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Design and Analysis of Multi Port Fuel Injection CNG Engine Manifold System

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Abstract - *The Intake Manifold system plays a crucial role to improve performance of the Internal Combustion Engine. Engine power, torque and volumetric efficiency are greatly affected by geometric aspect of intake manifold. The purpose of the intake manifold is to distribute Air-Fuel mixture uniformly for all cylinders. The paper aims to design Intake Manifold and investigate the effects of its runner length and runner diameter on the performance of the CNG multi point fuel injection Engine. The intake manifold is designed and modelled using pressure wave tuning theory. The Air-Fuel mixture is evaluated using Computational Fluid Dynamics analysis based on uniformity index. The performance of the Engine is estimated using 1D simulation software and the simulation results are compared with Experimental result.*

***Key Words*: Intake manifold, MPFI, Design of runner length and diameter, CFD, Uniformity Index**

1. INTRODUCTION

In Internal Combustion engine the intake manifold is the part of the engine between the Cylinders and the throttle body. In a multi-cylinder engine its primary purpose is to evenly distribute the air flow between each cylinder, and to create the homogeneous fuel air mixture. The mass flow rate of air which is entering in the engines cylinders plays a large impact on the volumetric efficiency. There are two types of fuel injection systems Single Point Fuel Injection (SPFI) and Multi Point Fuel Injection (MPFI) System. Multi-point, or multi-port is when there is a fuel injector for each cylinder and they are located as close as possible to the intake valve. These systems allow the engine management computer to hit a desired air fuel ratio very accurately for each cylinder. Multipoint fuel injection devotes a separate injector nozzle to each cylinder, right outside its intake port, which is why the system is sometimes called port injection. Shooting the fuel vapour this close to the intake port almost ensures that it will be drawn completely into the cylinder. The main advantage is that MPFI meters fuel more precisely than do TBI designs, better achieving the desired air-fuel ratio and improving all related aspects.

V. S. Midhun et.al [1] have discussed methodology for conversion of diesel engine to CNG engine and to make the engine to meet BS VI norms. For that primary modifications are made on piston, cylinder head, intake manifold, throttle body adaptation and exhaust system. Two different configurations like SPFI Injection and MPFI Injection were evaluated. In the initial trial 1.1 *l* intake manifold was used to develop power greater than 55 kW. When manifold volume increased by 4.6 *l* there was increased in the power and torque. Engine has showed that there is slight improvement in power in MPFI configuration as compared to SPFI one. Ishant gupta et.al [2] have carried out the theoretical study on MPFI System and its advantages on the SPFI System. The researchers have elaborated all the components and functions of MPFI System. Advantages and problems of MPFI System over SPFI System have been discussed.

M. A. Ceviz et.al [3] have investigated the effect of intake plenum length on the performance of spark ignited engine. Engine test have been carried out for different plenum length. It is observed that plenum length must be extended for low engine speeds and shortened as engine speed increases. L. J. Hamilton et.al [4] have carried out testing of various runner length and cross section geometries on a Honda CBR600 F4i gasoline engine. Also the effect of adding 180 degree bends to intake runners is evaluated. It is observed that the 0.25 to 0.45 is the optimum runner length for the application.

Shrinath Potul et.al [5] have investigated the effect of intake runner length on the performance of four stroke, single cylinder spark ignited engine. They have described basic intake tuning mechanism. LOTUS ENGINE SIMULATION software was used to evaluate the effect of the variation in the length of intake plenum. Plenum length must be extended for low engine speed in order to increase torque performance. Bayas Jagadishsingh G et.al [6] have carried out 1D simulation of engine on Lotus engine simulation to predict effect of intake manifold length on single cylinder four stroke IC engine. They have concluded that the volumetric efficiency of engine increased by varying intake length and at different speed of engine the brake power improved.

Chawin Chantharasenawong et.al [7] have designed variable length intake manifold using pressure wave tuning theory. Computers simulation are performed to calculate the pressure at various runner length. Chassis dynamometer test have been performed to determine the engine torque for 3000 to 10500 rpm. Shashank Ghodke et.al [8] have worked on the intake runner diameter and valve timing of manifold system by individually varying them. simulation were carried out using Engine simulation software Ricardo wave to find the effect of intake runner diameter and timing on the engine performance and the results are compared with chassis dyno test results.

Dileep Namdeorao Malkhede et.al [9] have investigated the effect of intake length for different speed of the Engine on volumetric efficiency. 1-D simulation was carried out to predict the pressure wave at two different locations on intake manifold and compared with test data. Michal Bialy et.al [10] have carried out CFD analysis of Engine head with different CNG injector location to demonstrate air fuel stratification using Influence of the injector nozzle position. Several authors have investigated the effect of intake runner length and diameter on the performance of Engine by using 1D Simulation model [3, 5, 6, 8, 9]. The effect of runner length on the uniformity index is estimated by CFD analysis [1, 7, 9, 10]. The main aim of the proposed work is to study the design of MPFI Intake manifold system and the effect of runner length and diameter on the engine performance using 3D CFD analysis. Another application of this study is the observation of the streamline inside the manifold. Performance of the engine is estimated using 1D Simulation model and the results are validated with experimental results. The work has been carried out on a 6 cylinder CNG Engine of 6 liter capacity. This produces a power of 130 HP at 2400 rpm.

2. INTAKE TUNING THEORY

There are two types of waves (compression and rarefaction) formed when the Inlet valve gets open and close. These waves are fundamentally importance for engine breathability. The singular waves are formed when the flow of the mixture strikes the valve when it closes and when it opens compression wave travels back and forth by the intake runner. These waves are used in internal combustion engines (ICE) to increase the volumetric efficiency of the engine through tuning theory. The rarefaction wave is formed at the moment of suction of the engine and when a compression wave reflects back on an obstacle. This type of wave is widely used to improve the scavenging of the exhaust gases. By taking advantage of these two waves, it is possible to obtain an overload at the moment of the admission and even achieve volumetric efficiencies higher than 100%.

There are three types of intake tuning theory Chrysler Ram Theory, Helmholtz Resonator Theory and Pressure wave tuning theory. Chrysler Ram Theory says the air flow dynamics inside the inlet manifold is alike unless the inlet valve closes. When the intake valve closes the gas dynamics gets disturbed. This highly pressurized wave keeps on oscillating in the intake manifold unless the inlet valve opens, if we tune the inlet manifold length properly this highly pressurized wave will enter the cylinder when the inlet valve opens after oscillating in the inlet manifold. In Helmholtz Resonator Theory it is considered that the volume of air inside the intake manifold acts like a spring. Which means that as when force is applied on spring its get compressed and it expands on removal of force. Air also acts like a spring which gets compressed when the inlet valve closes and it gets expanded when the inlet valve opens. The air is considered as mass inside the combustion chamber. At mid stroke effective volume is considered to be the cylinder volume

3. DESIGN OF MULTI POINT FUEL INJECTION SYSTEM

The runner length is determined using the pressure wave tuning method which is based on utilizing the pressure wave pulses produced by the valve timing. The adjusted runner length, *L*, provides a supercharge effect of air in the cylinder and therefore increases volumetric efficiency as described by the equation.

$$L = \left(\frac{ECD * 0.0127 * V}{rpm * RV}\right) - \frac{1}{2}D \qquad (1)$$

Where, ECD is the effective cam duration in degrees, V is the speed of sound at intake temperature in meter per second , RV is the reflective value (count of each pulse from one end of pipe and back), D is the runner diameter in meter

4. EFFECT OF RUNNER LENGTH ON UNIFORMITY INDEX

This section deals with the prediction of the uniformity index of Air-Fuel mixture induced in the Intake manifold. The analytical design of intake manifold has been done by using pressure wave tuning theory. The existing CNG Engine MPFI System is modeled using CATIA software. The assembly of manifold system consists of plenum, hub, throttle body, Runners; these are created separately and assembled by applying appropriate tolerances and constraints.

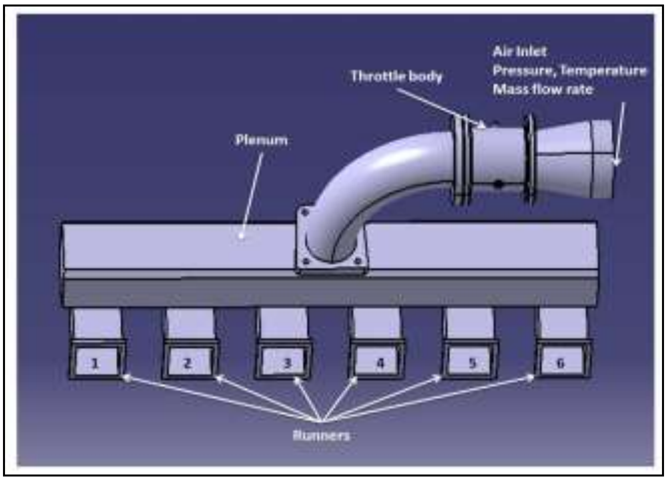

Fig-1: Multi Point Fuel Injection Manifold System

The CAD model is saved in STP file and imported into ANSYS environment. The imported geometry was then cleaned for its missing line, gap filling and ambiguous sections etc. Imported and meshed cleaned geometry is meshed with tetrahedral element having 0.5mm minimum size and 40mm maximum size of the element.

The minimum size of meshing has been generated at the critical part of the geometry. Tetrahedral elements can fit better complex geometry. The type and size is decided based on suitability and type of analysis. Meshed Intake manifold system consists of 174012 elements and 928472 nodes.

Different boundary conditions are provided at inlet of the manifold and outlet of the runners. Ambient pressure and temperature is given at Air inlet and CNG inlet. Mass flow rate are provided 0.09638 kg/s at air inlet and 0.005608kg/s at CNG inlet during analysis. When suction stroke occurs piston sucks air through manifold so the negative pressure comes at the outlet of the manifold which is -3600 Pascal.

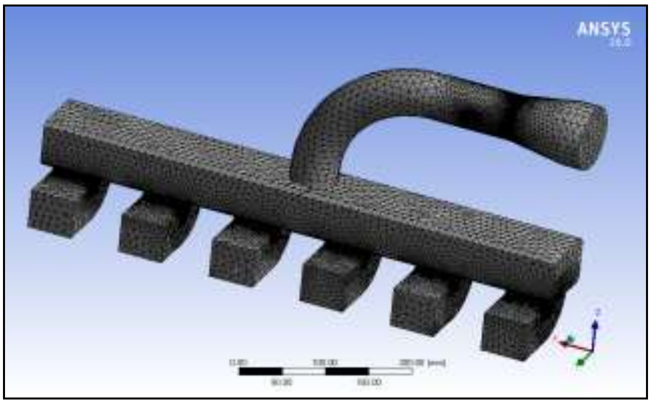

Fig-2: Meshed geometry of MPFI Manifold System

To verify the velocity distribution and uniformity index of the Air\Fuel mixture computational fluid dynamics of manifold system has been carried out. A three dimensional CFD model has been built in order to accomplished the targets involved. All the relevant aspects of the flow have been taken into account and fully incompressible viscous flow simulation with turbulence modeling for steady state condition has been performed. k-ε model has been employed to model turbulence phenomenon.

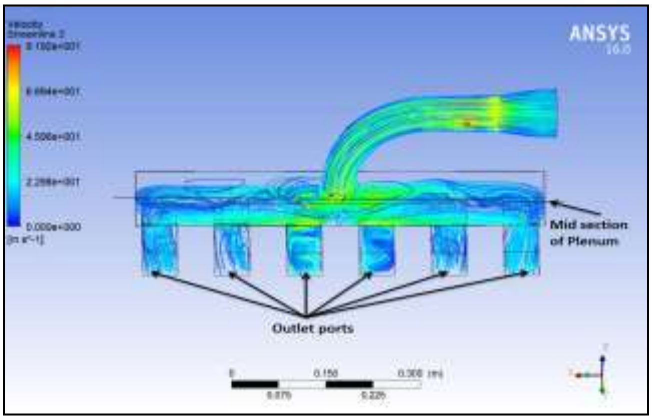

Fig-3: Velocity streamline for MPFI Manifold System

From above result it is found that the flow uniformity index at outlet of each runner is 0.7290 and the maximum velocity magnitude in the manifold is 91.92 m/s. It is observed that the streamlines are more turbulent in the region of cylinder 1, 3, 4, 5 and 6. It is observed that the cylinder no 2 is having less Air-Fuel mixture than the other cylinders. The streamlines are laminar in the region of hub, throttle body and pipe. It is seen that the velocity is more for the runner no 3 and 4 because these runners are near to the hub. so from velocity magnitude it can be conclude that the runner 3and 4 are having more turbulent mixture than other runners.

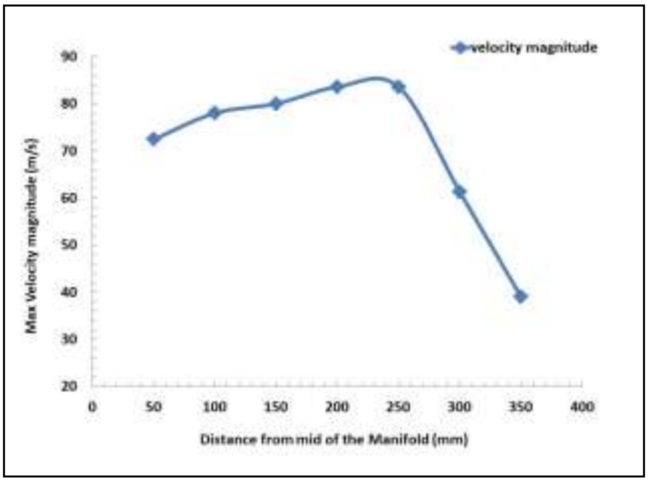

Fig-4: Velocity magnitude representation for different section of hub and pipe

Fig 4 shows the velocity magnitude for different injection location over different section of hub and throttle body.it is observed that for every section of area the velocity magnitude is different. It is seen that the velocity magnitude is more in the region of throttle body. The throttle shaft and throttle plate provide restriction to the flow of intake air. This increases velocity at the outlet of throttle body.

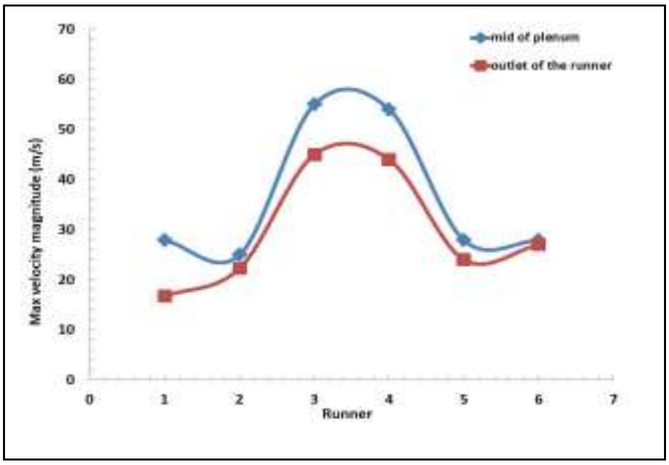

Fig-5: velocity magnitude in the region of plenum and runner

Fig 5 shows the maximum velocity magnitude over the plenum for different runners. It is seen that the velocity is more for the runner no 3 and 4 because these runners are near to the hub. 1, 2, 5, 6 runners are away from hub due to that Velocity is less for these runners.so from velocity magnitude it can be conclude that the runner 3and 4 are having more turbulent mixture than other runners.

5. PERFORMANCE PREDICTION FOR CNG SPFI AND MPFI ENGINE

GT Power is effective tool used in industry to perform 1D simulation so the benchmarked data is used to prepare GT-Model. Figure shows the 1D model which is used for simulation of SPFI and modified SPFI Engine to validate Engine power, Engine torque and break specific fuel consumption of the engine. The intake manifold details are also given so the précised performance of the engine is traced. The Existing injector position 175 mm is used in the model. From the results, we can conclude that the power, torque parameters of the CNG engine are within acceptable limits for the simulated results. The model now can used to predict engine performance for engine.

Same benchmarked data has been used to prepare MPFI GT-Model. The Newly Designed intake manifold details are also given so the précised performance of the engine is traced. From the results, we can conclude that the power, torque parameters of the CNG engine are within acceptable limits for the simulated results. The model now can used to predict engine performance for CNG Engine.

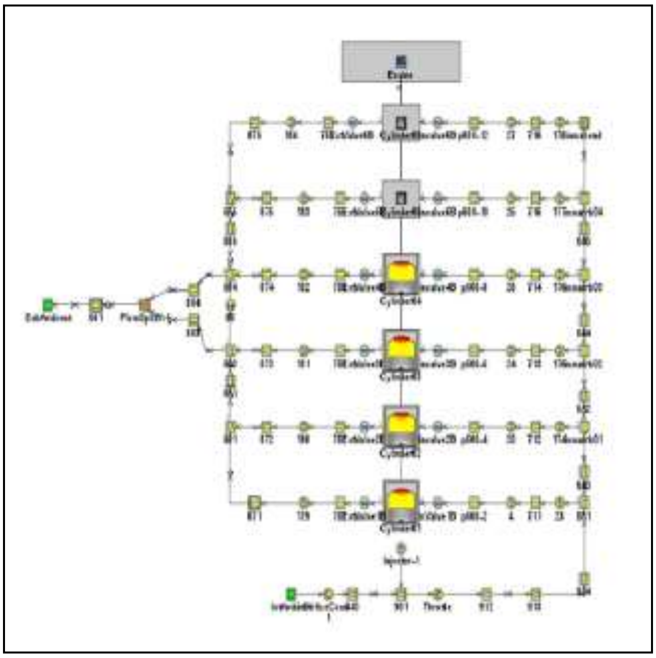

Fig-6: 1-D Simulation Model of Existing SPFI CNG Engine

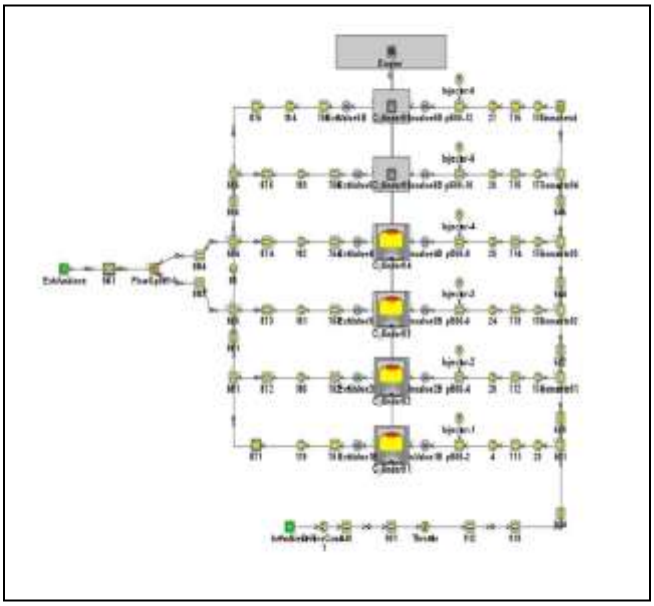

Fig-7: 1-D Simulation Model of MPFI CNG Engine

Engine performance is assessed for speed range of 1000 to 2400 rpm. For the same speed range Power, Torque and Volumetric Efficiency is recorded for SPFI Fuel injection system. Similarly MPFI Fuel injection manifold system is designed and developed and its performance is evaluated under similar condition of SPFI system using GT-Power. From the result of both systems it is found that the nature of both curves is same and the new designed MPFI system provides 1.5% to 2% greater power, Torque and Volumetric efficiency as compared to Existing SPFI system.

6. RESULT AND DISCUSSION

In Internal Combustion engine primary purpose of intake manifold is to evenly distribute the air flow between each cylinder, and to create the homogeneous air fuel mixture. The injection location plays key role to improve Uniformity index of mixture. Uniformity index and velocity distribution determines the optimum injection location for Single point fuel injection manifold system and optimum runner length for Multi point fuel injection system. The comparison of all six models is done to find out geometric parameters which give optimum uniformity index of mixture. Engine 1D Simulation determines the performance of the engine. It gives the range of Power, Torque and Volumetric Efficiency for SPFI and MPFI Injection system. The following figures shows the result of CFD analysis and 1D analysis.

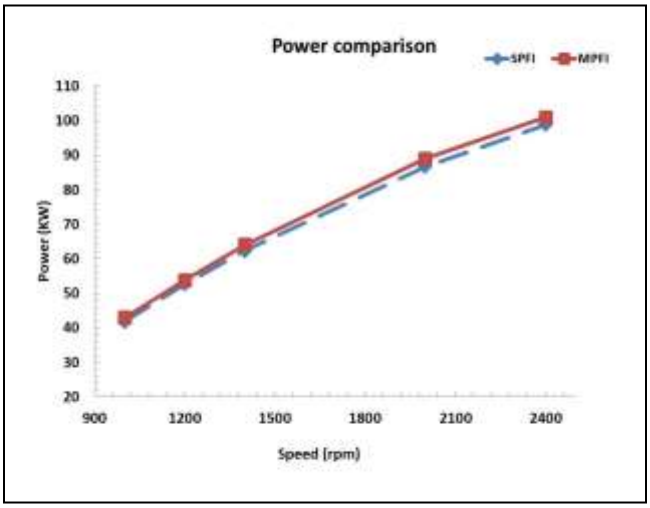

Fig-8: Power Comparison of SPFI and MPFI Systems

Fig 8 shows the normalized brake power of the engine for SPFI and MPFI with speed rang of 1000 to 2400 rpm. It is observed that power increased by 1% for MPFI compared with SPFI for same Engine. In MPFI system injector inject fuel to the admission valve which admits the fuel and air into the cylinder. This gives individual control of the cylinder and hence for each and every cylinder same amount of fuel is delivered. The lambda range is effectively controlled by MPFI System.

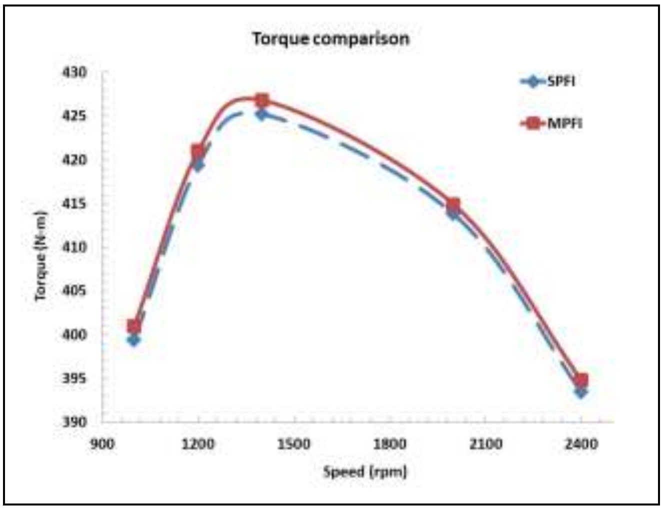

Fig-9: Torque comparison of SPFI and MPFI Manifold Systems

Fig 9 shows the normalized Torque of the engine for SPFI and MPFI with speed rang of 1000 to 2400 rpm. It is observed that for MPFI system torque increased by 1%. The maximum torque obtained for both system at the speed of 1400 rpm. It is seen that the engine efficiency is at the maximum at a speed where it produces its peak-torque.

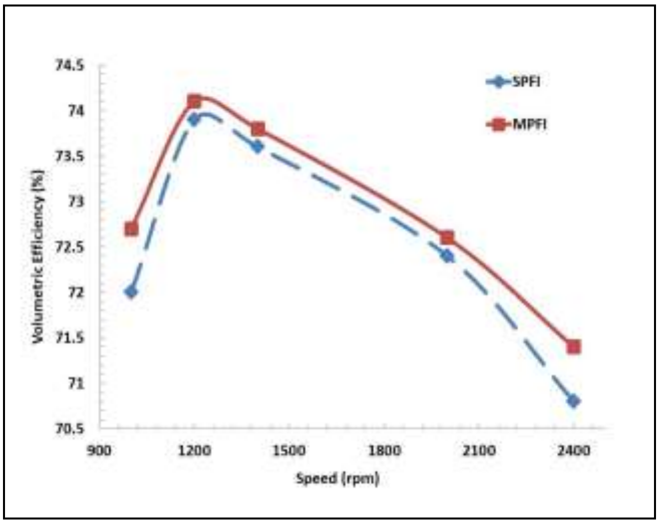

Fig-10: Volumetric Efficiency of SPFI and MPFI Manifold Systems

Fig 10 shows the Volumetric Efficiency of the engine for SPFI and MPFI with speed rang of 1000 to 2400 rpm. As the engine speed increased from 1000 to 1400 improvement in volumetric efficiency is achieved. In MPFI System the volumetric efficiency improved due to the Tuned runner length and diameter. It is observed that with increase in engine speed, intake length required for best volumetric efficiency reduced.

7. CONCLUSIONS

1. In MPFI the injection is done individually for each cylinder over runner so the fuel doesn't get sufficient volume to get mixed with air due to that less uniform mixture produced. From above result it is found that the flow uniformity index at outlet of each runner is 0.7290 and the maximum velocity magnitude in the manifold is 91.92 m/s.
2. The maximum velocity magnitude is observed for all runners and runner no 3, 4 are having maximum velocity magnitude so from velocity magnitude it is concluded that the runner 3and 4 are having more turbulent mixture than other runners.
3. It is observed that power increased by 1% to 2% for MPFI as compared to SPFI for same Engine. In MPFI system injector inject fuel to the admission valve which admits the fuel and air into the cylinder. This gives individual control of the cylinder and hence for each and every cylinder same amount of fuel is delivered. The lambda range is effectively controlled by MPFI System.
4. As the engine speed increased from 1000 to 1400 improvement in volumetric efficiency is achieved. In MPFI System the volumetric efficiency improved due to the Tuned runner length and diameter. It is observed that with increase in engine speed, intake length required for best volumetric efficiency reduced.

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