Performance Analysis of Intake Manifold For Injection Systems of CNG Engine

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Abstract- *The primary modifications are required in Internal Combustion Engine System viz intake manifold, piston and Exhaust after treatment system to obtain optimum power, torque, fuel efficiency and to reduce harmful emission gases. These parameters are responsible for improvement in the performance of Engine. 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 effect of Fuel Injection location and Air-Fuel mixture on the Performance of the CNG Single point fuel injection Engine. The intake manifold is modeled using reverse engineering data. The manifold system is analyzed for stress and deflection. The Air Fuel mixture is evaluated using Computational Fluid Dynamics analysis based on the uniformity index by varying injection location. The effects of turbulence are represented by k-Ɛ turbulence model. The Engine Performance is estimated using 1D simulation software and the results are compared with Experimental results.*

Keywords- Intake Manifold, SPFI, CFD, Uniformity Index, Design of Injection Location.

I. 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 does 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. SPFI is a system that has a single injector, or a group of injectors clustered together in one, usually centralized spot on the intake manifold. In this system the injection location plays vital role to improve the uniformity of the Air-Fuel Mixture.

Maji Luo Guohua etal [1] have numerically simulated Three-dimensional steady flowin two types of inlet manifold using the arbitrary Lagrangian – Eulerian(ALE) method. The effects of turbulence are represented by k-Ɛturbulence model. Mass flow rates of the systems are calculated and compared to choose the efficient intake manifold design. Harishchandra Jagtap et.al [2] have studied the air-fuel flow pattern of long and short runner intake manifold with different plenum chambers and the flow distribution of air from plenum to individual runners using CFD analysis. LuizOtavioF.T.Alves et.al [3] have investigated the effects of different intake runner length and diameter on the performance of a four stroke and single cylinder IC Engine and results are validated using GT-Power simulation software.

Massimo Masi et.al [4] have showed that the design of intake manifold and the valve port in IC Engine effects on volumetric efficiency and flow intensity. CFD analysis has been performed on the intake valve of the high speed spark ignition Engine to investigate the reliability of polyhedral grids of different size and to assess the required mesh size. A Manmadhachary et.al [5] have carried out the study to develop a spiral intake manifold model to predict gas flow in the intake system of single cylinder IC Engine. Intake manifold has significant effect on the volumetric efficiency and the performance of the engine.

Shashank Ghodke et.al [6] 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 [7] 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. Kriti Gupta et.al [8] have carried out the fluid flow analysis for the flow through the intake manifold with different cross section of throttle body using CFD analysis. The nature of the flow through the valve and the comparative study of the pressure and velocity variation have been made. Michal Bialy et.al [9] 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

II. MODELING AND SIMULATION OF SPFI MANIFOLD SYSTEM

This section deals with the prediction of stress and deformation induced in the intake manifold. The database for intake manifold is obtained by Re-engineering of existing box manifold used in automobiles. The Existing H4TC CNG Engine SPFI Intake manifold system is modified with different Injection location is then modeled using CATIA software. The assembly of manifold system consists of plenum, hub, throttle body; these are created separately and assembled by applying appropriate tolerances and constraints. In existing box manifold system the injection position 175 mm away from throttle body. The developed model was then extruded to meet 3.65 liter volume requirements. To obtain improved uniformity index the modified intake manifold is Re-modified with a different injection location at 155mm, 225mm, 145mm, 125 mm away from throttle body excluding 175mm. The Intake manifold refers to an engine part that supplies the air and fuel mixture to the cylinders. Intake manifold plenum facilitates the distribution of this mixture. It's of rectangular shape having volume 2.65 litres, length and width is 655mm and 113mm respectively. Hub is the part between throttle body and plenum. It's of circular shaped pipe having 60mm diameter. Throttle body is responsible for controlling the amount of Air-Fuel that flows into an engine. In Single point fuel injection system the fuel injection location plays a crucial role on Air-Fuel mixture. The system has 14 inlets of 6mm diameters and 175mm length away from throttle body.

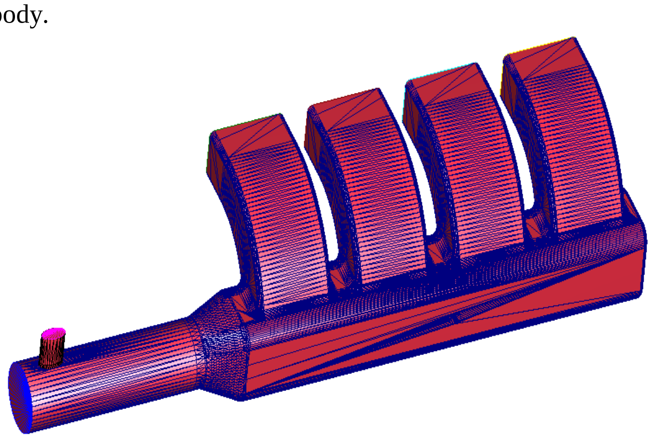


Fig. 1. Intake manifold Core

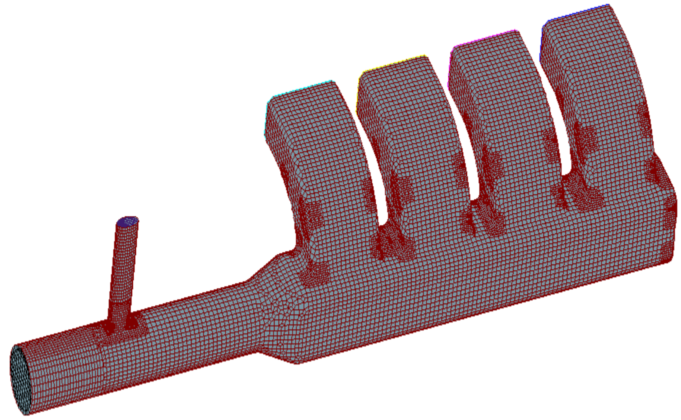


Fig.2. Mesh Geometry of Intake Manifold

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 0.6433mm minimum size and 82.34mm maximum size of the element.

III. 3D CFD SIMULATION: SPFI CONFIGURATION

Different mass flow rate are provided during analysis on CNG inlet and air inlet whereas different pressure conditions are given at inlet and outlet. Ambient pressure and temperature is given at Air inlet and CNG inlet

The 3D CFD Boundary Conditions are as, air inlet pressure 0 pascal, temperature 300k and mass flow rate 0.09638kg/sec, and CNG inlet pressure 0 pascal, flow rate 0.005606kg/sec. the mixture condition at engine let is -3600 pascal.

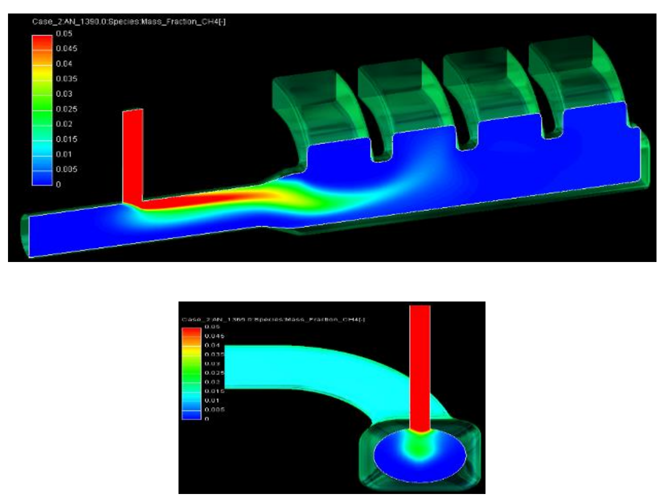
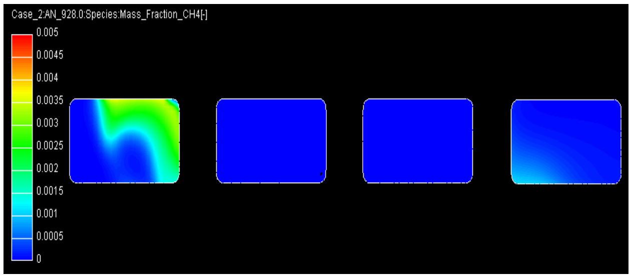


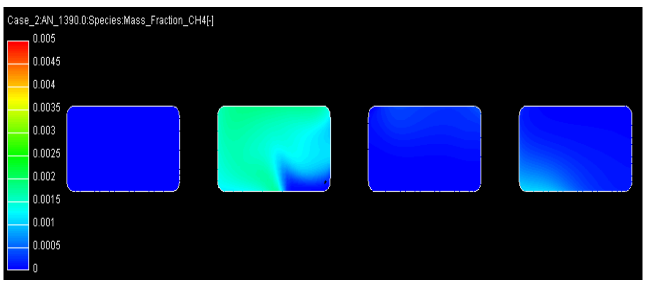
Fig.3. 3D CFD Simulation for SPFI Configuration

For the 90º CNG injector position, the mixing of CNG with air is satisfactory. Engine is giving the desired power.

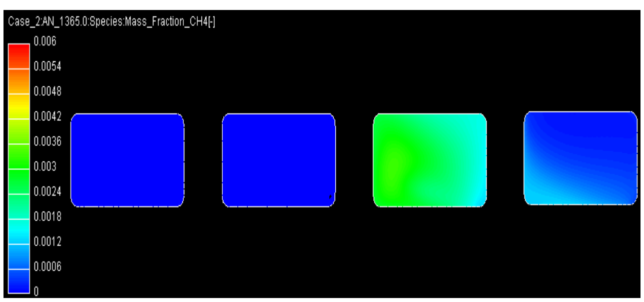
Flow in Cylinder 4, when active



Flow in Cylinder 3, when active



Flow in Cylinder 2, when active



Flow in Cylinder 1, when active

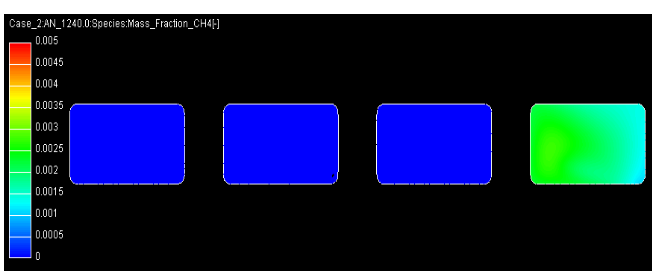


Fig. 4. Air flow distribution at Inlet port

Flow in runner outlet no.1, 2 & 3 is uniformly distributed across the cross section. However, flow is comparatively less through runner 1 since its location is farthest from the air inlet. Flow in runner outlet No.4 is concentrated in the upper half across the cross section. This is attributed to the fact that, there is a sudden diversion of the incoming flow and by geometry hence; it is not reaching the inner corners of the cross section. However flow is good owing to nearest vicinity of runner4 to the incoming air from air filter.

IV. 1D CFD ANALYSIS OF SPFI CONFIGURATION

The boundary conditions for the 1 D analysis of Turbo charged 4 Cylinder SPFI CNG engine manifold are the Engine cylinder geometry, Valve timing profile, firing order, fuel properties, throttle body characteristic, Turbo charger Map and characteristics, Inlet port flow profile and coefficient, inlet pipe diameter of the manifold, Length of the inlet manifold (Plenum length), etc….

Engine performance is assessed for speed rang of 1000 to 2600 rpm for modified SPFI system from GT Power and on an actual engine in engine test cell. The results are as follows-

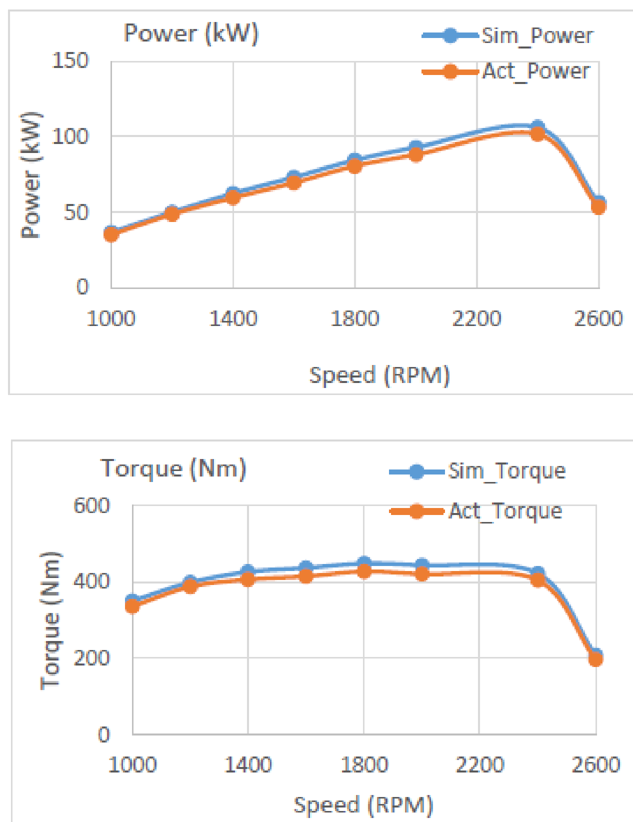


Fig. 5. 1D Performance analysis of SPFI system

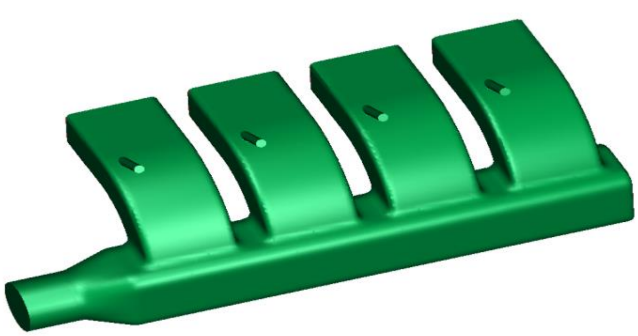
From the result of both systems, it is found that the nature of both curves is same and the modified SPFI system from GT power analysis provides 4% to 5% greater power as compared to actual engine test results collected from engine test laboratory.

V. MODELING AND SIMULATION OF MPFI MANIFOLD SYSTEM

This type of injection system uses a gas injector rail for inducting CNG to the engine. These systems work on the principle of speed density and use MAP sensor to estimate the load on the engine. The injectors used in these systems are low impedance and have high flow rates. Sequential gas injection systems are superior to air gas valve type kits as the dead gas volume and leakage is highly reduced. These systems are expensive but offer reliable operation and higher fuel economy in comparison to air gas valve kits.

The characteristic of the fuel- air mixture, which is formed in the intake port, depends upon several factors. Among these are air velocity and pressure distribution, turbulence valve etc. however; the temperature profile in the intake port is the factor that has a most pronounced local effect upon the fuel vaporization process.

Intake manifold plenum facilitates the distribution of this mixture. It's of rectangular shape having volume 2.65 litres, length is of 660 mm, height and width of plenum is 65 × 80 mm respectively. Hub is the part between throttle body and plenum. It's used to supply air fuel mixture towards the plenum. It's of square shaped pipe. Throttle body is responsible for controlling the amount of Air-Fuel that flows into an engine. It is having 55 mm inner diameter. Intake manifold Runners are the part of intake manifold which supplies air-fuel mixture to the individual cylinders. The fuel injection is done on the runners in MPFI System. They are of rectangular shape and having length 65mm and height and width is 48 mm and 53 mm.



Intake manifold Core

Fig.6. Intake Manifold Core

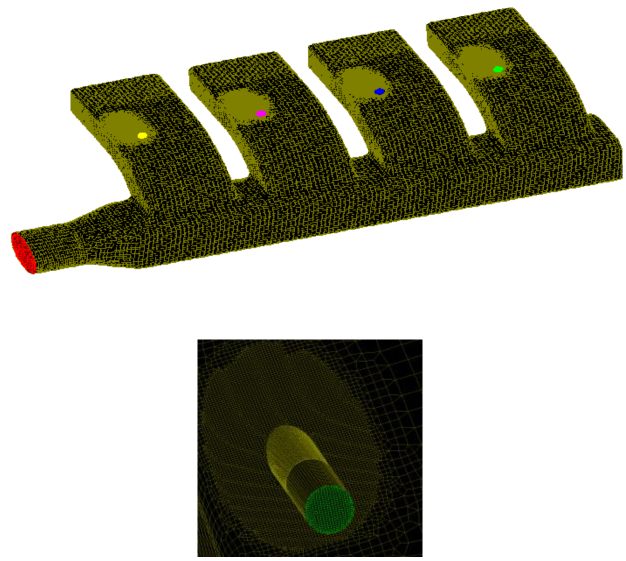


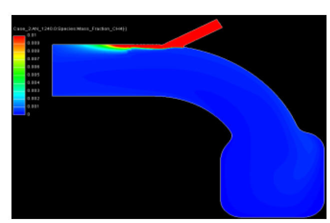
Fig. 7. Meshed geometry of MPFI System

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. The type and size is decided based on suitability and type of analysis. Meshed Intake manifold system consist of 174012 elements and 928472 nodes.

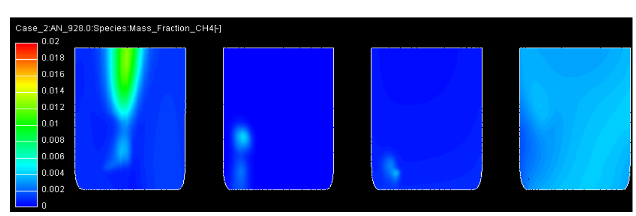
VI. 3D CFD SIMULATION OF MPFI CONFIGURATION

For the 30º CNG injector position, the mixing of CNG with air is initiated at the upper area and expected to fill-up the cross section as it flows through intake port. Engine is giving the desired power.

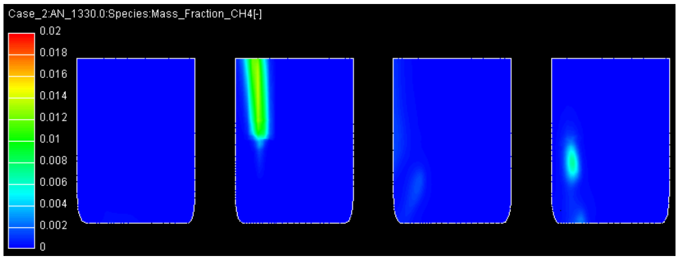
View from 'Y



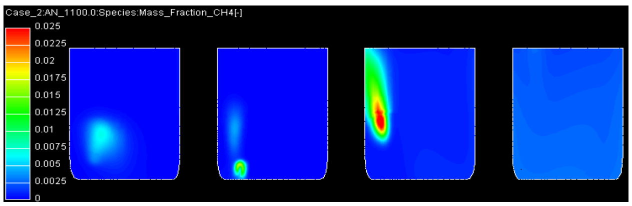
Flow in Runner Outlet 4, When Active



Flow in Runner Outlet 3, When Active



Flow in Runner Outlet 2, When Active



Flow in Runner Outlet 1, When Active

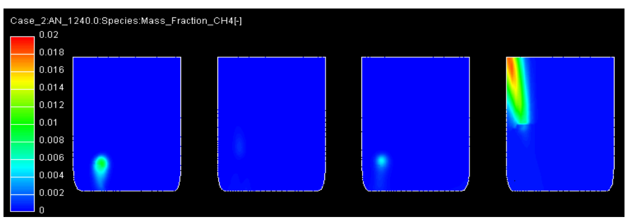


Fig.8. 3D CFD simulation

Flow pattern at each runner outlet is fairly uniform. The wavy nature is due to wave dynamics inside the runner which acts as a pipe. Average deviation in flow at runner no. 1, 2 & 3 w.r.t. runner no.4 is 5.98%. Average mass flow rate of the mixture for the major portion of positive flow during the cycle is 0.1711 Kg/s. This improvement over the baseline simulation (0.1678 Kg/s) is due to shifting from SPFI to MPFI configuration. SPFI may reduce the airflow due to interaction of incoming air with CNG at the inlet of the intake manifold.

VII. 1D CFD ANALYSIS OF MPFI CONFIGURATION

The boundary conditions for the 1 D analysis of Turbo charged 4 Cylinder MPFI CNG engine manifold are the Engine cylinder geometry, Valve timing profile, Firing order, Fuel properties, Injectors characteristics, Injector location angle, Turbo charger Map and characteristics, Inlet port flow profile and coefficient, Inlet pipe diameter of the manifold, Length of the inlet manifold (Plenum length), etc….

Engine performance is assessed for speed rang of 1000 to 2600 rpm for modified MPFI system from GT Power and on an actual engine in engine test cell. The results are as follows-

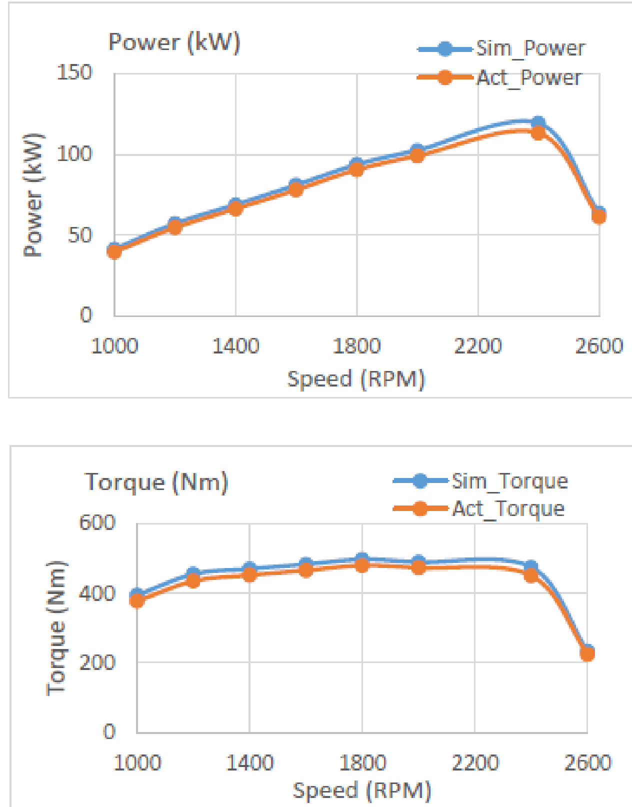


Fig. 9. 1D Performance analysis MPFI system

From the result of both systems it is found that the nature of both curves is same and the modified MPFI system from GT power analysis provides 3.5% to 5% greater power as compared to actual engine test results collected from engine test laboratory.

VIII. PERFORMANCE COMPARISON OF SPFI AND MPFI CNG ENGINE

With that analysis we can summarized the data for air fuel mixture flow in MPFI & SPFI engines. In case of MPFI configuration, Air+CNG mixture flow is improved as compared to SPFI configuration. SPFI may reduce the airflow due to interaction of incoming air with CNG at the inlet of the intake manifold.

Analysis on the basis of 1D CFD Analysis

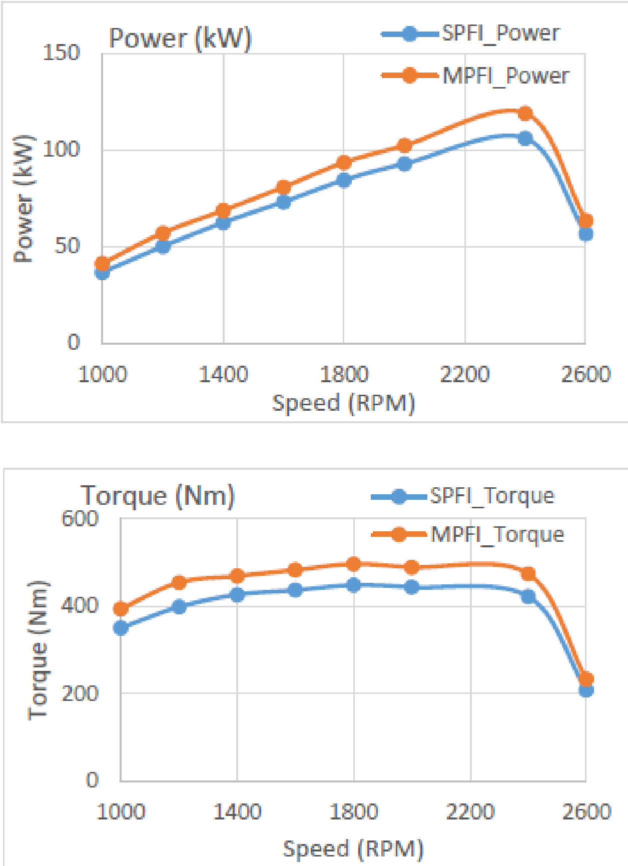


Fig. 10. 1D Comparison of SPFI and MPFI system

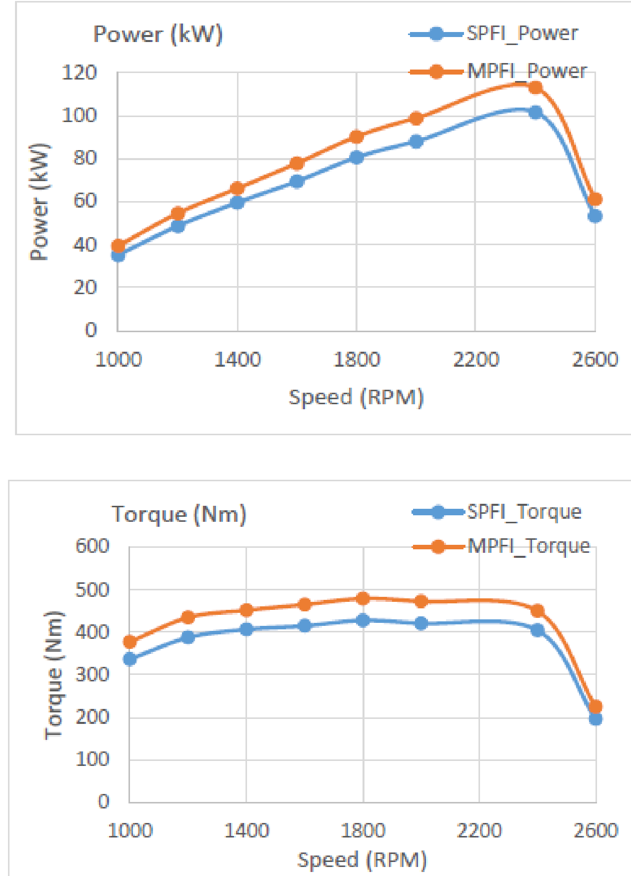


Fig. 11. Engine test comparison of SPFI and MPFI system

Comparing the results shown in the 1D CFD analysis for SPFI & MPFI engines. The observation are, power & torque increased in MPFI engine by 9.16 to 12.26 % of SPFI engine.

Analysis on the basis of Engine tests in test cells

The same engines are tested in the test lab on engine test bed. Engines warm up and conduct the full throttle performance from 1000RPM to 2600RPM. After analysis of both the results, power and torque observed in the MPFI engine is approximately 10% more as compare to SPFI engine.

IX. CONCLUSION

The following conclusions are obtained from the research work carried out using 3D CFD analysis, 1D analysis and Experimental test results of intake manifold.

SPFI system

- The 90° CNG injector position is satisfactory for required engine performance and observed that the air fuel mixture is uniformly distributed at each manifold port outlet.
- As compare within the four runner outlet, the flow distribution is comparatively less through runner1 since its location is farthest from the air inlet. Also the flow in runner outlet No.4 is concentrated in the upper half across the cross section. This is attributed to the fact that, there is a sudden diversion of the incoming flow and by geometry hence; it is not reaching the inner corners of the cross section.
- From 1D analysis, it is observed that the nature of both curves is same and the modified SPFI system from GT power analysis provides 4% to 5% greater power as

compared to actual engine test results collected from engine test cell.

MPFI System

- The 30º CNG injector position is enough good for the mixing of CNG with air is initiated at the upper area and expected to fill-up the cross section as it flows through intake port.
- Average deviation in flow at runner no. 1, 2 & 3 w.r.t. runner no.4 is 5.98%. And average mass flow rate of the mixture for the major portion of positive flow during the cycle is 0.1711 Kg/s.

Assessment of SPFI and MPFI System

- In case of MPFI configuration, Air+CNG mixture flow is improved as compared to SPFI configuration. SPFI may reduce the airflow due to interaction of incoming air with CNG at the inlet of the intake manifold.
- There is an improvement in flow while shifting from SPFI to MPFI configuration. This has reflected in improvement in full load power performance at 2400 RPM for MPFI engine (113.1 kW) as compared to SPFI engine (101.7 kW).
- Engine torque also shows an improvement at 1800RPM from 427.6NM to 479.06NM
- In MPFI system it is recommended to have an injector inclination angle of 30º w.r.to the inlet air flow axis, in order to further improve the mixing quality.

It is advisable to have curved surface at the end of the manifold to improve the flow through runner1 outlet in MPFI system

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