

Design and Analysis of an Intake Manifold in a Multi-Cylinder Engine Student Formula Car Using Solid Works and Ansys.

Shivdeep D R¹, Dr. Gowreesh S S²

¹Shivdeep D R, student Dept. of Mechanical Engineering JSS Academy of technical Education, Karnataka, India.

²Dr Gowreesh S S, Associate professor JSS Academy of technical education Dept. of Mechanical Engineering, Karnataka, India.

ABSTRACT - In this research paper volumetric efficiency of Student Formula car's Intake Manifold is analyzed and increased. Intake Manifold is designed and analyzed according to the FSAE rule book. The rule book is drafted by the SAE committee. Intake Manifold is a device which serves the purpose of feeding air and fuel to the Engine where the combustion process takes place (It plays the role of human nose in automobiles). It sits above the engine and in between the air filter and inlet valves. It plays a key role in both fuel efficiency and power output of the engine. This is more prominent in naturally aspirated engines. Analytical calculation is performed to present maximum theoretical results. CFD analysis is performed to present simulation results. Analysis is conducted on the number of design iteration. The results have been tabulated, the modeling and design is done using Solid works. Meshing and analysis is done using Ansys.

KEY WORDS:

Air Restrictor, Intake Manifold, Plenum, Runner, Turbulence, Venturi.

INDRODUCTION

The main aim of this paper is to increase the volumetric efficiency of an intake manifold. The FSAE rules are as stated: -

- 1) A 20mm diameter restrictor must be present in between the engine inlet valves and Throttle body.
- 2) All the air navigating to the engine must flow through this 20mm restrictor.
- 3) The intake manifold and throttle body must lie within the top roll hoop and the outside edge of the rear tires.

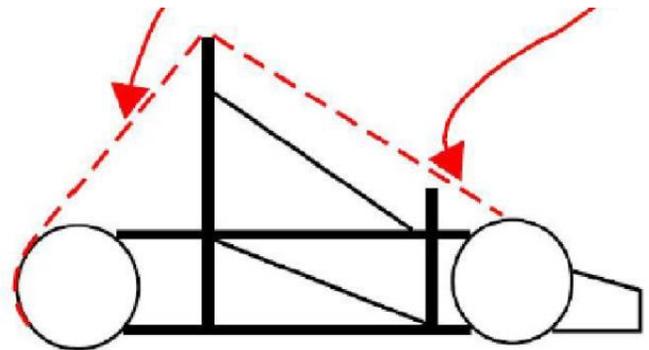


Fig 1

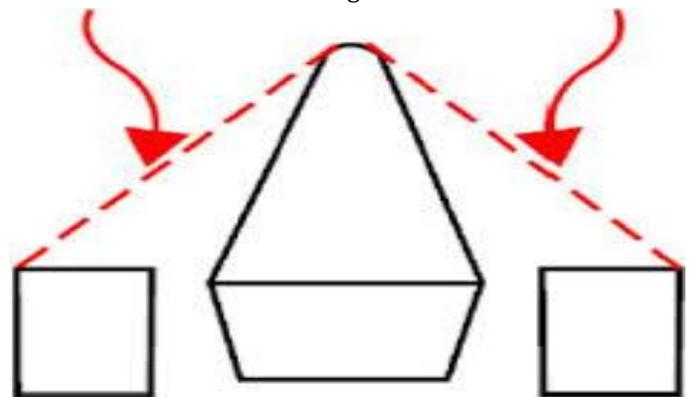


Fig 1 and 2 shows the envelope within which all the components must be mounted.

The 20mm restrictor is present to restrict the mass flow rate of air entering the engine. At high RPM engine requires more air for combustions as the cycle time for combustion process is reduced. This can be achieved by increasing the velocity of air in the manifold by a wide-open throttle and reducing the pressure drop across the venturi type restrictor. The 3rd rule is more of a safety rule. It is there to protect the components in case the vehicle

rolls over. It prevents the debris from being spread all over the track in case the car rolls over.

CBR 600RR (2008) is the engine to which the intake manifold is designed. The manifold is designed for 8000 – 10000 RPM. This is the range over which the manifold has highest efficiency that is the power band and torque band are present in this RPM range. Since it is a race vehicle the RPM selected are high.

Power band is the range of RPM over which maximum power/peak power can be harvested. Torque band is the range of RPM over which peak torque can be achieved.

The tests conducted are: Measure of pressure drop across the venturi (restrictor) to increase efficiency, reduce the turbulence in the manifold especially in the plenum. Obtain an optimum runner length to serve air at a particular harmonic.

LITERATURE SURVEY

For the completion of the paper “Design and Analysis of an Intake Manifold in a multi-cylinder engine Student Formula car using Solid works and Ansys” various papers were referred. They are as followed: -

- 1) **S. A. Elder** [3], this provides insight into the phenomenon of acoustic resonance in organ pipes, and also discusses the mathematical formulation.
- 2) **Constandi John Shami** [1], features of an air induction system are explained, and evaluation of different designs for plenum geometry. Also gives the procedure for flow analysis using ANSYS Fluent, and presents analyses of various restrictor and plenum geometries.
- 3) **O’Keefe Control Co.** [4], explains parameters governing choked flow through hollow sections and presents supporting mathematical formulation.
- 4) **P. M. V. Subbarao** [6], explains the acoustic phenomena occurring in intake and exhaust systems.
- 5) **A. K. Majumdar** provides procedure for flow prediction in combining and dividing flow manifolds. Explains the concept of converging and diverging flow.

6) **M. A. Ceviz** [5], “Intake Plenum Volume and its Influence on the Engine Performance, Cyclic Variability and Emissions”, Energy Conversion and Management 48 (2007) 961–966, Elsevier.

7) **Dr. S N wagnare** [8], Analysis of Air Intake for Formula Student Race Car in this research paper intake manifold of a single cylinder was analyzed. The main area of focus was determining the pressure drop across the restrictor by changing the converging and diverging angles. Analysis of plenum was done for a single cylinder KTM 390 engine.

8) Optimized design of engine intake manifold based on 3D scanner of reverse engineering, reverse engineering was performed to arrive at the desired results. It also focuses on mapping grid and dividing them. A basic algorithm for the solving process is provided in the paper. A multi cylinder engine intake manifold is analyzed and the results are shown to be converging.

9) **Pranav Anil Shinde** [9], Research and optimization of intake restrictor for Formula SAE car engine contour pressure analysis is performed for different iterations of venturi models.

THEORY

The restrictor can be of two types. It can either be an orifice or venturi type. Both have their own pros and cons. The venturi type has better co-efficient of discharge than the orifice type. The pressure drop across the 20mm restrictor is less in case of a converging diverging venturi. Although the cost of manufacturing is less and the manufacturing process is easy in case of the orifice type, this does not outweigh the efficiency of the venturi type. Hence a converging diverging venturi is selected to be used as a restrictor.

The reason why the pressure drop must be low across the restrictor that is $P_1 - P_2$ must be as low as possible because if it is high the engine has to do excess work to obtain enough air for complete combustion process. At high RPM when the ignition timings are advanced there will be less air for combustion this is called as choking of the engine and the combustion process will be incomplete. It will reduce the engine power and the efficiency of the engine. It also reduces the life of the engine due to

deposition of carbon on cylinder head, piston, cylinder walls etc. due to incomplete combustion.

Position of the manifold on the car: -

The air intake system can be placed in multiple ways, they are.

- 1 Top intake
- 2 Side intake
- 3 rear intake

All the three types have their own pros and cons we have chosen the top intake type. This is because fresh unaffected charge of air hits the air filters. The air flowing into the air filter is not obstructed by the tire wake (Turbulence caused to by the tiers). No spinning vortices created by the body parts enter the manifold. Also, air enters the manifold at atmospheric temperature, if the air would have interacted with powerful vortices caused by body panels it would increase the temperature of air. Since the manifold is not projecting out it does not affect the air flow to the rear which is very important to create effective down force.

CALCULATIONS

For CFD analysis inlet and outlet boundary conditions must be found. These boundary conditions are found out using theoretical calculations.

Theoretical pressure drop across the venturi can be found out using Bernoulli's equation and continuity equation.

Assumptions made: -

- 1) The flow is incompressible which is the density of the fluid does not change with respect to temperature.
- 2) The flow is smooth and effectively in viscid that is friction is negligible.
- 3) Rate of fluid flow through any section remains constant that is mass is preserved.

From Bernoulli's equation we have.

$$P_1 - P_2 = \frac{\rho}{2} (v_2^2 - v_1^2)$$

P_1 = Pressure at the inlet.

P_2 = Pressure at the outlet

V_1 = Velocity at inlet.

V_2 = Velocity at outlet.

From continuity equation

$$Q = V_1 A_1 = V_2 A_2$$

Q = Flow rate

A_1 = Area of cross section at inlet.

A_2 = Area of cross section at outlet.

$$Q = A_1 \sqrt{\frac{2}{\rho} * \frac{(P_1 - P_2)}{((\frac{A_1}{A_2})^2 - 1)}} = A_2 \sqrt{\frac{2}{\rho} * \frac{(P_1 - P_2)}{1 - (\frac{A_2}{A_1})^2}}$$

Note: - The above calculations are done with the assumption that the flow is incompressible.

maximum mass flow rate is given by
 $m = \rho * v * A$

For ideal compressible gas

$$m_{max} = A * P_0 \sqrt{\frac{K}{RT_0} \frac{2}{(k+1)} \frac{(k+1)}{(2(k-1))}}$$

A = Area of cross section where the flow is supersonic.

P_0 = Stagnation pressure

T_0 = Stagnation temperature.

R = Specific gas constant.

K = Specific heat ratio of gas (cp/cv)

$$T_0 = T_i + \frac{V_i^2}{2C_p}$$

T_i = Inlet temperature

T_0 = Stagnation temperature.

V_i = Inlet velocity.

$$P_0 = P_i * \frac{T_0^{\frac{k}{(k-1)}}}{T_i}$$

The analysis is done using K-epsilon because it is used for analysis of cars and bikes.

K-omega is not used as it used for analysis of high-speed jets and aero planes hence it cannot be used to analyze a FSAE car.

When the inlet valve at the engine end is closes the runner behaves as a Helmholtz resonator. Pressure waves are

formed inside a runner due to springing action of air. These Pressure waves undergo Simple Harmonic Motion inside the intake manifold. The new jet of air ramming into the runners keeps this process continuous.

Mass flow rate is maximum when $M=1$ and at this stage the flow is choked.

$$M=1$$

$$A= 0.001256 \text{ m}^2 \text{ (Restrictor diameter 20mm)}$$

$$R= 0.286 \text{ Kj/Kg-k}$$

$$\gamma = 1.4$$

$$P_0= 101325 \text{ Pascal}$$

$$T= 300\text{k}$$

$$\text{Mass flow rate} = 0.0703\text{Kg/sec.}$$

RESTRICTOR

The theoretical values obtained by the calculations are applied as boundary condition to perform the CFD analysis.

The design of the restrictor starts with identifying the known values which are the inlet diameter (Throttle body) and the restrictor diameter(20mm). The outlet diameter of restrictor and inlet and outlet angles are unknown variables, these are determined on the basis of data obtained through analysis. We know from principal of convergent divergent nozzle, for it to be efficient the pressure drop across the ends must be less.

Appropriate inlet and outlet boundary conditions were assumed. The CFD analysis was performed for multiple design iterations. The results of various iterations are tabulated below.

SL No.	Converging angle (Degree)	Diverging angle (Degree)	Pressure difference (Pascal)
1	12	6	1215
2	14	6	1280
3	16	6	1250
4	18	6	1323

5	9	5	1596
6	12	8	1974
7	14	8	2430
8	8	12	1363

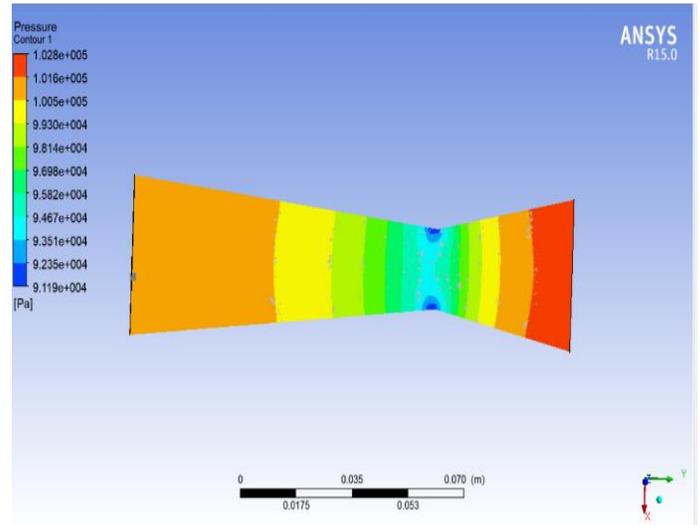


Fig 3 Contour pressure for restrictor

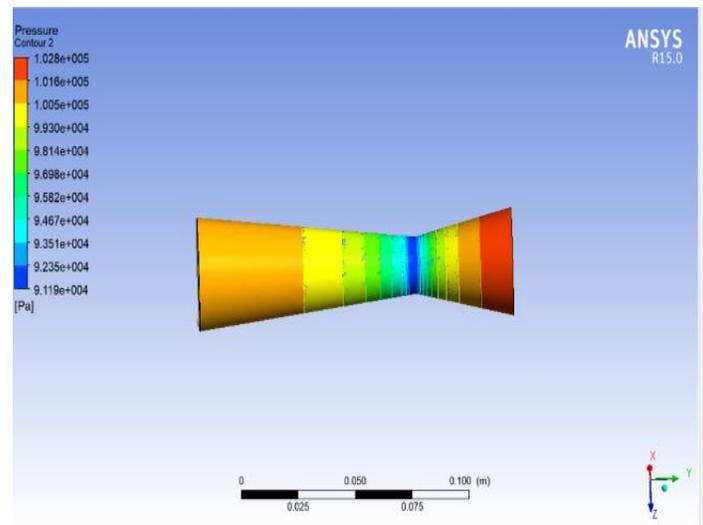


Fig 4 Contours pressure for 1st iteration

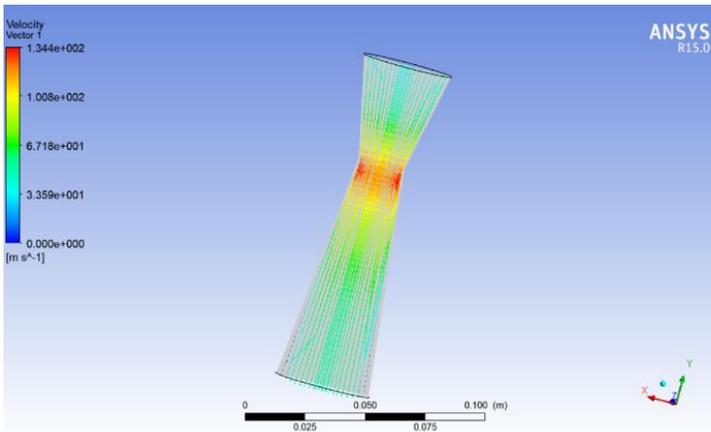


Fig 5 Velocity vector for 1st iteration.

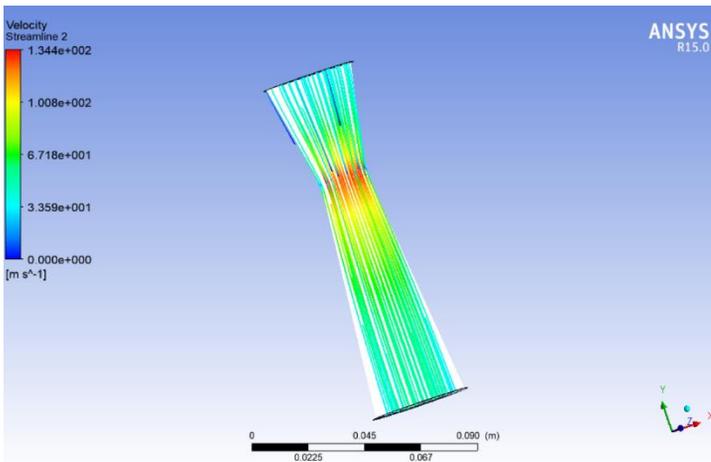


Fig 6 Streamline flow for 1st iteration.

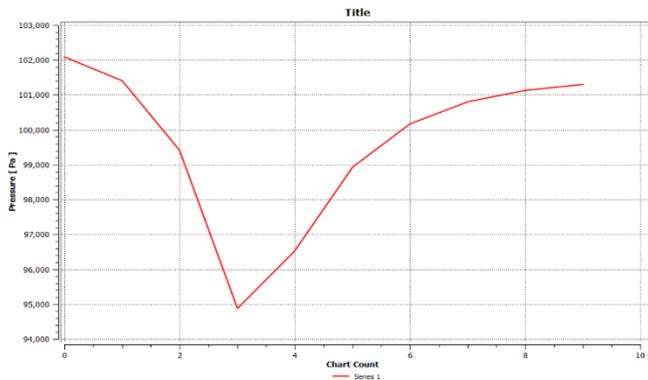


Fig 7 Pressure difference graph for 1st iteration

The graph shows low pressure drop across the venturi increases efficiency.

The converging angle of 12 and diverging angle of 6 and outer diameter of 40mm was found to be the best fit to have an efficient restrictor. If the diverging angle was further increased outlet pressure used to increase and if the inlet converging angle was increased the pressure at the inlet would spike up.

PLENUM

Plenum is a reservoir of air. The air in the plenum makes up for the deficit created by the restrictor. Optimization of plenum volume is key in balancing engine power, mass flow distribution, and throttle response. The shape of the plenum was chosen to be triangular as it improves the stream line flow and reduces turbulence of air. Choosing the correct sized plenum is very important. If the plenum is too small the engine is choked, if it is too large it results in throttle delay. The plenum size was selected to be 1617cc which is 2.7 times the engine displacement. This value of 2.7 times is justified by duke university [5] by experimental methods.

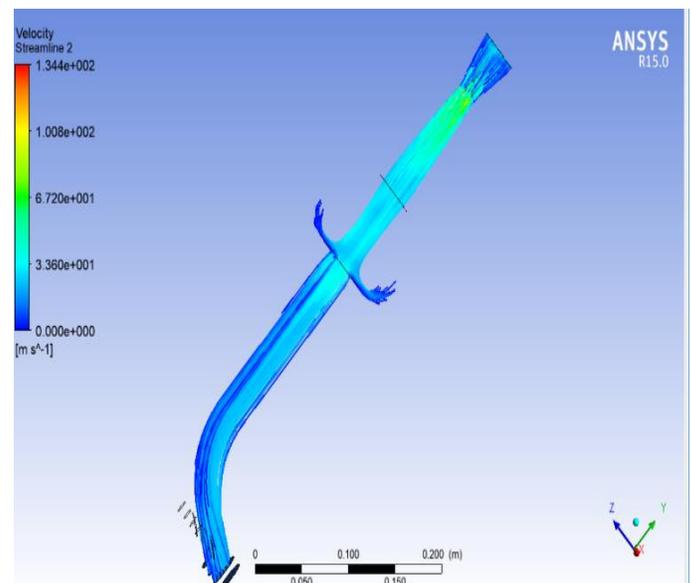


Fig 8 Streamline flow for Intake manifold.

RUNNER

The runner is a hollow cylindrical tube which connects the plenum to the Engine. The diameter of the runner is the same as the engine inlet valve diameter. The runners in an intake manifold hold the key to the position the peak power and torque bands that is the range of engine speeds over which maximum power or torque are obtained. Another aspect of tuned runner is it provides a supercharger effect as explained in S A Elder [3]. The length of the runner plays a very important in attaining efficiency of manifold. It is important to choose the correct power and torque band. This is the range over which maximum power and torque is available. Since this vehicle is used for race purpose a higher RPM of 8000 was selected as explained earlier the air inside the runner undergoes SHM, this is explained by Helmholtz Theory. The inlet valve is closed for a very small interval of time. When the air approaches the inlet valve when it's closed it reflects back to the runner. The reflected pressure wave over shoots the runner due to its momentum. The air pocket is pulls back to the runner. This action is repetitive and at every harmonic the air becomes more turbulent. The runner length can be determined by using organs theory and formation of pressure waves [3,4]. Hence to obtain an efficient runner a length of 289mm was determined where the air enters the Engine at 6th harmonic. Odd harmonics are not selected as pressure ratio and pressure amplitude ratio drops below one.

CONCLUSION

The CFD analysis was performed to multiple design iterations and volumetric efficiency of the manifold has been increased. Maximum efficiency of the restrictor was found at 12-degree converging and 6 degree diverging angle where the pressure drop is least. The plenum was shaped to reduce turbulence and an accurate size was obtained. The runner length was determined to be 289mm and the air enters the combustion chamber at 6th Harmonic.

ACKNOWLEDGEMENT

I would sincerely like to thank Dr. Gowreesh S S, Associate Professor Dept. of Mechanical Engineering, JSS Academy of

technical education, Bangalore for his excellent guidance during this research work and teaching me to use the software and other tools required.

REFERENCES

- 1) Constandi John Shami, "Air Induction Design for Restricted Race Engines", Master's Thesis, Dept. of Mechanical Engineering and Materials Science, Duke University, 2014
- 2) Ryan Ilardo, Christopher B. Williams, "Design and Manufacture of a Formula SAE Intake System using Fused Deposition Modeling and Fiber-Reinforced Composite Materials", International Solid Freeform Fabrication Symposium, 3-5 August 2009, Austin, Texas, USA
- 3) S.A. Elder, "Theory of Organ Pipe Sound Generation", The Journal of Acoustical Society of America 48, 89(1970)
- 4) "Choked Flow of Gases", O'Keefe Control Co., 2003
- 5) M. A. Ceviz, "Intake Plenum Volume and its Influence on the Engine Performance, Cyclic Variability and Emissions", Energy Conversion and Management 48 (2007) 961-966, Elsevier
- 6) P. M. V. Subbarao, "Design Steps for Intake and Exhaust Systems - Acoustic Theory to Maximize Volumetric Efficiency", Indian Institute of Technology - Delhi
- 7) Andre Oh Yide, "Design and Analysis of the Intake System of a Formula SAE Car", Master's Thesis, 2012, Dept. of Mechanical Engineering, National University of Singapore.
- 8) P M Sawanth, S S Sawanth, P N Gaurav, P S Nivalkar and Dr. S N wagmare "Analysis of Air Intake for Formula Student Race Car"
- 9) Pranav Anil Shinde "Research and optimization of intake restrictor for Formula SAE car engine.