Experimental and CFD Analysis of Exhaust Manifold to Improve Performance of IC Engine

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Abstract -*Exhaust manifold collect the exhaust gases from the engine cylinders and discharge to the atmosphere through the exhaust system. The engine efficiency, combustion characteristics would depend upon how the exhaust gases were removed from the cylinder. The design of an exhaust manifold for the internal combustion engine depends on many parameters such as exhaust back pressure, velocity of exhaust gases etc. In this paper, the recent research on design of exhaust manifold, their performance evaluation using experimental methods as well as Numerical methods (CFD), various geometrical types of exhaust manifold and their impact on the performance has been collected and discussed.*

Key words: Exhaust Manifold, Engine Efficiency, Back Pressure, Numerical Method, Experimental Method.

1. INTRODUCTION

The exhaust system of an IC engine has a significant influence on the global engine operation. Among the different component of the system the exhaust Manifold has a paramount relevance on the gas exchange process. Though the intake system is dominant on the cylinder filling process, the exhaust manifold is able to influence the gas exchange process in several aspects, like the piston work during the exhaust stroke, the short-circuit of fresh charge from the intake into the exhaust and even the filling of the cylinder. In this sense, the most influential boundary condition imposed by the manifold is the pressure at the valve and especially the instantaneous pressure evolution. The mean backpressure is determined mainly by the singular elements, such as the turbine, the catalytic converter and the silencer. The instantaneous pressure evolution imposed by the manifold at the exhaust valve depends essentially on the layout and dimensions of the pipes, therefore an adequate design of the manifold geometry can improve the engine power and efficiency, and reduce the emissions of pollutants. Exhaust manifold design parameters are

Minimum possible resistance in runners.

1) Properly design of Manifold geometry to reduce the pressure drop.
2) Eliminate the unnecessary turbulence & eddies in the manifold.

2. EXPERIMENTATION

Experimentation on Diesel engine Test rig For various manifold geometries are attached to engine one by one. First will take experiment on existing model which is T-section. This experiment is conducted at SGDP College, Jalgaon, India. Every geometry is observed under different loads, Speed and Water flow rate of the engine take constant.

Table 1: Engine Specifications:

1	Engine type	Single cylinder, four stroke compression ignition engine
2	Rated power output	5 H.P.
3	Speed	1500 R.P.M.
4	Stroke length	110 mm
5	Bore diameter	80mm
6	Type of dynamometer	Rope brake dynamometer
7	Lubricant	SAE 30/40
8	Orifice diameter (for air box)	15mm
9	Co-efficient of discharge for orifice	0.64
10	Diameter of rope brake Drum	250mm
11	Diameter of rope	25mm

Figure 1: Different Geometries, 1) Sharp Bend 2)Short Bend and 3) Long Bend.

3. Sample Calculations (sharp bend), 2 Kg load.

1) Torque (T):

T = (W-S)* Re = 2.67 N.m

2) Brake Power (BP):

$$BP = \frac{2 * \pi * N * T}{60 * 1000} \; Kw$$

$$BP = \frac{2 * \pi * 1500 * 3.805695539}{60 * 1000}$$

$$BP = 0.419 \; Kw$$

3) Measurement of fuel consumption (M_f):

$$M_f = \frac{X * \rho_f}{t} = 0.0002625 \text{ Kg/s}$$

4) Brake Thermal Efficiency (η_{bth}) :

$$\eta_{bth} = \frac{BP}{M_f * CV} * 100$$

$$\eta_{bth} = 4.98 \%$$

5)Heat Supplied by combustion (Q_{sup}) :

$$Q_{sup} = M_f * CV$$

$$Q_{sup} = 8.4 \text{ KJ/s}$$

6) The heat carried away by Jacket cooling water (Q_w):

$$Q_w = M_w * C_{pw} * (T_{out} - T_{in})$$

$$Q_w = 0.083 * 4.187 * (28 - 24)$$

$$Q_w = 1.39 \text{ KJ/s}$$

4) Measurement of Air consumptions (M_a):

$$M_a = c_d * \frac{\pi}{4} * d^2 * \sqrt{(2 * g * ha}$$

Density of air, $\rho_a = \frac{P}{RT}$

=1.1729 Kg/m³

& $h_a = \rho_w \; h_w / \rho_a$

h_a =68.20 m of air

M_a=0.00483 Kg/s

$$Mg = Ma + Mf$$

$$Mg = 0.00509 \; Kg/s$$

7) Heat carried away by the exhaust gas (Q_g) :

$$Q_g = M_g * C_{pg} * (T_3 - T_a)$$

$$Q_g = 0.00509 * 1 * (139 - 28)$$

$$Q_g = 0.2392 \text{ KJ/s}$$

8) Heat Supplied by combustion(Q_{sup}) :

$$Q_{sup} = M_f * CV = 8.4 \text{ KJ/s}$$

$$Q_{Unacc} = Q_{sup} - (Q_{BP} + Q_W + Q_g)$$

9) Heat utilised in Brake power (Q_{BP}):

$$Q_{BP} = \frac{Q_{BP}}{Q_{sup}} * 100$$

$$Q_{BP} = \frac{0.419}{8.4} * 100$$

$$Q_{BP} = 4.98 \%$$

10) Heat carried away by Jacket cooling water (Q_W):

$$Q_W = \frac{Q_W}{Q_{sup}} * 100$$

$$Q_W = \frac{1.39}{8.4} * 100$$

$$Q_W = 16.54 \%$$

11) Heat carried away by the exhaust gas (Q_g):

$$Q_g = \frac{Q_g}{Q_{sup}} * 100$$

$$Q_g = \frac{0.2392}{8.4} * 100$$

$$Q_g = 2.84\ \%$$

12) Heat Unaccounted for (Q_{Unacc}):

$$Q_{Unacc} = \frac{Q_{sup} - (Q_{BP} + Q_W + Q_g)}{Q_{sup}} * 100$$

$$Q_{Unacc} = \frac{8.4 - (0.419 + 1.39 + 0.2393)}{8.4} * 100$$

$$Q_g = 75.59\ \%$$

4. Experimental results and Calculations:

Table 2 : Computation of percentage of heat balance sheet of C.I. engine, various load conditions and at constant RPM - 1500.

Sr. No.	Experimental Model	Load (W) in Kg	Heat Total supplied in KJ/s	Percent of heat equivalent to brake Power in %	Percent of heat carried away by Jacket cooling water in %	Percent of heat carried away by exhaust gases in %	Percent of heat for unaccounted in %
1	Sharp Bend	2	8.40	4.98	16.54	2.84	75.59
2		4	8.66	9.73	19.97	2.82	67.43
3		6	8.96	14.14	27.12	2.67	56.13
4	Short Bend	2	7.90	5.30	21.88	6.99	65.81
5		4	8.12	10.38	29.92	6.94	52.74
6		6	8.40	15.08	33.09	6.78	45.03
7	Long Bend	2	7.26	5.76	28.63	7.50	58.08
8		4	7.48	11.25	37.12	7.43	44.17
9		6	7.68	16.49	40.72	7.32	35.54

Table 3: Computation of Experimental Results for Long Bend model.

Load=> Properties	2 kg	4Kg	6Kg
Torque in Nm	2.67	5.37	8.07
Mass of air Supplied (M_a)in kg/s	0.00483	0.00483	0.00483
Back Pressure in Pa	1863.9	2040.48	2187.63
Brake Thermal Efficiency in %	5.768	11.25	16.49
Mass of Fuel Supplied (M_f)in kg/s	0.000227	0.000234	0.000240
Mass of Exhaust gases produced ($Mg = M_a + M_f$) in kg/s	0.00505	0.00506	0.00507

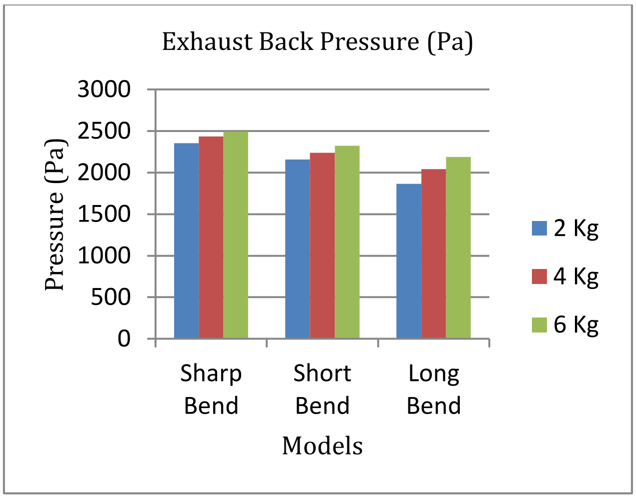

Chart 1: Graphical presentation of exhaust back pressure at different loads.

The Chart 1 shows the back pressure variation of different models on different loads. It seen that while using long bend back pressure decreases considerably. The Chart 2 shows that the variations in the brake thermal efficiency of different models on different loads. Considerable increase in brake thermal efficiency is observed while using the long Bend.

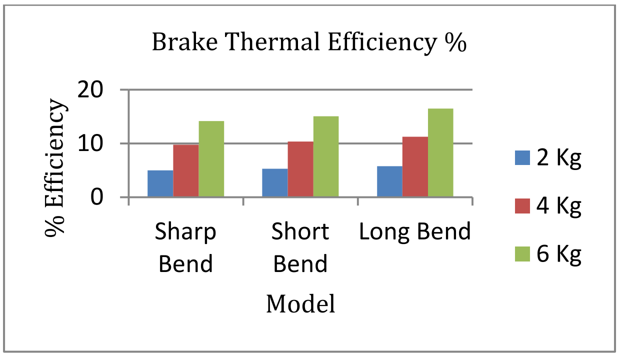

Chart 2: Graphical presentation of percentage of brake thermal efficiency at different loads.

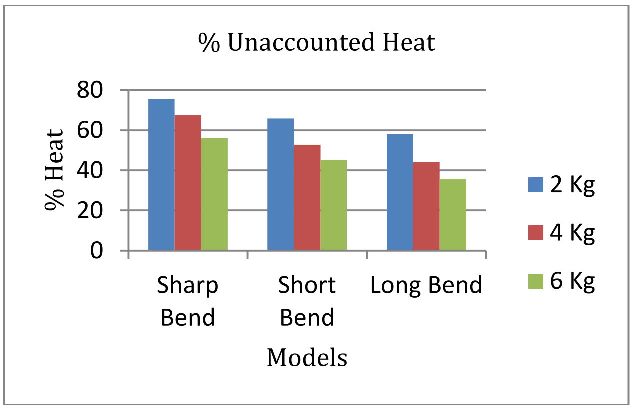

Chart 3: Graphical presentation of percentage of unaccounted heat at different loads.

The Chart 3 shows that the variation of percentage of Unaccounted heat of different models on different loads. Considerable decrease in unaccounted heat is observed while using long bend.

5. CFD Analysis

Table 4: Meshing of Long Bend

Object Name	Long Bend
Use Advanced Size Function	On: Curvature
nodes	14114
Elements	7008
Mesh metric	Non
smoothing	High
Transition	Fast

Fig. 2: Meshing of Long Bend

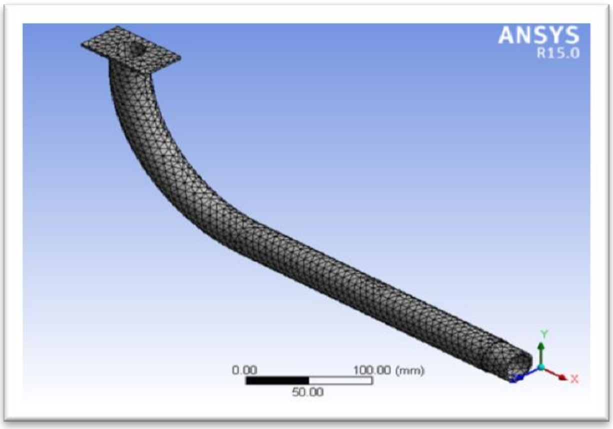

Fig. 3: Pressure Analysis of Long Bend

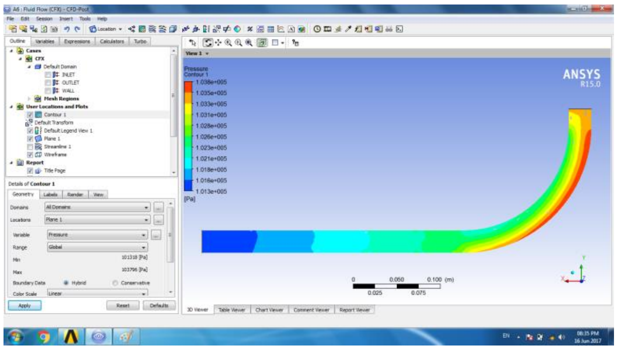

Fig 3 shows the Pressure variation of Long bend, it is that Pressure at the inlet of the model are exist in different layers, outer part of the bend have slight more Pressure than that of inner part of the body. Pressure at the outer Part of the body is much lower in comparison with sharp bend and short bend which leads to lower the back pressure.

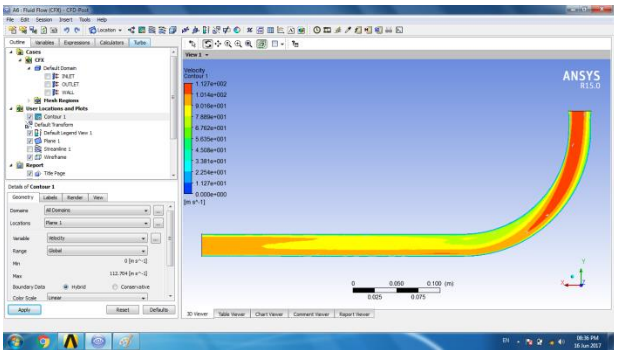

Fig. 4: Velocity Analysis of Long Bend

Fig 4 shows the velocity contour of long bend. Improvement in bend radius affects the velocity of gases, it seen from above fig inlet velocity of the long bend is higher than that other models.

6. Validation of Project

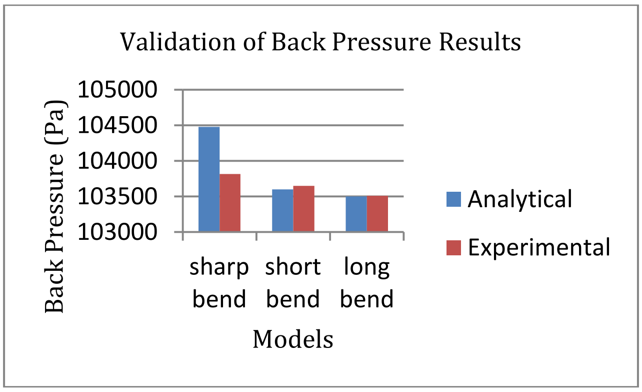

Chart 4: Comparison of Experimental and analytical Results

Graph shows Experimental and analytical results. Experimental Results of CI engine are compared with CFD results and results shows that, the sharp bend have high back pressure than other two models. Long bend model is more efficient than sharp bend and short bend.

Conclusion

In this work different Exhaust manifolds were analysed using Experimental and Analytical method. In Experimental method Exhaust back pressure, fuel consumption, brake thermal efficiency, and Heat utilization of different Manifolds on changing load were observed. In analytical method velocity and pressure distribution along the length of exhaust manifold is obtained through simulation. Three different models designed and results were analyzed. The use of different shapes of exhaust manifold helps in easy flow of exhaust. We conclude that,

1. Long bend model facilitates easy flow of exhaust gases and low backpressure at the exhaust outlet in comparisons with all other two models.
2. The minimum backpressure and higher exhaust velocities are achieved by using long bend Exhaust manifold.
3. Velocity at the outlet of long bend model is more and hence the backpressure reduces considerably.
4. The percentage of unaccounted heat is decreased considerably when use long bend exhaust model than other two models.
5. Brake thermal efficiency is more of long bend exhaust model in comparison with sharp bend and short bend.
6. Fuel consumption rate decreases when used long bend exhaust model.

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