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Review IJICEGT

Modified Design Improvement Study and Optimization of a intake Manifold to Obtain Unequal Distribution of Velocity for Optimal Diesel Engine Performance

Ashis Acharjee[1,*], Sushovan Chatterjee[2], Prasun Chakraborti[3]

Abstract

Geometrical design of intake manifold has been found very significant for the better performance of an I.C. Engine. It becomes less effective at the intake manifold's runner's outlets due to an uneven flow distribution of the intake air. With an increase in velocity at the distribution channels, the presented study seeks to make this uneven velocity distribution nearly equal without requiring any additional significant changes to the entrance manifold's construction. Standard engine intake manifold elsewhere available is used for experimental testing, to examine the variation of velocity of air flow at outlet of four runners. To change the intake manifold's geometry, a 3-D model of the real manifold is first created using software for designing (PRO-E), and the design model's certification is subsequently completed using the FLUENT commercial CFD program. To get the intended better outcomes, two additional models of the same intake manifold with different design configurations are completed in software then examine the result of these two models with original one to locate out pressure and velocity losses. Following model analysis, it is shown that pressure losses are caused by the depth cuts at the extreme of the plenum, projected stiffeners, and veiled nut extensions. As a result, there is uneven distribution at the runner's outlets. By restructuring the intake manifold's plenum and releasing it from undesired hidden projection inside the plenum, the inlet manifold can achieve virtually similar velocities in all four runners. The findings indicate a virtually equal distribution in all four runners, with outlet 1 seeing a 14% increase in air flow velocity and the other three runners of the input manifold experiencing approximate 5% to 7% increases.

Keywords: Intake manifold, runners outlet velocity and efficiency, CFD, Pro-E, genetic algotithm

INTRODUCTION

Engines are being developed to achieve high performance and gain the potential to fulfill the need of next generation. Major challenges for the future will be to reduce global emissions and crude oil consumption. Because it offers significant advantages over gasoline and diesel, compressed natural gas, or CNG, is a gaseous form of natural gas that has gained recognition as one of the promising alternative fuels. But the fact that natural gas needs to be compressed to fit in a car or truck is its major disadvantage. instead, bus, so heavy tanks are required to store it, and the pressure required (200 – 300 bar) is high enough to place considerable safety demands on the system [1].

Research in CNG engine essentially focused on three main areas: intake process, combustion system and exhaust treatment. When comparing CNG to

***Author for Correspondence**
Ashis Acharjee
E-mail: ashisacharjee76@gmail.com

[1,3]Assistant Professor, Department of Mechanical Engineering, NIT Agartala, Tripura, India
[2]Assistant Professor, Department of Mechanical Engineering, Cooch Behar Government Engineering College, Kolkata, West Bengal, India

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gasoline, the average power and torque losses are between 3 and 19.7% and 1.6 and 21.6%, respectively. Losses in volumetric productivity and poor flame speed are two of the factors behind the low engine power and torque. Therefore, to maximize engine performance and achieve a faster burn, natural gas gasoline internal combustion engine manufacturers must modify their engine designs. The blending process and the within-cylinder flow movements should be taken into account in these modifications [2].

The component of an engine that feeds the fuel/air combination to the combustion is called an intake manifold. The main job of the intake manifold is to evenly distribute the fuel to each cylinder head's intake port uniformly, either with the combust mixture or merely air in the case of a directly injected engine To maximize the engine's power and efficiency, even distribution is crucial. At specific speeds, resonant states in the airflow may form due to the intermittent or pulsing character of the airflow via the intake manifold into each cylinder. Depending on the size and shape of the manifold, these might improve engine performance characteristics at some engine speeds while decreasing them at other speeds [3].

These days, there are two types of manifolds used: static length and variable length. Less volumetric efficiency, power loss, and higher fuel consumption are the results of an uneven air distribution [4, 5].

The amplitude and phase of atmospheric pressure waves within the input manifold might have a positive or negative impact on the air filling of pistons. These compression waves' amplitude and phase are influenced by valve timing, engine speed, and I.M. design. The engine speed has a significant impact on the manifold's charging action and the erratic character of the induction mechanism. This is so because different pulses influence the air that enters the input manifold. To provide the necessary power, engine manifolds should adjust these pulses [4, 6, 7].

CFD prediction techniques for IC engine in-cylinder flow have gained popularity. They could shorten the time needed to construct the intake system of an internal combustion engine and can provide extremely helpful information about the way air flows. The physical mechanisms involved in the shift of kinetic energy are analyzed using the renormalization group theory (RNG k-ε) turbulent model [8]. Depending on the needs, several types of manifold models are utilized in different cars, and the designs are modified accordingly. However, there are a few common elements that are crucial to the construction of a well-designed manifold. When the engine speed reaches 1250 rpm, the manifold profiles around the corners of a three-cylinder diesel engine can be smoothed out to prevent the higher-velocity reflecting shock waves. The original IM design's inappropriate distribution of air to all the runners was caused by flow reversals that exist in the plenum. According to optimization, all three runners exhibit a 76% mass fraction of air at 1800 rpm and a 13% rise in air pressure [9]. The helical manifold yields improved volumetric efficiency as compared to the spiral and helical-spiral combination manifolds. Higher mean swirl velocity at TDC of compression is provided by the helical-spiral combined manifold [8]. The relative air distribution rate in a six-cylinder manifold was found to be between 14% and 19% for all ports, with port No. 4 having the lowest air distribution rate. Compared to the other model without a spacer, the model with a spacer is more efficient [10]. Numerous factors, including the lung chamber's volume, the ingress manifold's length, and the pipe length connecting the plenum region and rush tank, can affect the volumetric effectiveness. Membrane length needs to be lowered when engine speed rises and expanded at low engine speeds [3, 11]. Regardless of the tendency, the maximum Turbulent Kinetic Energy (TKE) was found at full intake valve lift [12]. Carbonaceous deposits develop in the fillets on the intake control valves and in the intake ports of the cylinder heads of diesel or carburetor engines. Deposits like this alter the intake passage's profile, which has a negative impact on both the engine's performance and properties. The pressure in the crankcase and intake manifold determines how much carbon dioxide intake is deposited [13]. Engine performance is further enhanced by a helical groove extending within the combustion manifold in stages of two millimeters, ranging from two to ten millimeters. The test's findings indicate a rise in air flow, a rise in mechanical and thermal braking efficiency, and a drop in HC and CO emissions. However, there is a 5% decrease in volumetric efficiency [14]. The engine's efficiency can be increased by tapering the runner. An experiment revealed that the air thorn entry and 2.5 deg tapered runner performed far better than the radius entry 5 deg tapered runner, producing an additional nearly 22 horsepower and 18 lb-ft of torque at only 14 psi [15].

An intake manifold from a four-cylinder normally aspirated diesel engine was selected for this investigation. To modify the intake manifold's configuration, the flow properties within it were investigated using the computational fluid dynamics (CFD) technique.

METHODOLOGY

The development of the entrance manifold's primary parameters and the corresponding quantitative computations are included in the technique. CAD and CAE tools are used to examine the geometry of the current intake manifold. After performing Reverse engineering, DOE and DFMEA analysis, an Intake Manifold is redesigned according to serviceability and durability. Computational Fluid Dynamic analysis to obtain necessary flow Pattern in order to obtain frictionless flow with minimum loss of air. Engine simulation on GT Simulation software to obtain to perform Real Time Engine performance in virtual environment. The final optimized Model is manufactured and installed on Stationary Engine to obtain actual Performance of an Engine.

Design of Intake Manifold

The CATIA V5R21 design for the induction manifold of a four-cylinder stationary gen-set engine includes the Plenum Chamber, Runner, Primary, and Supplementary Pipes, all of which are simply welded together to produce the combined manifold superstructure. The Volumetric efficiency of intake manifold is calculated by considering Mass flow rate of air and Engine Displacement (Table 1).

Table 1. Engine Specifications.

Engine Specifications	Values
Engine bore (mm)	105 mm
Stroke length (mm)	117 mm
Engine brake power (Kw)	19
Compression ratio	19:1
Constant engine speed (rpm)	1500

Engine Displacement = (swept volume / cylinder)× No of cylinder = (1013.10) × 2 = 2026.2 cc

Volumetric efficiency = 60 × mi/ ((N/2) × Vd × ρi)= 60 * 0.025 /(750 *0.02026 * 1.169)

So, η_v = 85.79 %.

Where, V_d = Engine displacement, ρ_i= Air Density

Tuning & Optimization of the Intake Manifold

A Design of Experiments (DOE) is a methodical and structured approach to ascertain the correlation between independent and dependent variables. GT-SUITE can be used to set up and conduct a DOE in order to ascertain the impact of one or more input parameters (factors) on various result quantities (responses). After the DOE has been run, the DOE Post Processor can be used to investigate the results and to perform optimization tasks (Figure 1).

Vehicle Entrance Manifold Tuning: There are many techniques available for tuning the engine intake manifold.

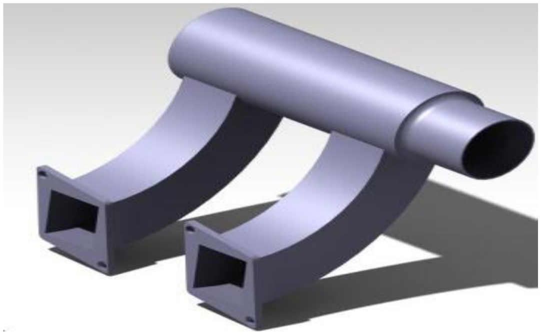
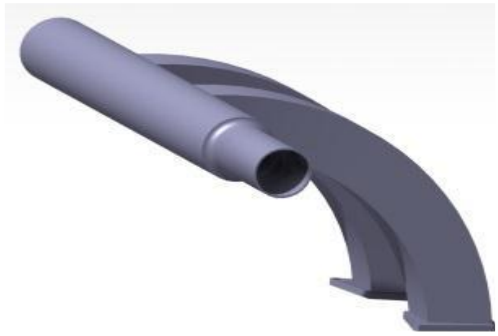

Figure 1. CAD model of the intake manifold of existing and optimized engine model.

1. Employing the Helmholtz Resonator
2. Applying the Ishida Ohata model
3. Using Differential Timings for Intake Valve

The variable time of valve approach is used to optimize the intake manifold to achieve maximum efficiency by volume. The other two methods as they are not able to quantify the performance effects and therefore provide no selection criterion for selecting between configurations which have the same natural frequency. It is impossible to forecast undesired troughs in the torque curve caused by manifold gas dynamics, nor is it possible to determine the engine speed range across which any relative performance increase may take place.

Optimizing the Intake Manifold

Manifolds can make use of this phenomenon to increase volumetric efficiency. Induction systems can be adjusted to provide better cylinder charging at specific speeds. The tuning of an engine is very much affected by length of the primary pipes, diameter of runners in the manifold. The manifolds can be increased and decreased in the intervals of 50 mm over a few steps. The infiltration system can be tuned in multiple modes thanks to the plenum (Figure 2). By adjusting the valve's timing to make full use of the manifold's action of waves. Modeling of the manifold and variation of the valve timing was independently carried out and the results of each of these sub models to obtain the overall performance of the manifolds. The reason for going for such a complexity is to obtain the best volumetric efficiency from the intake manifold engine combination. The Brent method was adopted during the optimization of these 5 parameters simultaneously to attain maximum volumetric efficiency for the given stationary engine (Tables 2,3).

Table 2. Variation in different geometric parameters of the existing intake manifold.

Geometric Parameter	Alteration
Secondary pipe diameter (Dse)	Decreased by 7 mm
Secondary pipe length (Lsep)	Increased by 25 mm
Plenum diameter (Dplp)	Increased by 6 mm
Plenum length (Lpup)	Increased by 110 mm
Runner length	Increased by 50 mm

Table 3. Comparison of optimized model with the existing parameters.

Parameter	Baseline model	Optimized model
Volumetric efficiency (%)	85.55	92.60
Mass flow rate of air (Kg/hr)	91.6	99.2
Brake power (kW)	19.1	19.2
BSFC(g/kW-hr)	240.2	241.4
Secondary pipe diameter (mm)	58	43

Secondary pipe length (mm)	50	100
Plenum pipe diameter (mm)	61	47
Plenum pipe length (mm)	198	418
Runner length (mm)	228	328

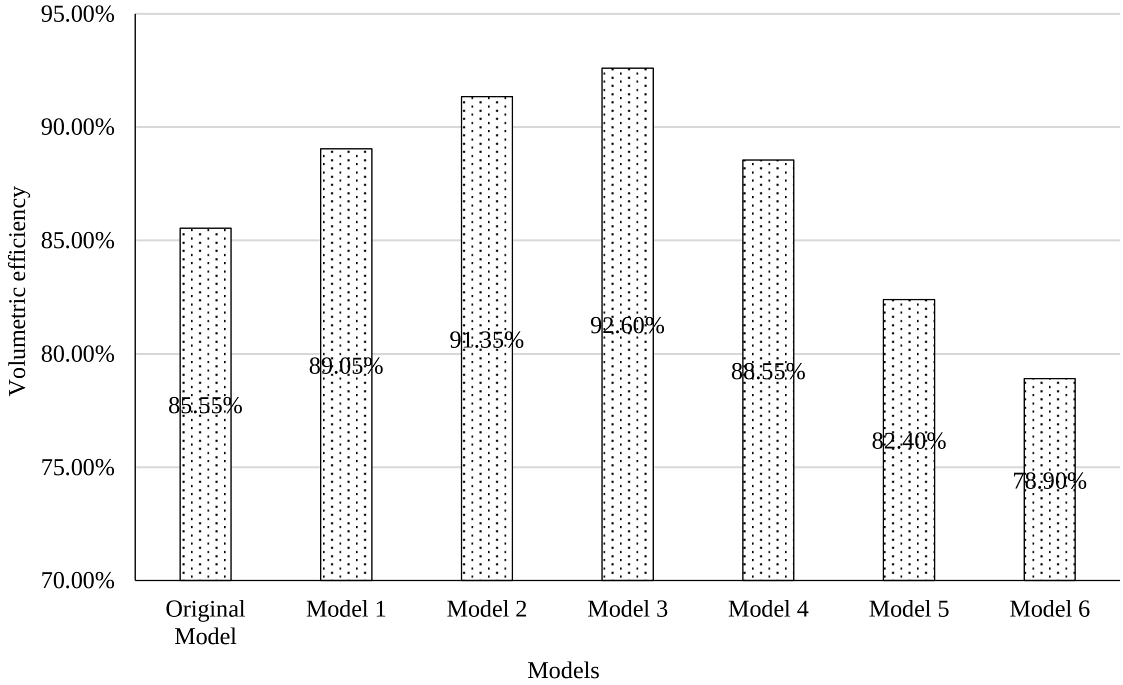

Figure 2. Comparison of the optimized models with existing model in terms of volumetric efficiency.

COMPUTATIONAL MODELING AND GRID GENERATION

The procedures of the grid generation for computational analysis were performed as follows. Using a three-dimensional CAD software, a three-dimensional wire frame and surface data were produced; and after that by using the gambit or fluent meshing is done. In this research, the internal air flow characteristic of a 2-cylinder diesel engine under transient conditions is studied by simulating pressure waves for the intake manifold using 1D GT POWER software. Using 3D CFD software, the intake manifold design is optimized under steady state conditions based on the findings of the 1D simulation. For each of the three runners under varying engine speed conditions, the program generates a variation of pressure pulses with different crank angles (Figures 3,4). The resulting graph indicates that the abrupt rise in incoming air velocity is the primary cause of pressure variance. Therefore, to prevent a sudden increase in pressure waves, the intake manifold (IM) shape around the corners should be made smooth (Table 4).

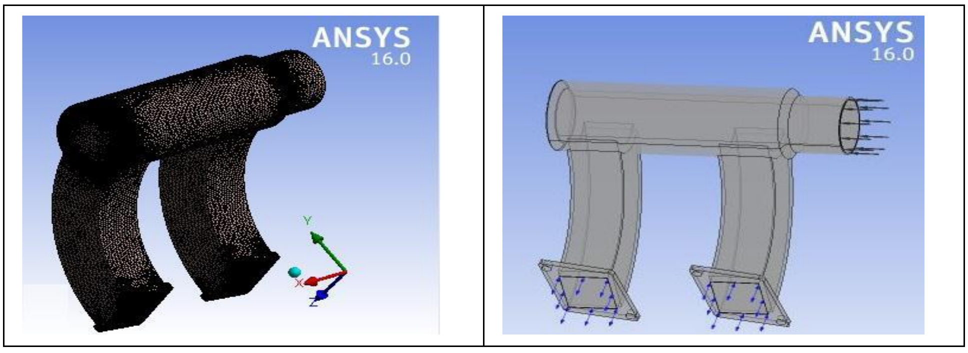

Figure 3. Mesh Model and Boundary conditions applied on intake manifolds.

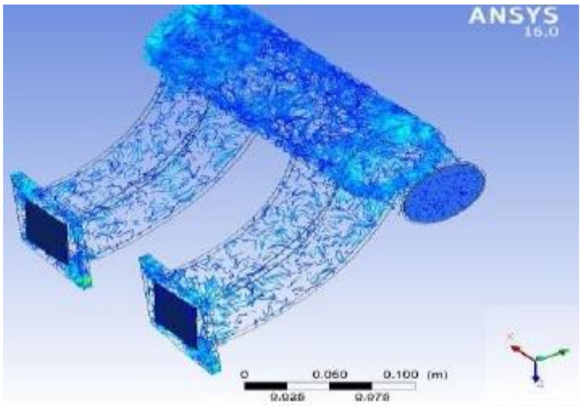

Figure 4. Flow of air inside intake manifold.

Table 4 Boundary condition for fluid flow of existing model.

Parameters	**Values**
Turbulence model	k-ε (enhanced wall treatment)
Inlet boundary condition	Total pressure (ambient)
Outlet boundary condition	Total pressure (vacuum)
Inlet pressure (atm)	1
Outlet pressure (bar)	0.9

EXPERIMENTAL APPARATUS AND PROCEDURE

To know the boundary condition an experiment was performed on given intake manifold. The pressure taps are located at the end of runner's outlets to know the pressure and with the help of blower and regulator inlet condition are varies and air is introduced at different velocity (5–14 m/s). Following measurements devices like anemometer and U-tube manometer are used to estimate the flow at outlets. To know the density variation a simple temperature change test at outlet comparison with inlet is done. The intake manifold used is shown in Figure 5 and schematic diagram of the experimental apparatus used on this experiment is shown in Figure 6.

Figure 5. Intake manifold.

Figure 6. Experimental setup.

EXPERIMENTAL RESULT AND DISCUSSIONS

At different velocities of air at inlet measurement are done on outlet to know in which runner pressure losses occur more Velocities are measured with the help of anemometer and U-tube manometer. Figures 7 and 8 show the anemometer data and show pressure at different outlet at different velocities, respectively. Pressure is inversely proportional to velocity so from Figures 5 and 6 result it conclude that the velocity is minimum at outlet-1 and maximum at outlet-4.

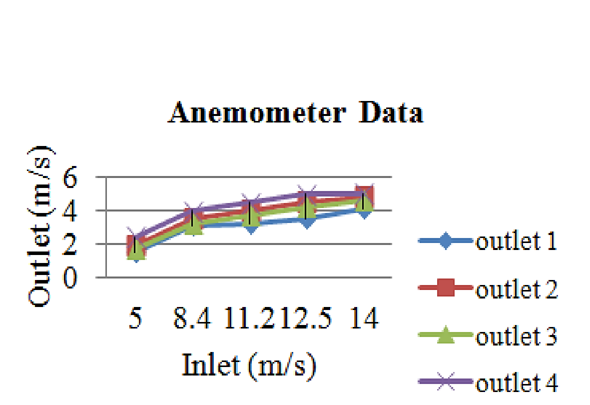

Figure 7. Velocities at outlets with variable inlet velocities.

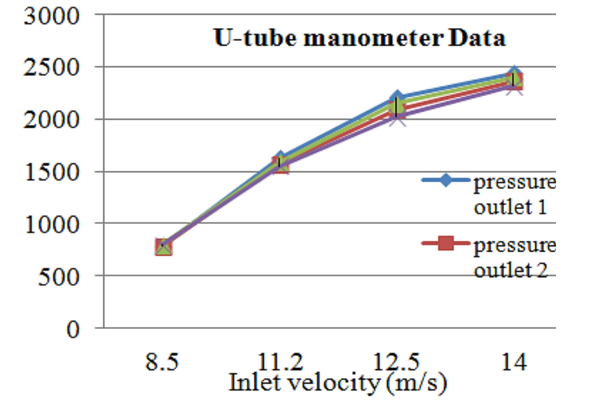

Figure 8. Pressure at outlets on variable inlet velocities.

COMPUTATIONAL RESULTS

CFD analysis is done on the three model of intake manifold to find out the reason of variation in velocities at outlets and validation of model (actual model) is done through comparing the result of CFD model (actual) with experimental. Figures 9, 10 show the velocity vector view of actual model. Figure 7 shows that velocities are very low at runners starting and some places of wall. After analysis of geometry, it seem that due to inside projection like stiffeners of runners and nut bolt inside projection and depth cuts at extreme side of plenum create pressure pocket due to which velocity become very low at these places (Tables 5,6).

Table-5. Results obtained from CFD analysis for existing intake manifold.

Sl.no	Dse (mm)	Lsep (mm)	Dplp (mm)	Lpup (mm)	Ma (Kg/hr)	ηv (%)
1	57.5	50.2	61	198	43.4	83.72

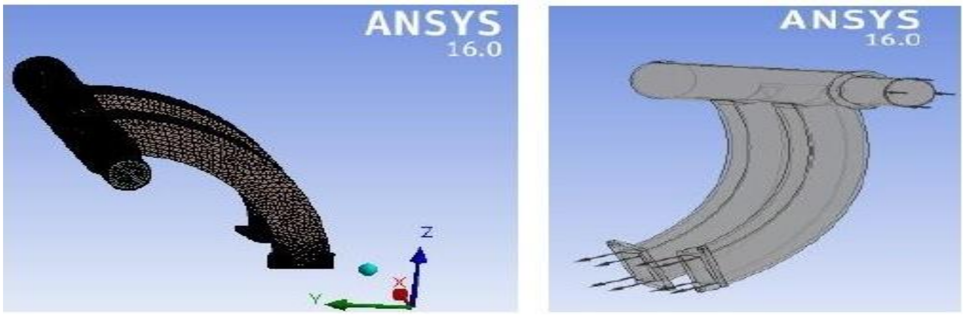

Figure 9. Mesh Model and Boundary conditions applied on optimized intake manifolds.

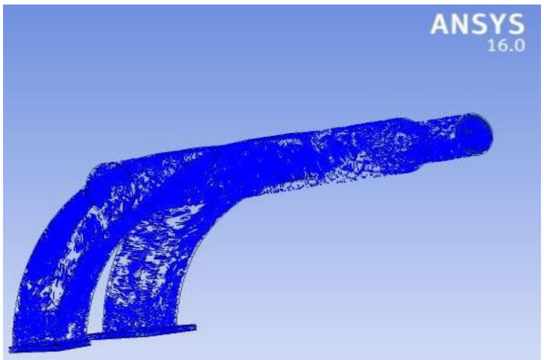

Figure 10. Uniform Flow of air inside optimized intake manifold.

Table 6. Results obtained from CFD analysis for optimized Intake Manifold.

Sl.no	D_{se} (mm)	L_{sep} (mm)	D_{plp} (mm)	L_{pup} (mm)	M_a (Kg/hr)	η_v(%)
1	43.5	100	47	418	48.2	92.1

GT 1D SIMULATION RESULTS

GT 1D Simulation results describe the Integrated and Volumetric mass flow rate of air at the end of Suction stroke at BDC Position considering variation in Plenum and runner parameters (Figure 11). From Figures 12 to 16 show the Variation of the Secondary Pipe Diameter, length, Variation of the Runner Length and Variation of the Plenum Diameter, length.

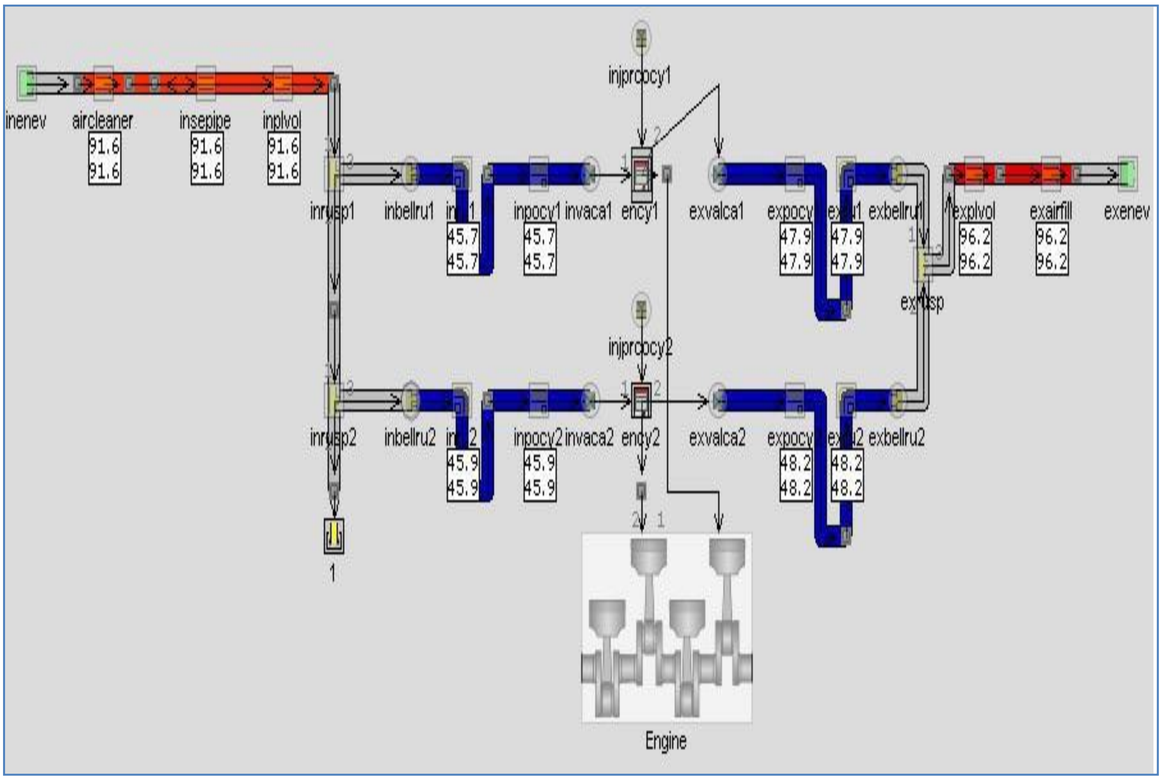

Figure 11, General layout of Engine model in GT-ISE with Profile Injection.

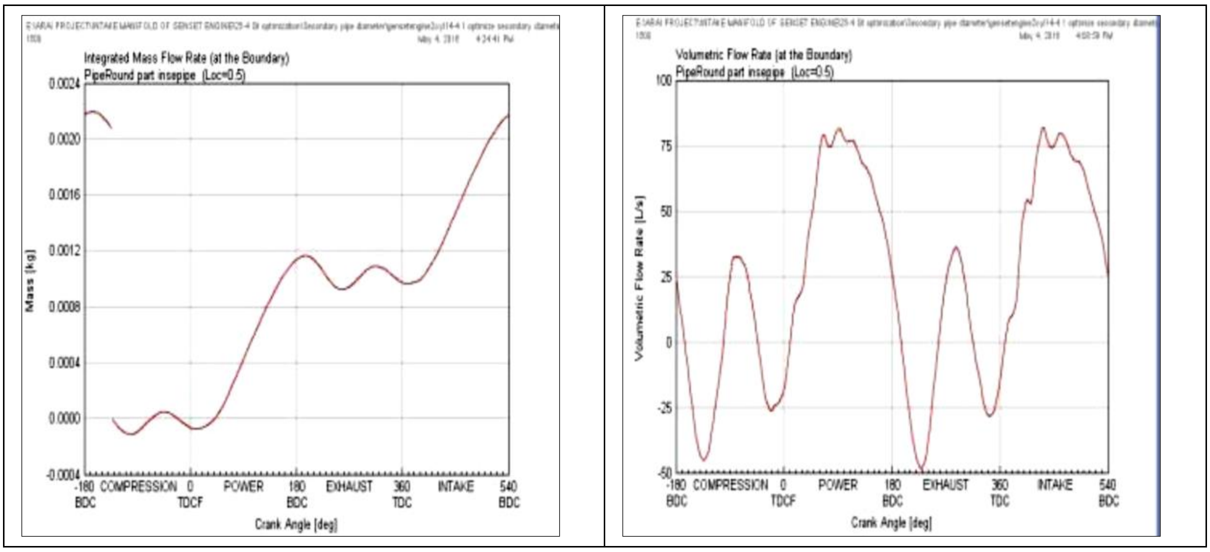

Figure 12. Integrated and Volumetric mass flow rate of air in the secondary pipe (diameter).

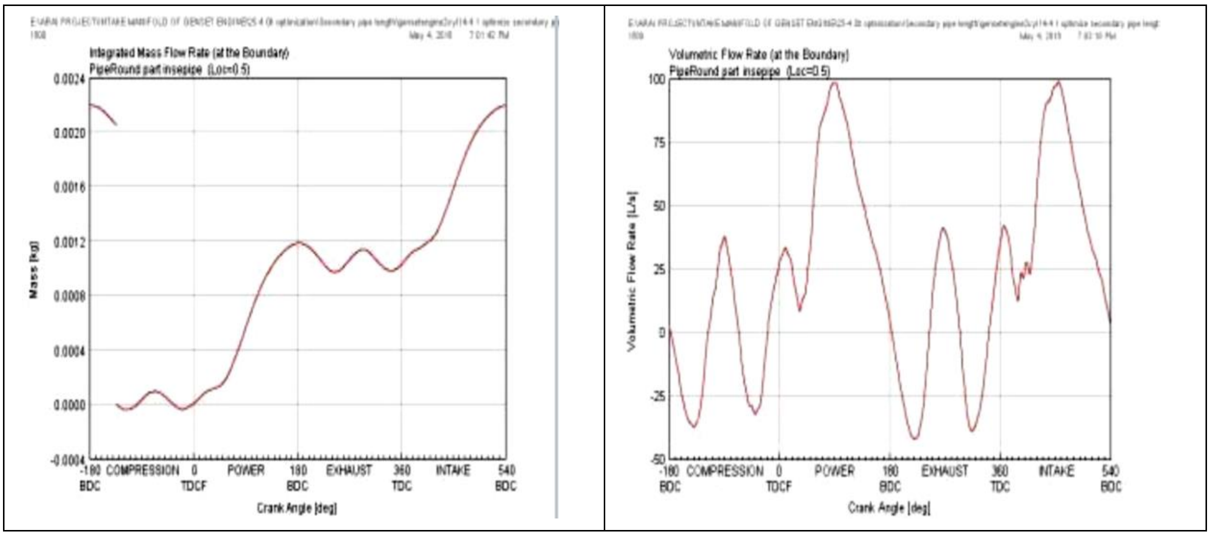

Figure 13. Integrated and Volumetric mass flow rate of air in the secondary pipe (diameter).

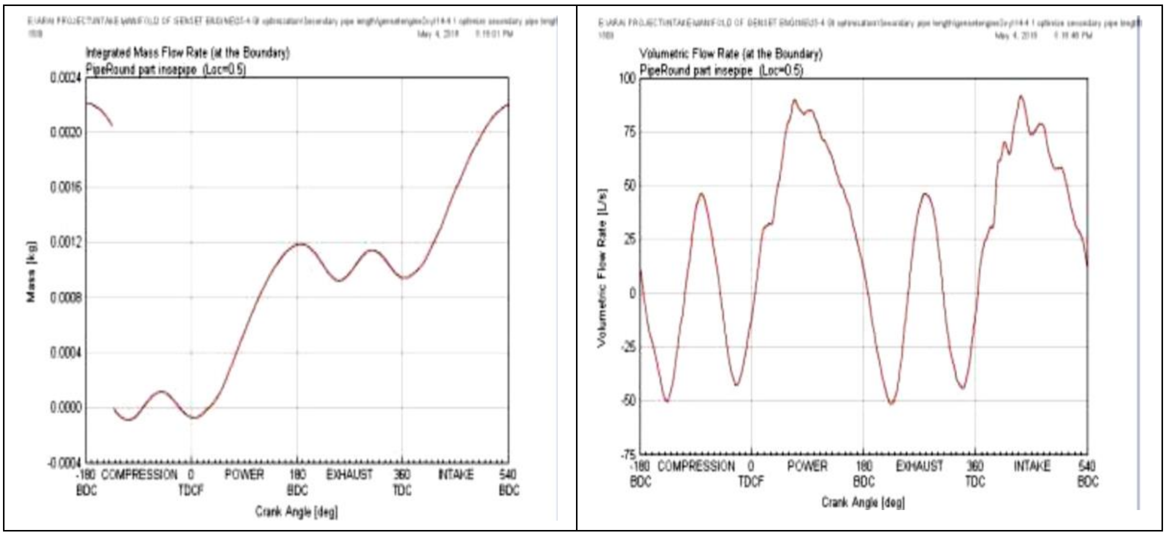

Figure 14. Integrated and Volumetric mass flow rate of air in the Plenum Pipe.

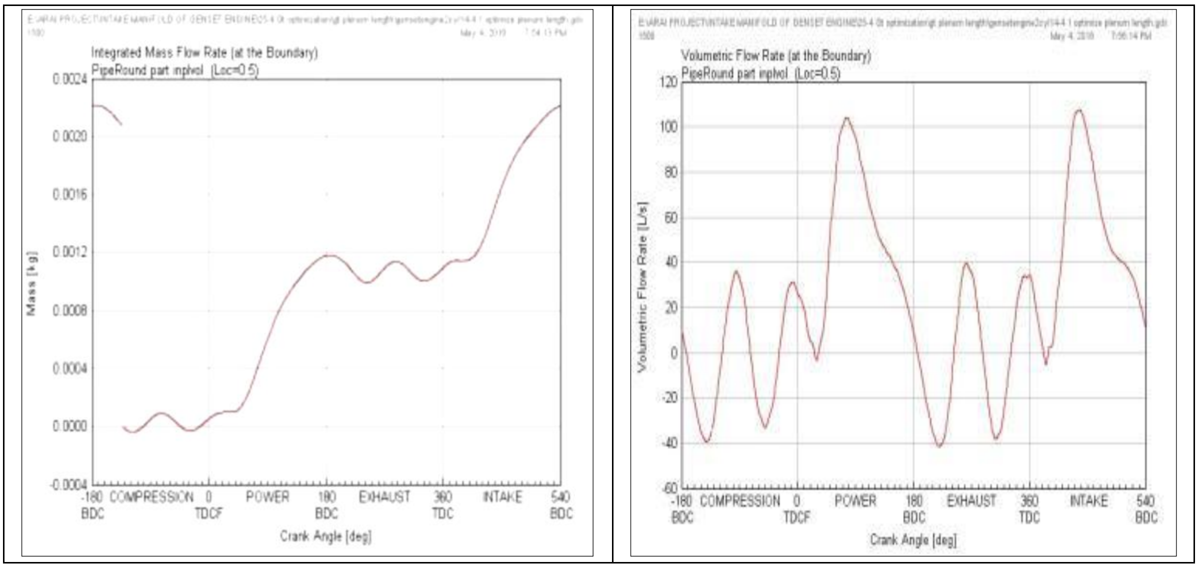

Figure 15. Integrated and Volumetric mass flow rate of air in the Plenum Pipe.

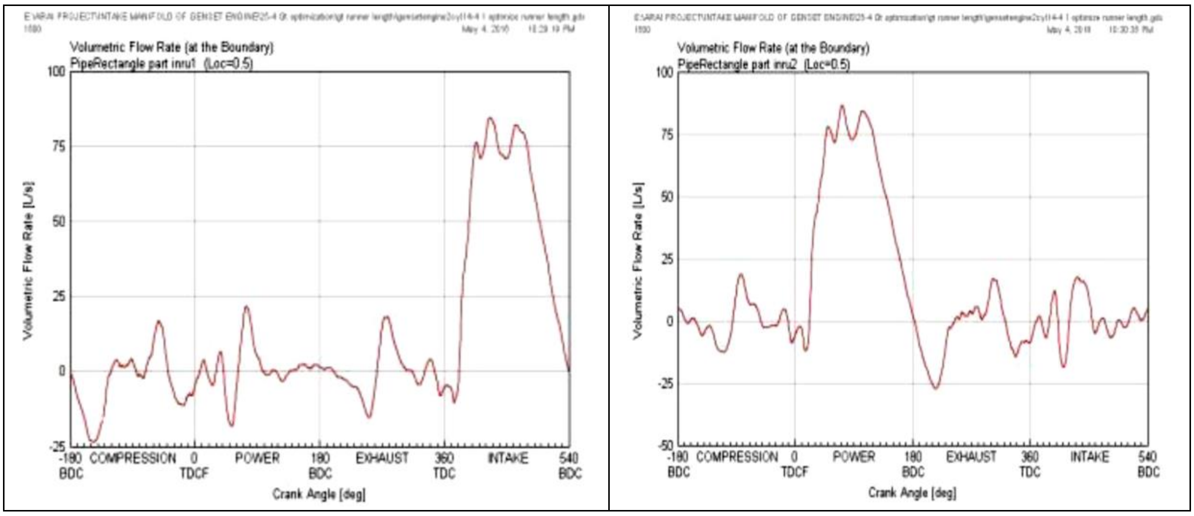

Figure 16. Volumetric mass flow rate of air in the cylinder 1 and cylinder 2.

CONCLUSIONS

Based on the observation of the study the following conclusions are made carefully:

1. The runners' end curvature is acceptable, and their design is appropriate for the specified intake manifold.
2. The plenum chamber's flawed design is to blame for the velocity fluctuation.
3. There are casting and design flaws in Plenum.
4. The intake manifold designed is compact and having minimum frictional resistance and the flow in the. Cylinders of the engine is uniform as volumetric efficiency difference between the cylinders is 0.6%.
5. It is observed that volumetric efficiency is increased considerably by altering various above parameters and the value of volumetric efficiency is increased by 7.05% from the existing model.
6. Intake manifold with volumetric efficiency 92.60% is finalized as optimum model after serious analysis of flow patterns and also considering mass flow rate, manufacturability, constraints on the engine and applicability of the same on existing engine.
7. The range for brake power is 18.7 kW to 19.3 kW and our value for optimized result is 19.2 kW which is within the limits. The range for brake specific fuel consumption is 240 to 242 g/kW-hr and our value for optimized result is 241.4 g/kW-hr.
8. The deviation in the volumetric efficiency of the intake manifold is 0.24% as per the experimental and GT-ISE simulation model. The permissible deviation of the volumetric efficiency is 3.37% as per the SAE paper 2007-01-3534.

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Data Availability

The authors confirm that this study's data are in this research report.

Conflict of Interests

All the authors contributed equally and has no conflict of interest in any way with this paper.

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