Improving the Performance of Single Cylinder Motorbike Engine for Formula Student Car by Proper Design and Optimization of the Air Intake System

[1]Ameya Gate, [2]Abhay Sawant, [3]Akash Wayal, [4]Omkar Phanse, [5]Mahesh Kavre

[1,2,3,4]Students, [5]Assistant Professor

[1,2,3,4,5]Mechanical Engineering Department,

[1,2,3,4,5]Terna Engineering College, Mumbai University, Nerul, Navi Mumbai, India.

Abstract: This study focuses on optimization of the air intake system of a single cylinder motorbike engine for formula student car using solidworks flow simulation. The performance of the vehicle highly depends on the air intake system and thus the need for its optimization is crucial to succeed in the competition. The design is critical as it has to satisfy all the norms stated in the formula student rulebook 2019. As per the formula student rulebook, the air entering the engine has to pass through the restrictor having 20mm throat diameter which results in decrease in pressure of the air. The purpose of study is to maximize the recovery of the pressure which was lost due to the restrictor thereby reducing the pressure drop across it.

***IndexTerms* - Air restrictor, Plenum, Runner, Single cylinder engine.**

I. Introduction

Every year SAEINDIA organizes student formula racing competition and provides a rulebook to the student teams wishing to participate. The rules mentioned in the rulebook play an important role in the design aspect of the FSAE car. The air intake system consists of three parts : Restrictor, Plenum and Runner (Jandid and Sharma, 2018). In the air intake system, the pressure lost due to the restrictor is recovered and proper tuning of the engine at required rpm can be achieved thereby increasing the pickup of the vehicle (Sawant et al., 2018). The restrictor must have throat diameter as 20mm as it is mandated in the student formula rulebook. This restricts the flow of air into the engine thereby reducing the pickup and efficiency. For our study, we have used KTM duke 390cc engine which lies within the allowed engine displacement (610cc) as per formula student rulebook 2019. The aim here is to minimize this pressure drop caused due to restrictor and to maximize the recovery of the pressure of air. Proper design of plenum and the optimization of runner length for proper tuning of the engine is essential.

II. Literature Review

In paper by Pant et.al (2018), selection of venturi as a restrictor over orifice is. Also calculations related to mass flow rate are referred. For mass flow rate formula and for calculations for chocked flow rate condition we referred Deshpande (2015). In the study by Jangid and Sharma (2018), author shows how to simulate the air intake system on soildworks flow simulation. In the research by Sawant et.al (2018), author shown different combinations of convergent and divergent angles for efficient design of the restrictor. In the paper by Puri and Darade (2016), author derived runner formulas which we used for calculation of runner length and was used for tuning at 5000rpm.

III. Research Methodology

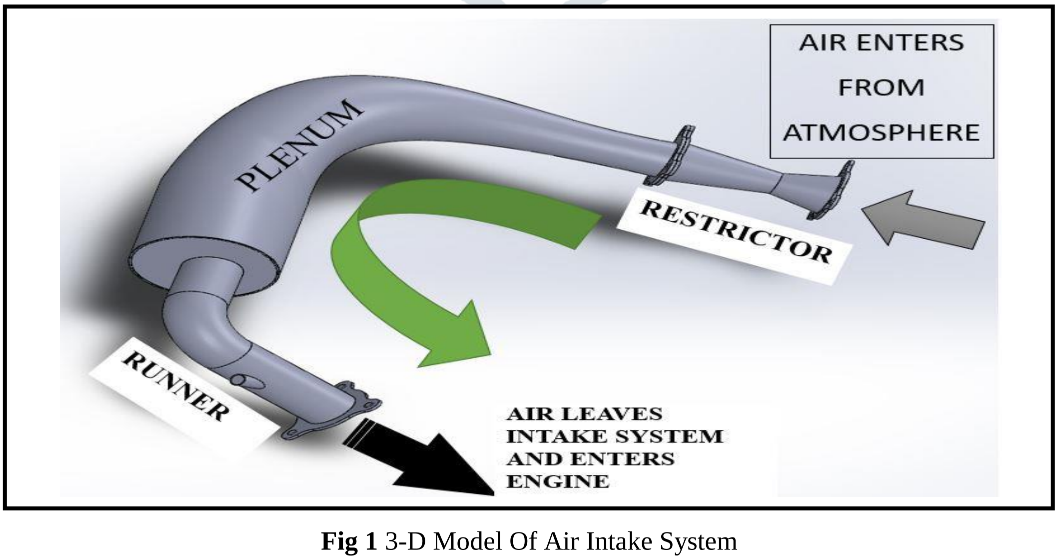

Fig 1 3-D Model Of Air Intake System

3.1Restrictor

Here we design the venturi type restrictor with the aim of minimizing the pressure drop across it. The air from the atmosphere enters the convergent end of the restrictor and leaves from the divergent end of restrictor to the plenum. The inlet and outlet diameters are 43.5 mm. The length of the restrictor is considered to be 124.75mm. Mass flow rate of air (m) can be calculated with the help of Helmholtz theory,

(1) m = $r \times V \times A$

r = density of air

V = velocity of air

A = Flow area = 0.001256 m^2

(2) V = $M \times V_s = M \times \sqrt{\gamma \times R \times T}$

M = mach number = 1 (chocked flow)

V_s = velocity of sound

R = gas constant = 0.286 kJ/Kg-K

γ = specific heat ratio = 1.4

T = temperature of the flow = 300K

(3) r = $\frac{P}{R \times T}$

P = pressure of air = 101325 Pa

(4) substituting (2) and (3) in (1) we get, m = $A \times M \times \sqrt{\gamma \times R \times T} \times \frac{P}{R \times T}$

(5) P = $P_t \times \left(\frac{T}{T_t}\right)$ ^ $(\gamma/(\gamma-1))$

$P_t = total\ pressure$

T_t = total temperature

(6) Substituting (5) in (4) we get,

m = (A ×Pt /$\sqrt{T_t}$)× $\sqrt{\frac{\gamma}{R}}$ ×M ×(T / Tt)^((γ+1) / (2 ×(γ -1)))

(7) Another isentropic relation gives: T/Tt = (1 + 0.5 × (γ -1) × M^2) ^-1

(8) Substituting (7) into (6) we get mass flow rate of air (m) as,

= (A × Pt /$\sqrt{T_t}$) × $\sqrt{\frac{\gamma}{R}}$ × M × [1 + .5 × (γ-1) × M^2]^-[(γ + 1)/(γ - 1)/2]

Result :

Mass flow rate at chocking (m) = 0.0703 kg/s

The result of simulation based on the input data is shown in the Table 1 :

Input data : Boundary conditions :

Inlet : pressure inlet : 1 atm

Outlet : mass flow rate = 0.0703 kg/s (calculated previously)

Table 3.1: Comparison Of Pressure At Different Convergent And Divergent Angles

Observation Number	Convergent Angle (degree)	Divergent Angle (degree)	Atmospheric Pressure (pascal)	Pressure at Restrictor Outlet (pascal)	Pressure Difference (pascal)
1	15	8	100821.79	97083.43	3738.36
2	12.5	8	100821.79	96599.17	4222.62
3	14.5	8	100821.79	96485.5	4336.29
4	13	8	100821.79	97028.26	3793.53

Considering divergent angle as constant at 8 degrees, calculating pressure differences at different convergent angles. The pressure at outlet is the result of flow simulation performed in solidworks. Considering observation no. 1 for selection of convergent and divergent angles for the restrictor as it has the lowest pressure difference. Hence, Convergent angle is 15° and Divergent angle is 8°are taken for analysis.

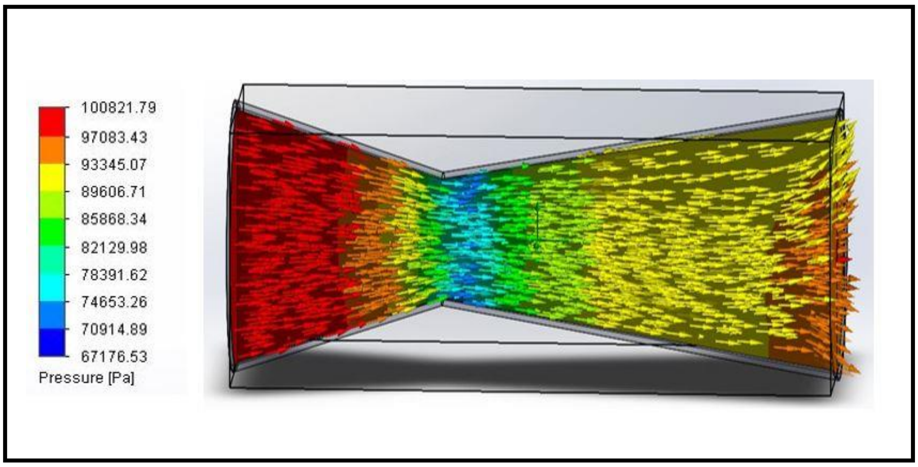

Fig 2 Pressure Analysis Of Restrictor

In the Figure 1, the pressure analysis for observation 1 is done using solidworks flow simulation and it is visible that air enters the restrictor at 100821.79 Pa (near to atmospheric pressure) and leaves at 97083.43 Pa. The velocity analysis for the same observation is shown below in the Figure 2 and it shows outlet velocity to be 79.982 m/s. As we try to increase pressure across the restrictor, the velocity decreases relatively.

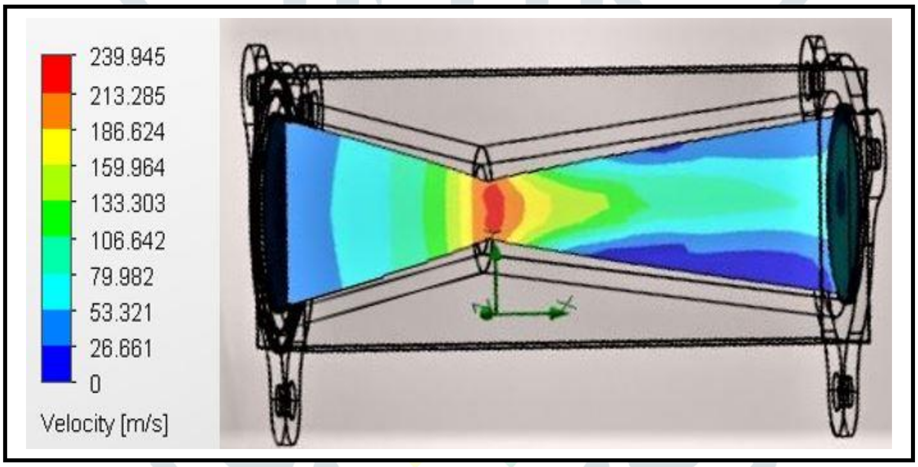

Fig 3 Velocity Analysis Of Restrictor

3.2Plenum

It is used as an air reservoir. The pressure of the air which decreased in the restrictor increases in plenum. The plenum shape and volume is decided on the basis of ricardo software results. For our intake system we used streamlined type of plenum and the volume of plenum is 9.33 times that of engine volume.

3.3Runner

The length of runner (L) is important factor while designing it and is given as,

$$L = \frac{EVCD \times 0.25 \times V \times 2}{RPM \times RV} - 0.5 \times D$$

where:
EVCD = Effective valve closed duration = 464°
V = speed of sound, ft/s = 1300 feets/sec
Rpm = Revolutions per minute = 5000
RV = Reflective value = 5
D = Runner Diameter = 43.5 mm

Thus we get optimum length of the runner as, L = 284.67 mm for our engine which is tuned at 5000 rpm.

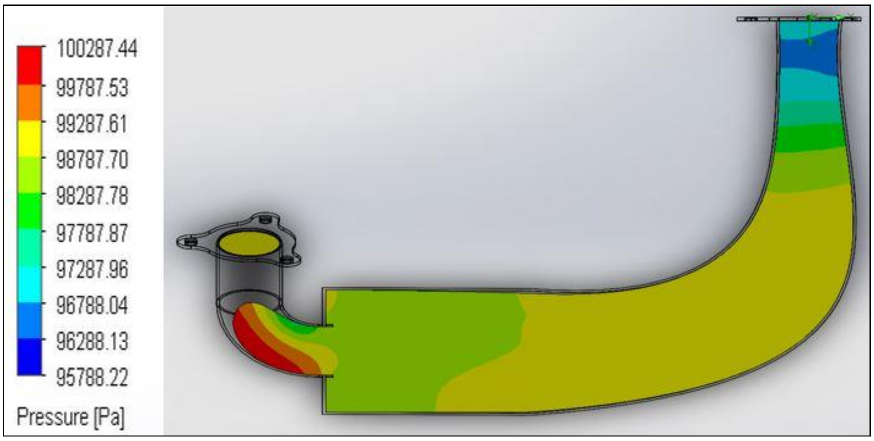

Fig 4 Pressure Analysis Of Plenum And Runner

The air enters into the engine from the runner through inlet valve. As the piston moves towards the bottom dead center, suction of air takes place into the engine form the runner. When the inlet valve closes, the air waves hitting the closed valve reflect back to runner creating acoustic waves in the runner. The optimum length of the runner help those reflected waves to reflect back into the engine at the proper timing of the valve opening. Here, at the end of the plenum we need high pressure as when exhaust valve of the engine opens the pressure inside the combustion chamber suddenly drops and air in the intake system is sucked into the engine. As shown in Figure 4 the difference in the velocity of air at the inlet of plenum and the outlet of runner is not high. From Figure 3 we can say that the air enters in plenum at 97287.96 Pa and leaves at 100287.44 (near to atmospheric pressure). Hence maximum recovery of air pressure takes place.

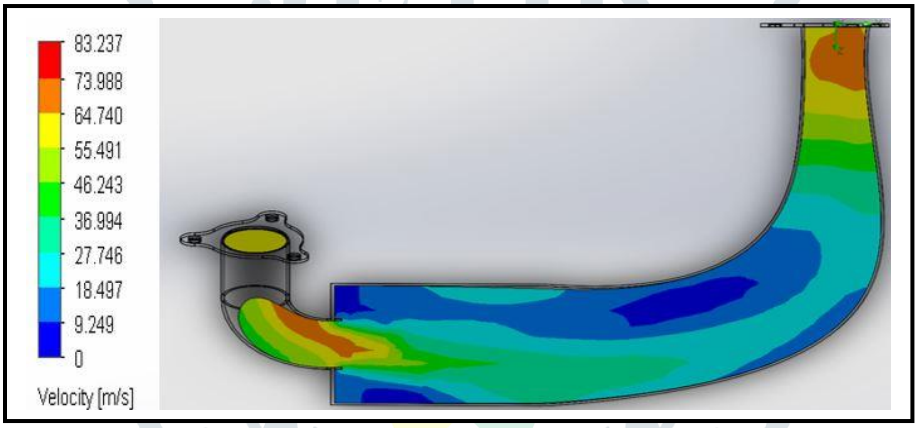

Fig 5 Velocity Analysis Of Plenum And Runner

IV. Conclusion

The design of restrictor is analyzed using solidworks flow simulation and the results are optimized as per the requirement. The design of plenum and runner is of significant importance for a single cylinder motorbike (KTM duke 390) engine. The restrictor having fixed throat diameter as 20mm is optimized with the help of proper combination of convergent and divergent angles such that the pressure drop across the restrictor is minimum. The selected convergent and divergent angles are 15° and 8° respectively based on results of solidworks flow simulation. With the help of the runner formula we decided that our runner length is 284.67 mm which is the optimum runner length which provides proper tuning of engine at 5000 rpm.

V. Acknowledgement

We would like to express our sincere thanks to Prof. M. S. Kavre of Mechanical Engineering Department for his guidance and supervision in all respects of this paper.

References

[1] D. Jandid, A. Sharma (2018), “Design and Analysis of Restricted Air Intake for Performance Optimization of Single-Cylinder Engine”, New Frontier in Energy, Engineering, Environment & Science.

[2] O. Deshpande, Nitin L. (2015), “Space Advantage Provided by De-Laval Nozzle and Bell Nozzle over Venturi”, Proceedings of thr World Congress on Engineering, vol. 2.

[3] P. Sawant, S. Sawant and Dr, S. Waghmare (2018), “Analysis of Air Intake For Formula Student Race Car”, International Research Journal Of Engineering And Technology, vol. 5, no. 4, pp. 4254-4258.

[4] R. Puri, H. Darade (2016), “Design and Analysis of Intake and Exhaust System of SAE Supra Race Car”, International Research Journal of Engineering and Technology, vol. 3, no. 6, pp. 839-841.

[5] S. Pant, P. Kumar and R. Kishor (2018), “Design and Analysis of Air Intake System for Single Cylinder Engine”, International Journal of Trend in Scientific Research and Development, vol. 2, no. 2, pp. 357-379.