Intake Manifold design for multi-point fuel injection CNG engine

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***Abstract*— The drivability of the vehicle is mostly depends on the torque produced by the engine and is a very critical parameter.Volumetric efficiency of an engine mostly decides the torque characteristics. Better torque curve can be achievedwith an overall improvement in volumetric efficiency throughout the engine operating conditions, which facilitates improved drivability. By tuning the intake manifold the volumetric efficiency of an engine can be improved to achieve the desired performance.**

Minimum possible resistance in intake manifold, Uniform distribution of air through all the cylinders, elimination of unnecessary turbulence and eddies in the manifold, engine packaging constraints needs to be addressed properly to achieve the optimum intake manifold design. Through this project, focus is given on the study of the effects of various parameters on the intake manifold design. The base engine considered for this project work is diesel engine which is converted to dedicated CNG application and for this engine new Intake manifold is designed. For that the existing intake manifold is analyzed and which founds unsuitable for the CNG application. So new intake manifold which reduces swirl effect is initially designed and accordingly runner length and plenum volume is finalized. Then by using 1D simulation software the effect of various runner length and plenum volume on engine performance characteristics such as power, torque, and volumetric efficiency is checked. Then on the basis of 1D simulation result the actual Intake Manifold is manufactured and same is checked for swirl test and actual engine test. It was found that the required, simulated and actual tested airflow with the newly designed Intake Manifold are within the 10% margin.

***Index Terms*— Intake Manifold, CNG**

I. INTRODUCTION

A properly designed Intake Manifold is vital for the optimal performance of an IC Engine. The main task of an Intake Manifold is to distribute air between cylinders properly. An uneven air distribution leads to Non-uniform cylinder volumetric efficiency, power loss, and increased fuel consumption.The volumetric efficiency of an engine can be improved by tuning the intake manifold to achieve the desired performance. To achieve the optimum intake manifold design various parameters such as uniform distribution of air through all the cylinders,elimination of unnecessary turbulence and eddies in the manifold,minimum possible resistance in intake manifold, engine packaging constraints needs to be addressed properly.

The combustion process of a natural gas engine is homogenous combustion. The concentration of charge in the cylinder must be in the flammable range, too lean or too rich in a mixture cannot form reliable combustion. Moreover, rich gas mixtures impact unfavorably with engine power, economy and emissions. Therefore, in order to keeps the quantity of flammable mixed gas entering the cylinders at the required value; the volume of intake manifold has to be increase compare to diesel engine.

The intake manifold guides the air to the cylinder head. The general construction is that a plenum is followed by intake runners (pipes) which go to the valves. The manifold may look different in different types of engines but the common function is that it should evenly distribute the intake air/charge to the cylinders. Intake manifold consists of typically of a plenum, to the inlet of which bolts the throttle body, with individual runners feeding branches which lead to each cylinder or plenum can feed the branches directly.

Mardani AH Sera et al, simulated effect of various mixer types (Venturi Mixer, Fan Mixer, Venturi burner Mixer) and found that there is an increase of 8% of power output due to the used of this advanced intake system. And the CNG fuelled engine is totally produced lesser emissions of CO, CO2 and hydro carbon (HC) compared to that of gasoline [2].

BadihJawad et al, studied the various engine parameters to get maximum engine performance and found out that intake manifold design is also one of the major factors deciding maximum engine performance [3].

NeginMaftouni et al, simulated the the effect of Intake Manifold Runners Length on the Volumetric Efficiency by using 3-D CFD Model. they found out that uniformdistribution of air to all cylinders, Minimum possible resistance in IM runners, utilization the pressure waves to improve induction process, elimination of the the unnecessary turbulence and eddies in intake manifold, throttle body position correctly are some of the parameters which needs to be keep in focus while designing intake manifold [4].

L. J. Hamilton et al studied the Effect of Intake geometry on engine performance. They investigated that intake manifold tuning, intake manifold runner length and bend pipes plays an important role in volumetric efficiency and subsequently to torque characteristics. Also engine/vehicle packaging system plays an important role while designing intake manifold [7].

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Devananda B Pai et al, found out Simulation based approach for Optimization of Intake Manifold. The modeling of the engine was done using GT-POWER software and the effect of manifold runner length and plenum volume and runner diameter on the performance was studied. When plenum volume is increased it was seen that it gives better performance at higher rpm but throttle response is less. The runner diameter is varied and is found that as the runner diameter was decreased the peak torque and volumetric efficiency is increasing at a lower rpm and reducing at higher rpm [9].

D. Saravanan et al, designed and developed Flow Based Dual Intake Manifold System to get better torque availability at Partially Open Throttle (POT) condition improves drivability at city driving condition and better torque at Wide Open Throttle (WOT) condition improves cruising at highway driving condition. With the flow based Dual Intake Manifold system more than 47% improvement in Torque and Power is observed at 25% throttle position and upto 11% improvement in torque and power is observed at 50% throttle position, this significantly improves the drivability at POT conditions [12].

As modern engines are expected to feature good response characteristics, maximum performance, i.e. high torque and low fuel consumption while keeping the pollutant emissions at minimum the intake manifold have to meet the following clearly defined main requirements:

Uniform air distribution of air to all cylinders
Minimum possible resistance in Intake Manifold runners
Utilization of pressure waves to improve induction process
Eliminate the unnecessary turbulence and eddies
Throttle body positioning
Low pressure loss

Intake manifold optimization mainly consists of properly design of below mentioned parameters.

Intake manifold runner length
Intake manifold runner diameter
Intake manifold plenum volume

II. WORK METHODOLOGY

For completing any task or achieving any goal a systematic approach is necessary. So for completing the desired result of this project work a methodology is finalized. In which the activity starts with the selection of engine, then analyzing the existing Intake manifold for its suitability for CNG engine application, then proposing new Intake manifold on the basis of available literature and engine boundary conditions, then simulation with the different cases and finally the actual testing. The detailed activities are well represented in the flow chart as shown in Fig.1.

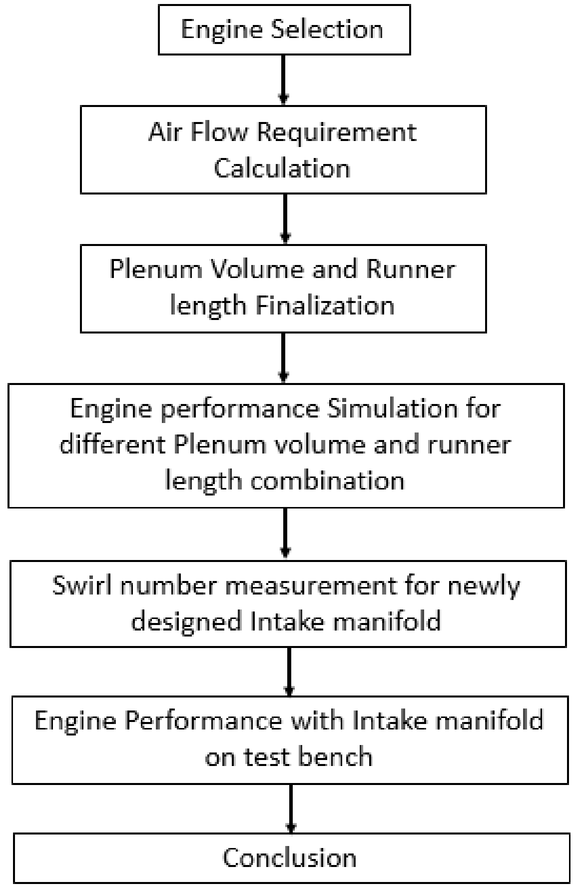

Fig. 1. Work methodology.

III. INTAKE MANIFOLD DESIGN

The combustion process of a natural gas engine is homogenous combustion. The concentration of mixed gas in the cylinder must be in the flammable range, too lean or too rich in a mixture cannot form reliable combustion. Moreover, rich gas mixtures impact unfavorably with engine power, economy and emissions. Therefore, in order to keeps the quantity of flammable mixed gas entering the cylinders at the required value; the volume of intake manifold plays an important role.The existing Intake manifold is checked for the suitability for modified SI engine. And it is tested on swirl test rig for Mean Swirl Number Values.

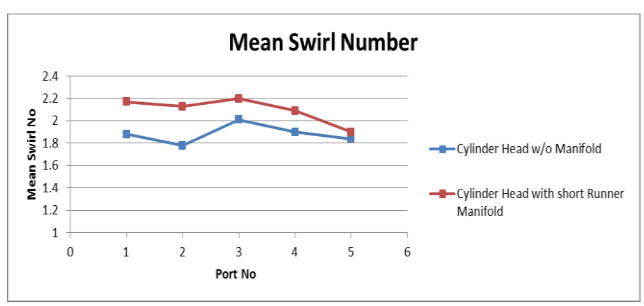

Fig. 2. Mean Swirl number for Diesel Intake Manifold.

Fig. 2. shows that the mean swirl number increases with the use of short runner intake manifold i.e. diesel engine intake

manifold. This higher swirl is not desirable for CNG application. Also it is found that existing quantity governed Diesel engine Intake manifold volume is about 60% of engine displacementwhich is not suitable for quality governed CNG engine application.

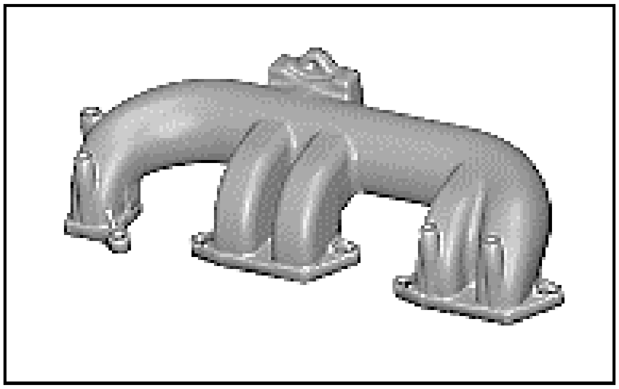

Fig. 3. Diesel Intake Manifold having angled short runners.

On the basis of the specific fuel consumption data and knowing that this is stoichiometric engine, the air flow required for different RPM is calculated and is tabulated as below.

TABLE I:
AIR FLOW REQUIREMENT

RPM	Required Air Flow	Power	Torque
	kg/h	kW	N-m
3000	322.0	78.00	248.4
2000	230.2	58.19	278
1800	207.2	52.38	278
1600	184.2	46.56	278
1400	161.2	40.74	278
1200	127.0	30.14	240
1000	103.0	23.03	220

The area immediately downstream where the runners join is referred as distribution area or the plenum. Generally plenum diameter in case of round plenum is around three fourth of bore diameter. A larger plenum volume leaves more available air to the engine within its reach and so long as the air can be replenished in time through the intake system, and then engine never has to work hard to get intake air because there is always enough of it sitting there in the larger plenum. As plenum volume gets smaller, it become easier for the engine to rapidly consume all of the air in the plenum and thus it would have to spend a lot of effort trying to suck air in all way through the entire intake system to stay alive. So on the basis of literature review the Plenum volume is decided as 2.40 lit, which is around 60~70% of engine displacement volume.

The next critical part of the Intake manifold is runner length. Intake runner will connect the intake manifold to intake port. The intake length is one such parameter that is depending upon cylinder bore diameter. And it is mostly kept twice the bore diameter. A straighter runner would result in a more uniform flow profile in the runner as all the flow travels approximately the same distance. Increasing the runner bend radius (going towards straight runners) does not however change the flow velocity profile much. The compactness of the system is more important in this case. Its design is mainly depend on the space available as longer the runner length more it is beneficial but restricted it is mostly depend on engine boundary condition. Also the runner should be as straight as possible it should not have angled connection towards cylinder as it will create more swirl which is not suitable for SI engine, specifically for CNG. Accordingly runner volume with 1.6 lit volume is finalized, which is around ~50% of engine capacity.

So the new Intake manifold having total volume of 3.96 liters which is around 1.15~.2 times of engine displacement volume is designed and is further considered for 1D simulation analysis.

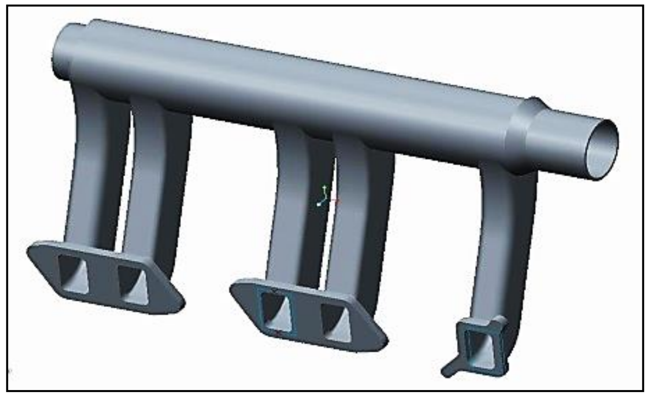

Fig. 4. Proposed Intake Manifold having straight long runners.

IV. 1D SIMULATION ANALYSIS

Simulation is the process of formulating a model of a physical system representing the actual processes and analyzing the same. Usually the model is a mathematical representation of actual processes through a set of algebraic, differential or integral functions and analysis is made by using computer. In modern research, computer simulation has become a powerful tool. It saves time and is also economical compared with experimental study.

The finalized intake manifold is then used for 1D simulation. Where the engine performance characteristics such as power, torque, volumetric efficiency can be obtained for different RPM. Three different cases each for plenum volume and runner length are considered.

Theoretically calculated plenum volume & runner length is considered as base case. Then two separate conditions (130% base plenum volume & 70% base plenum volume) are taken for simulation purpose. And similarly with increased & decreased runner length simulation is carried out. The 1D simulation case set up and Intake manifold 1D simulation model is shown in fig. 5.

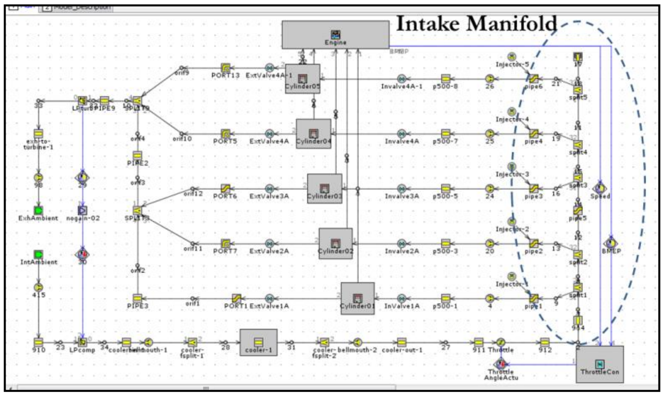

Fig. 5. 1D simulation case set up

The Intake manifold is made up of straight, bend and curved portion. So for the accurate results it is required to split the intake manifold in different sections and the same is replicated in simulation model. Below figure shows the discretized 3D model and converted 1D model of proposed intake manifold.

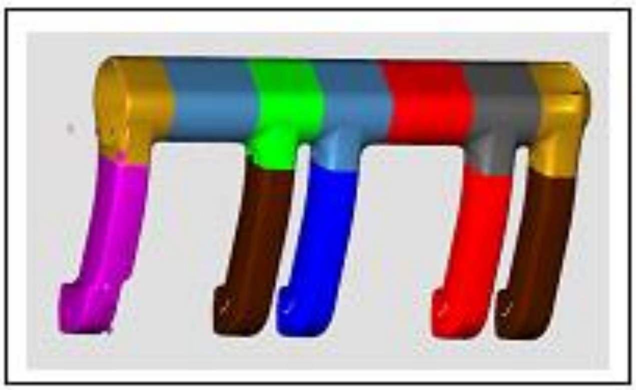

Fig. 6. Discretized 3D Model

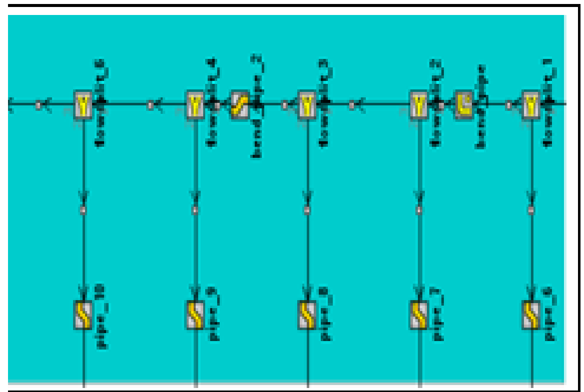

Fig. 7. Converted1D Model

V. SIMULATION STUDY RESULTS AND DISCUSSIONS

1D simulation gives the good insight in deciding the optimized runner length and plenum volume. Different cases are simulated and the graphs showing the effect of runner length and plenum volume on engine performance for various engine RPMS are simulated.

Effect of Runner length on various engine performance characteristics are shown in below figures.

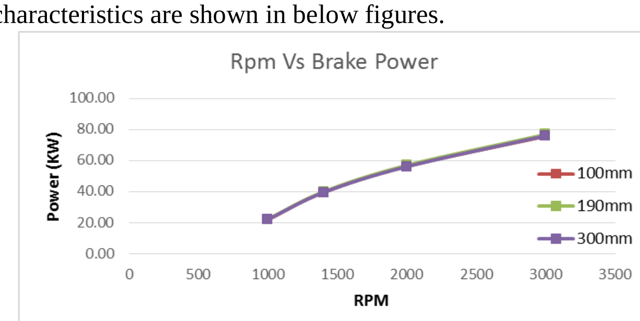

Fig. 8. Effect of different Runner length on brake power

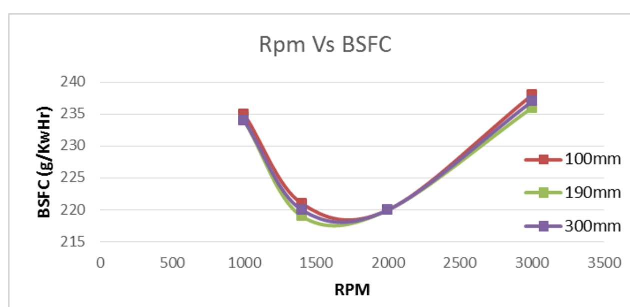

Fig. 9. Effect of different Runner length on BSFC

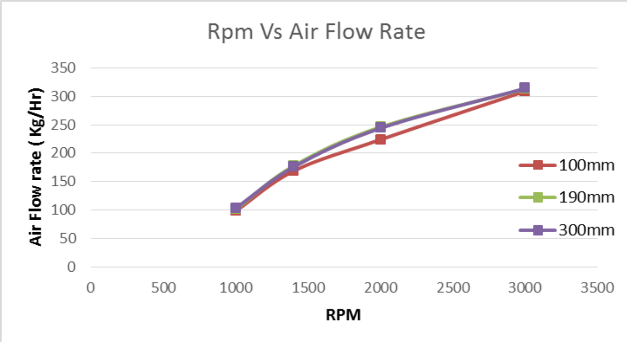

Fig. 10. Effect of different Runner length on Air Flow

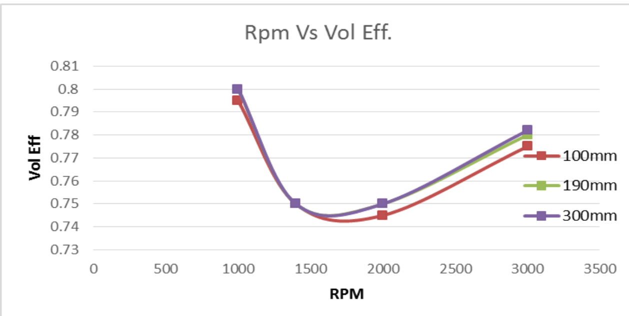

Fig. 11. Effect of different Runner length on Volumetric Efficiency

It is observed that there is minimal improvement (Maximum 2%) observed with increasing runner length. So it is not advisable to increase runner length by 100mm to get only 2% of volumetric efficiency. As the height of the intake manifold with 300 mm runner length is too big to accommodate it on the engine due to packaging constraints. Whereas there is drop in volumetric efficiency and air flow with 100 mm runner length. Also CNG injector positioning on shorter runner length is having engine boundary limitations so it is not suitable.

Hence runner length (190mm) is suitable for this engine operation.

Effect of Plenum volume on various engine performance characteristics are shown in below figures.

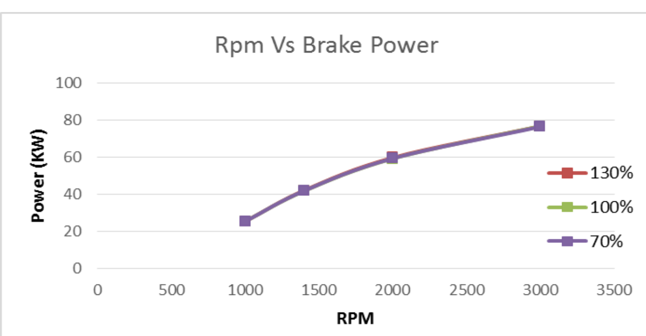

Fig.12. Effect of different Plenum Volume on Brake Power

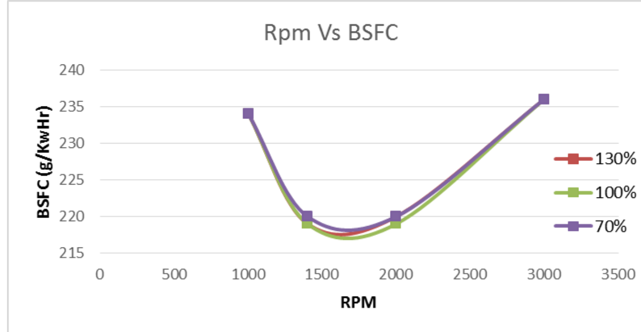

Fig. 13. Effect of different Plenum Volume on BSFC

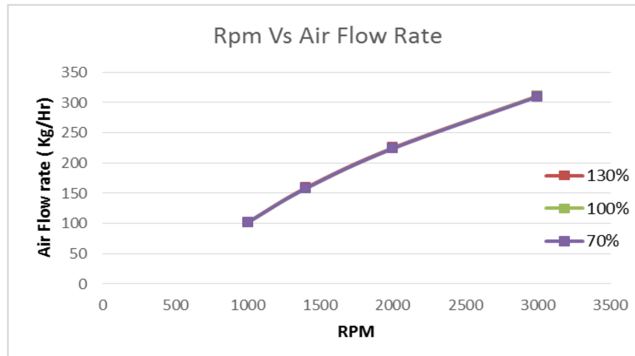

Fig. 14. Effect of different Plenum Volume on Air Flow Rate

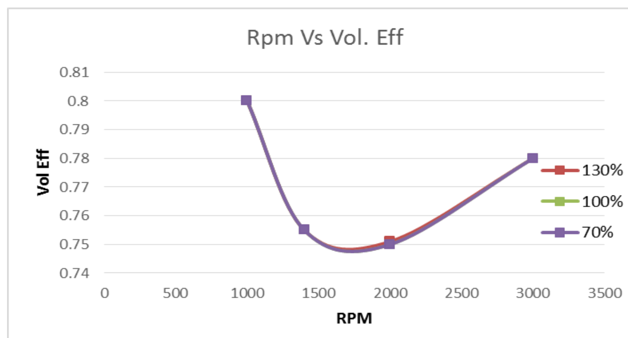

Fig. 15. Effect of different Plenum Volume on volumetric efficiency.

It is seen that there is minimal improvement observed with increasing Plenum volume. So it is not advisable to increase plenum volume to get minimal improvement of volumetric efficiency. Whereas there is drop in volumetric efficiency and deterioration inBSFC observed due to reduced plenum volume. Hence base plenum volume is suitable for this engine operation.

The same manifold is tested for mean flow coefficient and swirl on swirl test rig. As we know for diesel engine swirl is important for air fuel mixing point of view. As diesel is in liquid form it should mix properly with air hence more swirl is required. So for diesel engine intake manifold is designed in such a way that the runners usually helps in generating more swirl.

But for the CNG engine as fuel is in gaseous form already, less swirl is desirable for proper burning. So considering this phenomenon Intake manifold is designed in such a way that swirl is killed. And same has been observed on swirl test rig and results are shown graphically.

It can be seen that the existing intake manifold is designed for diesel engine where in mean swirl value found higher (Swirl No is ranging from 1.78 to 2.01) and for CNG intake manifold it drops and ranges from 1.4 to 1.5 which is desirable and as required.

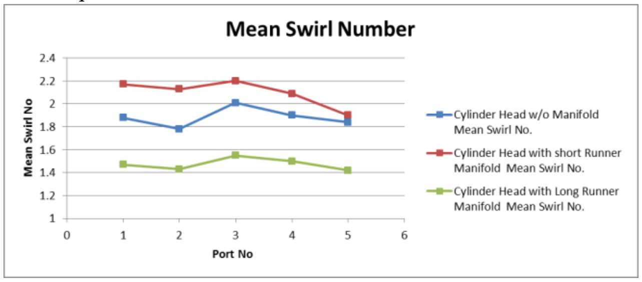

Fig. 16. Mean swirl number for diesel and CNG intake manifold

The newly designed intake manifold is then tested on actual engine and actual air flow is measured. It was found out that there is around 10% of deviation in the simulated and measured air flow rate values. This deviation is because all actual boundary conditions cannot be simulated as it is very difficult to define in the software. So the designed intake manifold is suitable for CNG engine application. The graph of simulated and measured airflow rate is shown in fig.18.

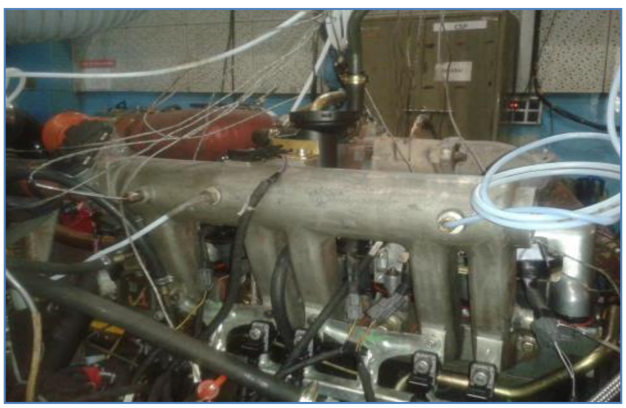

Fig. 17. Actual intake manifold on engine test bed

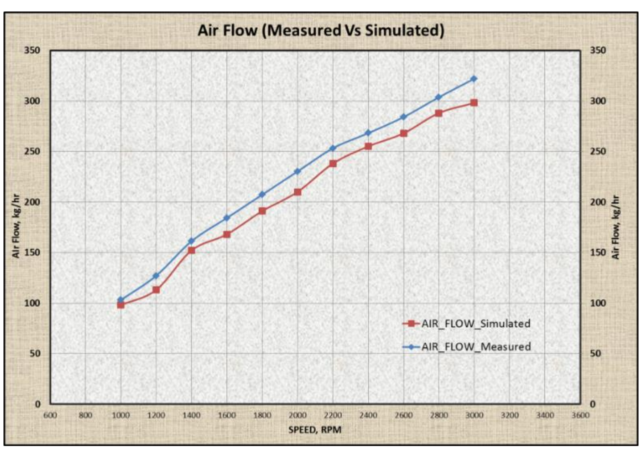

Fig. 18. Air flow Measured Vs Air Flow Simulated

VI. CONCLUSION

The performance and torque requirement for the engine determine the geometry of the intake manifold-in particular the diameter, the length and the plenum volume of the air distributor.

The Diesel engine Intake manifold is not suitable for CNG engine application. The properly designed intake manifold can improve the volumetric efficiency of an engine.

While converting diesel engine to spark ignition engine various components of the engine needs to be changed. Intake manifold is one of the critical components for achieving the desired engine performance.

As CNG is quality governed engine the air or charge should be kept as a reservoir in intake manifold so for CNG engine intake manifold plenum volume should be large as compared to diesel engine.

Also for CNG engines the runner length and its orientation should be such that swirl should be reduced as swirl is not desirous for CNG engines.

The volume of an intake manifold is defined by the length and cross-section of its runner as well as by the volume of the distributor or the plenum.

1D simulation tool is used for finding the effect for different runner length and plenum volume on the engine performance and it was observed that 190mm runner length is optimum for desired engine performance, wherein plenum volume should be around 60% of engine displacement.

The actual Intake manifold is further tested on swirl test rig and the intake manifold has less swirl number value compared to diesel intake manifold. And same manifold is further tested on engine. And measured air flow value was similar to simulated air flow value with around 10% of max deviation which is also acceptable considering simulation limitations. This approach of intake manifold design can be adapted for optimum design. Difference between existing and proposed Intake manifold volume is tabulated in below table.

TABLE II
INTAKE MANIFOLD VOLUMES

	Diesel engine Intake Manifold	CNG Engine Intake Manifold
Intake Manifold Volume	60% of engine capacity	100 - 110 % of engine capacity
Plenum Volume	35 % of engine capacity	60 - 70 % of engine capacity
Runner volume	25% of engine capacity	40 - 50% of engine capacity

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