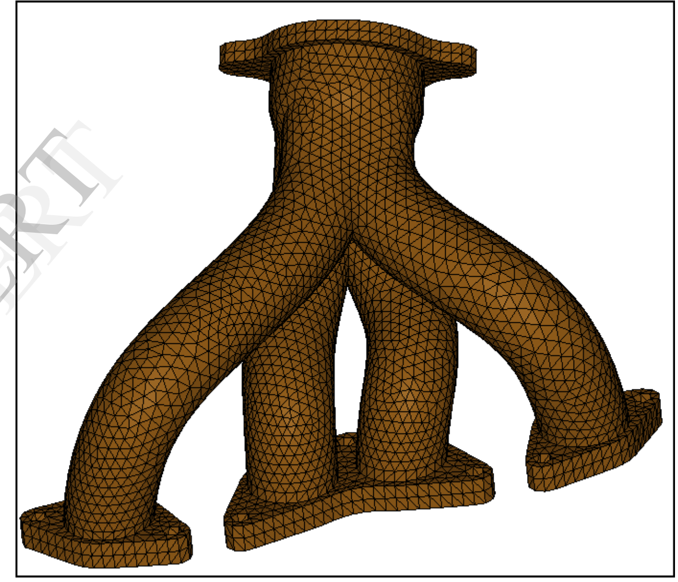


Fig. 1 Model of exhaust manifold (solid part)

Type of element used is Tetra. Similarly the fluid part was also meshed which is used for flow analysis.

Fig. 2 show the fluid part of the mesh.

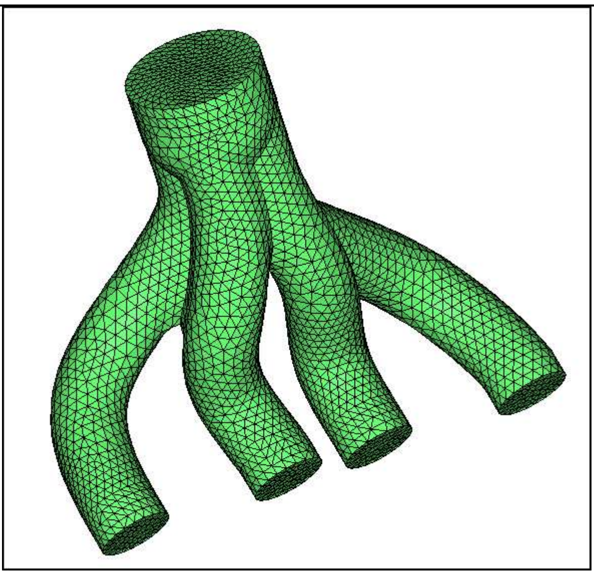


Fig. 3 Model of exhaust manifold (fluid part)

Fig. 3 shows the fluid part of the exhaust manifold which will be utilised for CFD calculation to predict the temperature distribution and heat transfer coefficient.

D. *Problem formulation*

Boundary conditions:

Domain	Type	Value
Inlet	Mass flow rate	302kg/h
	Temperature	700°C
Outlet	Pressure outlet	1atm (assumption)

Fig. 2 Boundary condition

Boundary Layer Parameters:

First height: 0.01
Growth factor: 1.2
Number of layers: 5 (with transition as in Fig. 4)
Type of element: Prism

The internal flow field are obtained using the CFD analysis which was performed using the FLUENT v.14 solver.

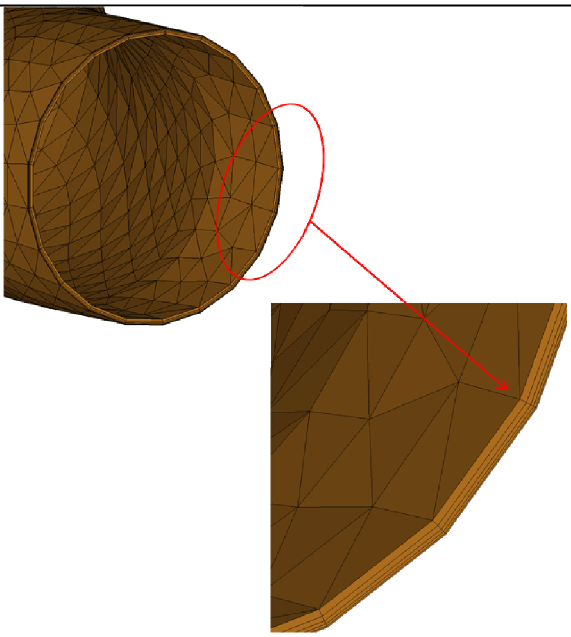


Fig. 4 Boundary layer thickness representation

E. *CFD Analysis Results*

As shown in Fig. 5 and Fig. 6, the temperature distribution and heat transfer coefficient values are obtained using CFD FLUENT solver.

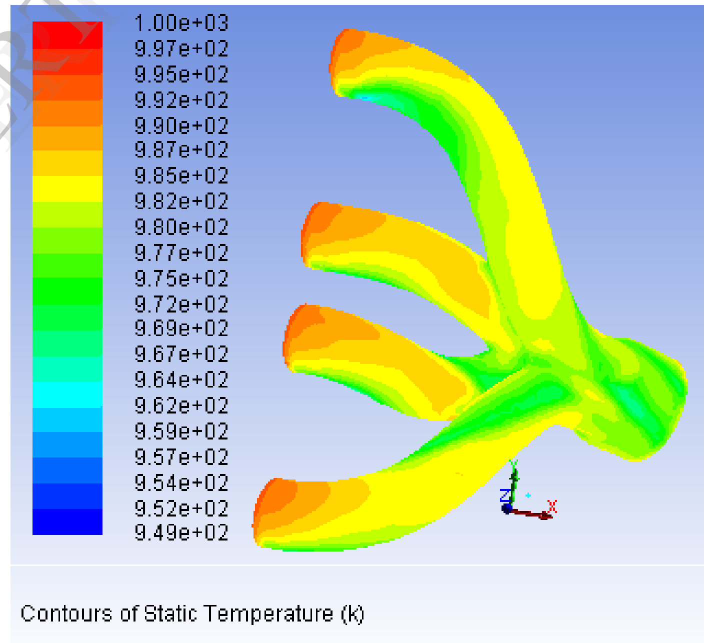


Fig. 5 Temperature distribution plot

Fig. 5 shows the temperature distribution plot where the temperature varies from 1000k to 949k.

Fig. 6 explains the heat transfer coefficient obtained.

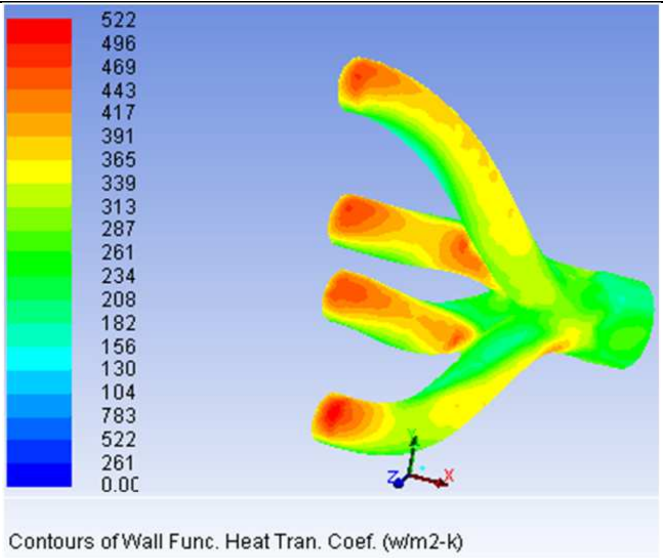
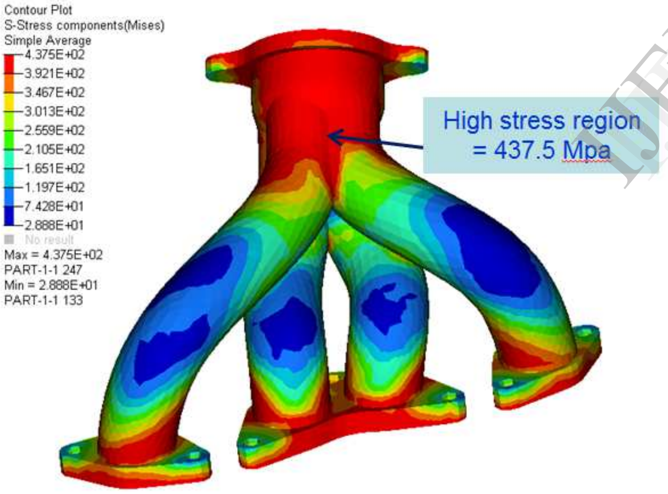


Fig. 6 Heat transfer coefficient

F. *The thermo mechanical Analysis Results*

The results obtained from CFD analysis are mapped to FE code ABAQUS and a thermal stress analysis was performed to find out the maximum stresses.

Fig. 7 and Fig. 8 shows the stress plot obtained from thermal stress analysis.



High stress region = 437.5 Mpa

Fig. 7 Max stress plot

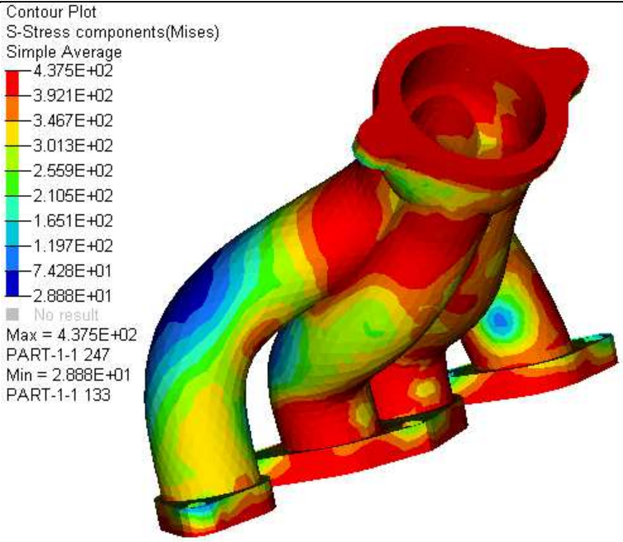


Fig. 8 Max stress plot

III. CONCLUSION

The simulation captures well the stress pattern and stress concentration at the failure location. The high stress region is at the junction of two exhaust ports and the region is discontinuous. The high stress region is at the junction of two exhaust ports and the region is discontinuous

Future scope of research in this area involves optmisation of high stress region according to the requirement and developing a heuristic which can find out optimal solutions from large search spaces efficiently.

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