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Design and Analysis of Exhaust Manifold with Modifications in Long Bend Side Exit, Long Bend Middle Exit

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Abstract

Exhaust manifold is one of the most critical components of an IC Engine. The designing of exhaust manifold is a complex procedure and is dependent on many parameters viz. back pressure, exhaust velocity, mechanical efficiency etc. Preference for any of this parameter varies as per designer's needs. Usually fuel economy, emissions and power requirement are three different streams or thought regarding exhaust manifold design. In any multi-cylinder IC engine, an exhaust manifold (also known as a header) collects the exhaust gases from multiple cylinders into one pipe. This header is connected to these cylinders through bends. It is attached downstream of the engine and is major part in multi cylinder engines where there are multiple exhaust streams that have to be collected into a single pipe.

Exhaust gases comes out of this Header as a single stream of hot exhaust gases through single outlet. This work comprehensively analyzes eight different models of exhaust manifold and concludes the best possible design for least emissions and complete combustion of fuel to ensure least pollution. The main objective of this investigation is to design an exhaust manifold by using CATIA V5 R20 software and also find out pressures and velocities at various mass flow rates in the exhaust manifolds with Long Bend Side Exit (LBSE), Long Bend Middle Exit (LBME) and Reducer and find out the performance of the exhaust manifold with various modifications in its design or adding a component for the exhaust manifold to increase its effectiveness.

In the current analysis mass flow rates considered in the exhaust manifold are 2 kg/s, 4 kg/s, 6 kg/s, 8 kg/s ,10 kg/s, 12 kg/s in all the various modification ns in the exhaust manifolds. The best results were obtained.

Key words: Exhaust Manifold, LBSE, LBME, mass flow rates, Effectiveness

1. Introduction

In an automobile engine, exhaust system is an important part which carries hot gases from the cylinder to atmosphere and also reduces the noise of the engine. An exhaust system consist of cylinder head, manifold, turbocharger, catalytic converter and muffler. The burnt hot gases from the engine cylinder as a temperature of 800˚C and pressure from 100Kpa to 500Kpa. Due to this high temperature the manifold suffers a lot of thermal stress during its life cycle, so it required more consideration while designing an exhaust system. They are typically made of cast iron or steel, although some latest-model cars use stainless steel manifolds. The exhaust manifold is under a thermal fatigue produced by the exhaust gases increasing and decreasing temperatures. The pressure waves of the emitted exhaust gases during particular times of the cycle subject internal pressure. These will lead to cracks in the exhaust manifold. Thermal and mechanical loadings are the majorfactors in the failure of the exhaust manifold.

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To maximize the engine power at high speeds, theexhaust gases should be vented out smoothly from the piston chambers to the exhaust manifold.Structural and thermal analysis is performed with an internal pressure load, and stresses anddeflections are documented. Efforts are made to optimize the design for the above said conditions.A great deal of efforts are done to increase the performance and to reduce the weight. Automotivecompanies are trying to achieve a goal in optimal engine design.Factors to be considered during the design and development of exhaust manifold.

A. Runner length

This is arguably one of the most important factors. First would be to make sure that the runners are as equal length as possible. The idea being that the exhaust pulses will be spaced out evenly and arriving at the turbine wheel on the turbo at their own time in the firing order.

B. Runner volume

Runner volume needs to be considered when building a turbo manifold. While a larger runner diameter does facilitate lower exhaust backpressure for better flow on the top-end, it does cause a lower exhaust velocity. A lower exhaust velocity will cause longer spool times, and less transient response out of the turbo.

C. Collectors

A collector's job is to tie all of the cylinder's pipes together in one common place and send them into a single exit pipe.A collector is generally aconglomeration of pipes all merged together, allowing for a smooth transition from the primaries or secondaries into the rest of the exhaust.

D. Back Pressure

Back pressure can be produced at two places, i.e., when the exhaust valve opens and cam overlap taking place. Pressure measurements at the exhaust valve during the start of the exhaust stroke at bottom dead center (BDC) to cam overlap at the end of the exhaust stroke/beginning of the intake stroke at top dead center (TDC).

2. Literature Survey

Jafar M Hassan et.al. [1]

In his paper they analyzed the performance of the manifolds with a tapered longitudinal section. The length of the manifold for this study was 127cm while the manifold diameter was 10.16 cm. Authors had used the numerical simulations (CFD) for this research work. The flow conditions corresponding to Re= 10x104, 15x104 and 20x104 were considered. The results were analyzed in terms of uniformity coefficient. Based on their CFD simulation results, they had concluded that the tapered header configuration provides better flow distribution as compared to the header with circular cross-section.

M.Usan et.al. [2]

In their research paper theyhad applied a multi - disciplinary optimization approach for the exhaust system, exhaust manifold and catalytic converter, in highly integrated concurrent engineering software framework. They had considered four- cylinder 1.4 liter engine as a baseline model. The optimization contained four major modules – Geometry, Structural, Cost and Fluid Dynamics – and the relevant software for each module was applied. 1-dimensional transient CFD simulations were carried out using AVL BOOST with the engine torque and catalytic converter inlet temperature over the engine rpm were being estimated.

HessamedinNaemi et.al. [3]

In their research they had employed numerical simulations (CFD methods) for estimating the flow loss coefficient in manifolds. The flow inlet and exit was modeled using _mass-flow-inlet‘ and _pressure-outlet‘ boundary conditions, with the consideration that the flow was compressible. The results from different turbulence models – standard k-ε, standard k-ω, SpalartAllmaras model and RNG k-ε model – were compared in terms of flow loss coefficient against the experimental data.

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Based on their results, the authors had observed that the RNG k-ε turbulence model predictions were in close agreement with the experimental data.

Masahiro Kanazaki [4]

In their research paper they have developed a multiobjective optimization method for the exhaust manifold by using Divided Range Multi-objective Genetic Algorithm. The three-dimensional fluid dynamics inside the manifold was simulated using transient, Euler flow solver. The two objective functions for the optimization was i) maximizing exhaust gas temperature at the end of exhaust pipe ii) maximize the charging efficiency. The authors were able to successfully optimize the manifold for both these objective functions and noted that the optimized model has high engine power than the baseline model.

Hong Han-Chi et.al. [5]

In their research paper they used GT-Power, 1-dimensional software, for estimating the engine performance of a single cylinder IC engine. The power output predicted from the software was compared against the experimental data. In their study, the authors had considered four parameters – the sphere style plenum diameter, the intake runner diameter, the exhaust runner lengths and the position of restrictor. The plenum for the intake and exhaust manifold was designed using Helmholtz theory. The optimization experimental study was conducted by using Orthogonal Array Testing Strategy (OATS). The results obtained from the experimental analysis were found to be in good agreement with the results from the GT-Power software predictions.

TanerGocmez et.al.[6]

in their ―Designing Exhaust Manifolds Using Integral Engineering Solutions‖ focused on the development of a reliable approach to predict failure of exhaust manifolds and on the removal of structural weaknesses through the optimization of design. The failure modes for TMF cracks, vibration and exhaust manifold gaskets are emphasized. Engineering expertise is required to fully utilize this technique as the results strongly depend on defining the problem. This study shows an optimization package, which provides practical solutions to engineering problems through the removal of local structural weaknesses on highly loaded exhaust manifolds.

3. Methodology

In this paper we designed the two exhaust manifold by using catia and done analysis using Ansys software. The model is made modifications in LONG BEND SIDE EXIT, LONG BEND MIDDLE EXIT.

Material Properties of Cast Iron:

Thermal conductivity, K (w/m k)	50
Density, (kg/m3)	7200
Specific heat, c (J/Kg k)	1.88
Poisson's ratio, v	0.3
Thermal expansion, á (10ı6 / k)	0.3
Elastic modulus, E (GPA)	105
Coefficient of friction, µ	0.2
Yield strength (MPa)	130

Element Descriptions:

1) 10 NODE SOLID87 – With one dof. Temperature at each node.
2) 10 NODE SOLID 92 – With three dof. Translations in the x, y and z directions at each node.

Exhaust gas:

Temperature – 8000 C
Pressure range – 100 to 500 kPa.

Methodology followed:

- Created the model of the exhaust manifold using CATIA software, and imported it to ANSYS software.
- Perform thermal analysis on the exhaust manifold for thermal loads.
- Perform coupled field analysis on the exhaust manifold for pressure loads and thermal loads to find deflections and stress

3D Model and Mesh generation

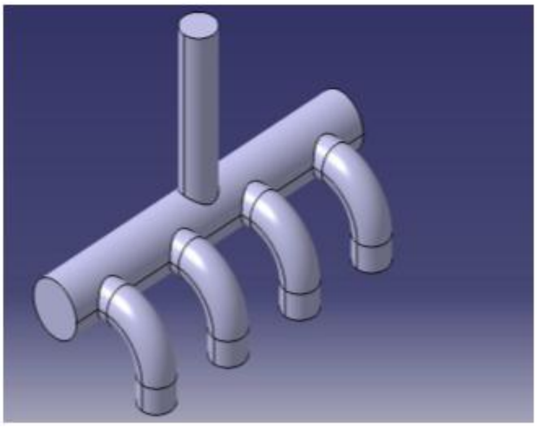

Fig 1 Catia Model of LBME

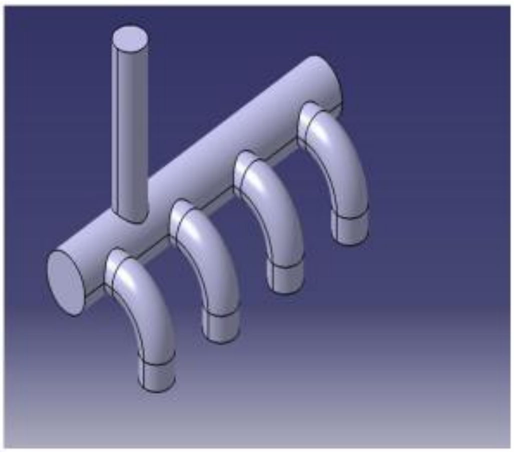

Fig 2 Catia Model of LBSE

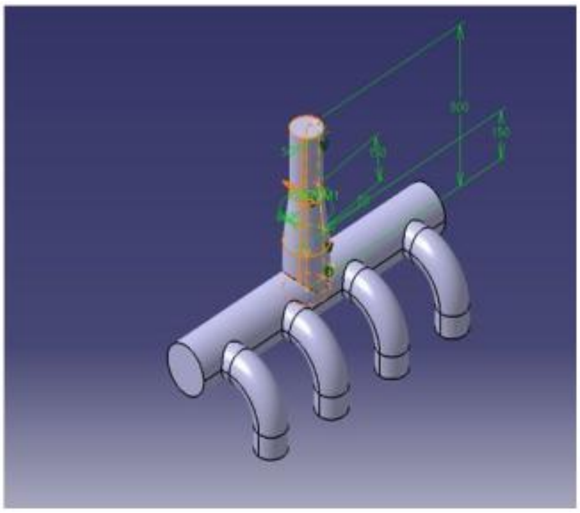

Fig 3 Catia Model of LBME with Reducer

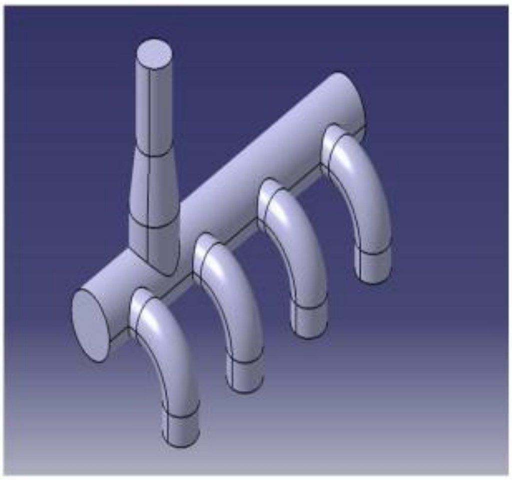

Fig 4Catia Model of LBSE with Reducer

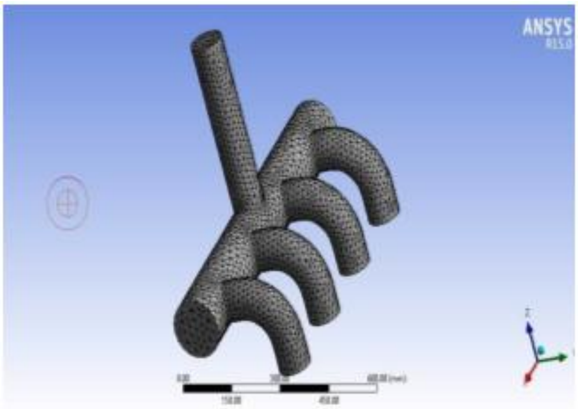

Fig 5Meshingof LBME

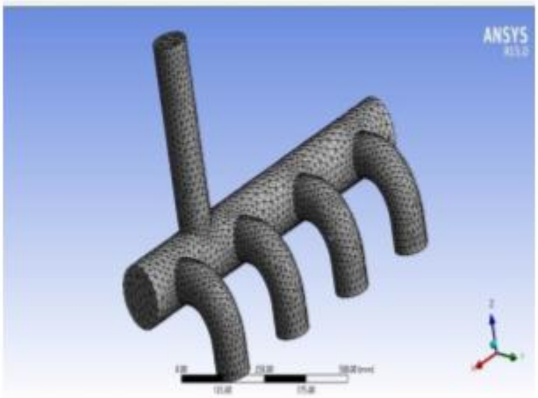

Fig 6 Meshingof LBSE

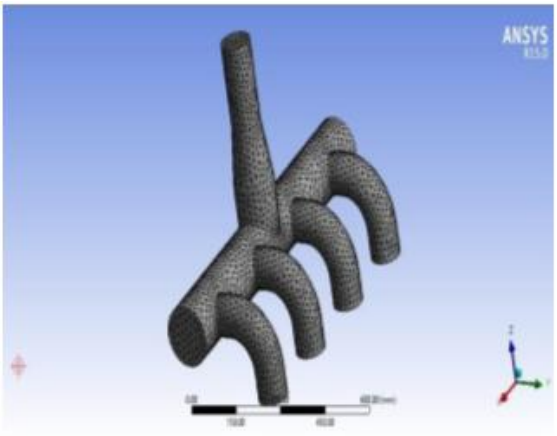

Fig 7Meshing of LBME with Reducer

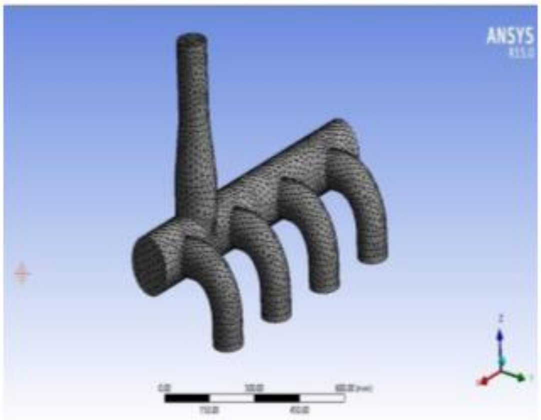

Fig 8 Meshing of LBSE with Reducer

4. Results and discussions

The main objective of this investigation is to find out pressures and velocities at various mass flow rates in the exhaust manifolds with Long Bend Side Exit (LBSE), Long Bend Middle Exit (LBME) and Reducer and find out the performance of the exhaust manifold with various modifications in its design or adding a component for the exhaust manifold to increase its effectiveness. In the current analysis mass flow rates considered in the exhaust manifold are 2 kg/s, 6 kg/s,12 kg/s in all the various modifications in the exhaust manifolds.

Pressure and Velocity Variations in Exhaust Manifold with LBSE

Mass Flow Rate: 2kg/s

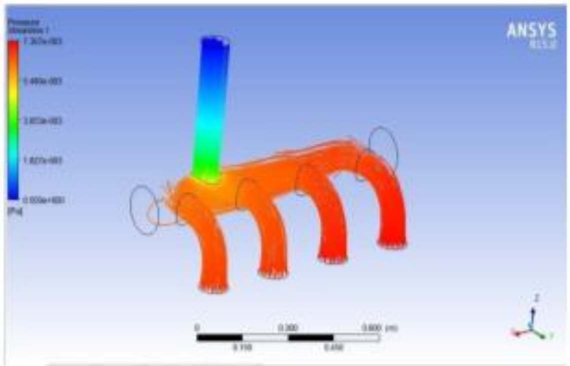

Fig 9Pressure Drop in Exhaust Manifold

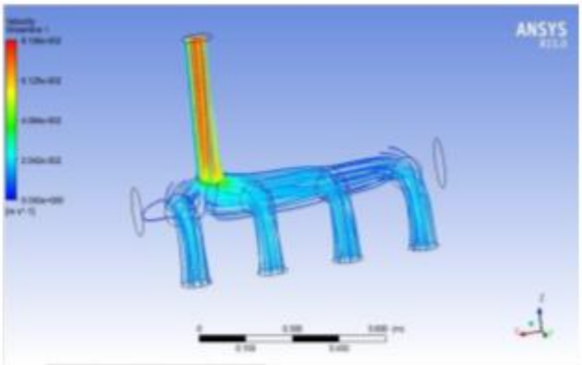

Fig 10Velocity in Exhaust Manifold

Table 1 Pressure and Velocity

S.No	Pressure Drop		Velocity	
	Maximum	Minimum	Maximum	Minimum
1	7.307e - 003	0.00e+00	8.168e - 0.002	0.00e+00

Mass Flow Rate: 6Kg/S

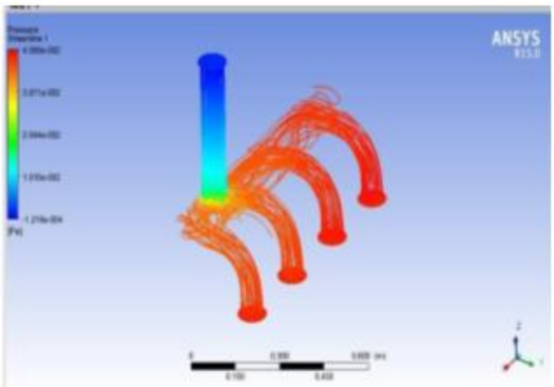

Fig 11Pressure Drop in Exhaust Manifold

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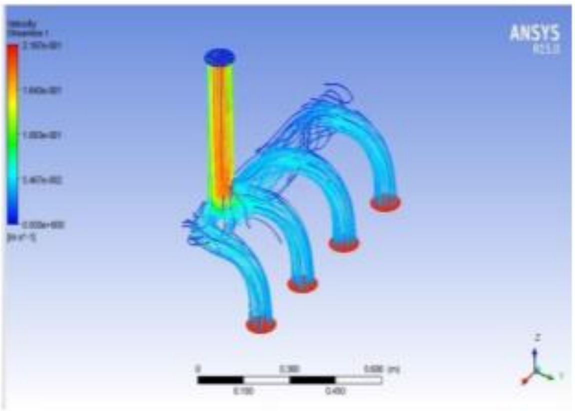

Fig 12 Velocity in Exhaust Manifold

Table 2 Pressure and Velocity

S.No	Pressure Drop		Velocity	
	Maximum	Minimum	Maximum	Minimum
1	4.099e-002	-1.216e-004	2.187e-001	0.00e+00

Mass Flow Rate: 12Kg/s

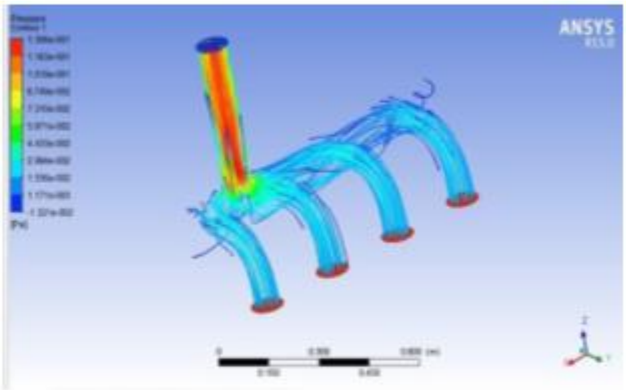

Fig 13Pressure Drop in Exhaust Manifold

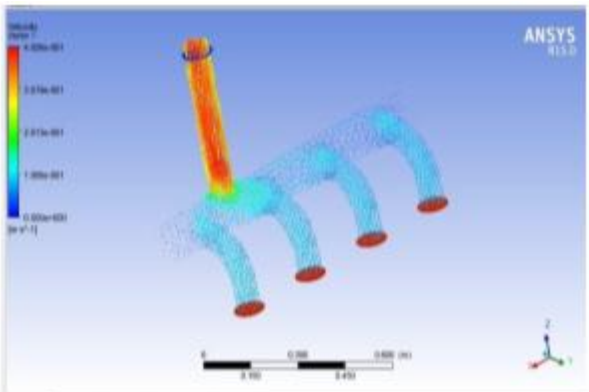

Fig 14 Velocity in Exhaust Manifold

Table 3Pressure and Velocity

S.No	Pressure Drop		Velocity	
	Maximum	Minimum	Maximum	Minimum
1	1.306 e-001	-1.321e-002	4.026e-001	0.00e+00

Pressure and Velocity Variations in Exhaust Manifold with LBCE

Mass Flow Rate: 2Kg/s

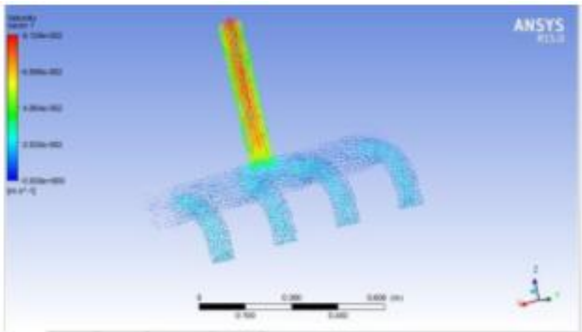

Fig 15Pressure Drop in Exhaust Manifold

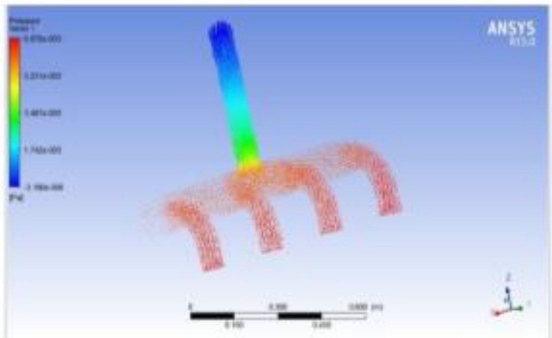

Fig 16 Velocity in Exhaust Manifold

Table 4Pressure and Velocity

S.No	Pressure Drop		Velocity	
	Maximum	Minimum	Maximum	Minimum
1	6.976e003	-3.186e005	8.129e002	0.00e+000

Mass FlowRate:6Kg/s

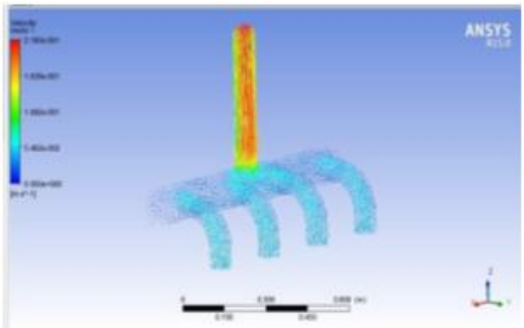

Fig 17Pressure Drop in Exhaust Manifold

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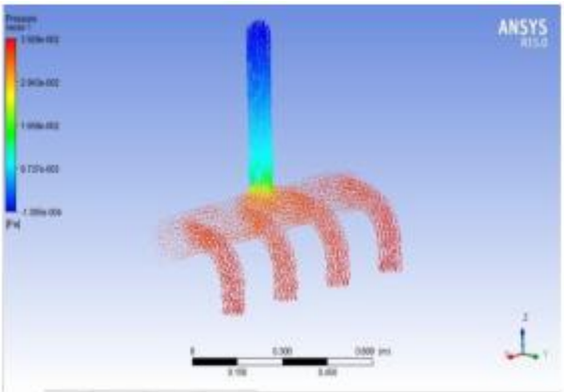

Fig 18 Velocity in Exhaust Manifold

Table 5Pressure and Velocity

S.No	Pressure Drop		Velocity	
	Maximum	Minimum	Maximum	Minimum
1	-1.095e-004	3.926e-002	2.185e-001	0.000e+00

Mass Flow Rate: 12 Kg/s

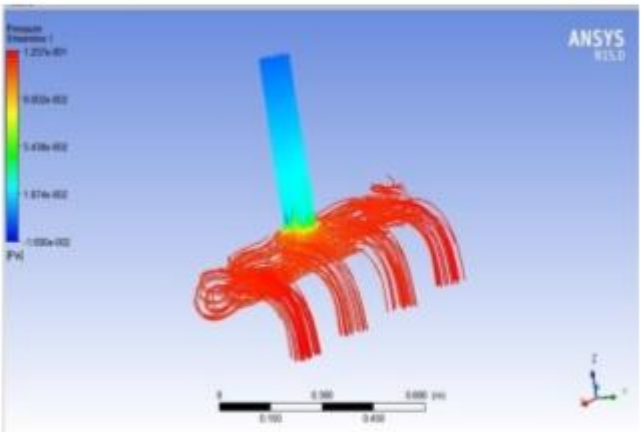

Fig 19Pressure Drop in Exhaust Manifold

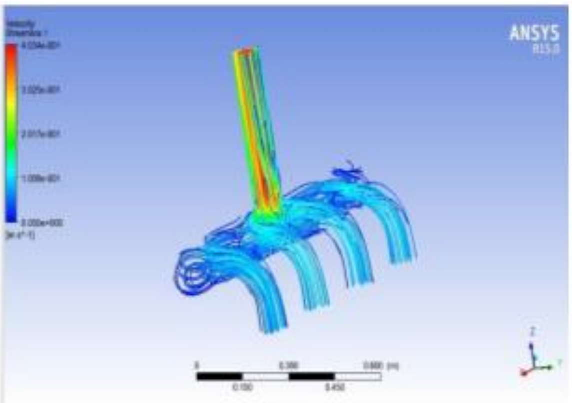

Fig 20 Velocity in Exhaust Manifold

Table 6Pressure and Velocity

S.No	Pressure Drop		Velocity	
	Maximum	Minimum	Maximum	Minimum
1	1.257e-001	-1.690e-002	4.034e-001	0.000e+000

Pressure and Velocity Variations in Exhaust Manifold with Reducer

Mass Flow Rate: 2 Kg/s

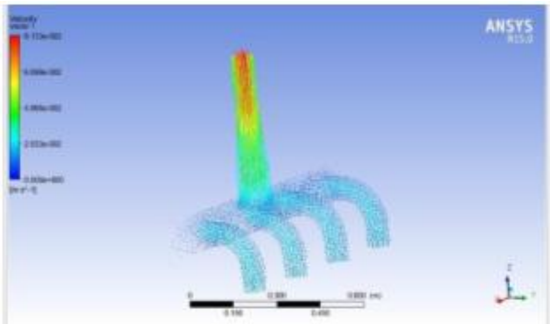

Fig 21Pressure Drop in Exhaust Manifold

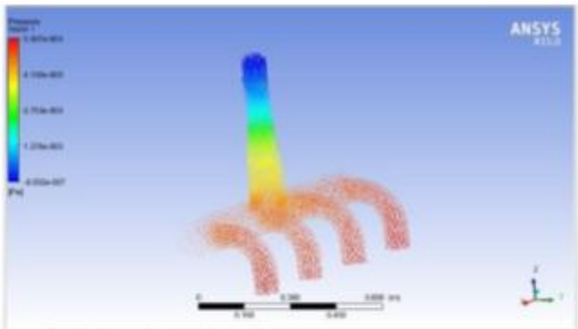

Fig 22 Velocity in Exhaust Manifold

Table 7Pressure and Velocity

S.No	Pressure Drop		Velocity	
	Maximum	Minimum	Maximum	Minimum
1	5.507e-003	-9.932e-007	8.133e-002	0.000e+000

Mass Flow Rate: 6kg/s

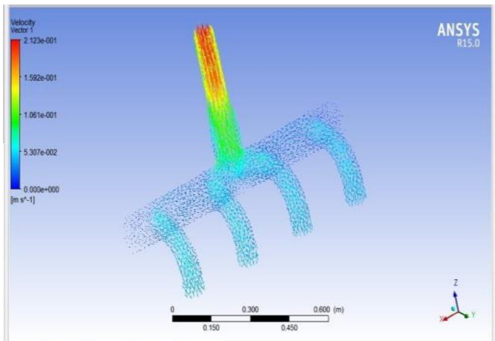

Fig 22Pressure Drop in Exhaust Manifold

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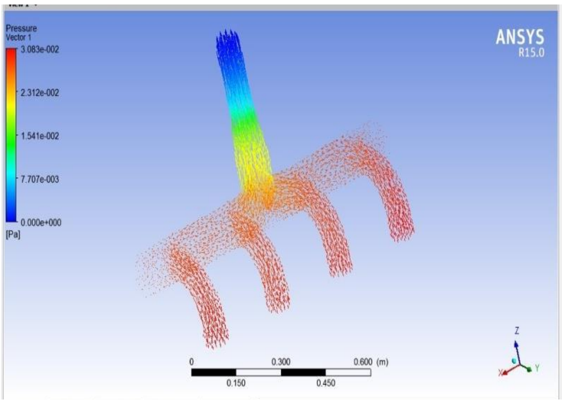

Fig 23 Velocity in Exhaust Manifold

Table 8Pressure and Velocity

S.No	Pressure Drop		Velocity	
	Maximum	Minimum	Maximum	Minimum
1	3.063e-002	0.000e+000	2.123e-001	0.000e+000

Mass Flow Rate:12kg/s

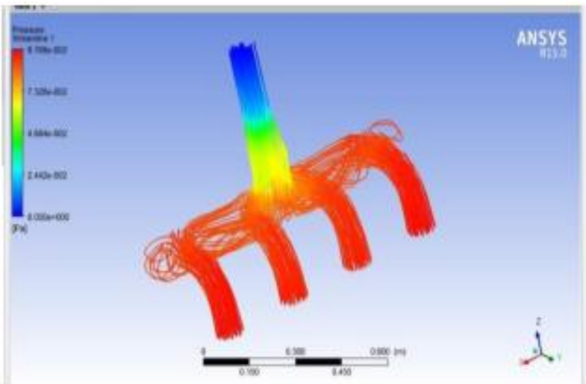

Fig 24Pressure Drop in Exhaust Manifold

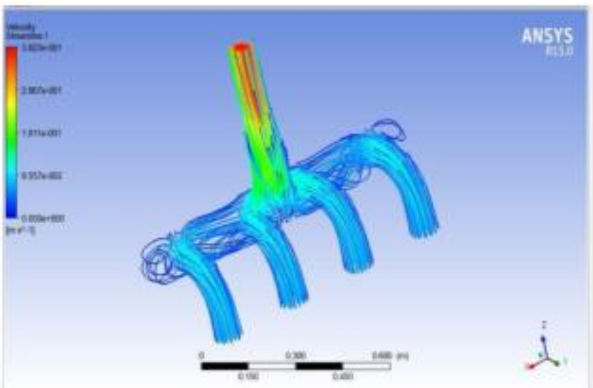

Fig 25 Velocity in Exhaust Manifold

Table 8 Pressure and Velocity

S.No	Pressure Drop		Velocity	
	Maximum	Minimum	Maximum	Minimum
1	9.768e-002	0.000e+000	3.823e-001	0.000e+000

5. Conclusion

In this thesis the investigation is to find out pressures and velocities at various mass flow rates in the exhaust manifolds with Long Bend Side Exit (LBSE), Long Bend Middle Exit (LBME) and Reducer and find out the performance of the exhaust manifold with various modifications in its design or adding a component for the Exhaust manifold to increase its effectiveness. In the current analysis mass flow rates considered in the exhaust manifold are 2 kg/s,6 kg/s, 12 kg/s in all the various modifications in the exhaust manifolds.

From the above investigations it is found that Long Bend Middle Exit (LBME) with Reducer is giving the better performance.

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