A LITERATURE REVIEW ON EXHAUST MANIFOLD DESIGN

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Abstract

Exhaust manifolds collects the exhaust gases from the engine cylinders and discharge to the atmosphere through the exhaust system. The engine efficiency, combustion characteristics would depend upon how the exhaust gases were removed from the cylinder. The design of an exhaust manifold for the internal combustion engine depends on many parameters such as exhaust back pressure, velocity of exhaust gases etc. In this literature review, the recent research on design of exhaust manifold, their performance evaluation using experimental methods as well as Numerical methods (CFD), various geometrical types of exhaust manifold and their impact on the performance had been collected and discussed.

Keywords: *Exhaust Manifold, IC Engine, CFD Modeling for Exhaust Manifold*

I. INTRODUCTION

Exhaust manifolds collects the exhaust gases from the engine cylinders and discharge to the atmosphere through the exhaust system. The engine efficiency, combustion characteristics would depend upon how the exhaust gases were removed from the cylinder. The following are some of the critical aspects related to the design of exhaust manifold for the internal combustion engine.

- The exhaust manifold design should result in maintaining high temperature in the exhaust pipe. This is necessary because the catalyst, placed near the end of the exhaust pipe, would absorb more pollutant in high temperature conditions.
- Also, the design should ensure that exhaust manifold natural frequencies are not in the range of the excitation frequency range of engine vibration to prevent any damages.
- The mass of the exhaust manifold should as low as possible

In this journal, the summary of the recent researches on the design of the exhaust manifold and their challenges, the performance estimation methods and procedures, critical factors had been provided.

II. LITERATURE REVIEW

The flow distribution in the exhaust manifold channels would be highly dependent on the header shape and the flow rate. **Jafar M Hassan** [1] had analyzed the performance of the manifolds with a tapered longitudinal section.The length of the manifold for this study was 127 cm while the manifold diameter was 10.16 cm. Authors had used the numerical simulations (CFD) for this research work. The flow conditions corresponding to Re = $10x10^4$, $15x10^4$ and $20x10^4$ were considered. The results were analyzed in terms of uniformity coefficient. Based on their CFD simulation results, they had concluded that the tapered header configuration provides better flow distribution as compared to the header with circular cross-section.

M.Usan[2] had applied a multi-disciplinary optimization approach for the exhaust system, exhaust manifold and catalytic converter, in highly integrated concurrent engineering software framework. They had considered four-cylinder 1.4 liter engine as a baseline model. The optimization contained four major modules – Geometry, Structural, Cost and Fluid Dynamics – and the relevant software for each module was applied. 1-dimensional transient CFD simulations were carried out using AVL BOOST with the engine torque and catalytic converter inlet temperature over the engine rpm were being estimated.

HessamedinNaemi[3] had employed numerical simulations (CFD methods) for estimating the flow loss coefficient in manifolds. The flow inlet and exit was modeled using 'mass-flow-inlet' and 'pressure-outlet' boundary conditions, with the consideration that the flow was compressible. The results from different turbulence models – standard k-ε, standard k-ω, SpalartAllmaras model and RNG k-ε model – were compared in terms of flow loss coefficient against the experimental data. Based on their results, the authors had observed that the RNG k-ε turbulence model predictions were in close agreement with the experimental data.

The design of exhaust manifold for a 4-stroke high power medium –speed diesel engine was carried out by **Kyung-Sang Cho** [4]. The typical operational range of the medium-speed diesel engine was in the range of 700 – 1500 rpm and has power outputs up to 6000 kW. The exhaust manifold will undergo thermal expansion due to high temperature of exhaust gas and also exposed to the vibration caused by the internal combustion engine. This was studied using experimental methods by the authors.

Masahiro Kanazaki[5] had developed a multi-objective optimization method for the exhaust manifold by using Divided Range Multi-objective Genetic Algorithm.The three-dimensional fluid dynamics inside the manifold was simulated using transient, Euler flow solver. The two objective functions for the optimization was i) maximizing exhaust gas temperature at the end of exhaust pipe ii) maximize the charging efficiency. The authors were able to successfully optimize the manifold for both these objective functions and noted that the optimized model has high engine power than the baseline model.

Hong Han-Chi [6] had used GT-Power, 1-dimensional software, for estimating the engine performance of a single cylinder IC engine. The power output predicted from the software was compared against the experimental data. In their study, the authors had considered four parameters – the sphere style plenum diameter, the intake runner diameter, the exhaust runner lengths and the position of restrictor. The plenum for the intake and exhaust manifold was designed using Helmholtz theory. The optimization experimental study was conducted by using Orthogonal Array Testing Strategy (OATS). The results obtained from the experimental analysis were found to be in good agreement with the results from the GT-Power software predictions.

In the research work carried out using numerical simulations (CFD), **K. S. Umesh**[7] had investigated the exhaust manifold performance for eight variants in terms of back pressure, exhaust velocity e.t.c. The flow conditions were varied from 2 kg to 12 kg, for every 2 kg, in their studies. The manifold configuration studied by the authors were Short Bend Center Exit (SBCE), Short Bend Side Exit (SBSE), Long Bend Center Exit (LBCE), Long Bend Side Exit (LBSE), Short Bend Center Exit with Reducer (SBCER), Short Bend Side Exit with Reducer (SBSER), Long Bend Center Exit with Reducer (LBCER), Long Bend Side Exit with Reducer(LBSER). These configurations were based on the location of the manifold pipe and the radius of the bend. Based on their results, the authors conclude that the Long Bend Center Exit (LBCE) configuration provide better performance.

The exhaust manifold will typically experience high thermal loads because of the exposure to high temperature exhaust gases. The exhaust manifold design should also consider such factors for preventing any material failure. **Xueyuan Zhang** [8] had conducted coupled thermo-fluid-solid analysis of an exhaust system with the consideration of welding stresses. The operating condition of 302 kg/hour flow rate of exhaust gas at 870 C was considered by the authors. The CFD simulations were performed using ANSYS FLUENT. The thermal profiles obtained from the exhaust manifold simulations were mapped as boundary conditions for the FEA solver. By this method, the welding residual stresses in the manifold were evaluated and the necessary design changes could be suggested.

The cold start emissions from the IC engine could be reduced by pre-heating the substrate to the optimum temperature. This could be achieved by placing the catalytic converter near the exhaust manifold. **Simon Martinez-Martinez** [9] had performed CFD analysis to estimate the performance of the exhaust manifold while placing the catalytic converter near to it (Close-Coupled Catalytic Converter). They had considered three types of manifold – Cast manifold, 4-2-1 manifold, L-Shaped manifold. The flow at the exhaust manifold was characterized by 90 g/s mass flow with 900 C gas temperature. The manifold's performance was defined by the flow uniformity index and the overall pressure drop. All three types of manifold had almost similar flow uniformity index (0.96) though the flow losses (total pressure drop) were significantly different. The L-shaped manifold had the least flow losses while the 4-2-1 manifold flow losses were 50% higher than the L-shaped manifold.

In their research work, **S. N. Ch. Dattu. V** [10] had performed thermal analysis for the tubular type IC-Engine exhaust manifold for various operating conditions. The authors had also considered four different manifolds – Radius 48 mm Exhaust Valve at Extremely Left, Radius 48 mm Exhaust Valve at Center, Radius 100 mm Exhaust Valve at Extremely Left, Radius 100 mm Exhaust Valve at Center. These configurations were carried out for two different material types – Cast Iron and Aluminum. Based on the results obtained from their simulations, the authors suggest aluminum as the material for the exhaust manifold due to their superior thermal performance. Also, the exhaust manifold of 48 mm radius with the exhaust valve at center

Benny Paul [11] had conducted CFD simulations on manifold of direct injection diesel engine. They had used the RANS (Reynolds Averaged Navier Stokes) solver approach with RNG k-ε turbulence model for the simulations. The flow inlet for the manifolds was modeled using 'pressure-inlet'. The wall regions in the manifold were considered as adiabatic with No-Slip condition being imposed. In order to ensure that the numerical solutions, obtained from the CFD simulations, were independent of the grid size, the authors had

performed grid-independence study with three different meshes. *STAR-CD* was used for this research work with the meshes had been generated using *Gambit*.
The various factors to be considered while designing an exhaust manifold were discussed by **Gopaal**[12]. They note that the exhaust pulse, created due to the release of high pressure exhaust gas from the cylinder to the exhaust manifold, would have three pressure heads – high, medium and low. They also note that 'scavenging effect' would be decreased in case of manifolds with large tubes. Also, the smaller tubes offer higher flow resistance and thus the engine power will be needed to push the exhaust gases.
MohdSajid Ahmed [13] had applied CFD methods to identify the optimum exhaust manifold for a 4-stroke 4-cylinder SI engine. They had considered five variants of exhaust manifold, based on the manifold pipe geometry, - convergent inlet pipe, divergent-straight-convergent, reduced convergent length and increased divergent length, reduced divergent length and increased convergent length, identical convergent and divergent and reduced straight length. The CFD simulations were performed using ANSYS FLUENT with un-structured meshes. 'Mass flow inlet' boundary condition was applied to model the flow inlet. Based on their results, the authors suggested that the minimum back-pressure at the exhaust manifold outlet could be achieved by having reducers.
The high temperature exhaust gases will induce thermal stresses on the exhaust manifold surfaces. The design procedure for the manifold must account for such heat transfer effects.**I.P. Kandylas**[14] had developed an exhaust system heat transfer model that included the steady state and transient heat conduction as well as convection and radiation. They had studied for various manifold materials such as Cast Iron, Mild Steel, and Stainless Steel e.t.c. Of the manifold surfaces, the authors had considered the component interior heat transfer and the convection and radiation to the surroundings.

III. OBSERVATIONS

The performance estimation for the exhaust manifold from the CFD simulations as well as the experimental methods was in good agreement.
RNG k-ε turbulence model had been noted to predict the flow and thermal fields in the exhaust manifolds much closer to the experimental results.
The coupled numerical analysis of thermo-fluid-solid analysis could provide the details of thermal stress distribution on the manifold surfaces. This might help in identifying potential failure zones in the exhaust manifold.
The performance of the exhaust manifold had been significantly influenced by the shape of the runner as well as orientation such as L-shaped, curved runners and also the bend radius.

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