REVIEW ON DESIGN OF INTAKE MANIFOLD FOR AIR RESTRICTED ENGINE

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Abstract - *SUPRA SAE is the formula student racing event, organized by SAE India, where students from all over India participate in event and apply their engineering knowledge to make the best formula-style racing car. The primary function of the intake manifold is to draw the air from the atmosphere and distribute it evenly to each cylinder and enhance the volumetric efficiency and power output of the engine. In this paper, we have reviewed the design, calculation, material selection, manufacturing process and optimization of intake manifold and restrictor. According to the rule of the competition, a 20mm diameter restrictor should be placed at the start of the intake manifold and all the air should pass through it. As restrictor restricts the mass flow rate going to the engine which results in reducing the volumetric efficiency, torque and power output of the engine, causing reduction in the overall performance of the engine. So, it becomes a challenging task for a student to design the intake manifold with an optimized restrictor which can allow maximum air to flow through it with minimum pressure losses and improved volumetric efficiency, torque, and power output. The overall design of intake manifold & restrictor is done using the solid works. The description of simulation of the intake manifold and restrictor is done using Ricardo software, WAVE for 1D simulation and VECTIS for 3D simulation and CFD using Ansys is also reviewed in this paper for the selection of better geometry of intake manifold.*

***Key Words*: Intake Manifold, Plenum Volume, Restrictor, Computational Fluid Dynamics, Ricardo Wave etc.**

1. INTRODUCTION

Ryan Ilardo, et al. [1] whenever it comes to optimize the efficiency and performance of the engine for the formula SAE car the main factor to be considered is the weight reduction of the components which are going to be placed on the engine i.e. intake manifold and exhaust. In this paper the main aim was to redesign and manufacture the intake manifold with minimum weight which would directly result in increment of overall efficiency of the engine and increase its performance. Habitually most of the teams manufacture intake manifold with aluminum pipes by bending and giving multiple welds at joints. But this type of manufacturing process essentially imposes the limitation on the geometry of the intake manifold that can be manufactured, which makes it's difficult to manufacture an intake manifold with a better geometry and power output with proper efficiency. After proper research and study, they manufactured plastic intake manifold with process called fused deposition modeling. The material used for manufacturing intake manifold was ABS plastic material. After this the plastic intake manifold was wrapped with the carbon fiber for more strength and flexibility. The FDM process resulted into flexibility for manufacturing of intake with complex geometry which would provide the equal amount of air to each cylinder with minimum pressure loss and also the plastic intake manifold wrapped in carbon fiber resulted in to overall weight reduction and improved the efficiency and performance of the engine.

Devananda B Pai, et al. [2] this paper intends to state the importance of simulation-based approach for the design of the intake manifold. According to their studies simulation is the most efficient way to develop a better design of the intake manifold. Carrying out simulation helps the designer to make the necessary changes in the design accordingly, and to achieve the best performance based on simulation results which also reduces the time which is not feasible in through experimentation. The aspects which affect the torque and volumetric efficiency of the engine are the intake manifold, runner length, runner diameter, Plenum volume and mass flow rate of air through the restrictor with the minimum pressure drop. 1D CFD analysis was done to improve the performance of various parts of the intake manifold for capturing 3D effects. 3D CFD simulation was also carried out and later on both the results were compiled for better optimization of the intake manifold.

Arbaaz Sayyed. [3] as the main rule according to the supra event is to place the restrictor with 20mm diameter to the intake manifold which restricts the mass flow rate going to the engine and results into reduction in power output and efficiency of the engine. Hence, the main objective of this research was to design and optimize the shape of the restrictor in such a way that it allows the maximum amount of air to flow through it. In their work they have compared two types of restrictor i.e. Orifice & venturi type restrictor.

On comparing both the restrictor based on various parameters it was concluded that venturi type restrictor was more efficient over the orifice with minimum pressure loss and better coefficient of discharge. Analytical calculations were done to calculate the maximum flow rate of air passing through the restrictor to the engine. As CFD is the most efficient way to carry out the flow simulation, the flow analysis was carried out on the venturi type restrictor measuring different converging and diverging angles. The results achieved at different angles are mentioned below in the table

Table -1: Pressure Loss

Iteration no	Converging Angle	Diverging Angle	Pressure loss (Pa)
1	12	6	8626.31
2	14	6	8961.82
3	16	6	9234.12
4	18	6	9389.57

Hence form the above table it can be concluded that for the converging & diverging angle of 12 and 6 degree respectively the minimum pressure drop is achieved with more velocity of air. Hence the design of restrictor was optimized.

Mark Claywell, et al. [4] the main problem which arises after placing the restrictor on the intake manifold is that it restricts the mass flow which eventually reduces the engine efficiency and power out of the engine. Hence the purpose of this review is to improve the restrictor performance using 1D and 1D/3D coupled analysis method. Ricardo wave and Vectis were used to carry out the respective simulations. In this using Helmholtz resonator, acoustic filtering was also determined with the help of the wave to see whether the performance of the restrictor can be increased by making the flow more uniform at the throat. The test was carried on restrictor with different diffuser angles such as 7˚, 5.5˚, 4˚ and 3˚ at different RPM's. The results achieved on the basis of simulation revealed that the difference in the distance from the restrictor to the bottom of the intake plenum due to different diffuser half angle greatly affects the volumetric efficiency between 10000 to 13000 rpm. Even after keeping the diffuser length same and increasing the plenum volume volumetric efficiency was not much affected by it. It was observed that the 3˚ half angle diffuser resulted in 4% improvement in volumetric efficiency over the remaining angle. The flow structure for 3˚, 4˚ and 5.5˚ was almost same but for the 7˚ it differed greatly. It was also observed that restrictor does not choke at any moment even at high speed. The percentage of choking was different for different angles. The tighter diffuser angle resulted into minimum pressure loss and turbulence. The use of acoustic filtering method based on Helmholtz resonator placed inside the plenum increased the volumetric efficiency by 2% by damping the velocity fluctuations, but the helmet resonator placed in line and upstream of reflector resulted into volumetric efficiency losses and hence it was concluded that the various factors can affect the performance of restrictor but the diffuser angle had a large impact on performance of the restrictor to gain or loss of volumetric efficiency.

Donald Horkheimer, et al. [5] intake manifold designs are classified according to the geometry and shape. This paper reviews the different type of the intake designs used by the various teams based on simulation. Intake geometry with best performance and power output was selected. The intake geometry such as top/center feed intake design, conical spline intake design & side entry intake design were investigated. The simulation was carried out using the Ricardo software WAVE for 1D simulation and VECTIS for 3D simulation. All the three types of intake geometry were simulated with the help of Ricardo software while carrying simulation each geometry had the identical restrictor and total plenum volume and runners with same diameter and length. All the intake geometry were compared on the basis of volumetric efficiency and performance. After simulation it was observed that the intake manifold with conical spline had the minimum volumetric efficiency imbalance and side entry intake had more volumetric imbalance. From going to straight runners to bend runners in conical spline intake manifold showed increase in volumetric efficiency at high speed but at low speed, bend runners didn't showed much improvement in volumetric efficiency. The volumetric efficiency of side intake geometry was also at the same level until high RPM. Finally, author suggested that the top/center feed intake concept with bend runners is the suitable option as it allows better flow of air and proper fuel injector targeting with minimum pressure losses and more power output.

Fawwaaz Hosein et al. [6] this paper describes the modeling & simulation of an intake manifold with top/center geometry which is to be fitted on a 600cc engine used in SAE event. The parameters such as the plenum volume, runner length and diameter, injector, position of the intake manifold which results into the best engine performance at a range of 7000 to 9000 rpm were determined by the author using 1D simulation in Ricardo software. Later two design concepts of the intake manifold were designed according to parameters determined through engine 1D simulation. Along with restrictor the bell mouth was also implemented to reduce the pressure losses and to allow continuous smooth flow of air through the intake manifold. Later on simulation was carried out in 3D CFD to record the behavior of flow of air in the intake manifold. The performance of the intake manifold was determined on the basis of restrictor choked flow, diffuser lag, uniformity of flow in the runner and volumetric efficiency. Along with CFD analysis, FEA static structural analysis was also carried out to check the structural strength of the intake manifold whether it can withstand the pressure difference between inside the intake manifold and outside environment. After carrying out all the analysis, according to the results, it was concluded that the intake geometry with top/center feed proved to be efficient. Plenum volume should be 5L to 6L which avoids the choking and the bend runners with minimum length of 120mm to 180mm for better performance. Along with it, a bell mouth of simple radius should also be implemented for the smooth flow of air.

Aman Agarwal, et al. [7] the main purpose of this study is to design and manufacture the intake manifold and restrictor which would increase the torque and power output off the engine used in formula SAE car. The main focus of this work was to reduce the velocity of the air and increase the pressure in the plenum along with increasing the mass flow rate in the runners, to maximize the velocity of the air in the restrictor with a minimum pressure loss. For the ease of manufacturing of complicated shape and to avoid the disturbance in the flow of air and formation of vortex, the Rapid prototyping manufacturing process called as Laser Sintering was used and the material used was nylon. Using Ricardo simulation software the one-dimensional engine model of CBR 600 RR was created with the help of several engine parameters. Which helped to determine the relation between various factors of intake manifold like Plenum volume, runner length etc. with the help of graphical representations. Engine volumetric efficiency, brake power and torque output were also determined with the help of Ricardo wave. Using this data, the runner length and the plenum volume of the intake manifold were finalized. For better understanding 3D simulation was done using star CCM+ followed by the structural analysis done with the help of FEA simulation using Ansys. The comparison between onion shaped and a log shaped intake manifold was done. As the performance of the log shaped intake manifold was better than the onion shaped intake manifold, the log shaped intake manifold having Plenum volume of 2.2 liter and the runner length of 240 mm was finalized. In this the two different intake geometry were designed and simulated one was upper entry and other was side entry. On the basis of simulation results achieved, the side entry intake manifold was finalized as there was more even distribution of air among all the runners. During simulation it was recorded that the velocity of the air inside the side entry plenum was 13% slower than the upper entry design. The restrictor of Venturi type with specific convergent and divergent angle was finalized as it had minimum pressure loss.

L. J. Hamilton, et al. [8] intake tuning is the most common and easy way to boost the performance of the engine. This paper deals with the different types of the intake manifold which improves the performance and volumetric efficiency of the engine. In this the author has tested the intake with different runner lengths and cross sections on Honda CBR 600 f4i engine which is to be fitted on SAE car. The comparison was also made between the straight runners and 180˚ bend runners. The whole simulation was carried out using Ricardo wave 1D simulation. On the basis of simulation, it was seen how the intake runner length affects the performance of the engine including volumetric efficiency, torque and horsepower. The results achieved from the simulation stated that long intake runners produce high torque and good volumetric efficiency till 6000 RPM. Beyond that RPM both the torque and volumetric efficiency drops down drastically. It was observed that the intake runners with short lengths perform better than the long intake runners resulting into higher volumetric efficiency and torque between 6000 to 11000 RPM. Normally the volumetric efficiency was seen to differ between 50% and 110 % and the torque between 25 to 55 NM over the speed range of 3000 to 12500 RPM. At last all the results achieved were compared with the 180˚ degree bend runners but there was not significant change in volumetric efficiency and torque, hence it was concluded that runners having bends are acceptable with varying runner length between 0.25 m & 0.45 m which improves the performance, volumetric efficiency and torque of the engine.

J. E. Lee, et al. [9] whenever it comes to race car application it is a widespread acceptance that the intake tuning is the most efficient way to enhance the performance of the engine. The main aim of this paper is to study the outcome of the plenum volume on the performance of the engine. Along with this, the wave resonance and Helmholtz theory are also beneficial to understand the impact of runner length on performance of the engine. In this experiment the testing was carried out on inline four-cylinder CBR 600f4i engine with 20 mm restrictor fitted on it. While testing the size of the plenum was varied 2 to 10 times of the engine displacement that is 1.2 to 6.0 litre with 0.6-litre increment engine speed varying from 3000 to 12500 RPM. As the torque is in direct relation with the volumetric efficiency, measuring the engine's air intake capacity was one of the most important parameters to be studied in this experiment. After carrying out the experiment on the basis of result achieved it was concluded that the size of the plenum did not have much effect on torque and power off the engine till 6500 RPM. Above 6500 RPM there was increase in torque and power output up to 31%. The plenum of volume 6.0 liter produced 17% more power than the plenum with the volume of 1.2 litre. It was observed that at low RPM the smaller plenum produced high torque than the larger plenum. But as the RPM was increased above 7000, torque was also increased as the plenum size was increased. Significantly 5% to 8% increment was observed in torque with the plenum of 6.0-liter volume compared to 1.2-litre plenum. The average pressure was seemed to be increased in the plenum beside the intake runner, intake valve open period as the volume of plenum was increased which resulted into rise in volumetric efficiency.

J. Ling, et al. [10] as there are different requirements and constraints for designing and manufacturing an intake manifold. Therefore, it leads to the design of the intake manifold with different geometry, shapes, and sizes. In this paper, the author J. Ling has looked upon the Non-symmetrical manifold for their advantages and complications. Years before 2004, he used Helmholtz's theory to design the intake manifold for their competition vehicle. It could only guess the engine speed and peak power. Thus from 2004, the author used a one-dimensional CFD simulation to check their intake and exhaust manifolds for energy loss, flow characteristics and dynamics of pressure waves. Due to non-symmetrical intake, there are no planes or axis of proportion which makes partial or 2d simulations is impossible. Further 3d CFD simulations, unsteady flows were visualized, which allowed the explorations of the flow characteristics in the manifold and also helped to enhance the geometrical design. To optimize the performance of the engine the author designed components with minimum pressure difference and maximum flow rate in the system. Venturi Restrictor of converging and diverging type with 46mm inlet of the converging portion narrowing it to 20mm diameter and then expanded to 50mm outlet for the diverging portion. Due to space constraints, the restrictor was connected through a 90˚ bend to a non-symmetrical log-style plenum of size 2.3 litre and, runners with uneven pressure distribution. Runners with the inner diameter delimited to 35 mm due to the port size of the CBR 600 F4 engine. The author states fluid through any opening produces the Vena Contract. Thus, to overcome the effect bell mouth at the entry of all runners with $r/D < 0.15$ ratio and a rollback of 90˚ to 270˚ were designed. 3D modelling was made using Solidworks and analysis was carried out in Fluent. Manifold system was analyzed in its steady-state and time dependent simulations were performed. Through which, it was seen that flow fluctuations occurred in the manifold. Pressure waves form as local expansions in the nearby runners caused reverse flow in the runners. Uneven pressure difference was seen in the system due to the unsymmetrical geometry, and the bend at the start of the plenum had suction losses in the duct. The author suggests to have sufficient volume for a manifold and not to place the runner closer to each other.

Arpit Singhal, et al. [11] this paper focuses on the significance of the intake manifold and its effect on the working of the engine. The intake manifold is drafted based on the rules set by the FSAE which states that a 20mm restrictor should be fixed between the air filter and the throttle body, all the air should pass through the restrictor to the engine. Upstream type manifold is designed and validated by Fluent Flow and CFD analysis. The length of each runner was calculated using the formula as follows.

□ = ((□□□□ × 0.25 × □ × 2) ÷ (□□□ × □□)) – (0.5 × D)

Where: L = Length of intake manifold runner
EVCD = Effective valve close duration
V = Speed of sound ft/s
RV = Reflected value (count of each pulse from one end of pipe and back)
RPM = Revolution per minute
D = Runner diameter (in)

But however the runner length is determined on the basis of results achieved form the simulation. Through CFD analysis the pressure and velocity at each runner was obtained which was used for determining the results. The Fluent flow analysis was performed and the flow trajectories were obtained for each runner. Thus, intake manifold designed provides equal amount of air to each engine cylinder thus improving the performance of engine by providing proper air fuel mixture.

3. CONCLUSIONS

This paper presents the basic knowledge of different aspects for designing and analysis of intake manifold for air restricted engine to be used in FSAE car. The overall intake geometry with the restrictor can be optimized with the help of software's like Ricardo wave for 1D and 3D simulation, CFD using Ansys, and FEA simulation for structural analysis using Ansys to obtain the required performance.

REFERENCES

[1] Ryan Ilardo, Christopher B. Williams "Design and Manufacturing of a formula SAE intake system using Fused Deposition Modeling And Fiber-Reinforced Composite Materials"

[2] Devananda B Pai, Hari Shankar Singh and P V Fayaz Muhammed "Simulation Based Approach for Optimization of Intake Manifold"

[3] Arbaaz Sayyed "Air Flow Optimization through an Intake System for a Single Cylinder Formula Student (FSAE) Race Car"

[4] Mark Claywell and Donald Horkheimer "Improvement of Intake Restrictor Performance for a Formula SAE Race Car through 1D & Coupled 1D/3D Analysis Methods"

[5] Mark Claywell, Donald Horkheimer and Garrett Stockburger "Investigation of Intake Concepts for a

Formula SAE Four-Cylinder Engine Using 1D/3D (Ricardo WAVE-VECTIS) Coupled Modeling Techniques”

[6] Fawwaaz Hosein “Modelling, Simulation and Validation of a Top/Central-Fed Air-Intake System for a FSAE Restricted 600cc Four-Stroke Engine”

[7] Aman Agarwal, Umashankar Lath, Saksham Bhardwaj, K Nantha Gopal, Ashok B, Akshyt Bimal Kumar, and Rishabh Khanna “Design and Development of a Restricted Intake Manifold for a Naturally Aspirated Four Cylinder SI Engine”

[8] L.J. Hamilton, J.S. Cowart and J.J. Rozich “The Effects of Intake Geometry on SI Engine Performance”

[9] L. J. Hamilton and J. E. Lee “The Effects of Intake Plenum Volume on the Performance of a Small Normally Aspirated Restricted Engine”

[10] J. Ling and L. T. Y. Tun “CFD Analysis of Non-Symmetrical Intake Manifold for Formula SAE Car”

[11] Arpit Singhal “Designing & Validating a New Intake Manifold for a Formula SAE Car”