Design and Optimisation of an FSAE Restrictor with Structured Mesh

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Abstract: ***Formula Student Racing Competitions are held across the world organized by SAE (Society of Automotive Engineers) . One such growing event is the Supra SAE India held by the Indian branch of the association. In order to restrict the power of the engine in the competition, SAE made a rule to put a 20mm air restrictor before reaching the cylinder head. In a field especially such as Mechanical Design, no model is perfect and there is always room for improvement . This has been our motto which has always been tried to be achieved. In order to overcome the effect of restrictor, it can be minimized by minimizing the pressure difference between the intake and outlet of the restrictor. In order to achieve this, we have used a convergent-divergent nozzle of 20mm diameter. Computational fluid dynamics gives an alternative method of experimenting without a prototype. Meshing plays a very important role in any numerical simulation, in order to get the accurate results, a structured mesh is created and analysed. The work in this paper is based on the car SHIV1.0 which was presented in the Supra SAE 2014-15 event .The air intake manifold which is modelled ,designed and optimized is based on KTM Duke 390 engine considering its throttle body and cylinder head specifications.***

Keywords: Convergence,Naviers stoke equation, Optimisation, Restrictor, Structured mesh

1. Introduction

The Supra SAE event attracts various SAE collegiate clubs for participating and competing in the Formula Student Racing events. The fabrication is carried out after qualifying from the Virtual Round, where there is an evaluation of the design procedures adapted and the manufacturing feasibility of the proposed design. The various type of events held at the final event include, static events (design report , cost report , business logic case, tilt test, noise test) and dynamic events (brake test , skid pad event , autocross , endurance, acceleration). The work on the paper is based on the air intake manifold used in the team’s particular car. The air intake is the underlying performance characteristic of any engine and has varied performance considering the throttle response and ECU mapping of the engine. The rule of restrictor manifold is to have a neck at any particular hold, whose diameter must be no more than 20mm. This is the most important characteristic of the restrictor mentioned in the Rulebook, which is used apart from the other known norms.

The KTM duke engine selected is a 390cc, which gives a power of 43 Bhp at 9500 rpm. It has a 54 mm cylinder head for the air intake, which is fitted with an air filter. But placing the restrictor reduces the area drastically from 54mm to 20mm diameter. When the engine is running at a low RPM, mass flow rate is compensated by the increase in the velocity of the restrictor's venturi. When the RPM of the engine reaches its maximum capacity, the engine burns more fuel and also urges for more air, this causes the velocity to reach its maximum of mach one speed which gives rise to the critical flow condition. Thus the mass flow rate can be used as a constant parameter for 20mm diameter which is used for further calculations.

2. Research Methodology

Basic Design

The basic design parameters to be considered for the air flow and Computational Fluid Dynamic(CFD) analysis, is the design constraints due to conglomerate of the rear part of the chassis and other various rules to be followed . This air intake manifold is placed between the air filter and the throttle body of the engine and hence the inner diameter at the inflow and outflow of the nozzle is pre-determined and cannot be changed.

The length of this body cannot be extended after a certain magnitude,since it will provide hindrance to the adjacent parts and must be within the height of the main roll hoop of the chassis. Thus the CFD analysis is carried out for the location of the neck, length and angle pertained in order for it to not have air resistive vortex regions and to reduce the drag flow.

Any CFD problem is solved by putting the appropriate boundary conditions to the Navier's stokes equation.Using Finite volume methods, the equations are recast in conservative form, and then solved on every discrete control volume. As there is no turbulence involved in the system, there is no involvement of Reynolds stresses and eddy currents. Thus the Navier stoke equation can be solved by treating the system as boundary value problem.

Selection of the appropriate boundary conditions are very important in the case of solving boundary value problems, otherwise leads to numerical instability of the system. Considering the above factors in mind, the mass flow rate for choking condition Is calculated as shown below.

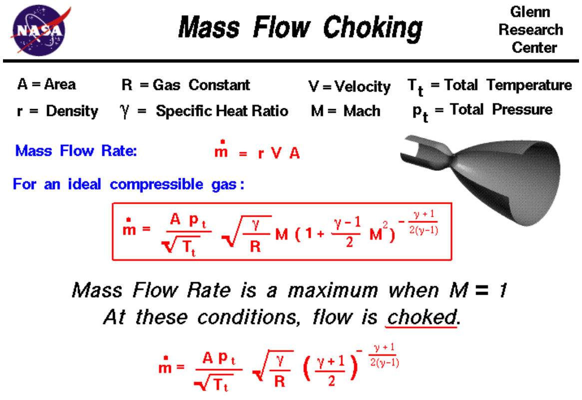

Figure 1: Mass Flow Choking Equation. [1]

Where,
M= 1(choked condition)
A= 0.001256(20mm diameter)
R= 0.286Kj/Kg-k
γ= 1.4
Pt= 101325 Pa (1atm)
T= 300K (Room temperature)
Mass flow rate is found to be 0.0703Kg/s.

This mass flow rate acts as the first boundary condition and pressure at the inlet is 1 atmospheric and hence the other boundary condition. Considering any models in CFD analysis, there can be 3 types of errors which have to be considered seriously while solving the problem.

1) Due to the improper meshing, there can be deviation from the actual model which leads to error in the system. This problem is solved by applying structured mesh and applying convergence criterion.
2) Numerical instability due to improper boundary conditions or truncation errors while conversion of partialdifferential equations into algebraic equations. The small error will grow rapidly diverging from the actual error. This problem is solved by giving appropriate and suitable space step.

3. Procedure

As the process of optimization is an iterative process, around 20 potential restrictor systems are modelled using CATIA V5, varying the convergent and divergent angles, which varies the length as the diameters are fixed.The restrictors one end will be fitted to the cylinder head and other to the air filter.

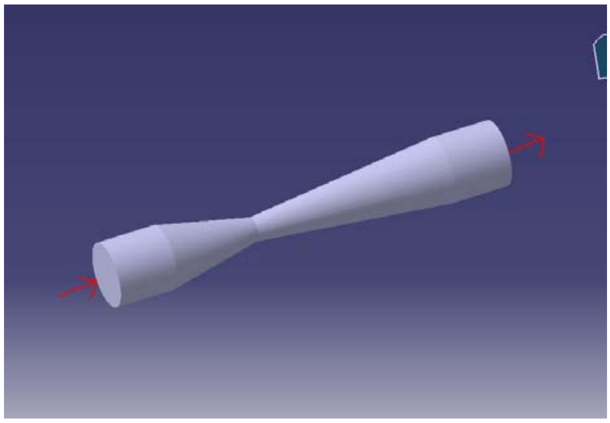

Figure 2: CATIA model of Restrictor.

The modelled restrictor is imported to Ansys workbench, where the structured mesh has been done using meshing modeller

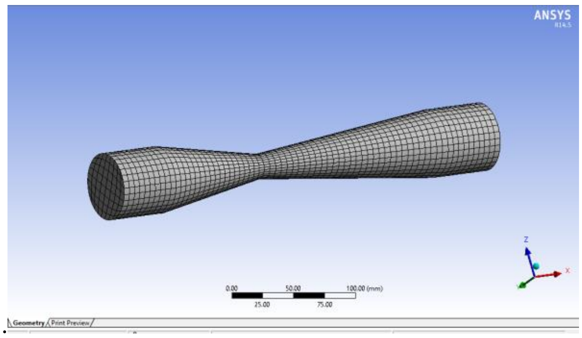

Figure 3: Meshed Model in ANSYS Workbench

The mesh has been imported into ansyscfx and solved. The numerical error is monitored till the value of error gets reduced to 0.001% so thatnumerical stability is achieved,and the results of different analysis is shown in the table.

Table 1: Total Pressure at Throttle

Convergent angle	10	12	14	16	18
Divergent angles					
6	77598.4	77312.2	76554	75674.1	74860.5
8	78010.6	77374.1	76484.6	75889.1	750148
10	76899.6	96374.6	75969.1	75197.6	74487.5
12	76431.4	75020.6	74584.4	74293.4	73578.9

Table 2: Total pressure at Engine Head

Convergent angles	10	12	14	16	18
Divergent angles					
6	97939.4	98016.1	96922.7	97393.3	97142
8	96701.6	97138	96983.2	96778.4	96581.5
10	95662.5	95060.4	95078.1	95097.8	94838.2
12	95095.7	94105	94076	93815.7	93955.9

We can see that the pressure at the engine head is comparably more for convergent angle of 12 degree and divergent angle of 6 degree. The length of the restrictor is 246mm. in order to fit the air filter and engine head, A 50mm clearance is given on either side.

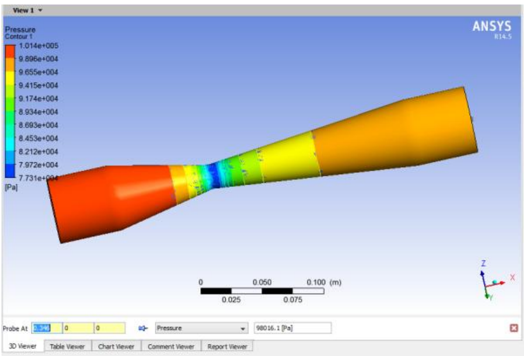

Figure 4: Pressure contour in ANSYS

4. Material Selection

The material selected for this kind of model can be variable since the static structural analysis doesn't come into the picture and the air flow occurring is at atmospheric pressure and temperature. The heat experienced and drag conditions on the walls is negligent.

Hence, in this scenario the manifold is preferred to be of a lightweight material in order to reduce the load and the stress acting on the throttle body when it is placed at that position.

The material consideration at this stage was given to a rubber mould but due to cost constraints (rubber grade material and preparation of the tool) , the focus was shifted to a light metal and hence Aluminium 6065 was used.

5. Manufacturing

The manufacturing of the proposed model was a tedious process since it could not be carried out on lathe due to machining at the inner surface . Hence a special tool had to be made from industry toolmakers and then fed into the CNC with incremental feeds for smooth finish and precision acquirement of 20mm neck diameter .

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