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Design and CFD Analysis of Automobile air Intake Manifold

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ABSTRACT: In automotive technology, an intake manifold is the component of an engine that transports the air-fuel mixture to the engine cylinders. The main purpose of the intake manifold is to evenly distribute the combustion mixture to each intake port of the engine cylinder. Even distribution is important to optimize the volumetric efficiency and performance of the engine. The scope of this paper is limited to designing the CAD model of the intake manifold using solidworks software and analysing the air flow inside it using ANSYS fluent CFD package. To do this, four different intake manifolds would be designed wherein, the shape of the plenum would be varied keeping the dimensions of the restrictor and the runners same. Flow would be analysed in each of the different geometries of the intake manifold and the results of each would be compared. After comparing the results of the analysis, the best geometry of the intake manifold that produces the most favourable outlet conditions would then be selected. Design parameters of the intake manifold are to be done by considering formula student (FSAE) rules.

KEYWORDS: Intake manifold, Solidworks, Volumetric efficiency, ANSYS, CFD, Plenum, Restrictor, Runner, FSAE

I. INTRODUCTION

In automotive technology, an intake manifold (in American English) is the component of an engine that transports the air-fuel mixture to the engine cylinders. The term manifold originated from the traditional English word manigfeald (from the Anglo-Saxon manig [many] and feald [fold]) and relates to the folding together of multiple inputs and outputs. The main purpose of the intake manifold is to evenly distribute the combustion mixture to each intake port of the engine cylinder, and to create the air-fuel mixture, unless the engine has direct injection. Even distribution is important to optimize the volumetric efficiency and performance of the engine, the two most desirable techniques was found to increase the volumetric efficiency, and they are intake manifold design and variable valve timing technology for intake and exhaust valves. The design of the variable valve timing technology is quite complex and expensive to produce, and it offers quite less scope of research, thus almost every researchers and automotive industry is focused on improvement of intake manifold.

However, there is always room for enhancement on intake system. The air intake system has seen many reiterations and improvements and substantially increased during the past years by controlling the dimension and shape, and permitting the engine to produce increasing amounts of power by improving their volumetric efficiency, best possible fuel consumption, reduced fuel emissions, and most of the research performed, by automotive researchers and engine manufacturers (i.e. Mazda, BMW, Audi, Ford, Renault etc.). Porsche in the 1980s developed an intake system to use on their vehicles that adjusted the length of the intake system by switching amongst the longer and shorter pair of tube utilizing a butterfly valve, developing some positive pressure, which usually enhances overall performance of the engine. Audi began to use a similar system in some cars in the 1990s and Ford Motor in 1997.

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Nomenclature of Intake

Intake system consists typically of throttle body, restrictor, inlet pipe, plenum, cylinder runner, fuel injectors, air temperature sensor and manifold pressure sensor. It composed of two main parts, in combination with the throttle body, which include the plenum and the cylinder runners. Air enters in to plenum through restrictor due to vacuum created by engine, plenum stores the combustion air as reservoir and then transport the combustion air to engine through the cylinder runner.

i. Plenum: It is storage device which placed between throttle valve and cylinder runner. The function of the plenum is to equalize pressure for more even distribution air-fuel mixture in side combustion chamber, because of irregular supply or demand of the engine cylinder, sometime plenum chamber also work as an acoustic silencer device.

ii. Restrictor (C-D nozzle): Restrictor is part of the intake manifold is similar to what is usually known as a “critical nozzle”, “critical flow venturi”, or “sonic choke”. Such components are often used in practice of industries as simple control devices to control the mass flow rate.

iii. Cylinder Runner: The cylinder runners are the parts of the air intake system which delivers air from plenum to the combustion chamber. In each runner, the principal phenomenon that governs its performance is actually, the effect of acoustic waves. As the purpose of the cylinder runner is distribution of air, performance to transport the maximum amount of air, and in the case of the engine, the successive enhancement in volumetric efficiency.

II. RELATED WORK

1. **E.R.Burnnett(1927)** designed first gaseous-fuel manifold for two stroke cycle internal combustion engines of the type in which no inlet valves are used to controlling for the entrance of gaseous fuel to the pre-compression chamber.

2. **Futakuchi(1984)** designed an improved intake manifold, which enhance both charging and volumetric efficiency of the engine throughout the large range of engine speed and load.

3. **Sattler et al. (1999)** found that, the previous research broken conventional intake manifold into three separate parts, plenum, runner cylinder and a supplement portion.

4. **Davis et al. (2001)** designed multiple stage ram intake manifold for a four-cycle internal combustion engine to minimize imbalances air/fuel ratio and volumetric efficiency.

5. **David Chalet et al. (2011)** studied on inlet manifold of internal combustion engine by frequency modelling of the pressure waves, they perform the simulation of pressure waves on inlet and exhaust manifolds of internal combustion engine, which remains challenging.

III. METHODOLOGY

First, various restrictor models are designed using solidworks software. In the restrictor models, the inlet and outlet diameter are kept constant, which will be equal to the engine specifications. The engine considered in this case is the KTM Duke 390 engine, which is used in two wheelers. The throat diameter of the restrictor is kept at 20mm abiding by the FSAE rules. The only thing varied in the restrictor models is the convergent and divergent angles. The convergent angles have values as 12°, 14°, 16°, 18° and 20°, the divergent angles have values as 4°, 6°, 8°, 10° and 12°. Flow analysis is carried out in these models and the results are compared. After this, the best restrictor model is selected. Now, various plenum shapes are designed which are cylindrical, elliptical, spherical and square in shape. The whole intake is then considered for flow analysis. The outlet boundary conditions are obtained by Ricardo WAVE software. The results of the analysis are compared to then select the best intake geometry giving optimum results.

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IV. RESTRICTOR ANALYSIS

The Mass Flow Rate for choking condition(throat) is given by [10],

$$\dot{m} = \rho VA$$

For an ideal compressible gas,

$$\dot{m} = \frac{Ap_t}{\sqrt{T_t}} \sqrt{\frac{\gamma}{R}} M \left(1 + \frac{\gamma-1}{2} M^2 \right)^{-\frac{\gamma-1}{2(\gamma-1)}}$$

Mass flow rate is maximum when $M = 1$, which is choked condition.

Therefore, putting $M = 1$ in above equation,

$$\dot{m} = \frac{Ap_t}{\sqrt{T_t}} \sqrt{\frac{\gamma}{R}} \left(\frac{\gamma+1}{2} \right)^{-\frac{\gamma-1}{2(\gamma-1)}}$$

From above equation, we can calculate mass flow rate by data values given below:

$M = 1$ (choked flow)

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

$R = 0.286 \text{ KJ/Kg-K}$

$\gamma = 1.4$

$P_t = 101325 \text{ Pa}$

$T = 300 \text{ K}$

Therefore,

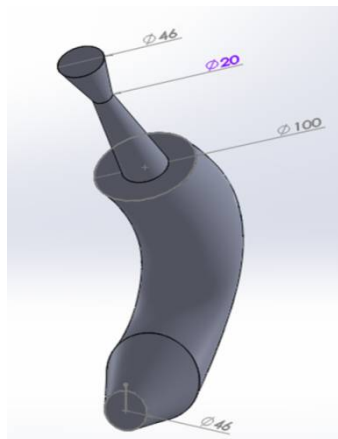
Mass Flow Rate, $\dot{m} = 0.0703 \text{ kg/s}$

Inlet Boundary Condition → Ambient Pressure = 101325 Pa

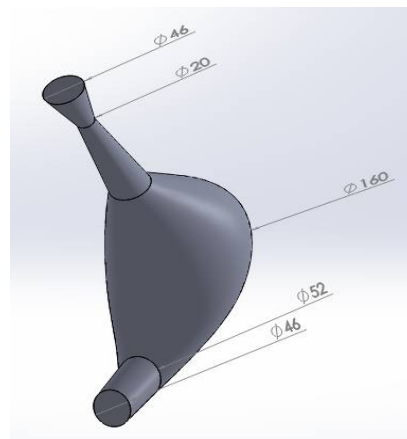
Outlet Boundary Condition → Mass flow rate = 0.0703 kg/s

V. INTAKE MODELS

The next is to select the best plenum geometry. In order to that, four different plenum shapes are modelled, roughly keeping the volume of the models same. The plenum shapes thus considered were, cylindrical, elliptical, spherical and square. These were modelled in solidworks software. After modelling fluid flow analysis was done on ANSYS CFX module.



(a)



(b)

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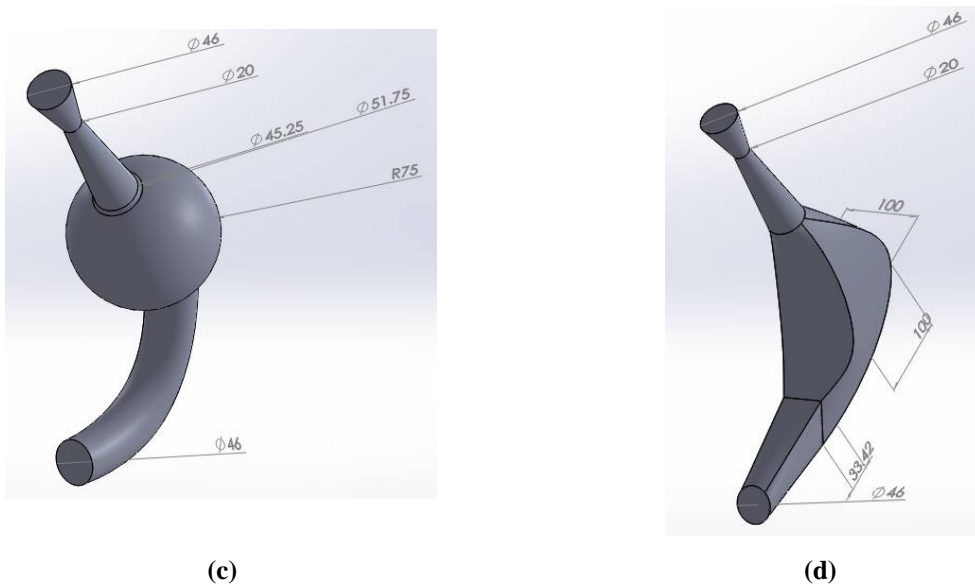


Fig.1 Various Intake Models: (a) Cylindrical Intake, (b) Elliptical Intake, (c) Spherical Intake, (d) Square Intake

Intake Analysis Procedure:

Transient analysis was done on the whole intake geometry using Ansys CFX CFD package.

The static pressure data at the engine inlet, for one whole engine cycle was found from Ricardo WAVE software.

The outlet pressures have values ranging from 0.7 bar to 1 bar.

The analysis time is found by calculating the time for 1 engine cycle at 8500RPM.

Time for 1 engine cycle = $2 \times 60 / 8500 = 0.01411764$ s

Taking 60 timesteps for more accurate results, time for 1 timestep = 0.0002353 s

Inlet Boundary Condition → Ambient Pressure = 101325 Pa

Outlet Boundary Condition → Function defined by the runner data.

VI. RESULTS & DISCUSSION

The static pressures at the throat section and the outlet for the various restrictor models are summarized in the following table. All values are in Pascals.

		DIVERGING				
C O N V E R G I N G	Angles	4°	6°	8°	10°	12°
	12°	75310	75370	74850	74250	73680
	14°	74570	74420	73680	73060	72370
	16°	73800	73280	72480	71730	71270
	18°	72980	72280	71490	70580	69810
	20°	72170	71260	70110	69430	68640

Table1. Static pressure values at throat section

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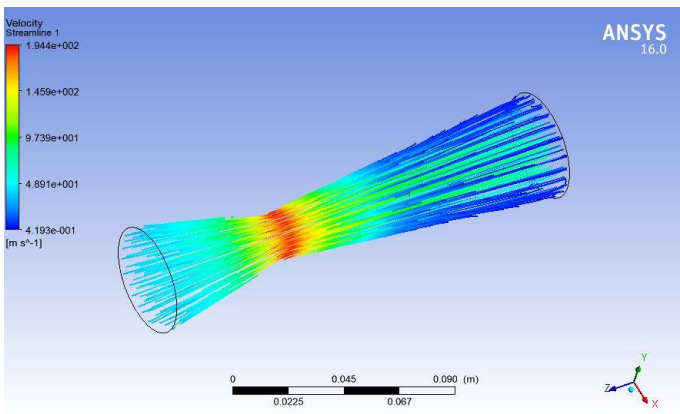
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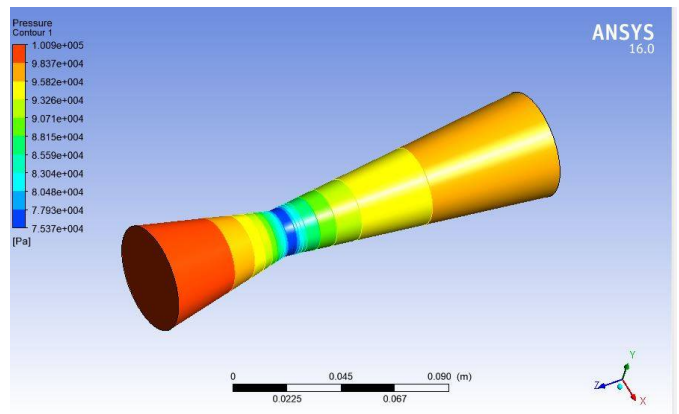
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C O N V E R G I N G	DIVERGING					
	Angles	4°	6°	8°	10°	12°
	12°	98340	98370	98340	95620	95510
	14°	98310	98330	98270	95430	95290
	16°	98280	98260	98200	95200	95120
	18°	98230	98200	98140	95010	94860
	20°	98190	98130	98040	94810	94660

Table2. Static pressure values at outlet



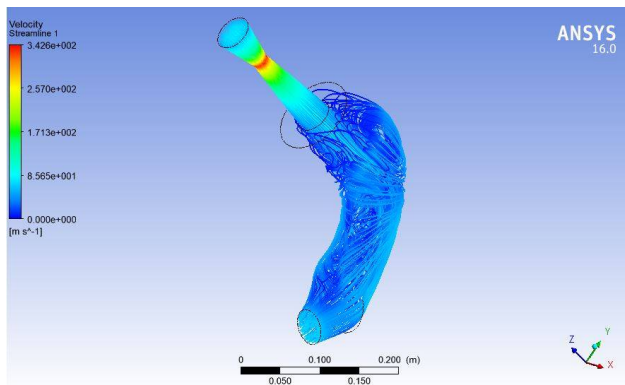
(a)



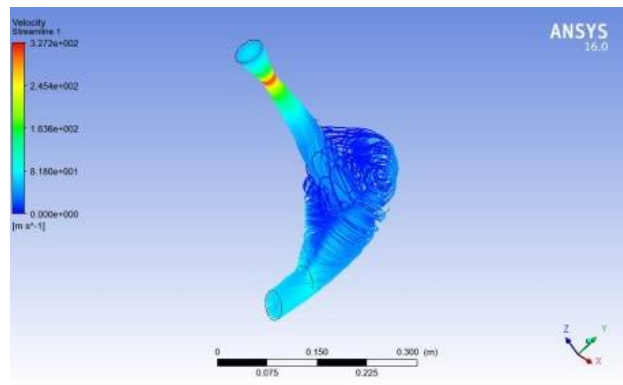
(b)

Fig.2 Fluid flow analysis of restrictor with 12° converging and 6° diverging angles (a) Velocity streamline, (b) Pressure Contour

The results of the transient fluid flow analysis on the intake geometries are as follows:



(a)



(b)

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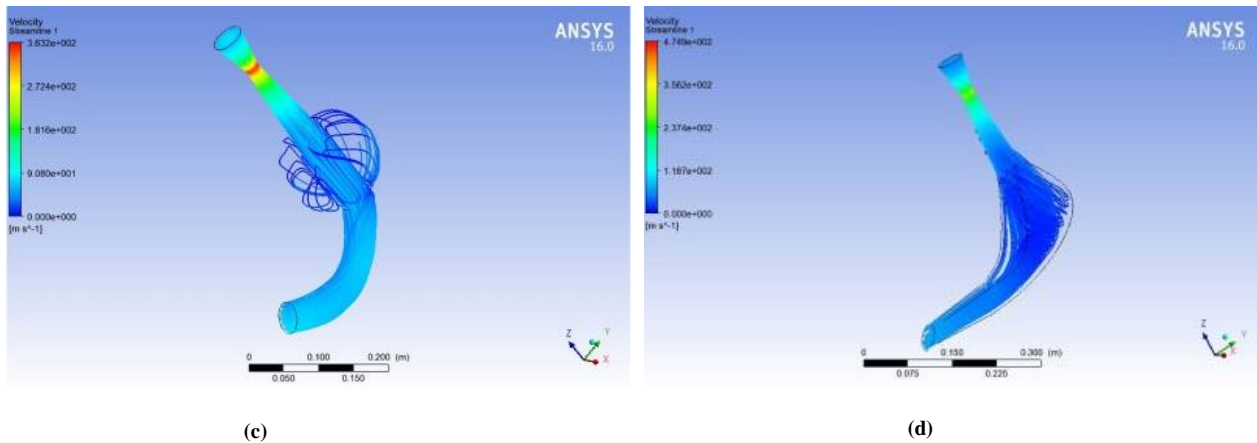


Fig.3 Velocity streamlines of different intake geometries (a) Cylindrical Plenum, (b) Elliptical Plenum, (c) Spherical Plenum, (d) Square Plenum

From the figures 2 and 3, we can make conclusions about the fluid flow in the restrictor model and the intake models respectively. In the figure 2, we can see that the restrictor model with 12° and 6° convergent and divergent angles respectively has the lowest pressure drop and fits our objective perfectly. Also this model is easy to manufacture. From the figure 3, the velocity streamline of the fluid, which is air in our case, can be seen. In order to select the best intake model, we want the vortices created in the plenum to be minimum and the velocity of central flow to be maximum. Also, the pressure drop in the intake should be less.

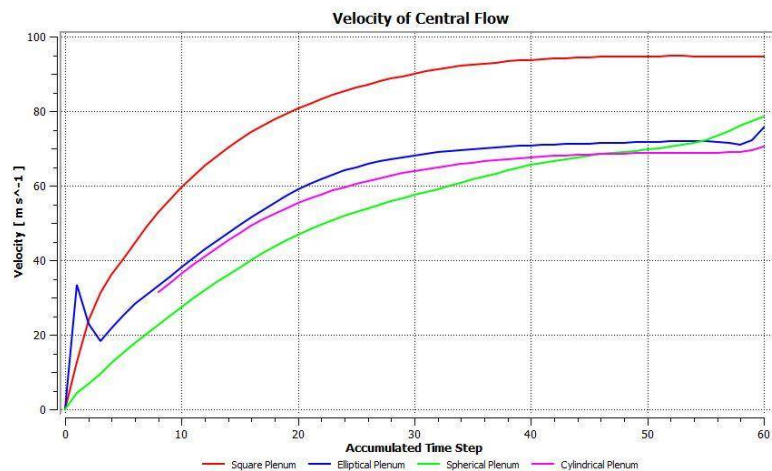


Fig.4 Comparative graph depicting the central flow velocities of different intakes

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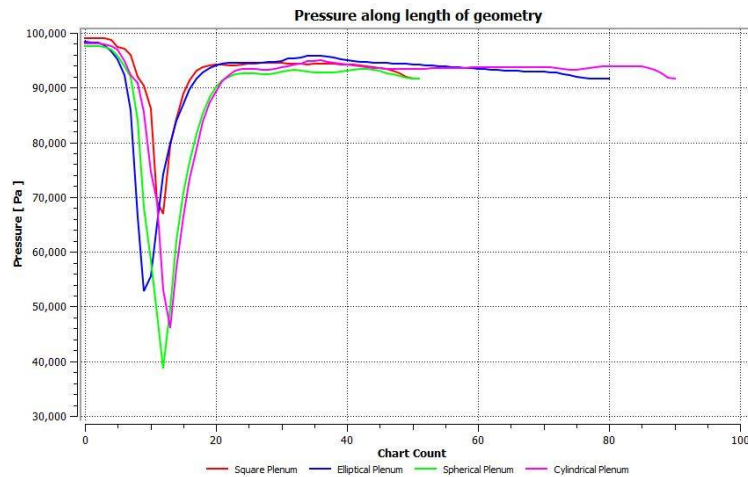


Fig.5 Comparative graph depicting the pressure drop along the length of different intakes

Optimum runner length calculation:

The formula for optimum intake runner length (L) according to induction wave theory is:

$$L = (EVCD * 0.25 * V * 2 / RPM * RV) - (0.5 * \text{runner diameter})$$

Where,

L = Runner Length

EVCD = Effective Valve Closed Duration

V = Pressure Wave Speed

RV = Reflective Value = 4

$$EVCD = (726^\circ - 226^\circ + 20^\circ) = 514^\circ \quad \{20^\circ \text{ is added to get effective valve open duration}\}$$

V = 1152 ft/s

RPM = 8500

Runner Diameter = 1.81102 inch {Diameter of throttle body on engine}

Therefore,

$$\text{Optimum intake runner length (L)} = 352.806 \text{ mm}$$

VII. CONCLUSIONS

From the results obtained from the restrictor analysis, it can be inferred that the restrictor model in which the pressure loss observed is minimum, is the best restrictor model. In this case the restrictor with converging and diverging angles as 12° and 6° respectively has the minimum pressure loss, so we considered it to be the ideal restrictor model.

After transient analysis, velocity vectors in different plenum shapes are compared. In square plenum, central high velocity flow has wider flow area, as fewer vortices are created. Also, velocity values are higher for this central flow in square plenum when compared with other shapes. Therefore, this geometry of the intake is considered to be best model. It is observed that engine performance at higher speeds improves with increase in plenum volume (torque peak shifts towards higher engine speeds). However, as design is primarily targeted at lower speed range of 4000 to 6000rpm, volume twice the engine displacement is best solution. The optimum runner length has been obtained by the calculations shown before and its value is $L = 352.806 \text{ mm}$. The runner diameter has been taken as 46mm since it is the diameter of the throttle body and it accounts in ease of manufacturability of the model.

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