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A Literature Review on Exhaust Manifold Optimisation and Structural Analysis through F.E.A Approach

Abhishek Srivastava
Institute of Engineering and Technology, Lucknow
sriabhi1991@gmail.com

Dr. Shailendra Sinha
Institute of Engineering and Technology, Lucknow
ssinhaiet@gmail.com

Abstract: An exhaust manifold collects the exhaust gases from multiple cylinders into one single pipe. Exhaust manifolds are generally made up of cast iron or stainless steel which collect engine exhaust gas from multiple cylinders and deliver it to the exhaust pipe. Individual exhaust head pipes for each cylinder are commonly collected into one tube called header. The design of an exhaust manifold which is studied and experimented in the paper depends on pressure drop and volumetric flow rate. Various geometrical types of exhaust manifold had been studied using experimental methods as well as numerical methods (CFD). This paper reveals about severe heat cycles conditions, the exhaust manifold of an engine can have problems of crack and extensive plastic deformations, and the finite element method is being applied to predict thermal stress and deformations in manifold area.

Keywords: Exhaust Manifold, CFD Analysis, Finite Element Approach, Plastic Deformations.

1. INTRODUCTION

During the power stroke, the temperature of gases reaches about 1200-1500k and cylinder pressure is about 4-6 bar. The pressure in the manifold area is of ambient pressure. Due to this pressure difference hot gases flows through the manifold and finally came out to the atmosphere. The temperature of flow gases is usually very high when it flows through the manifold and due to this thermal load plastic deformations occur. When the thermal stress exceeds the yield strength of the material of which exhaust manifold made plastic deformations occur. The design is also optimised by placing the exhaust at the center of the header, a reduced pressure drop is obtained when compared to an existing one.

II. LITERATURE REVIEW

The exhaust manifold is the vital component in the exhaust system of a vehicle. The exhaust manifold is modeled in 3D modeling software (Unigraphics NX), for this design has changed, in existing model of an engine **B VENKATA SAI KIRAN**[1] et al. has taken bend radius of 48 mm and exhaust is at the center of the header. CFD analysis has been carried out in both the models and see that at different mass flow rate outlet pressure, velocity and heat transfer rates are increasing by increasing the mass flow rates and they are more for modified model when compared with an existing one.

The analysis of exhaust manifold structure, yield margins are calculated over the manifold area. The idea is to develop a new approach (elastic-plastic) given by **A.U KURBET** [2] et al. captures the actual material behaviour beyond the yield limit at thermal load. For elastic- plastic analysis yield ratio is calculated. The results were being carried in ANSYS WORKBENCH (F.E.A Analysis) and Von Mises stresses are calculated, if Von Mises stresses are greater than yield strength at particular temperature, the material is said to be yielding. Consequently, if Von Mises stresses are lower than yielding strength of the material, the material is said to be an inelastic range.

The performance of an exhaust manifold in terms of back pressure, exhaust velocity had been investigated by **K.S UMESH** [3] et al.In the research work he uses CFD simulations for the analysis of four variants configuration models namely SBSE (short bend side exit), SBCE (short bend centre exit), LBSE (long bend side exit), LBCE(long bend centre exit). The results were being tallied with experimental data carried by him by placing existing and modified model in an experimental setup and found that long bend center exit configuration provides better performance.

High back pressure condition in the automotive exhaust system is an important consideration in the optimisation of exhaust system, as it lowers down the volumetric efficiency of an engine. Back pressure is the pressure exerted by the atmosphere against exhaust system. Any fluid moving in a pipe or a channel system it offers some frictional resistance which depends on the diameter of a pipe, smoothness of a pipe material, viscosity of a fluid moving in it and velocity of moving the fluid. It also tells about exhaust piping design to ensure that the restrictions on exhaust gas flow are within acceptable limit. In this paper, **SHAILDA SARDA** [4] developed a method to design exhaust outlet pipe against exhaust pressure. CFD analysis is also used to calculate flow restrictions of exhaust line elements within the flow. The conclusion was made that pressure drop of bent type sheet metal exhaust pipe is higher than those of cast designs at same flow conditions and pressure drop increases when there is a sharp bend when cast material is chosen.

Engine exhaust manifold is exposed to high temperature during engine operation. The change in temperature over manifold during running conditions can cause cracks and deformations. **T.NOGUCHI**[5] et al. had done an analysis of thermal stress and elastic-plastic deformations through F.E.M. Thermal analysis is carried by making a finite element model, changing temperature distribution of exhaust manifold, inputting the measured exhaust gas temperature, ambient temperature, and heat transfer coefficient. By taking F.E.M results calculation of temperature distribution over manifold area and deformations in elastic-plastic range becomes possible in a certain operating mode.

For the modern exhaust after-treatment system, ex.(use of catalytic converter for the reduction of NO_x particulate matter) heat transfer study is very important such that it efficiency(converter) increases by 80%, this is only possible when the exhaust gases entering the catalytic converter reduces less than 550^0c, for this optimum model are used to analyse the effect of various parameters that govern heat transfer in a manifold, parameters such as temperature, stress, and deformations. **MISS POOJA NEMADE** [6] et al. developed a thermal- coupled approach which determines the optimum coolant velocity over the manifold for the various mass flow rate in order to maintain the temperature of gases entering the catalytic converter above 550^0c. Beside this, a polynomial expression is determined for particular coolant velocity at a various mass flow rate over the manifold area.

The gas dynamic behaviour study of exhaust gases entering the exhaust manifold, several computational fluid dynamics codes are used to simulate the behaviour of gas under laminar and turbulent flow. Since the exhaust gases entering the exhaust manifold are in the range of $5000\text{-}10^8$ turbulent flow is predicted. **HESSAMEDIN NAEIMI** [7] et al. has used turbulent model (K-epsilon RNG) for the effect of swirl on turbulence, enhancing the accuracy for swirling flows. The turbulence model is based on the 3-D compressible adiabatic steady-state form of Reynolds Averaged Navier-Stokes (RANS) conservation equations for the studying of Reynolds stress and turbulent diffusivity terms. By studying K-epsilon RNG model, pressure loss coefficient is obtained by both combining and dividing flow by comparing the predicted with experimented data.

Fatigue analysis is also an important factor for the optimisation of an exhaust manifold, for this vibrational analysis is carried out to check the thermal expansion of exhaust manifold system. To validate the design concept **KYUNG-SANG CHO** [8] et al. design a test rig to simulate the combination of two different fatigues namely thermal expansion and vibrational movements. For the simulation of high temperature of exhaust gases, a set of LPG gas torch are used. To prevent early failure combination of thermal expansion due to vibrational movements exhaust gases and high temperature caused by internal combustion were considered.

The exhaust manifold is subjected to a very high temperature of gases, for this appropriate material is chosen for designing purpose. Cast iron and stainless steel are considered as best material in terms of exhaust manifold material selection. The material should withstand with high temperature deplete gases, oxidation resistance. Ferrite stainless steel would best match for every one of these properties. **N SABAREESH** [9] et al. illustrated each type of manifolds like dry, water cooled, and air shielded water cooled manifold. For the analysis of thermal stress and deformations, the model has been made in CATIA software and finite element analysis is done on it. The material selection for the analysis is structural steel and found that there is less twisting when compared with the results of cast iron.

Flow through an exhaust manifold is time dependent with respect to crank angle position. **MARUPILLA AKHIL TEJA** [10] et al. has done a numerical study on 4-cylinder petrol engine with two exhaust manifold running at 2800 rpm. The main objective of this study and presented work is to determine theoretical values for input boundary conditions, preparing cad model for F.E.A analysis, flow pattern study of exhaust gases, pressure distribution at maximum flow rate, the study of static pressure drop, total pressure drop, and energy loss in the flow pattern.

Thermo-mechanical analysis of an exhaust manifold is studied in detailed approach by **K.HOSCHLER** [11] et al., for this, a method has been developed to calculate quasi-steady state heat transfer conditions and gas temperatures along the inner manifold gas path. For the analysis of heat transfer coefficients and gas temperature, all parameters must be described within gas flow in channels. In this work different sections of exhaust manifold are studied namely straight channel, nozzle, diffuser, bend, flow combining T-segment, flow dividing T-segment and one-dimensional equation are applied in it for simultaneous computation. These equations are the equation of continuity, the equation of momentum including gas friction, the equation of energy including heat flux in-out of manifold walls, the equation of ideal gas and pressure loss due to combining and dividing flow. This method allows the proper identification of fatigue failure at each component of the exhaust manifold.

Thermal deformations occur in exhaust manifold due to periodically recurring of thermal conditions of overheat and overcooling time. To understand the thermal deformations it is necessary to consider flow pattern of exhaust gases of high temperature. **JAE UNG CHO** [12] had studied two different kinds of turbo diesel exhaust model. Model 1 has larger bend radius than Model 2. The analysis of thermal stress and deformations showed that model 1 has fewer deformations(4.5067mm) and stress level(1369.1Mpa) when compared to model 2 (12.985,2520.7Mpa). Similarly, difference in velocity(14.993m/s) and pressure drop(500Pa) of model

1 is also less than when it compared to model 2(16.361m/s,700Mpa).Thus we can say that model 1 has more superior performance than model 2.

Exhaust manifold contains three major components manifold runner, plenum, and exhaust tail pipe. The exhaust tail pipe delivers the gases from the plenum, so to develop an optimising model **NIKHIL KANAWADE** [13] introduced a taper section on the tail pipe to reduce the flow swirl in the plenum. By introducing a taper section exhaust pipe had become a converging nozzle which helped in accelerating the flow. This flow acceleration would ensure the faster removal of exhaust gases. The taper angle considered was 2.5^0,5^0 and 7.5^0. The analysis is carried on CFD simulations and software used to perform simulations is STAR CCM+.

Different kind of materials of an exhaust manifold has been studied. The maximum temperature in a diesel engine would raise up to 800-950^0, so the material should with this temperature, also factors like corrosion, high-temperature oxidation, high fatigue strength, should be economical. The materials used for manufacturing these manifold are cast iron, ferrite stainless steel, and titanium alloy. **AAKASH SUNIL MUTKULE** [14] et al. has done analysis in ANSYS Workbench 14 and geometric model has been prepared in CREO Parametric 2.0. The dimensions of the manifold are taken from TATA SAFARI 2.0 DICOR vehicle. Results are evaluated in terms of total deformations, von Mises stress, and temperature distribution. The results show that all the materials taken are good enough to be selected in fabricating the exhaust manifold.

The exhaust manifold is also investigated in terms of welding residual stress distribution over the manifold area is predicted by thermo-elastic-plastic FEM. **XUEYUAN ZHANG**[15] et al. has applied FEM approach through ABAQUS FE over the structure to simulate thermal boundary coefficients of an exhaust manifold wall under loading conditions. Later on, thermal boundary conditions and welding residual stresses are mapped to the structural element surfaces of an exhaust manifold. By considering welding residual stress effects it is easier to make analysis accurately in terms of simulating the loading condition of an exhaust manifold.

III. OBSERVATIONS

The comparison of the experimental method with CFD analysis was quite close in the analysis of an exhaust manifold structure. Several analysis is done on an exhaust manifold structure to predict thermal stress, deformations, and temperature distribution over the manifold area. These analysis helps us to determine the failures in an exhaust manifold. RNG-K-epsilon turbulence model has been used to predict the flow of exhaust gases and temperature distribution. Structural analysis is done to find equivalent von-mises stress, deformations, and fatigue life and these results were closed to experimental data.

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