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Design and Experimental Validation of Intake System to Improve Performance of Race Car

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Abstract —The design of induction system play vital role to optimize the engine performance. The objective of this work is to design induction system for race car as per requirement of 20mm restrictor, which limits the generated power. This concept has been developed to achieve the homogeneous flow into the cylinders in four stroke four cylinder Engine and separate plenums used to prevent the overlapping. In this design dual plenum used for the intake system which incorporates with the throttle valve and venture to reduce the pressure difference and improve the engine performance, inertial wave charging and resonance peak is achieved by optimizing the runner length. The modeling of system is done in Pro-E and simulation is carried out by using ANSYS Fluent software. Based on computational result, the protype is fabricated and validated with experimental & simulation data. The result shows that the use of dual plenum helps to maintain the uniform flow into the cylinders, increases the engine power and optimum pressure drop.

Index Terms — Restrictor, Plenum, Intake Runner, Manifold, Resonance.

1 Introduction

The design and orientation of the intake manifold is a major factor of an engine. Abrupt contour changes provoke pressure drops, resulting in less air (and/or fuel) entering the combustion chamber; high-performance manifolds have smooth contours and gradual transitions between adjacent segments.

Modern intake manifolds usually employ runners, individual tubes extending to each intake port on the cylinder head which emanate from a central volume or "plenum" beneath the carburetor. The purpose of the runner is to take advantage of the Helmholtz resonance property of air. Air flows at considerable speed through the open valve. When the valve closes, the air that has not yet entered the valve still has a lot of momentum and compresses against the valve, creating a pocket of high pressure. This high-pressure air begins to equalize with low pressure air in the manifold. Due to air's inertia, the equalization will tend to oscillate. At first the air in the runner will be at a lower pressure than the manifold. The air in the manifold then tries to equalize back into the runner, and the oscillation repeats. This process occurs at the speed of sound, and in most manifolds travels up and down the runner many times before the valve opens again. As a result of "resonance tuning", some naturally aspirated intake systems operate at high volumetric efficiency. The air pressure in the combustion chamber before the compression stroke is greater than the atmospheric pressure.

In combination with this intake manifold design feature, the exhaust manifold design, as well as the exhaust valve opening time can be so calibrated as to achieve greater evacuation of the cylinder. The exhaust manifolds achieve a vacuum in the cylinder just before the piston reaches top dead centre. The openings of inlet valve at typical compression ratios fill 10% of the cylinder before beginning downward travel. Instead of achieving higher pressure in the cylinder, the inlet valve stay open after the piston reaches bottom dead centre while the air still flows in.

In some engines the intake runners are straight for minimal resistance. In most engines, however, the runners have curves and some very convoluted to achieve desired runner length. These turns allow for a more compact manifold, with denser packaging of the whole engine, as a result. Also, these "snaked" runners are needed for some variable length/ split runner designs, and allow the size of the plenum to be reduced. In an engine with at least six cylinders the averaged intake flow is nearly constant and the plenum volume can be smaller. To avoid standing waves within the plenum it is made as compact as possible. The intake runners each use a smaller part of the plenum surface than the inlet, which supplies air to the plenum, for aerodynamic reasons. Each runner is placed to have nearly the same distance to the main inlet. Runners, whose cylinders fire close after each other, are not placed as neighbours. The system consists of following important parts:

- Throttle body- throttle mechanism that regulates the amount of air flow into the engine and thus engine power output.
- Restrictor- conical duct that leads air from the throttle body to the plenum.
- Plenum- collecting chamber for incoming air into the engine.
- Intake runners- ducts connecting the plenum to the engine intake ports.

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2 Air Intake System Requirements

All parts of the engine air and fuel control systems must lie within the surface defined by the top of the roll bar and the outside edge of the four tires. As shown in Figure 1. Any portion of the air intake system that is less than 350mm above the ground must be shielded from side or rear impact collisions by structure built.

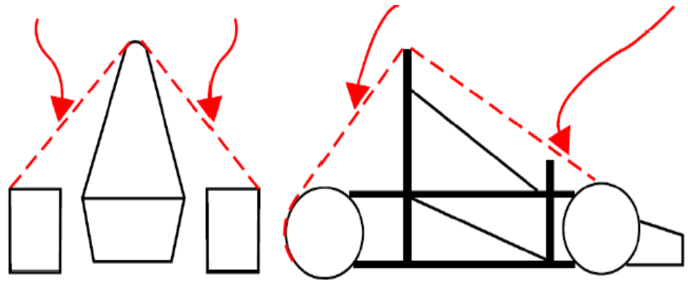

Figure 1: Rear and Side View of Envelope

The intake manifold must be securely attached to the engine block or cylinder head with brackets and mechanical fasteners. This precludes the use of hose clamps, plastic ties, or safety wires. The use of rubber bushings or hose is acceptable for creating and sealing air passages, but is not considered a structural attachment. Intake systems with significant mass or cantilever from the cylinder head must be supported to prevent stress to the intake system. Supports to the engine must be rigid. Supports to the frame or chassis must incorporate some isolation to allow for engine movement and chassis flex. In order to limit the power capability from the engine, a single circular restrictor must be placed in the intake system between the throttle and the engine and all engine airflow must pass through the restrictor. The maximum restrictor diameter is 20mm. The restrictor must be located to facilitate measurement during the inspection process. The circular restricting cross section may NOT be movable or flexible in any way, e.g. the restrictor may not be part of the movable portion of a barrel throttle body.

3 Design & Analysis of intake system

3.1 Venturi Design

Based on literature survey, it is observed that cone and diffuser angles are important parameters in venturi design. The three designs of venturi with different angle combinations are considered as shown in Table 1 and 2.

Table1: Determination of Cone angle

Sr. No.	Cone Angle (degree)	Velocity at throat in m/s
1.	13	296
2.	14	302
3.	15	309
4.	16	315
5.	17	333
6.	18	353
7.	19	367

Table2: Determination of Diffuser angle

Finally 170 cone angle with 50mm cone diameter and 70 dif-

Sr. no.	Diffuser Angle in degree	Guage Pressure at the diffuser end in 10^2 Pascal	Velocity at the diffuser end in m/s
1.	4	3.24	95.2
2.	5	8.68	91.9
3.	6	13.6	87.7
4.	7	19.2	86.2
5.	8	14.2	88.1
6.	9	9.4	90.4

fuser angle with 20mm throat diameter are selected to design venturi. The total length of the venturi is 310mm. The design of venturi is shown in figure 2.

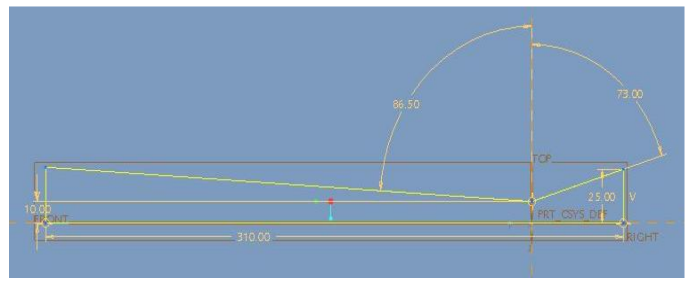

Figure 2: Venturi

3.2 Dual Plenum Intake Manifold

The distinguishing aspect of the intake manifold design is the use of dual plenum to eliminate the effects of overlapping intake events. During normal engine operation, a cylinder intake valve (V1) opens slightly before the piston reaches top dead centre to enable air-fuel mixture to be drawn into the cylinder as the piston descends. This occurs prior to the completion of a similar event in a nearly charged second cylinder, just before its intake valve (V2) closes. When a single induction manifold joins the two cylinders, the filling event of the second cylinder overlaps with that of the first, causing interference and uneven filling between cylinders. Flow to the initial cylinder is created by reduced pressure caused by outgoing exhausts gases [4,5]. The net effect is a reduction in potential cylinder charge and decreased engine power output. In an effort to significantly reduce this effect, a dual plenum manifold design implemented.

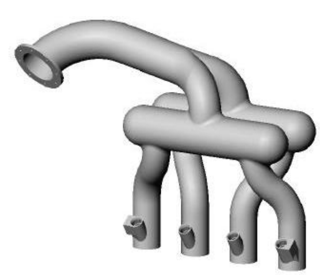

Figure 3: Dual Plenum Intake Manifold

Cylinder pairs with potentially overlapping events in a selected 4 stroke 4 cylinder engine are C1+C3, and C2+C4. For this reason, C1+C4 are fed by one manifold, and C2+C3 are fed by a second manifold as shown in Figure 3. Initial runners length are designed to take advantage of inertial wave charge primary volume reflections [6, 7]. The design of variable intake pipe length allowing maximum volumetric efficiency over the range of operating speeds discarded due to complexity and cost. Typical operating speeds in past designs at peak efficiency determined to be most beneficial between 8000 and 9000 rpm. Primary runner lengths adjusted to correspond with Helmholtz resonance tuning peaks predicted by the electrical circuit resonance analogy developed by W. Englemann. Depending on amplitude and phase of theses pressure waves, filling of cylinders can be affected positively or negatively. The amplitude and phase of theses pressure waves depend on inlet manifold geometry, engine speed and valve timing.

3.3 Plenum Geometry

The plenum geometry features four runners equally spaced from the restrictor's exit located at the bottom portion of the domed plenum. This plenum shape requires incoming air to make a 180 degree turn to enter the runners.

3.4 Plenum Design Parameters

Based on design calculations, the output parameters are shown in table 3.

Table3: Plenum Design Parameters

Restrictor inlet diameter	50mm
Restrictor throat diameter	20mm
Length of runner	247mm
Mass of the air required per cylinder per cycle	0.178 g
Mass of the fuel required per cylinder per cycle	0.0123 g
specific gravity of fuel	0.75
volume of fuel required per cylinder per cycle	0.0164 ml
Restrictor inlet diameter	20mm
Restrictor cone angle	17 degree
Restrictor diffuser angle	7 degree
Maximum velocity in venturi at throat	336m/s
Plenum diameter	70mm
Plenum length	250mm
Intake manifold runner length	24.7mm

3.5 Intake Restrictor

The cone angle is considered on the basis of maximum velocity at the throat but it must be less than the mach-1 velocity otherwise, it leads to the chocked condition and the mass flow rate will be reduced. The figure 4 shows the pressure and velocity contour flow through restrictor which is close to the requirements.

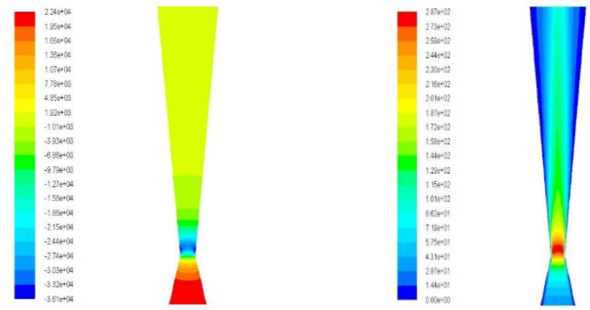

Figure 4: Pressure and Velocity Contour in Intake Restrictor

3.6 Plenum

Five different designs are considered for best output required parameters. In most of the cases, it is observed that distribution of air in all the cylinders is not same which affect the performance of engine. The analysis shows that dual plenum design gives even velocity and pressure distribution is as shown in figure 5.

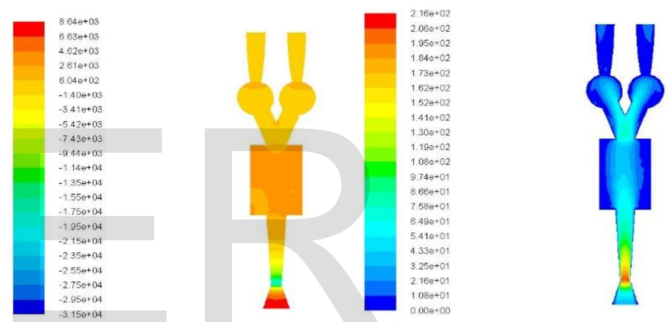

Figure 5: Pressure and Velocity Contour in Dual Plenum

Also the pressure drop in inlet manifold is also less as compared to other designs. This gives prominent results, as all the cylinders are having same flow rate which will improve the performance of the engine significantly.

4. Experimental Validation

To validate the simulation result, a prototype of dual plenum is fabricated as shown in figure 6 and experiment performed by using manometer.

Figure 6: Dual Plenum Prototype

The prototype is fabricated by using aluminium material because of its durability, corrosion resistance and structural rigidity properties. The thickness of pipe used for inlet & outlet is 3 mm to ensure proper weld without any leakage. The butterfly valve is placed at the top of venturi. The mass flow rate set near to wide open throttle condition to measure pressure loss. This pressure drop depends mainly upon the convergent angle. This venturi also creates restriction while air flows through it. The experimental data is tabulated in table 3.

Table3: Pressure v/s Position Experimental data on Plenum

Sr. No.	Position (mm)	Pressure Difference (Pascal)
1.	0	8000
2.	50	-22000
3.	200	2000
4.	310	0
5.	400	1000
6.	450	2500
7.	500	1000

The result shows that there is a single negative value of pressure difference i.e. -22000 resulting at position 50 due to the convergence of flow of air whereas At position 200, due to the sudden expansion of air, the pressure difference became 2000. Then, due to the sudden contraction of air flow at position 310, the pressure difference lowered down to 0. Also it is observed that at position 400, the flow is equally distributed in both the plenum which again raises the pressure difference to 1000. Eventually due to again sudden contraction of air at position 450, the pressure difference raises to 2500.

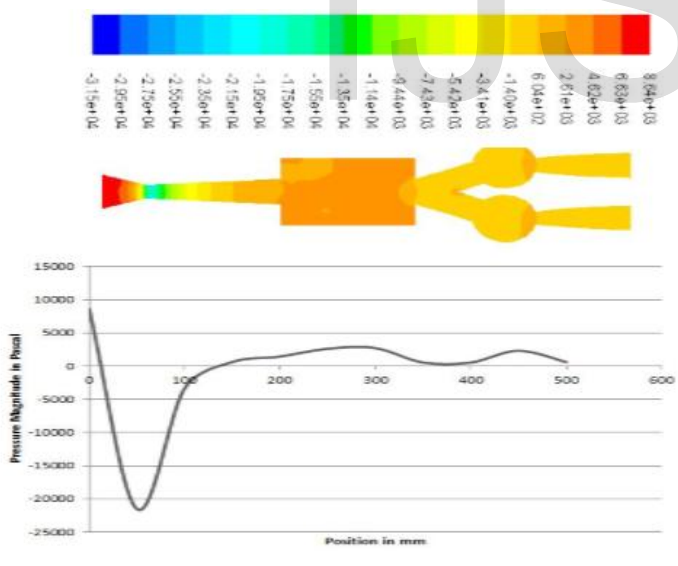

Figure 7: Correlation between Simulation & Experiment

The figure 7 shows the correlation between simulation and experimental data on pressure magnitude which indicates close relation between them.

Also this dual plenum intake system compared with previous intake system to simulate the engine output power with respect to engine rpm. The result of same is shown in figure 8.

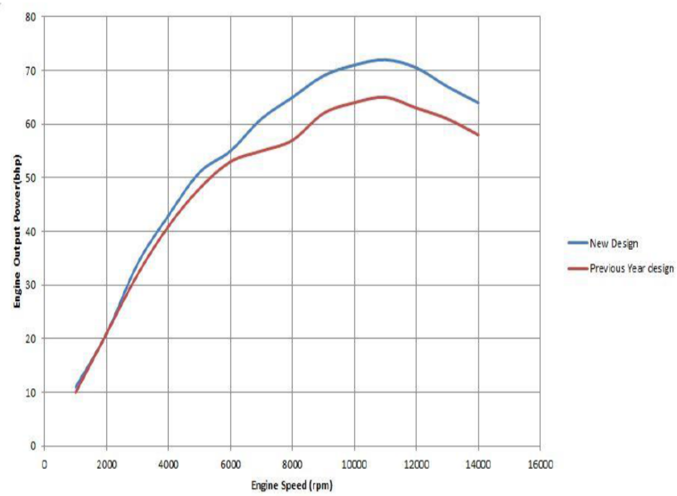

Figure 8: Power v/s Engine rpm

The result shows that the power increases with speed as expected. The maximum power occurs at 11000 rpm. The power output reduces after 11000 rpm due reduction of engine torque with speed. This torque reduces because of reduction in volumetric efficiency & increase of friction loss. Overall result shows that the total amount of power is increased by 11.5% which will leads to improvement in engine significantly.

5. Conclusion

The dual plenum is giving most prominent results as compared to others as all the cylinders are having same flow rate. This unique design of the intake system helps to reduce the pressure drop across the intake manifold. Also there is a collector which helps in recovering the pressure of the intake system. Since single plenum design has the drawback of uneven distribution of the flow hence to overcome the same issue, this design incorporates with two plenums. Also separate over lapping intake events minimize the inertial charging losses. Overall this system increases engine power, extends peak engine performance and optimum pressure drop with minimum internal losses.

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