Analysis of Intake Manifold Using Computational Fluid Dynamics

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Abstract- *An inlet manifold or intake manifold is the part of an engine that supplies the fuel/air mixture to the cylinders. The intake manifold is essential for the optimal performance of an internal combustion engine. The objective of present paper is to predict and analyze the flow through intake manifold of four cylinder spark ignition engine. One of the important factors is air flow inside the intake manifold; the ideal intake manifold distributes flow evenly to the piston valves. Even distribution is important to optimize the efficiency of the engine. Hence the flow phenomenon inside the intake manifold should be fully optimized to produce more engine power with better combustion and further reduces the emission.*

Keywords- Intake Manifold, Plenum, Restrictor, Cylinder Runner, Volumetric Efficiency, Computational Fluid Dynamics.

I. INTRODUCTION

An engine intake manifold is the part of the engine, between the throttle body and the engine cylinders. In a multi-cylinder engine, the primary function of the intake manifold is to transport combustion air to the engine cylinder, and to create the fuel air mixture, unless the engine has direct injection. The intake manifold controls how much air can be drawn through, including the effects both in steady state and transients, how fast that air is moving, and how well it can be mixed with fuel, and restriction of the 20mm set how much mass of air can flow inside engine cylinder. Because the throat area of restrictor determines exactly the mass air flow, it has a large influence on engine volumetric efficiency.

An intake manifold is one of the primary components regarding the performance of an internal combustion engine. An intake manifold is usually made up of a plenum inlet duct, connected to the plenum are runners depending on the number of cylinders which leads to the engine cylinder. Intake manifolds have to be designed to improve engine performance by avoiding the phenomena like inter-cylinder robbery of charge, inertia of the flow in the individual branch pipes, resonance of the air masses in the pipes and the Helmholtz effect. Tuning the intake manifold means the intake runners are of proper size and length to produce the highest possible pressure in the cylinder when the intake valve closes. S.Karthikeyan[1] shows, pressure waves for the intake manifold is simulated using 1D AVL-Boost software, to study the internal air flow characteristic for the 3-cylinder diesel engine during transient conditions.

Fluid Flow through Duct and Pipe

An intake manifold is ostensibly a network of pipes and ducts which feed air into the engine to feed the combustion process. As such it is open to analysis and optimization as any network of pipes and ducts may be. One well documented and theorized section of pipe flows involves a head loss, or pressure loss due to certain geometries within the flow, specifically for bends, valves, entrance and re-entrance flows. Another well researched characteristic of pipe flow is velocity profiles for both turbulent and laminar flows.

Pressure Losses in Pipes

Pressure losses in pipes are split into two categories, major and minor. Major losses occur due to the physical length of the pipe and the viscous losses associated with the friction between the wall and the fluid. Minor losses occur due to variations in geometry through the piping such as bends, elbows, valves, entrances and re-entrances. The terms major and minor do not refer to the relative sizes of the losses necessarily, but in typical piping systems involving many long straight sections with few bends and valves the major losses are more substantial than the minor. In the case of an intake manifold however, the minor losses are far more significant, and typically dominate the pressure losses experienced. Several text books quote pressure loss coefficients for various geometries whether they be entrances, re- entrances, bends or valves. While these particular values are important in an analysis of a pipe system their values are not important specifically for the design of a new intake, but their relative size is.

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.

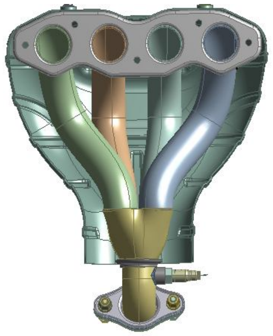

Fig 1: Intake manifold model with highlight (a) Inlet (b) Plenum (c) Cylinder Runner (d) outlets

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. There are two types of intake manifold on the basis of manifold dimension, fixed length intake manifold and variable length intake manifold.

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. All such type of devices will be discussed to as ―restrictors‖ throughout the rest of this report. Excessive pressure losses caused by the high flow velocities.

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 thepurpose 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. LITERATURE REVIEW

Burtnett (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 gaseousfuel to the pre-compression chamber. The determination of this invention was toimprovethe volumetric efficiency of the engine. As result of this invention, the quick demand developed by suction stroke from one of the pistons within the engine, the gaseous fuel volume within the manifold does not cause an unexpected or unusual of velocity and pressure on the carburetor.

Sullivan (1939) designed an improved intake manifold for and method of supplying fuel mixture to combustion chamber to improve the volumetric efficiency of the engine. One of the goal of the research was to offer comparatively short passages splitting without any obstructions passage for flow of the fuel mixture on all cylinders of an engine of this nature and that therefore, affords free breathing action, another goal of the research was to provide a manifold of such kind in which the air-fuel ratio produced by carburation means remains same throughout the intake manifold.

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. He found that the efficiency of the engine intake and combustion, especially at low and medium speeds can be improved by providing an auxiliary intake that communicates with the combustion chamber and that had a relatively small effective area. He found that such auxiliary intakes to result in a high velocity and turbulence in the combustion chamber at ignition time and that improve flame propagation and engine running. These devices also improve the efficiency of load to minimize pulsations in the intake system.

Sattler et al. (1999) found that, the previous research broken conventional intake manifold into three separate parts, plenum, runner cylinder and a supplement portion. Since a fixed runner length can be tuned optimally for a particular engine speed. In order to overcome this, a continuously adjustable runner length was needed to design. So that, they designed continuously adjustable runner length manifold for an internal combustion engine. Incorporating the purpose of a plenum, supplement flange, and continuously adjustable length runner into a plastic box designed from distinct shaped sections. The alternating or pulsating nature flow of the air through the manifold into each cylinder may create resonances (analogous to the vibrations in structure pipes) in the flow of air at specific speeds, This may increase volumetric efficiency and hence the power at certain engine speed but may reduce the efficiency at other speeds, depending on the dimensions and shape of the manifold.

Stuart (2005) further proceed the research of Sattler et al. [1999] and Davis et al. [2001] and, He designed a continuously variable intake manifold with an flexible plenum, which communicates with intake manifold of the internal combustion engine, and mainly to an intake manifold having an flexible plenum to offer adjustable runner length during engine operation. The intake manifold assembly was including a plenum volume at that time and mounted for movement within housing. There was movement of the plenum within the housing in order to response to a drive system to define an effective runner length. A multiple of deformable runner passage was including a flexible section such that the plenum can retract and extend within the housing, the flexible section provide the variation in length while structural support provided by the housing.

Ceviz et al. (2010) further proceed the research of Sattler et al. [1999], Stuart [2005] and Ceviz [2006] and, he studied the effects of variable intake plenum length on the engine performance characteristics of a SI engine with MPFI system using electronically controlled fuel injectors. He describes that, the intake manifold only transport the air from plenum to engine cylinder whereas, the fuel was injected onto the intake valve, the and also found that supercharging effects of the variable length intake plenum will be different from carbureted engine. He carried out the engine test with the purpose of establishing a base study to design a new variable length intake manifold plenum. He takes consideration of Engine performance characteristics such as brake torque; brake power, thermal efficiency and specific fuel consumption into to estimate the effects of the different length of intake plenum. According to the test results, as the engine speed increases, the plenum is driven to shorten the deformable runner for maximum speed operation and also shows that the improvement on the engine performance characteristics caused by the variation in the intake plenum length, especially on the fuel consumption at low engine speed and high load which are put forward the system using for urban roads.

III. STEPS INVOLVED IN ANSYS

In general, a finite element solution can be broken into the following these categories.

1. **Preprocessing module***:* Defining the problem

The major steps in pre-processing are given below

- defining key points /lines/areas/volumes
- define element type and material /geometric /properties
- mesh lines/areas/volumes/are required

The amount of detail required will depend on the dimensionality of the analysis (i.e. 1D, 2D, axis, symmetric)

2. **Solution processor module***:* assigning the loads ,constraints and solving

Here we specify the loads (point or pressure), constraints (translation, rotational) and finally solve the resulting set of equations.

3. **Post processing module***:* further processing and viewing of results

In this stage we can see:

- List of nodal displacement
- Elements forces and moments
- Deflection plots
- Stress contour diagrams

IV. WORKBENCH MODEL

Geometry is created in ANSYS workbench.

Table 1. Dimensions of intake manifold

Section	Diameter (mm)
Intake	51
Outlet 1	52
Outlet 2	52
Outlet 3	52
Outlet 4	52

Table 2. Material properties

Aluminum properties	
Youngs' modulus	7e+010N-m2
Poisson's ratio	0.346
Density	2710 kg/m^3
Coefficient of thermal expansion	2.36e^{-5} /^{0}K
Yield strength	9.5e^7 N-m^2

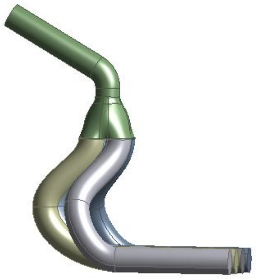

Fig. 2: Manifold Geometry side view

V. MESHING AND BOUNDARY CONDITIONS

Meshing: The accuracy of the results depends highly upon the mesh quality. Thus the choice of meshing scheme (grid pattern) is very important for fluent to provide accurate results. For doing simulation of the intake manifold model we have to do first meshing ,in this technique the flow domain is converted or split into various subdomain primitives like hexahedral and tetrahedral. Care must be taken to ensure proper continuity of solution across the common interfaces between two subdomains, so that the approximate solutions inside various portions can be put together to give a complete picture of fluid flow in the entire domain. We use the tetrahedral mesh for this purpose which imposed on model. Fig. 3 shows the mesh of intake manifold.

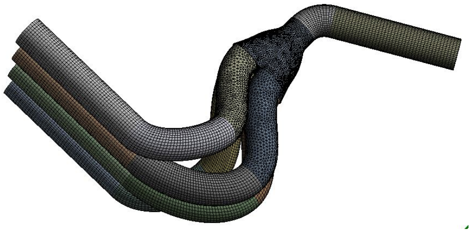

Fig 3: Mesh of intake manifold

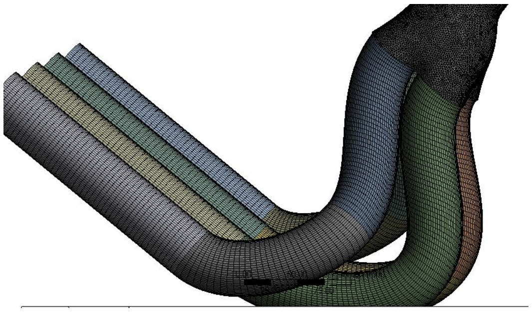

Fig 4: Refined mesh

Table 3. Mesh details

Nodes	149696
Elements	215742
Skewness	0.9

Boundary conditions

Boundary conditions are essential to do a simulation. In this problem inlet is open to atmosphere and at outlet suction pressure will act due to pistons down motion. So inlet is chosen as Mass flow rate and outlet is chosen as pressure outlet. In the Turbulent – specification method needs to choose Intensity and length scale. Turbulent intensity value is assumed as per standard CFD assumption. Turbulent length scale value is assumed as 5% of inlet diameter as per standard CFD assumption. Remaining is needed to keep it as default for this problem.

Table 4. Boundary conditions

Mass flow rate at flow inlet	0.12 kg/ms
outlet	pascals
Hydraulic diameter	100mm
Turbulence intensity	5%
Pressure at runner outlet	-101325 pascals

VI. RESULTS AND DISCUSSION

The steady state analysis has been carried out for three different conditions for all the Intake Manifold Designs.

1. All runners Open
2. 1st & 3rd runner open
3. 2nd & 4th runner open.

1. CASE 1: All runners open

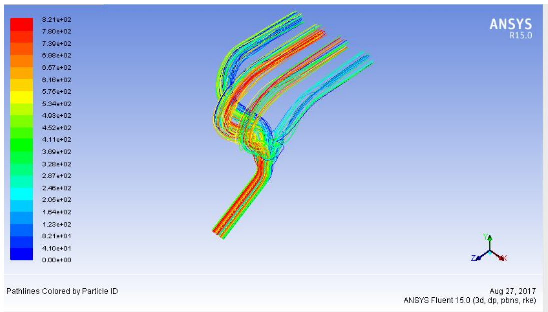

Fig 5: Streamlines (all runners open)

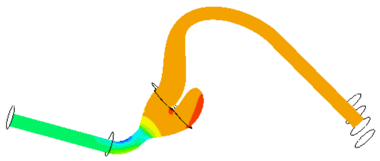

Fig 6: Pressure contour (all runners open)

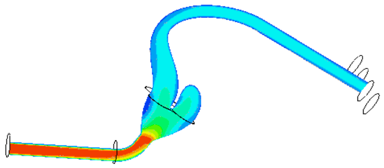

Fig 7: Velocity Contour (all runners open)

Fig. 6 & 7 shows the velocity and pressure contours for all runners open. It is observed that velocity drops as the flow proceeds through the plenum chamber. This is due to sudden increase of the area within the plenum.

2. CASE 2: 1st & 3rd runners open:

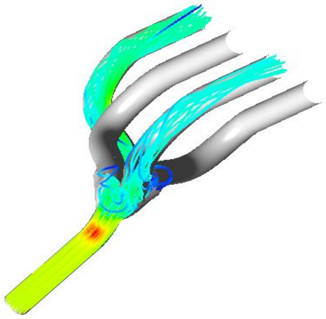

Fig 8: Streamlines (1st & 3rd runners open)

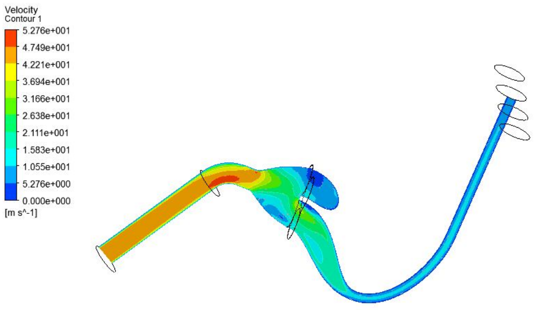

Fig 9: Pressure contour (1st & 3rd runners open)

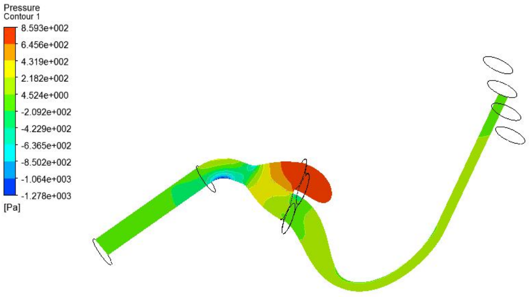

Fig 10: velocity contour (1st & 3rd runners open)

When 1st and 3rd runners are open, then the other two runners i.e. 2nd and 4th are considered as wall in the named selection so that there will be no flow in those runners.
From Fig. 9 & 10 it is observed that when runner 1st and 3rd are open the velocity distribution from plenum to the 1st and 3rd runner is uniform due to good geometry.

3. CASE 3: 2nd & 4th runners open

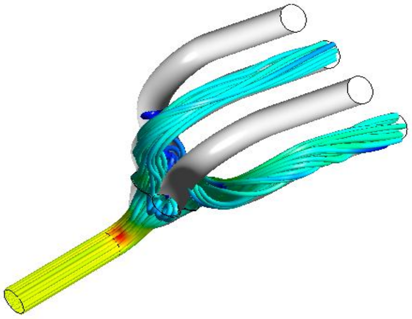

Fig 11: Streamlines (2nd & 4th runners open)

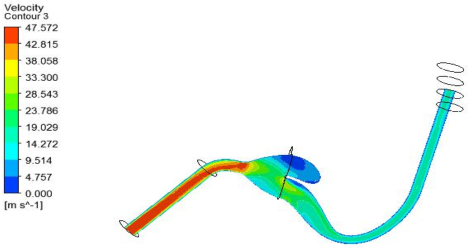

Fig 12: Velocity Contour (2nd & 4th runners open)

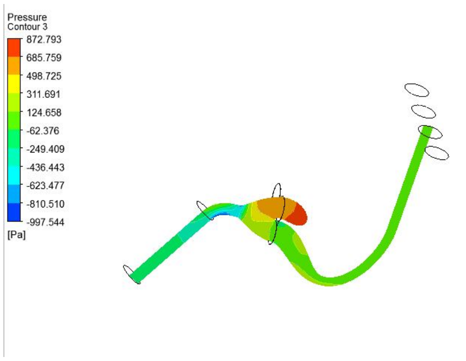

Fig 13: Pressure Contour (2nd & 4th runners open)

Fig. 12& 13 shows thatWhen 2nd and 4th runners are open, then the other two runners i.e. 1st and 3rd are considered as wall in the named selection so that there will be no flow in those runners. Here also we can see that the flow is uniform.

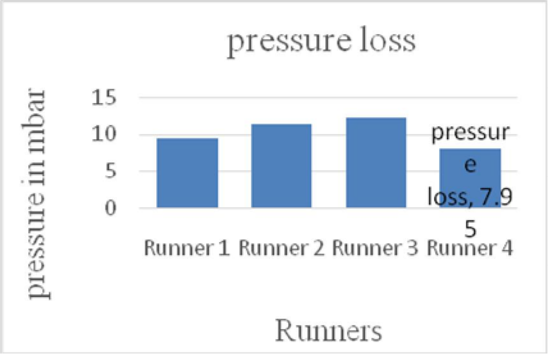

Fig 14: Total Pressure loss of all Runners

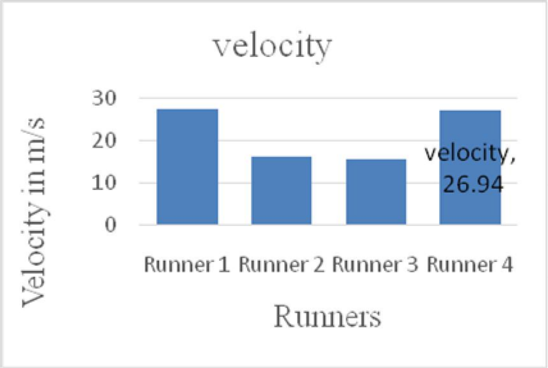

Fig 15: velocities at diff Runners

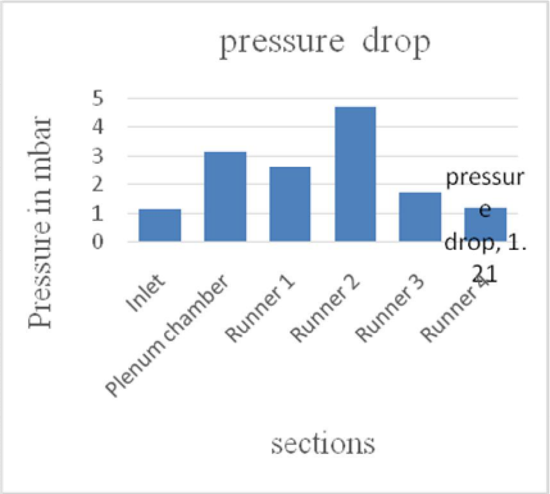

Fig 16: pressure drop at diff sections

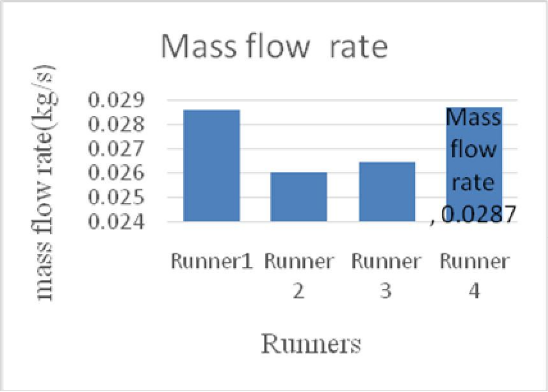

Fig 17: Mass flow rate at diff Runners

From figs [14], [15], [16] and [17], it is observed that the pressure loss at all the runners is less and is nearly equal, and velocities are also equal and pressure drops at different sections is less and has uniform mass flow rate at all the runners.

By simulating all the various design parameters, a significantly improved design was obtained as shown. The improved design has a much higher mass flow rate which in turn helps increase the performance of the engine. Furthermore, the flow distribution between all four cylinders is near equal which will also help improve the volumetric efficiency of each cylinder.

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