VALIDIFICATION OF ENGINE INTAKE SYSTEM

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ABSTRACT

The concept is to design an intake system for Formula Student race car using KTM RC 390 engine. The main objectives taken under consideration for the design are to minimize the restriction to flow, use of tuned pressure wave to increase the charge intake and the optimisation of flow rate.

KEYWORDS: Engine Intake System, Restrictor, Plenum, Intake Runner, Resonator, Back Pressure.

I. INTRODUCTION

The design of the intake system must be inclusive of all system components. Therefore, the design focus incorporates: fuel delivery device, restrictor, plenum, intake runners. In addition to each of these components satisfying engine operating requirements, they must also fulfil another important design criterion: system packaging. That is, all system must fit into the physical space available.

The overall design of the intake system features a vertical configuration; that is, the intake system will essentially be built 'upward' from the engine. This means that the runner will extend towards upward from the inlet port, with the plenum, restrictor, carburettor (or throttle body) and air filter being positioned one on top of the other.

1.1. INTAKE RUNNER

Intake runners perform a vital function by delivering intake charge to the cylinders. The design of these runners must therefore ensure that the mixture arrives in a highly combustible state, which inducing as few losses as possible throughout the mixture's journey from carburettor to intake port.

A number of factors must be considered to determine the overall runner design, including manifold type, runner dimensions and configuration. The inlet manifold will incorporate tuned. Achieving calculated length in a streamlined design will necessitate the inclusion of additional bends in the inner runner. The main objective to design the runner is to improve engine performance, with highprecision bending methods employed to minimise losses.

Empirical formulae will dictate runner lengths for a desired tuned speed. However, the actual runner lengths will necessarily be a compromise between the desired tuning range and the space available.

Bell (1997) recommends long-length pipes to tune for maximum torque at low to mid-range speeds. The recommendation is to use as long a length as possible within the allocated space. Smaller diameters have also been empirically found to increase torque and power in the low to mid-range. The configuration of the formula SAE completion track enables speed no greater than 100 km/hr, with average speeds of around 50-60 km/hr. therefore, engines used in this application required good low to mid-range torque. Long pipes and small diameters will therefore characterise intake manifold design, with specific dimensions to be determined by empirical formulae.

1.1.1. Shape and Length

In order to provide as direct a path as possible, the orientation of the manifold runners is essentially dictated by the positioning of the central plenum and an inlet port. With the general orientation of the runners decided, determining the appropriate length for tuning at the desired speed now becomes the

crucial aspect of the manifold design. Intake ramming is the desired effect of tuning intake runners. The pressure waves travelling through the intake system actually generate a number of reflected waves. That is, when the first reflected wave travels from the runner entrance and contacts the inlet valve, it generates another reflected wave, which is sent back towards the runner entrance. This generation continues again and again. Each successive reflected wave takes more time than the previous to arise and travel through the system; therefore, depending on the desired tuned speed, and taking the engine's valve timing consideration, tuning for a certain pulse can be achieved.

We can determine the tuned inlet length (in inches) for the third reflected pulse, (L)

$L = 97000 / n$, here n is the desired tuned speed (rpm)

Tuning for between 4000 and 8000 rpm is desired for AeroX Motorsports race car in Formula SAE Competition. Therefore, lower and upper length limits will be calculated, according to these two speeds.

Lower Limit: Tuned speed = 8000 rpm

$L = 97000 / 8000 = 12.1$ inches or 308 mm

Upper Limit: Tuned speed = 4000 rpm

$L = 97000 / 4000 = 2403$ inches or 616 mm

If we go through the specification of the 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 rpm.

Taking a compromise between two lengths 8000 rpm, 4000 rpm and also considering maximum torque at 7250 rpm, 7000 rpm produces a desired tuned length of:

Tuned Inlet Length: Tuned Speed = 7000 rpm

$L = 97000 / 7000 = 13.85$ inches or 351.97 mm

Here, a tuned length of approximately 350 mm should provide increased charge volume and improved expulsion of exhaust gases at 7000 rpm.

1.2. INTAKE RESTRICTOR

Formula SAE rules mandate the inclusion of a single, circular restrictor in the inlet system, no more than 20 mm in diameter (2016-17 Formula SAE Rules). This restrictor is required to be placed between the throttle and the engine, with all airflow passing through this contraction, with the purpose of limiting engine power.

The fluid dynamics largely governs design of the intake restrictor. A decreased flow area results in a reduced amount of charge flowing to the engine. Therefore, to extract maximum power from the engine, the restrictor must be designed to produce maximum flow through the 20 mm contraction.

Restrictor design is governed by: specified dimensions (20mm diameter), flow characteristics, available space in intake system.

Flow rate through the restrictor depends upon: entrance shape, exist shape, throat shape, length, surface finish and charge density (affected by pressure and temperature).

1.2.1. ENTRANCE, EXIT AND THROAT SHAPE

Losses in pressure occur when flow travels through a sudden expansion or contraction in a pipe. However, losses due to change can be somewhat reduced by installing a nozzle or diffuser between the sections of interest (Fox & McDonald 2003).

The restrictor must be placed between the throttle and engine, and have a maximum diameter of 20 mm. in this case, the carburettor (or throttle body for injected systems) will lead into the restrictor, which will then fellow on to the plenum. Therefore, a reduction in section from the specified 20 mm diameter to the diameter of the plenum opening is also required. Consequently, the most suitable shape for the restrictor becomes a conical converging diverging (nozzlediffuser) arrangement.

1.2.2. ENTRANCE REGION 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

In case of constant area ratios (AR = A_2 / A_1), 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 minimise 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 carburettor throat (40 mm) to the restrictor throat (20 mm). The AR is thus: A_2 / A_1 = 20 / 40 = 0.50

Using the minimum included angle provided (Θ = 10˚, means Θ/2 = 5˚), the length of the nozzle can be calculated as,

Nozzle length, (L_N) = 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 is,

L_N = 10 / tan (10) = 56.71 mm

1.2.3. DIFFUSER EXIT

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 (R_{DO}), taking exit length of 75 mm

R_{DO} = 80 * tan (5) = 6.99 mm or 7 mm approximately.

Diffuser outlet Diameter, D_{DO} = (Throat diameter) + 2 R_{DO}

D_{DO} = 20 + (2 * 7) = 34 mm

II.   THROAT DESIGN

Design parameters for the throat region dictate: maximum diameter of 20 mm and optimisation of flow rate. Essentially, the throat must provide least restriction to flow by minimising 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 minimise 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.

III.   PLENUM DESIGN

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 carburettor (or 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 atomised 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 carburettor (or throttle body) throat size have been found to be inter-dependent, with smaller carburettors generally producing better performance when combined with larger plenums, and vice versa (Bell 1997). For our engine KTM RC 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, (V_P) = 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.

IV. BACK PRESSURE

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 atomised 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 minimised at all times. Enlarging intake runner pipes and using well designed runner reduces back pressure and helps to increase power.

Atmospheric pressure (P_1) = 101326.38 Pascal

Inlet temperature (T_1) = 300 K

For air at 300 K,

Υ = 1.4; C_p =1.005 KJ / Kg.K

R = 287 KJ /Kg.K

Speed of sound, $C_1 = (\Upsilon R T_1)^{1/2}$ = 113.37 m/s

Stagnation Temperature, $T_o = T_1 + (C_1)^2 / (2 C_p)$ = 306.3944 K

T_1 / T_o = 0.979

From gas table for isentropic gas flow at Υ = 1.4, we get the value of Mach No. and other essential values. i.e.

P_1 / P_o = 1.00594; A_1 / A^* = 1.922

For an adiabatic irreversible process, $(T_1 / T_o)^{\Upsilon-1/\Upsilon} = (P_1 / P_o)$

Stagnation Pressure, P_o = 101928.3194 Pascal

Critical Area, A^* = 3.14 X 0.2 X 0.2 / 1.922 = 0.0163 m^2

Critical Pressure, $P^* = P_o (2 / \Upsilon + 1)^{\Upsilon / \Upsilon-1}$ = 53818.15266 Pascal

P^* / P_o = 0.588

Let back pressure acting on the system be P_b. There are 2 cases that can take place due to back pressure. i.e.

$P^* / P_O \leq P_b / P_o$ and, $P^* / P_o \geq P_b / P_o$ If $P^* / P_o \leq P_b /$

P_o equation is satisfying, $\dot{m}_{max} (T_o R)_{1/2} / A_* P_o (\Upsilon)_{1/2}$

$= (2 / \Upsilon+1)_{\Upsilon+1 / 2(\Upsilon-1)}$

$\dot{m}_{max}$ = 0.2805 Kg/s

If $P^* / P_o \geq P_b / P_o$ equation is satisfying,

$\dot{m}_{max} = \rho A_2 C_2 \rho = P_b$

$/ R T_2$

$P^* / P_O \geq P_b / P_o$ or $0.588 \geq P_b / P_o$

For gas table at this pressure ration in isentropic gas flow at Υ = 1.4. We get,

Mach no (M) = 0.9; M^* = 0.915; T_2 / T_o = 0.861; A_2 / A^* = 1.009 T_2

= 263.805 K and P_b = 59933.85 Pascal ρ = 0.7924 Kg / m^3

$C_2 = (\Upsilon R T_2)^{1/2}$ = 293.014 m/s $\dot{m}_{max} = \rho A_2$

C_2; A_2 is at radius 0.017 m $\dot{m}_{max}$ = 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. RESONANCE FREQUENCY

The design of resonator is characterized by the large cavity at its belly and a thin neck. It basically works on the theory of harmony. As the air tries to ram into the resonator through its neck, the pressure

inside the cavity increases and the air bounces out, but while bouncing out quickly due to inertia, it creates a partial vacuum near the neck of the resonator and the air is again sucked in it. The process continues like the phenomenon of a Ping-Pong ball hitting the ground. The resonator acts like a shock absorber for the pressure waves.

The frequency of a resonator can be calculated by (f) = $(C/2\pi)$ $(A/VL)^{1/2}$ f = (113.37 / 2 X 3.141) (3.141 X 0.017 X 0.017 / 0.000312 X 0.350) $^{1/2}$ f = 1499.137 hz

VI. FIGURES & TABLES
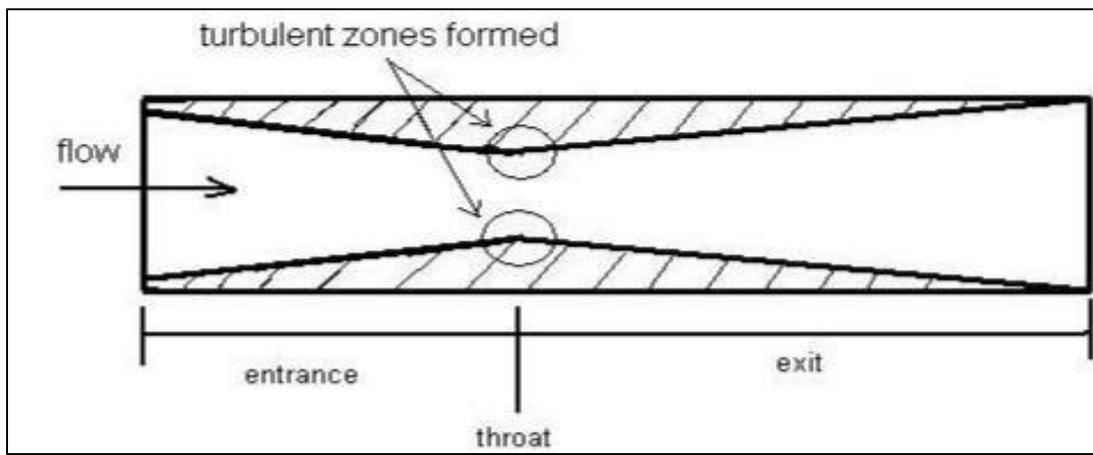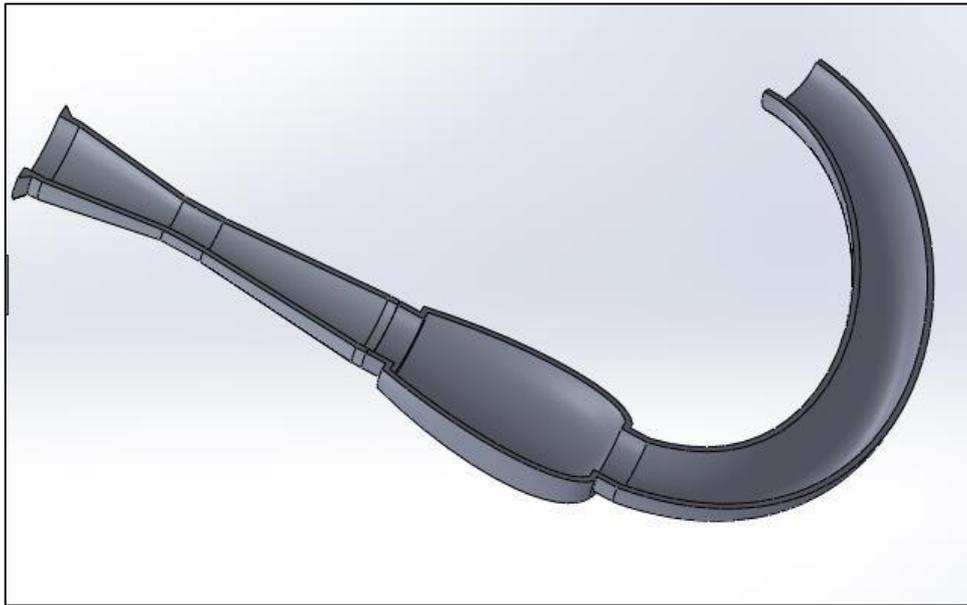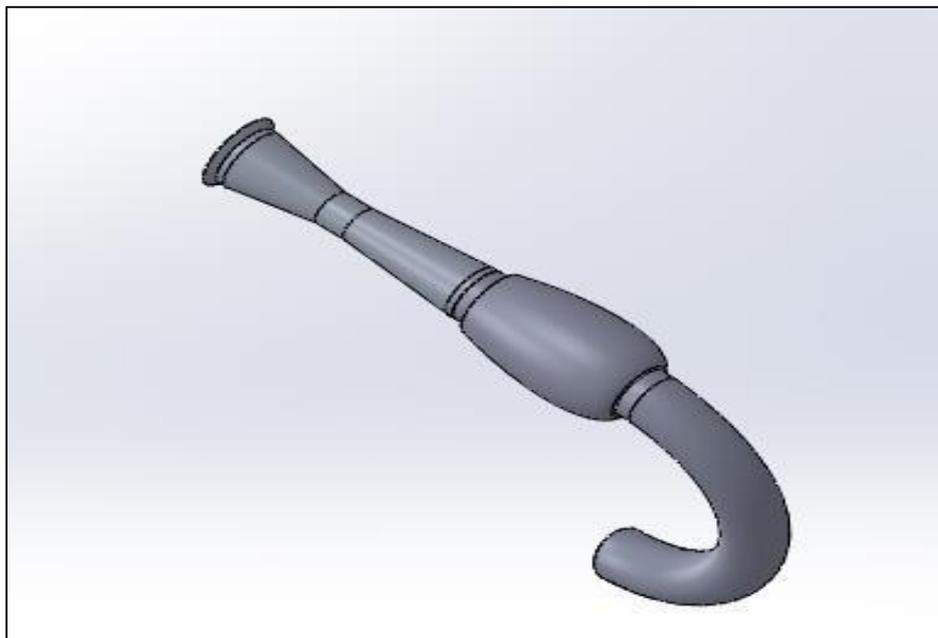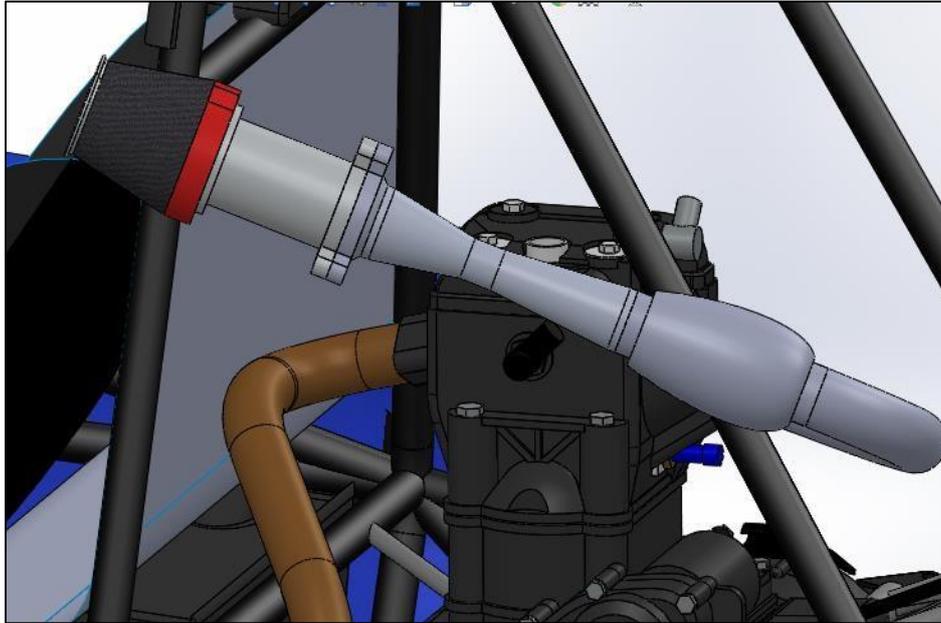

Figure 1. Restrictor Design
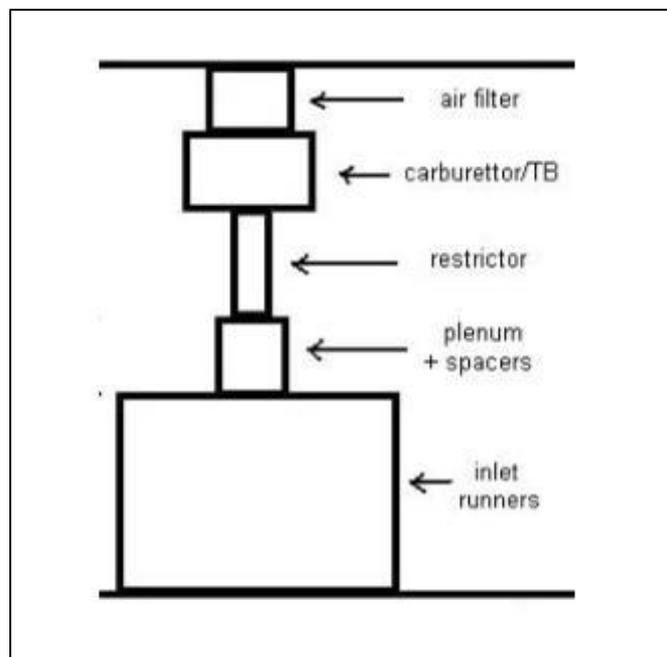
Figure 2. Intake System assembly

Figure 3. Internal section of Intake System

Figure 4. Final Intake System

Figure 5. Intake System Assembled on Race Car.

VII. CONCLUSIONS

The overall manifold design has evolved through a series of preliminary designs, and should provide efficient flow and combustion, with improved fuel efficiency and increased power output. While compromises have been necessary in some aspects of this design, the overall design philosophy has been maintained, with the intake system designed in accordance with engineering principles and empirical data.

The overall performance of the engine is increased and the results are good as compared to past results of the engine performance.

ACKNOWLEDGEMENTS

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