Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 06, June-2019

Study on Air-Intake System of A Student Formula Vehicle

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***Abstract*— We are planning to design an air intake system for the SAE SUPRA formula race car which having the rules to restrict the diameter of air inlet diameter up to 19.9mm to reduce the power output from the power train in this document we are going to see the design and conclusion of the total setup and their position.**

Keywords*— *Air intake manifold ; restrictor ; plenum ; runner and power train requirements (throttle bodies

I. INTRODUCTION

The design of the air intake system incorporates of all the components like throttle body, restrictor, plenum, runner and power train these were designed by the considerations To control unnecessary rpm spike while throttling To limit noise level to 110 dB at 7500 rpm and then physical volume occupation of these components inside the rear part of the vehicle since this vehicle is the Rear wheel drive then another one is the position of this intake system whether it comes from upward of the main roll hoop or side(right or left) of the bracings or facing rearwards to the total vehicle these were the physical consideration in this design parameters then this vehicle uses KTM RC 390 engine we can see, the engine is having 373.2 cc displacement with maximum power of 43 Bhp @ 9500 rpm and maximum torque of 35 Nm @ 7250 and then by satisfying this engine intake requirements (because of using restrictor of 19.9mm)

II INTAKE ASSEMBLY

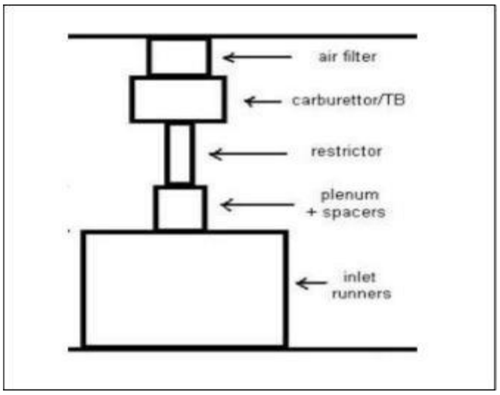


Figure 1: block diagram of power drain

The purpose of the restrictor is to reduce the airflow to the engine. There are two types of instruments which can be used as a restrictor i.e. the Orifice plate as well as the Venturi tube. The Orifice plate is a simple rectangular plate with a hole drilled in it. The Venturi tube is a tube having a converging and a diverging section with a throat section of circular shape connecting the both. The choice of restrictor to be used is laid out in the below comparison.

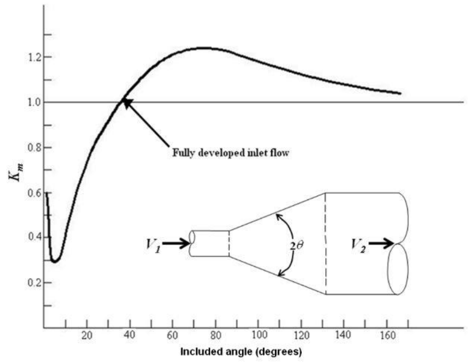
III DIFFERENCE BETWEEN ORIFICE AND VENTURI

Orifice plate/Venturi tube
The coefficient of discharge is between 0.58 to 0.65 . The coefficient of discharge is between 0.95 to 0.975. The pressure loss is medium on a scale of high to low. The pressure loss is low on a scale of high to low. The cost of manufacturing is cheaper. The cost of manufacturing is high. The manufacturing is easy as there is just a hole to be drilled on a plate. The manufacturing is difficult as there is a conical profile to be made.
On considering the above it can be seen that Venturi tube is much better as compared to the orifice plate in overall terms. As seen from the above table the pressure loss and coefficient of discharge for Venturi tube is much better as compared to orifice plate. According to the restriction on engine, the more efficient design would help for the competition. Cost and manufacturing were not taken into account for this part. Comparing the above, Venturi tube was selected as the restrictor. According to the rules the restriction is 19.9mm in diameter. This will be the throat of the Venturi tube.
Design and calculation:-
This design comprise of the three components Entrance Region (convergent Region)
Diffuser Exit Region (Divergent Region)
Throat Region (restrictor area)
Entrance Region (convergent Design):-

Area Ratio	Included Angle, Θ (in Degree)						
A_2 / A_1	10	15-40	50-60	90	120	150	180
0.5	0.05	0.05	0.06	0.12	0.18	0.24	0.26
0.25	0.05	0.04	0.07	0.17	0.27	0.35	0.41
0.10	0.05	0.05	0.08	0.19	0.29	0.37	0.43

Table 1: Angle to Area ratio

Figure 2: Loss coefficient for Gradual Contractions: Round and Rectangular Ducts



In case of constant area ratios (AR = A2 / A1), the nozzle length (the length between the two straight sections of pipe) then becomes critical: for constant AR, a shorter nozzle length requires a greater included angle, resulting in an increased loss coefficient K It is evident then, that to minimize losses through the restrictor entrance, a compromise must be taken between the length of the section and taper angle. The restrictor entrance region must provide for a reduction in section from the throttle body throat (40 mm) to the restrictor throat (20 mm).

The AR is thus:

A2 / A1 = 20 / 40 = 0.50

Using the minimum included angle provided (Ѳ = 10˚, means Ѳ/2 = 5˚),

the length of the nozzle can be calculated as,

Nozzle length, (LN) = 10 / tan (5) = 114.3 mm It can however, be seen from table that the loss coefficient does not change appreciably for included angles between 10˚ and 40˚; consequently, it is conceivable that the taper angle could be increased from anywhere between 5˚ and 20˚ without resulting in any further loss in pressure.

As the length that we calculated is quite large and we have to reduce it. We increases the angle from 10˚ to 20˚; now the length

we got this, LN = 10 / tan (10) = 56.71 mm

Diffuser Exit Region (Exit area):-

The intake restrictor has been allowed a maximum length of 150 mm, measured from the design of the vehicle having space in it. Entrance length is 56.71 mm, throat length taken can be 15 to 20 mm which results the exit length of 75 mm to 80 mm.

Increase in radius (RDO),

Taking exit length of 75 mm RDO = 80 * tan (5) = 6.99 mm or 7 mm approximately.

Diffuser outlet Diameter, DDO = (Throat diameter) + 2 RDO

DDO = 20 + (2 * 7) = 34 mm

Throat Region (restrictor area):-

Design parameters for the throat region dictate: maximum diameter of 20 mm and optimization of flow rate. Essentially, the throat must provide least restriction to flow by minimizing frictional losses. If the nozzle were to taper in to 20 mm and simply be joined to the diffuser at a point, a turbulent region would more than likely form at this point due to the sudden change in direction of flow. Therefore, the throat region, which provides the required 20 mm restriction, must be designed to minimize flow losses. Design of the throat region thus will incorporate a large bend radius, rounding into the minimum throat size of 20 mm, and leading back into the diffuser. Given that the geometries of the restrictor entrance and exit have been determined, and knowing that the minimum throat area will be 20 mm, a bend radius should be given so that the ratio of bend radius and 20 will be greater than 0.15 Because it can be said that any losses resulting from the ratio higher than 0.15 in section will be negligible. In our design we took D = 50, 50 / 20 = 2.5 which is greater than 0.15 and can be said that there is negligible losses in the section.

IV PLENUM

In automotive engineering, an inlet manifold or intake manifold is the part of an engine that supplies the fuel / air mixture to the cylinder. The plenum is a common volume from which intake runner extends. Intake charge flows from the throttle body and accumulates in the plenum, creating a ‘reserve’ from which individual intake runners draw charge. Plenum is an intake manifold is designed such that it will provide enough amount of atomized air to the cylinder of engine and also to keep laminar air flow passing through it. Plenum volume is specific to each engine, with larger-capacity engines requiring larger plenum volume. Empirically, plenum volume and or throttle body throat size have been found to be interdependent, with smaller throttle body generally producing better performance when combined with larger plenums, and vice versa. For our engine KTM 390 the volumetric displacement is 390 cc and the plenum designed should have 0.8 times of engine volumetric displacement in order to get good performance by engine.

Volume of plenum, (VP) = 0.8 times (displacement of engine) = 0.8 X 390 = 312 cc

Creating a chamber in which inlet charge is able to accumulate provides a constant supply of charge in close proximity to the inlet runners. This reserve of charge provides additional momentum to the air / fuel flowing into the cylinder, creating a more efficient intake process, increasing inlet charge and hence providing greater power production.

Backpressure:-

The ‘Back Pressure’ is often used in relation to intake systems and has an effect on engine power. Pressure is built up within the system due to the motion of atomized gases regularly pulsating from intake port. This back pressure resists the motion of gas flow, and is an undesirable quantity when chasing increased engine performance. Back pressure typically reduces engine power and should be minimized at all times.

Enlarging intake runner pipes and using well designed runner reduces back pressure and helps to increase power.

Atmospheric pressure (P1) = 101326.38 Pascal
Inlet temperature (T1) = 300 K
For air at 300 K, $\Upsilon = 1.4$; Cp =1.005 KJ / Kg.K R = 287 KJ /Kg.K
Speed of sound, C1 = (ΥRT1) 1/2 = 113.37 m/s
Stagnation Temperature,
To = T1 + (C1) 2 / (2 Cp) = 306.3944 K T1 / To = 0.979
From gas table for isentropic gas flow at $\Upsilon = 1.4$,
we get the value of Mach No. and other essential values.
i.e. P1 /Po = 1.00594; A1 / A* = 1.922
For an adiabatic irreversible process, (T1 / To) Υ-1 / Υ = (P1 /Po)
Stagnation Pressure,
Po = 101928.3194 Pascal
Critical Area, A* = 3.14 X 0.2 X 0.2 / 1.922 = 0.0163 m2
Critical Pressure, P* = Po (2 / Υ + 1) Υ / Υ-1 = 53818.15266 Pascal
P * / Po = 0.588
Let back pressure acting on the system be Pb.
There are 2 cases that can take place due to back pressure.
i.e. P * / PO $\leq$ Pb / Po and, P* / PO $\geq$ Pb / Po
If P* / PO $\leq$ Pb / Po equation is satisfying,
m˚max (To R) 1/2 / A* PO (Υ) 1/2 = (2 / Υ+1) Υ+1 / 2(Υ-1)
m˚max = 0.2805 Kg/s
If P* / PO $\geq$ Pb / Po equation is satisfying,
m˚max = ρ A2 C2 ρ = Pb / R T2 P * / PO $\geq$ Pb / Po or 0.588 $\geq$ Pb / Po
For gas table at this pressure ration in isentropic gas flow at $\Upsilon = 1.4$.
We get,
Mach no (M) = 0.9;
M* = 0.915;
T2 / To = 0.861;
A2 / A* = 1.009 T2 = 263.805 K;
Pb = 59933.85 Pascal
ρ = 0.7924 Kg / m3
C2 = (ΥRT2) 1/2 = 293.014 m/s
m˚max = ρ A2 C2;
A2 is at radius 0.017 m m˚max = 0.2108 Kg/s The calculated mass flow rate is the maximum amount of mass flow of air that can pass to the inlet port after having back pressure in the system.

V INTAKE RUNNER

The runners are the third member of the intake system. They are the connection members which connect the plenum to the engine. The runner is a tube which can have varying diameter and length. Air from the plenum is feed to the engine depending to the stroke cycle. The runners apart from being the transporting members they also serve the purpose of tuning the engine according to the RPM range. The runners can be tuned for Low-End Torque as well as for High-End Horsepower. The shape and size of the runner determine what purpose is it going to serve. The length of the runners determines which RPM range will it benefit. The shorter sized runner are used for High end Horsepower as the suction is quite small and the stroke can be completed as fast as possible, tending to give more power at the Higher end. On the other side the bigger length runner are used for lower end torque, as the passage being long the air has to travel longer than required giving that extra space at the bottom end. The whole analogy has a understanding that air is in form of waves that travel from the plenum to the engine as per the stroke. As the air is being sucked during the suction stroke the air waves try to rush into the combustion chamber and during the closing of the valves these waves are reflected back which causes them to revert back to plenum side. As soon as the waves reach the far end of the runner they are met with a new boundary which reflect them back toward the valves. However the valves being closed and no place being available for the waves to go, the stack upon themselves. Creating a higher pressure wave behind the valves. This creation of altering compression and decompression, an acoustic waves is formed. This alternating waves can be utilized for the stacking in more air into the combustion chamber which would increase its volumetric efficiency. This serves as the purpose of natural turbocharger which can be used only at a specific RPM range. This phenomenon is always present irrespective of which RPM range the engine is running on. The optimum design would be to tune this alternating acoustic wave at the peak torque RPM range

VI CALCULATION

For this we referred many formulas and journals which would help us in calculating the effective length of the runner so as to achieve the best and efficient output of the air intake manifold. The best effective formula used were:-

1) David Vizzard's Rule
2) Helmhotz Approximation

David Vizzard's Rule:

The rule states that to begin with the calculations initially take 17.8cm as a length, this initial length will be considered for a max torque of 10,000 RPM. Further as we carry and want to lower the RPM, the condition is that for every 1000 RPM
we add a total of 4.3 to the runner length.
For example, we want to find the runner length of RPM=6000i.e. given is 6000RPM
Thus Runner Length L will be given by the formula
L=initial runner length at 10,000 RPM + (reduction in the RPM from 10000 to 6000*4.3 added to the length)
=17.8 + (4*4.3) =35cm or 13.7”
Position of intake and shape of plenum:-
According to the rules, the vehicle has to be rear wheel drive. This places the engine on the rear of the car after the main hoop and in between the main hoop braces. This positon of the engine gives us 4 positon in which the Plenum and Venturi can be placed.

1) Top facing
2) Besides Left side Main hoop Bracing
3) Besides Right side Main hoop Bracing
4) Towards the Rear end of the car

The shape of the plenum plays a vital role in maximizing the pressure loss as this varies the volumetric flow type. This shape houses the air from Venturi and recovers the lost pressure. There are 2 shapes which can be adopted i.e. Log shaped and Streamlined shaped. The Log shaped is quite useful for 1st and 4th positon mentioned above as not much design profiles and curves are required. The log shaped are used in simpler shape and not much complexion. Those are beneficial for small plenums as all the air collected can be use at once for the suction stroke and engine does not have to strive hard. The streamlined shape is useful for the 2nd and 3rd position as these positions demand curved plenums , so that the overall CG of the vehicle can be balanced. These provide an even flow when the air has to pass through a curved section.

This was visualized according to all the above calculations and assumptions.

VII CONCLUSION

Thus The Team Griffin Riderz conclude this following details for the Engine intake system for the SAESUPRA INDIA 2019 competition all the objectives were satisfied without violating any rules instruct in the SAE SUPRA rules book

The following data were obtained from the above calculations and also referred from some international journals

Restrictor Data:-

Convergent angle 20degree
Divergent angle 10degree
Intake length of restrictor 56.71mm
Intake Diameter of Restrictor 40mm
Throat diameter 20mm
Exit length of restrictor 75mm
Exit diameter of restrictor 34mm

Plenum Data:-

Volume of plenum 312cc
Shape : log shaped or stream lined

Runner data:-

Runner length 350mm
Diameter : (as per in the KTM390 engine mount)

ACKNOWLEDGEMENT

I would like to express my gratitude to Naveen Raj R and Krishnan R my Faculty advisers of my team who gave me golden opportunity and helped me in SAE SUPRA 2019

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