Vibration and Thermal Analysis of Exhaust Manifold System

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The primary function of the exhaust manifold is to collect exhaust gases from each individual cylinder and merge them into a single exhaust stream. This helps to improve the engine's performance by reducing back pressure and increasing exhaust flow. The exhaust gases are then directed to the catalytic converter, where harmful emissions are reduced before being released into the atmosphere. The present study concludes that a CFD simulation was conducted to examine the flow characteristics of the exhaust manifold system. The exhaust manifold system has been analyzed to obtain plots of velocity, pressure distribution, velocity streamline flow, turbulence kinetic energy distribution, and temperature distribution. The objective of current research is to conduct fluid flow analysis of exhaust system using ANSYS CFX simulation package. From the CFD simulation, pressure distribution, velocity distribution is evaluated. The pressure is higher at the inlet and reduces as the gas moves towards outlet. The turbulence kinetic energy distribution and temperature distribution are evaluated for entire geometry.

1. INTRODUCTION

The exhaust manifold is a component of an automobile's exhaust system. It is responsible for collecting the exhaust gases that are produced by the engine's combustion process and directing them to the exhaust system for expulsion out of the vehicle. The exhaust manifold is typically made of cast iron or stainless steel and is bolted directly to the engine's cylinder head. It is designed with individual runners or channels that collect the exhaust gases from each cylinder and combine them into a single outlet. The primary function of the exhaust manifold is to transport the exhaust gases away from the engine quickly and efficiently. This helps to reduce back pressure, which can cause engine damage, and also improves engine performance by increasing horsepower and torque.

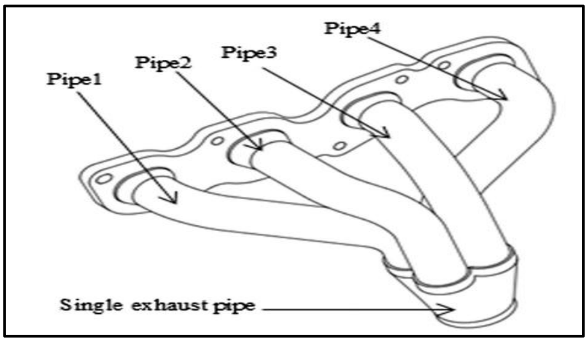

Figure 1: Schematic of the exhaust manifold of a four-cylinder naturally aspirated engine [1]

Exhaust manifolds can be either "header-style," which means each cylinder has its own individual runner and outlet, or "log-style," which means all cylinders share a single outlet. Header-style exhaust manifolds are generally preferred for their improved exhaust flow and increased performance benefits.

Amruthrajet. al. [2] aimed to design and analyze the exhaust manifold for a single-cylinder diesel engine. The researchers used a computational fluid dynamics (CFD) simulation to optimize the manifold design for better performance. The results showed that the optimized design had a lower pressure drop and better exhaust gas flow distribution, which led to improved engine performance and reduced emissions.

Whitelawet. al. [3] analyzed various materials used in the construction of exhaust manifolds for internal combustion engines. The researchers examined the advantages and disadvantages of different materials, such as cast iron, stainless steel, and titanium. The study found that the choice of material for an exhaust manifold depends on factors such as cost, weight, and durability.

Baeet. al. [4] aimed to investigate the performance of an engine with an optimized exhaust manifold design. The researchers used experimental and analytical methods to evaluate the performance of the engine with the optimized exhaust manifold. The results showed that the optimized design improved engine performance by increasing horsepower and torque, while also reducing fuel consumption and emissions.

Bafghiet. al. [5] discussed the design and testing of a custom exhaust manifold for a turbocharged engine. The authors used computer-aided design (CAD) software to design the manifold, and then 3D printed a prototype for testing. The results of the experiments showed that the custom manifold was able to significantly increase the engine's horsepower and torque, as well as improve its overall efficiency.

Chiavolaet. al. [6] present a thermal analysis of exhaust manifolds for internal combustion engines. They used a computational fluid dynamics (CFD) simulation to model the heat transfer and fluid flow within the manifold, and then compared their results to experimental data. The findings showed that the CFD simulation was able to accurately predict the temperature distribution within the manifold, and that the geometry of the manifold had a significant impact on its thermal performance.

Sonet. al. [7]focuse on the optimization of an exhaust manifold for a single cylinder diesel engine. The authors used a combination of computational and experimental methods to design and test the manifold, and found that the optimized design was able to improve the engine's performance and reduce its emissions. Specifically, the optimized manifold was able to increase the engine's torque and reduce its nitrogen oxide (NOx) emissions by up to 17%.

2. METHODOLOGY

The objective of current research is to conduct fluid flow analysis of exhaust system using ANSYS CFX simulation package. From the CFD simulation, pressure distribution, velocity distribution is evaluated. The model of exhaust manifold is imported in design modeler of ANSYS and checked for surface imperfections or other errors. The imported design of exhaust manifold is shown in figure 2. The model of exhaust manifold is meshed. The meshing of exhaust manifold is based on geometry type, complexity of geometry and topological consistency.

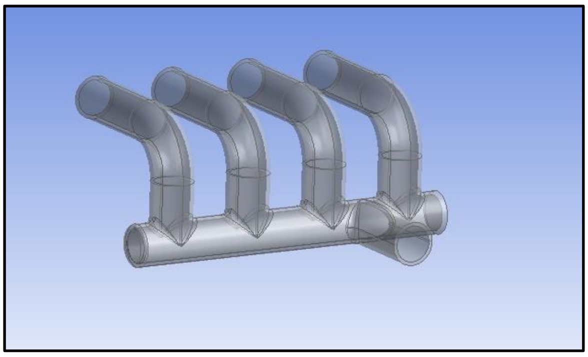

Figure 2: Design of exhaust manifold

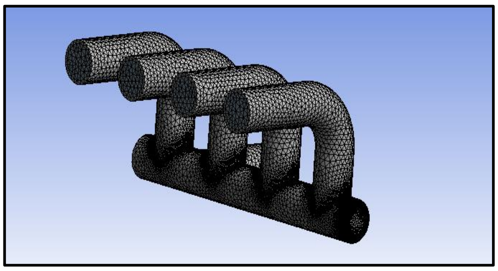

Figure 3: Meshed model of exhaust manifold

The fluid flow boundary conditions are defined for exhaust manifold. The fluid flow conditions involve defining reference pressure of 1 atm, gas inlet boundary, gas outlet boundary. The applied boundary conditions are shown in figure 4 and figure 5.

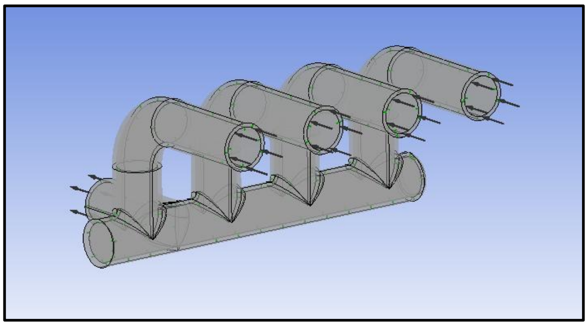

Figure 4: Loads and boundary conditions

After fluid flow boundary condition, the simulation is run as per convergence criteria defined. The convergence criteria involve setting RMS value of .0001. The interpolation is set to upwind type.

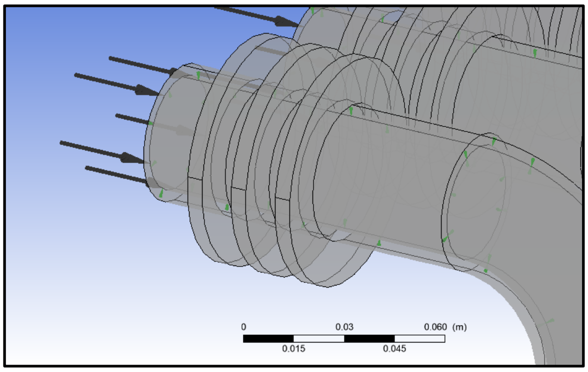

Figure 5: Loads and boundary conditions for finned geometry

3. RESULTS AND DISCUSSION

The CFD simulation is run to determine the velocity plot, pressure distribution plot and velocity streamline flow.

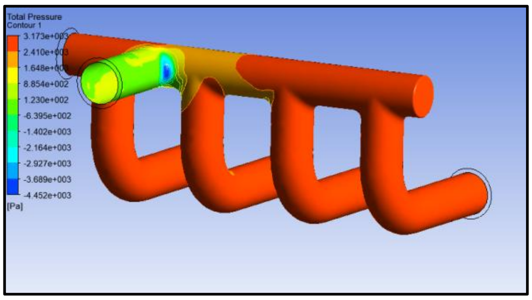

Figure 6: Total pressure distribution on exhaust manifold

The total pressure distribution plot is obtained for exhaust gas manifold system as shown in figure 6. The air pressure is almost uniform for all the 4 intake tubes and is of maximum magnitude at the intersection and outlet tube surface.

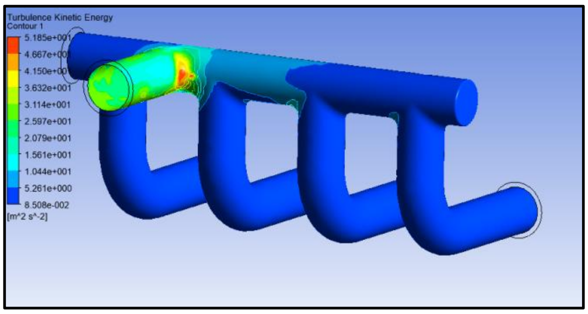

Figure 7: Turbulence kinetic energy distribution plot on exhaust manifold

The turbulence kinetic energy distribution plot is obtained for exhaust manifold. The turbulence kinetic energy is uniform for all the four intake tubes and is maximum at the intersection zone. The maximum turbulence kinetic energy is more than 36.32 m^2/s^2.

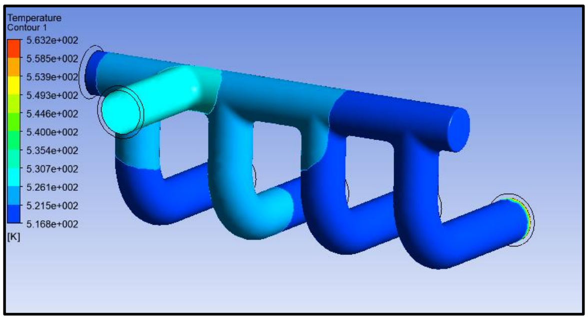

Figure 8: Temperature distribution plot on exhaust manifold

The temperature distribution plot is obtained for exhaust manifold as shown in figure 8. The temperature at certain regions is more than 530K and is lower at the gas inlet tubes.

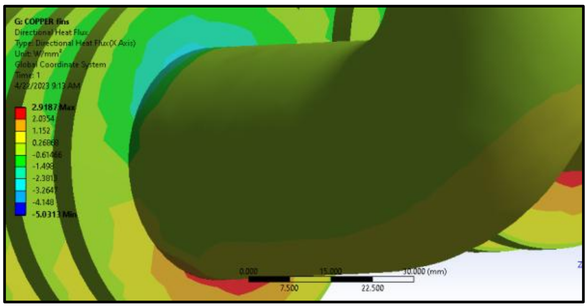

Figure 9: Heat flux plot on exhaust manifold

The thermal flux distribution is obtained for manifold with fins as shown in figure 9. The heat flux value is maximum at the intersection of tube and fin along the lateral direction. The heat flux value is 5.031W/mm^2at the bottom intersecting edge of fins. The many vibratory patterns that an exhaust manifold may display in response to external forces or thermal expansion are referred to as the mode forms of the manifold. These mode forms, which are based on the manifold's geometry and material characteristics, may significantly affect the exhaust system's performance and robustness. The vibrational analysis is conducted on exhaust manifold to determine natural frequencies.

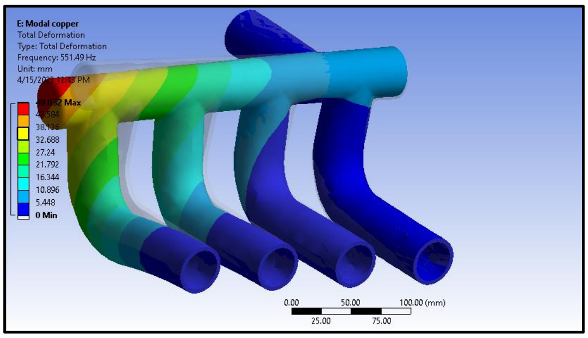

Figure 10: 1st mode shape of copper exhaust manifold

The 1st natural frequency is obtained for exhaust manifold as shown in figure 10. The mode shape of exhaust manifold is axial with magnitude of more than 32mm.

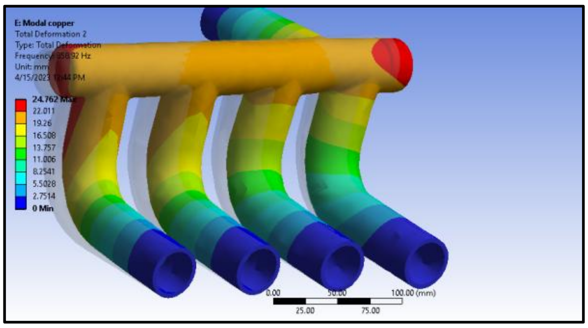

Figure 11: 2nd mode shape of copper exhaust manifold

The 2nd natural frequency is obtained for exhaust manifold as shown in figure 11. The mode shape of exhaust manifold is axial with magnitude of more than 13.75mm.

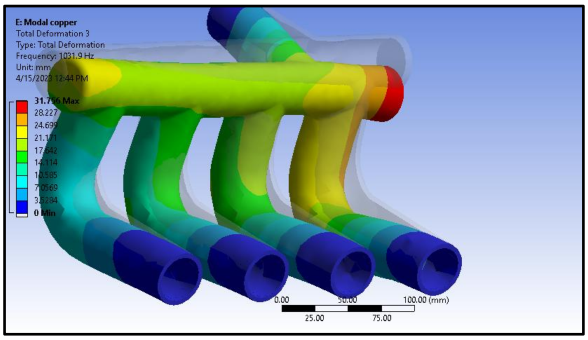

Figure 12: 3rd mode shape of copper exhaust manifold

The 3rd natural frequency is obtained for exhaust manifold as shown in figure 12. The mode shape of exhaust manifold is flexural with magnitude of more than 21.17mm.

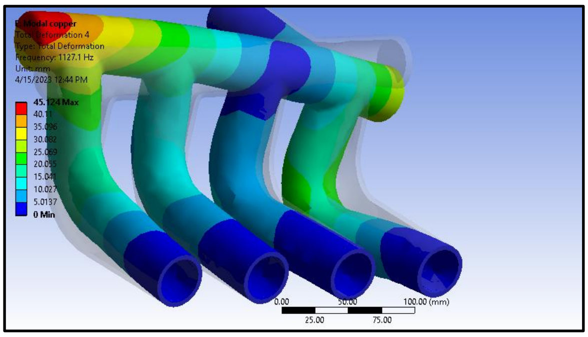

Figure 13: 4th mode shape of copper exhaust manifold

The 4th natural frequency is obtained for exhaust manifold as shown in figure 13. The mode shape of exhaust manifold is torsional with magnitude of more than 30.032mm.

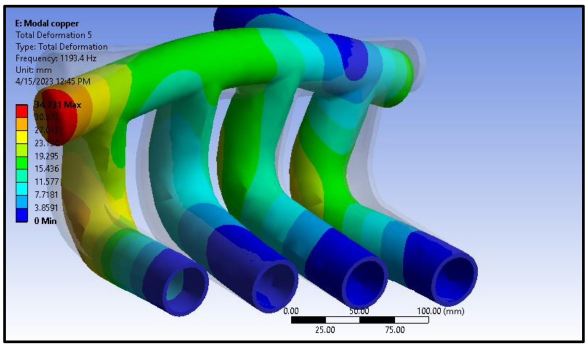

Figure 14: 5th mode shape of copper exhaust manifold

The 5th natural frequency is obtained for exhaust manifold as shown in figure 14. The mode shape of exhaust manifold is transverse type with magnitude of more than 19.2mm.

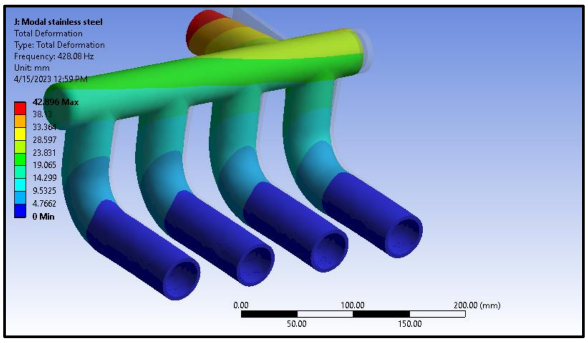

Figure 15: 1st mode shape of steel exhaust manifold

The 1st natural frequency is obtained for steel exhaust manifold as shown in figure 15. The mode shape of exhaust manifold is axial with magnitude of more than 23mm.

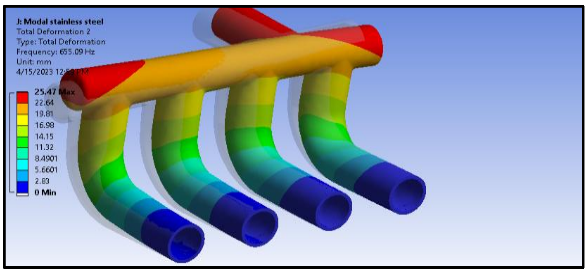

Figure 16: 2nd mode shape of steel exhaust manifold

The 2nd natural frequency is obtained for steel exhaust manifold as shown in figure 16. The mode shape of exhaust manifold is axial with magnitude of more than 14.15mm.

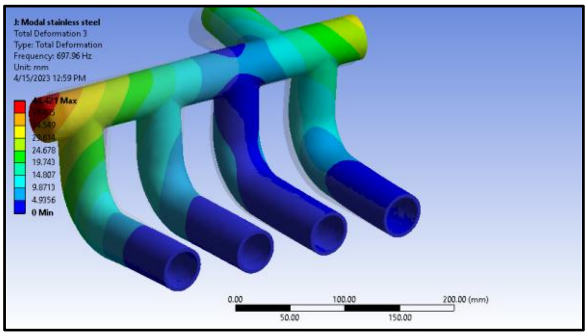

Figure 17: 3rd mode shape of steel exhaust manifold

The 3rd natural frequency is obtained for steel exhaust manifold as shown in figure 17. The mode shape of exhaust manifold is axial with magnitude of more than 19.74mm.

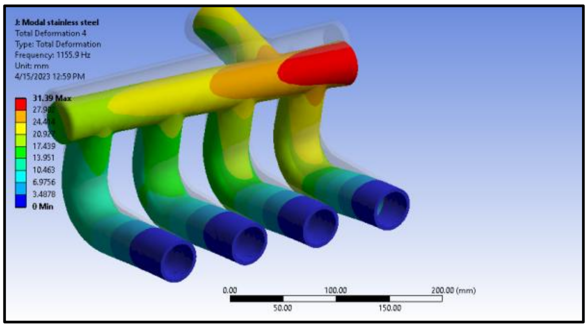

Figure 18: 4th mode shape of steel exhaust manifold

The 4th natural frequency is obtained for steel exhaust manifold as shown in figure 18. The mode shape of exhaust manifold is axial with magnitude of more than 17.439mm.

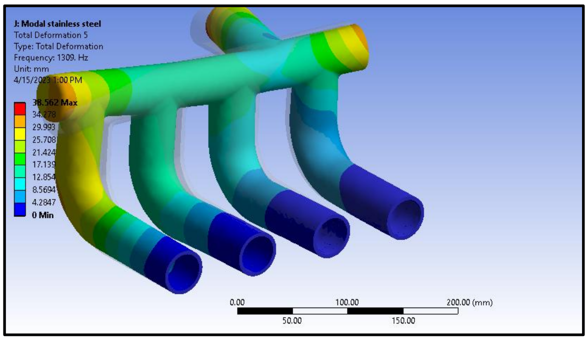

Figure 19: 5th mode shape of steel exhaust manifold

The 5th natural frequency is obtained for steel exhaust manifold as shown in figure 19. The mode shape of exhaust manifold is axial with magnitude of more than 21.42mm.

4. CONCLUSION

The present study concludes that a CFD simulation was conducted to examine the flow characteristics of the exhaust manifold system. The exhaust manifold system has been analyzed to obtain plots of velocity, pressure distribution, velocity streamline flow, turbulence kinetic energy distribution, and temperature distribution. According to the findings, the air pressure is nearly homogeneous across the four intake tubes, while the maximum turbulence kinetic energy exceeds 36.32 m^2/s^2. The manifold exhibits a non-uniform temperature distribution, wherein the highest temperature surpasses 530K. Additionally, a vibrational analysis has been performed on the exhaust manifold in order to ascertain its inherent frequencies and mode configurations. The identified mode shapes include axial, flexural, torsional, and transverse, and their respective magnitudes have been quantified. The examination of mode shapes holds significance as it offers valuable understanding regarding the vibrational characteristics of the exhaust system. This knowledge can be utilized in the development of other constituents, including exhaust hangers, brackets, and supports. To enhance the performance and durability of the exhaust manifold system, valuable information can be obtained through CFD simulation and vibrational analysis, which can be used to optimize its design. Through comprehending the flow dynamics and vibrational tendencies of the system, engineers can implement design alterations aimed at mitigating stress, resonance, and other prospective complications, thereby yielding an exhaust system that is more efficient, dependable, and resilient.

REFERENCES

[1] Sen Qiu, Zhao cheng Yuan, "Effects of exhaust manifold with different structures on sound order distribution in exhaust system of four-cylinder engine" Applied Acoustics 145 (2019) 176–183

[2] Amruthraj. M, Nataraj J.R. &SushmitPoojary (2012). Emission control in IC engines. International Journal of Engineering Research and Development, 4(4), 69-72.

[3] Arcoumanis, C., Whitelaw, J. H., Hentschel, W., & Schindler, K. P. (1994). Flow and combustion in a transparent 1.9 litre direct injection Diesel engine. Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, 208(3), 191-205.

[4] Bae, C., Koo, J., & Cho, Y. (2001, June). Exhaust Gas Recirculation in a Spark-Ignition LPG Engine. In The Third Asia-Pacific Conference on Combustion, Seoul, Korea.

[5] Bafghi, A. T. (2013). Effect of Exhaust Gas Recirculation in a Spark-Ignition Engine. Bull. Env. Pharmacol. Life Sci, 2(11), 155-161.

[6] Chiavola, O. (2001). Integrated modelling of internal combustion engine intake and exhaust systems. Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy, 215(4), 495-506.

[7] Cho, K. S., Son, K. B., & Kim, U. K. (2013). Design of exhaust manifold for pulse converters considering fatigue strength due to vibration. Journal of the Korean Society of Marine Engineering, 37(7), 694- 700.

[8] Dattatray, D. G., Shinde, V. B., Kulkarni, S. S., "Thermal analysis for motor bike exhaust silencer for ensuring reduction in hot spots through design enhancement", International Journal of Advanced Engineering Research and Studies, Vol. II/ IV, pp.134-137, 2013.

[9] Domkundwar V.M. Internal combustion engines.DhanpatRai& Co.

[10] Durat, M., Parlak, Z., Kapsiz, M., Parlak, A., &Ficici, F. (2013). CFD and experimental analysis on thermal performance of exhaust system of a spark ignition engine. Isi BilimiveTeknigiDergisi/Journal of Thermal Science &