Modeling and Analysis of Exhaust Manifold using CFD

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Abstract. This project goal is re-designing an exhaust manifold by means of determining the thermal stresses and deflections exhibited underneath various operating situations with distinctive materials and temperatures. The objective is to make certain the suitability of the design for two different fabric from the view point of reliability and serviceability. Defects in present manifold are cracks normally occur because of prolonged publicity to severe temperatures, defects in casting and repeated warmness cycling. Welded regions and the curved profiles are the essential regions of failure. A methodology is developed to ensure the best suited design and material for the given operating conditions. Manifold behaviour is analysed on two different materials such as stainless steel and grey cast iron. Redesigning the curved profiles can reduce the turbulence effect of the exhaust gases on the welds. High-end CAD/CAM software such as SOLIDWORKS 2016 and ANSYS 16.0 are used for modelling and analysis. Exhaust manifold is design by using solidworks software and transfer to ansys software. Computational fluid dynamic analysis is performed to study flow characteristics such as pressure velocity and temperature to study its performance and back pressure factors, and temperature after convection by surrounding air, than the same temperature after CFD analysis is applied on body in static structural analysis module to study its strength on thermal load that is to find out its stresses and deformation on working thermal load conditions, the material which give good strength to weight ratio will conclude the best material.

1. Introduction

The exhaust manifold is part of a diesel engine that can be required to accumulate exhaust gases from the cylinder head and send it to the exhaust device. Exhaust distributor plays a key role in the overall efficiency of a motor gadget. Especially, the emission efficiency and gas consumption are almost linked to the exhaust manifold. The collector can be cast or made from a rather light cloth. The cause of the exhaust manifold is the acquisition and delivery of these exhaust gases away from the cylinder with no less stress. Exhaust manifolds are fatigued due to thermal strain and deformation due to temperature distribution, heat accumulations or dissipation, and various related thermal magnitude. The aim of our analysis is to find precision fabric by evaluating thermal strain and deformation induced by mapping the temperature on one
of the types of substance for the off-road diesel engine exhaust manifold. In this venture, we are investigating the off-road diesel engine exhaust manifold. In the first step, FEM analyzes were made on the problem by using first-order tetrahedrone detail and the convergence test was achieved by structural load, recognition of the favorite length of detail. Thermal evaluation in the second step to determine the temperature map, heat skidding, and average heat switch characteristics. The results are sequentially used as an input in the calculation of stress, stress and deformation, and confirm whether the component geometry meets a certain need for conductivity. Input values of the temperature are collected through experimental testing of the evaluation comments. The experimental values of the temperature distribution were tested with the results of the FEA constant thermal analysis. The exhaust manifold is a pipe that drains the exhaust gases from the combustion chamber to the exhaust pipe. The exhaust manifold is part of an internal engine that collects exhaust gases from more than one cylinder into one pipe. Many exhaust manifolds are made of cast iron or nodular iron. Some are made of stainless steel or heavy steel. The exhaust manifold includes an exhaust port for each outlet inside the cylinder head and the flat machine surface on this manifold corresponds to the opposite

The exhaust manifold of a car motor is continuously supplied to warm gases. Cast iron has been being used for the era of exhaust structures usually. The essential traits required for the exhaust manifold material comprise heat weariness high-quality required to face up to the high temperature deplete gasses, oxidation resistance , terrific manufacture houses and low warm ability to improve the reactant paintings. Ferritic stainless steel display each this sort of homes and gives large weight lessening too. The advancements in vacuum throwing system has helped inside the manufacture of stainless-steel complicated with segment thickness of 2-5mm. Higher requests in infection manage will upward thrust the fumes temperatures as properly and in this way, ferritic stainless-steel may be in actual use for fumes framework producing. Ferritic stainless-steel presentations enhances warm weariness attributes when prepared via sturdy association reinforcing with molybdenum or niobium. This system likewise complements the oxidation resistance and microstructural protection. Ferritic stainless-steel additionally has fetched factors of interest due to the nonattendance of nickel in its creation. Another variant known as the austenite stainless-steel is applied in which ferritic stainless-steel is unacceptable. Austenite stainless-steel can improve its houses when enough carbon is brought to it. Be that as it could, the higher cost constrains its use contrasted with the ferritic variant.

The corresponding area in the area of the exhaust ports within the cylinder head. Some exhaust pipes have a seal between the pipe and the cylinder head. The seals are designed to leak air / gases between the manifold head and the cylinders. Seals are typically made of copper, asbestos or paper. In
different packages, the machined surface immediately touches the corresponding floor on the cylinder head. The exhaust ducts from each port within the manifold are connected to the usual uncontrolled passageway before reaching the manifold flange. The exhaust pipe is connected to the exhaust pipe flange. On a V-type engine, a header pipe is attached to each cylinder head. TMF breaking on exhaust manifolds is an issue that motor makers had been experiencing more noteworthy habitually finished the most recent decade. The essential explanation behind the TMF breaking is the altogether expanding gas temperatures. Those temperatures have increment due to commercial center requests for high specific power and rules requiring low emanations. The expanding fuel temperature is likened to 3 basic disappointment components in the exhaust manifolds:

- Oxidation (natural impacts)
- Crawl (time impacts)
- Mechanical weariness (cyclic pliancy)

Every one of these disappointment instrument's commitments to the general harm is an element of plan, material and stacking:

\[ D_{overall} = \sum D_i \text{(plan, material, stacking)} \]

where \( I = \text{oxidation, crawl, pliancy} \)

Oxidation issues are by and large settled through the use of substances that have a superior oxidation opposition. In any case, seeing that oxidation is overall dependant on temperature, sensible arrangements with nearby format changes (material, stacking = unaltering) are exceptionally troublesome. Extra troubles lie in evaluating the oxidation harm, particularly where a strong history is absent. Studies were finished, which offer an oxidation harm forecast display with a staging component that has demonstrated great connections for 1070 steel. However, to choose the form parameters, an enormous assortment of material tests are required and it is questionable that the model could be substantial for different materials. The essential aim in texture choice isn't generally to achieve the phenomenal oxidization zone under running circumstances. Current documentation isn't generally reliable relatively about the amount of sneak mischief in exhaust manifold applications. In any case, unique creators layout crawl disfigurement as the essential effect on general harm or bear in mind gooey strain either unequivocally or certainly in lifetime assessment. Testing of the exhaust manifold warm cycle comprises of abide time under both full load and motoring conditions. Working the motor under full load conditions (most extreme temperature), challenge
the exhaust manifold to compressive hundreds (out-of portion stacking). Under these events, crawl hurt is viewed as an auxiliary effect. In any case, the amount of close-by unwinding and its effect on foreseeing the lifetime of the manifolds should think about the unequivocal key elements of crawl strain/harm or certain contemplations of the utilization of mean/greatest weight reliance.

![Figure 1. Top view of exhaust manifold](image)

2. Methodology

2.1. Failure Modes of Exhaust Manifolds

Fail of exhaust manifolds are specifically because of the outrageous temperature amplitudes/angles the component needs to withstand. An auxiliary reason for screw ups is the dynamic excitation of the fumes subsystem, specifically if not immaterial several associated components like turbocharger or close-coupled-impetus are crashed into reverberation. Average basic disappointment modes are complex breaking and spillage. Those are related with the design and limit circumstances if an appropriate texture inclination was executed in any case. Understanding the establishment intention of a disappointment is the most extreme troublesome component at the path to an answer

2.2. Understanding Failures

1) TMF Cracking A primer warm stacking of exhaust manifolds would motive be able to the material to surpass the yield strain in huge locales of the exhaust manifold. Cyclic temperature stacking reasons a few districts to exhibit adjacent cyclic plastic stressing of the material, which may furthermore thought process a split inception. Depending at the zone of the unnecessary stacked territories, singular format parameters should be considered for you to discover an objective situated improvement procedure. It ends up evident that an inside and out learning of the gadget direct is needed, a great method to decipher results effectively. From a recreation perspective the designs utilized for examination need to allow for a nitty
gritty assessment of individual parameters. The architect needs to find a trade off between many-sided quality of model and limit circumstances instead of unwavering quality. Particular format restrictions for each motor make individual complex answers. In this manner, affecting parameters should be reflected for each design before a framework enhancement. Recreation is appropriate here an absolutely adaptable instrument to evaluate the effect of each parameter. Depending at the assortment of parameters, factual DOE techniques might be utilized to proficiently instructional meeting the guideline impacting parameters.

2.3. Leakage
Other than splitting of exhaust manifold frameworks, the spillage inconvenience might be every now and again also connected with cyclic plastification of exhaust manifolds. This disappointment might be frequently decided at the check seat with expanding number of test cycles. When spillage happens, a halfway pulverization of the gasket and the spine happens, which may likewise bring about a resulting complex split because of a changed weight skim inside the exhaust manifold.

2.4. High Cycle Fatigue
High cycle fatigue (HCF) issues at the exhaust manifold are caused by unique excitation. This kind of problem isn't generally found every now and again, and is exceptionally connected with unfriendly section format. In an essential advance, an Eigen recurrence assessment of the complex subsystem offers an underlying thought; if the framework is upbeat in the main overwhelming motor requests. In any case, this offers just an essential review of the subsystem excitation and can be viewed as a show for assist examinations, in which an inside and out unique investigation veiling the gathering, temperature and dynamic stacking of the machine is led to compute the unnecessary cycle weakness insurance edge.

2.5. Problem definition
In current years the engine running temperatures of cars, vehicles and heavy items motors had been growing due to environmental law on emissions and the need to improve engine performance. The motor enterprise worldwide is rather aggressive, running on small margins and large volumes. Therefore, the profitability is extraordinarily geared to reductions in design, development and production costs. There are very extensive financial and environmental advantages from using current substances. Automobiles have performed a few fulfillment with an method termed right here FEA validation (FEAV) for high temperature additives. Moving away from a design process which relied mainly on element testing in the
direction of a predictive functionality based totally on standardized cloth statistics and laptop predicted overall performance of components has ended in reductions in improvement fees and timescale. This mission describes the analysis method with its numerous elements in regards to a specific instance of an exhaust manifold which has now entered service.

Figure 2. Defects in End connections due to thermal stress

Figure 3. Model exhaust manifold

Figure 4. Mesh
2.6. CFD Analysis

BOUNDARY CONDITIONS:

Inlet mass flow rate = 0.000424 Kg/s and Inlet temperature = 900 K

Table 1. Temperature, pressure and velocity at various inlet positions

| Average of Facet Values | Static Temperature | (K) |
|-------------------------|--------------------|-----|
| inlet1                  | 900                |
| inlet2                  | 900                |
| inlet3                  | 900                |
| inlet4                  | 900                |
| outlet                  | 435.74015          |
| wall_wall               | 416.68616          |
| Net                     | 426.18472          |

| Average of Facet Values | Static Pressure | (pascal) |
|-------------------------|-----------------|----------|
| inlet1                  | 0.64737653      |
| inlet2                  | 0.64068136      |
| inlet3                  | 0.64068667      |
| inlet4                  | 0.64157004      |
| interior-fluid_body     | 0.61156245      |
| Net                     | 0.62474168      |

| Average of Facet Values | Velocity Magnitude | (m/s) |
|-------------------------|--------------------|-------|
| inlet1                  | 0.30221538         |
| inlet2                  | 0.30221537         |
| inlet3                  | 0.30221549         |
| inlet4                  | 0.30221547         |
| outlet                  | 0.57158709         |
| Net                     | 0.33710356         |

Table 2. Thermal stress analysis at 416 deg K (144 deg C)

| Material   | Max stress (Mpa) | Max strain (mm) | Max deformation (mm) | Total Heat flux (W/mm²) | Mass(kg) |
|------------|------------------|-----------------|----------------------|-------------------------|----------|
| Stainless Steel | 590.84         | 0.0032726       | 2.8427               | 0.024853                | 11.421   |
| Grey Cast Iron   | 221.03         | 0.0020896       | 1.7403               | 0.040791                | 10.611   |
3. Conclusion

Brief study about exhaust manifold types working is done in this project. Exhaust manifold is modeled using solidworks 2016 software using different commands and tools. Model is converted into IGES (initial graphics exchange specification) file, and transferred to ANSYS 16 Workbench software for analysis. Computational fluid dynamic analysis is performed on exhaust manifold to study its flow characteristics such as pressure, velocity and temperature. Inlet temperature is taken as 900 deg K, and CFD analysis is performed by two different materials such as stainless steel and grey cast iron. Temperature, pressure and velocity are noted and tabulated. Pressure drop and increase of flow velocity from inlet to outlet of hot gasses are noted according geometry of model. Temperature after force convection during diving of vehicle is calculated by software is noted and tabulated as 416 deg K. Than thermal stress analysis is performed by applying thermal load on exhaust manifold in ansys software using the module of structural analysis. Two different materials such as stainless steel and grey cast iron are used for thermal stress analysis. Boundary conditions are applied on body. Thermal load of 416deg K (144 deg C) value got in CFD analysis is applied on model. Self-load due to gravity is applied on model. Stress, stain, deformation,
heat flux and mass of model on each material selection is noted and tabulated. According to the result, grey cast iron is showing a good strength to weight ratio compared to stainless steel material as it is showing less stress that is good strength and less weight. Hence, we can conclude that grey cast iron is exhibiting good strength and economically better material than stainless steel. Design and analysis of exhaust manifold is done. Modal analysis can also perform on exhaust manifold to study its natural frequency, as it will be connected to moving body, to make it safe in dynamic loading conditions. And we can use advanced composite materials also to increase its performance strength and to decrease the cost.

References
[1] Swathi Satish, Mani Prithviraj, and Sridhar Hari, “Comparison of predictions obtained on an exhaust manifold analysis using conformal and indirect mapped interface”, International Congress on Computational Mechanics and Simulation, IIT Hyderabad, 10 – 12 December 2012.
[2] J. David Rathnaraj, “Thermo mechanical fatigue analysis of stainless steel exhaust manifolds”, IRACST – Engineering Science and Technology, Vol 2, No. 2, April 2012, PP 265 – 267.
[3] M. Rajasekhar Reddy, Dr. K. Madhava Reddy, “Design And Optimization Of Exhaust Muffler In Automobiles”, International Journal of Engineering Research and Applications, Vol 2, Issue 5, Sept-Oct 2012, PP 395 – 398.
[4] Bin Zou, Yaqian Hu, Zhien Liu, Fuwu Yan and Chao Wang, “The Impact of Temperature Effect on Exhaust Manifold Thermal Modal Analysis”, Research Journal of Applied Sciences Engineering and Technology, August 20, 2013, PP 2824-2829.
[5] A. K. M. Mohiuddin, Ataur Rahamn and Mohd. Dzaidin, “Optimal design of automobile exhaust system using gt-power”, International Journal of Mechanical and Materials Engineering, Vol 2 No. 1, 2007, PP 40 – 47.
[6] Modeling and Design of Exhaust Manifold Under Thermo mechanical Loading by K.H. Park, B.L. Choi, K.W. Lee, K.-S.Kim, and Y.Y. Earmme.