

Modeling, Analysis and Fabrication of Intake System FSAE

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ABSTRACT: This study takes a look at the design process of the air intake system of the FSAE car. Over the years, much of the design of this system had been carried out through an iterative trial and-error process, so the study attempts to identify the scientific and engineering principles pertaining to the design of this system. The intake system is being subdivided into various components, and the relevant principles will be discussed. Following that, data is collected from the engine cylinders, cam-profile, intake valves etc. and a simulation model of the engine will be developed. This model is then being applied, sequentially, to the various components. Flow analysis for individual components are carried out, and verified against performance simulations of the entire engine system, followed by physical testing of several of the components using a flow bench. This copy proposed the restrictor geometry to achieve a maximum airflow with minimum pressure drop to improve engine performance of a FSAE car. Formula SAE competition has imposed a rule of including a 20mm (0.787 inches) restrictor in the intake manifold allowing all the air flow to the engine through this single restrictor whether it may be a single cylinder or a multi cylinder engine. Due to 20mm restrictor rule, the designed intake of 390CC engine is reduced. This drastic change reduces the air flow to the engine thereby controlling its poweroutput. An efficiently design manifold is pivotal for optimal performance of IC Engine. This copy will discuss about the 3-D stimulation of single cylinder KTM 390 Duke Engine. Both steady and unsteady analysis has been done using ANSYSFLUENT.

KEYWORDS: Intake Manifold, Plenum, Restrictor, Velocity vectors, Pressure contour

I.INTRODUCTION

This is a study on the design of the various parts of the Air Intake system, specifically one that suits the requirements and restrictions of the Formula SAE Collegiate Series competition.

The air intake system is a major component required by the Engine system and is critical in determining the amount of power produced by the engine system. However, it is made up of many sub-components that need to work well and together in order for the engine to perform up to par. With the introduction of a mandated air-restrictor, the off-the shelf engine is unable to continue using the air intake system that was originally designed for it. Over the years of the FSAE project, the air intake system had seen many iterations and improvements allowing the engine to produce increasing amounts of power. However, there is always room for improvement and this study aims to create a foundation of knowledge on which to build the next generation of air intake systems.

This foundation is to be built upon the basic physics theories that govern the air intake system, the “good practices” of the industry discussions on the variation in design for various components and how they affect performance as well as to establish the procedures of making use of available tools to improve the quality of the final design of the air intake system.

A. INTAKE MANIFOLD

The basic function of the intake manifold is to get the air from the carburetor or throttle body directed into the intake parts. A great intake manifold design can provide substantial performance advantages than a less optimal one. The primary function of the intake manifold is to evenly distribute the combustion mixture to each intake port in the engine head(s). Even distribution is important to optimize the efficiency and performance of the engine. It may also serve as a mount for the carburetor, throttle body, fuel injectors and other components of the engine.

Due to the downward movement of the pistons and the restriction caused by the throttle valve in reciprocating spark ignition piston engine, a partial vacuum exists in the intake manifold. This manifold vacuum can be substantial and can be used as a source of automobile ancillary power to drive auxiliary systems: power assisted brakes, emission control devices, windshield wipers, power windows, ventilation system valves, etc.

As per the rules of FORMULA STUDENT INDIA competition, there is a 20mm restrictor present between throttle body and engine to limit engine power capability. To achieve stagnation of air, plenum is used. Runner connects the plenum with engine and is tuned at certain rpm to optimize the engine performance. As KTM 390 Duke engine performance was used for the competition, all analysis was done on three parts – Restrictor, Plenum and Runner.

Standard parts used as a part of the assembly to form the intake system are:

B. AIR FILTER

A particular air filter is a device composed of fibrous or porous materials which removes solid particulates such as dust, pollen, mold and bacteria from the air.

Engine air filters are an important part of intake systems since they are responsible for providing filtered, particulate-free air to the engine. Since the internal combustion engines rely on air for use as an oxidizer in the process of burning fuel, and contaminants can damage various components in both intake and the engine itself, operating an engine without an air filter typically isn't recommended. However, a plugged air filter can create an artificial constriction on airflow through the intake system, which can result in a lack of power.

Air filter construction materials

1. Paper.
2. Cotton.
3. Foam.
4. Oil bath.

Working of Air Filter

Air filters work by trapping some of the small particles that exist in most environments while allowing air to flow relevantly unimpeded. In an automotive intake system, the air filter always sits ahead of the throttle body and mass air flow sensor.

In older applications, the air filter typically sat directly on the top of the carburetor. In newer applications, air filters are typically installed in "air filter boxes" at the head end of the intake system. In those cases, the inlet may be located on the box or there may be a tube that leads from the box to the front of the engine compartment.

When air first enters the intake system, it has to pass through the air filter. As it passes through the filtration media, any particulate matter larger than the porous in the filter gets stuck, while the air itself is able to pass through. This causes a certain level of restriction on the air flow of air but typically negligible when the filter is relatively clean.

Without an air filter, particulate matter would be able to enter the throttle body and pass into the combustion chambers. Depending on the amount of particulate matter in the air, this could potentially cause damage to the engine or various components. In that way an air filter "sacrifices" itself to protect the engine. Over time, the filter will gradually become clogged up, and it will be eventually have to be cleaned or replaced.

C. THROTTLE BODY

The most common way of controlling the air and fuel that entered an engine consisted of a carburetor mounted on top of an intake manifold. As technology improved and emissions standards tightened, fuel injection became the standard system because of its improved efficiency and ability to better control pollutant. A throttle is the mechanism by which fluid flow is managed by constriction or obstruction.

An engine's power can be increased or decreased by the restriction of inlet gases, but usually decreased. The term throttle has come to refer, informally, to any mechanism by which the power or speed of an engine is regulated, such as a car's accelerator pedal. What is often termed a throttle is called a thrust lever, particularly for jet engine powered aircraft. For a steam locomotive, the valve which controls the steam known as the regulator.

In an internal combustion engine, the throttle is a means of controlling an engine's power by regulating the amount of fuel or air entering the engine. In a motor vehicle the control used by the driver to regulate power is sometimes called the throttle, accelerator, or a gas pedal. For a gasoline engine, the throttle most commonly regulates the amount of air and fuel allowed to enter the engine. Recently, for a GDI engine, the throttle regulates the amount of air allowed to enter the engine.

D. NOZZLE

The nozzle was developed by German engineer and inventor Ernst korting in 1878 and Swedish inventor Gustaf de Laval in 1888. A nozzle is a device designed to control the direction or characteristics of a fluid flow as it exits an enclosed chamber or pipe. A nozzle is often a pipe or tube of varying cross-sectional area and it can be used to direct or modify the flow of a fluid. Nozzles are frequently used to control the rate of flow, speed, direction, mass, shape and the pressure of the stream that emerges from them. In a nozzle, the velocity of fluid increases at the expense of its pressure

energy.

Types of nozzles

1. Convergent nozzles.
2. Divergent nozzles.
3. Convergent-divergent nozzles.

Convergent nozzles

Convergent nozzles accelerate subsonic fluids. If the nozzle pressure ratio is high enough, then the flow will reach sonic velocity at the narrowest point. In this situation, the nozzle is said to be choked. The cross-sectional area decreases as the length increases. The area at which the cross-sectional area is less is called throat.

Divergent nozzles

Divergent nozzles slow fluids if the flow is subsonic, but they accelerate sonic or supersonic fluids. The cross-sectional area increases as the length increases. The area at which the cross-sectional area is less is called throat.

Convergent-divergent nozzles

Convergent-divergent nozzles can therefore accelerate fluids that have choked in the convergent section to supersonic speeds. This CD process is more efficient than allowing a convergent nozzle to expand supersonically externally. The shape of the divergent section also ensures that the direction of the escaping gases is directly backwards, as any sideways component would not contribute to thrust.

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.

E.PLENUM

Plenum is the second part that comes in the assembly of the intake system. The intake plenum's function is to produce high pressure, because the pressure in the intake manifold should be higher than that in the cylinders during their intake stroke. This is basically a pressurized air enclosure. It is connected after the Venturi in the whole intake assembly. The intake manifold serves the purpose of air environment which stores the surplus air ready to be sucked by the engine. After the air passes through the Venturi there is loss in pressure. This pressure loss occurs as the air passes through a small opening which creates a condition of choked flow, causing the pressure to drop at a remarkable level. This low-pressure air is not sufficient for the suction stroke of the engine.

The intake manifold serves as the purpose of pressure recovery. It helps in minimizing the pressure losses that occur after the Venturi as it stores a volume of air in accordance with the engine volume. As the pressure drops after the Venturi, the air is moved into the intake manifold. The first aim for designing the Plenum is to minimize the pressure loss from inlet of the throttle body to the start of the Plenum.

F.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 fed 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 it will benefit.

G.SOLID WORKS

SolidWorks is a solid modeling computer-aided design (CAD) and computer-aided engineering (CAE) computer program that runs primarily on Microsoft Windows. While it is possible to run SolidWorks on MacOS, that is not supported by SolidWorks. SolidWorks is published by Dassault Systems.

According to the publisher, over two million engineers and designers at more than 165,000 companies were using SolidWorks as of 2013. Also, according to the company, fiscal year 2011–12 revenue for SolidWorks totaled \$483 million. SolidWorks is a solid modeler and utilizes a parametric feature-based approach which was initially developed by PTC (Creo/Pro-Engineer) to create models and assemblies. The software is written on Para solid kernel.

Parameters refer to constraints whose values determine the shape or geometry of the model or assembly. Parameters can be either numeric parameters, such as line lengths or circle diameters, or geometric parameters, such as tangent,

parallel, concentric, horizontal or vertical, etc. Numeric parameters can be associated with each other through the use of relations, which allow them to capture design intent.

H.ANSYS

Ansys is an American public company based in Canonsburg, Pennsylvania. It develops and markets engineering simulation software. Ansys software is used to design products and semiconductors, as well as to create simulations that test a product's durability, temperature distribution, fluid movements, and electromagnetic properties.

Ansys was founded in 1970 by John Swanson. Swanson sold his interest in the company to venture capitalists in 1993. Ansys went public on NASDAQ in 1996. In the 2000s, Ansys made numerous acquisitions of other engineering design companies, acquiring additional technology for fluid dynamics, electronics design, and other physics analysis.

I.3D PRINTER

3D-Printer is a machine reminiscent of the Star Trek Replicator, something magical that can create objects out of thin air. It can “print” in plastic, metal, nylon, and over a hundred other materials. It can be used for making nonsensical little models like the over-printed

Yoda, yet it can also print manufacturing prototypes, end user products, quasi-legal guns, aircraft engine parts and even human organs using a person’s own cells. We live in an age that is witness to what many are calling the Third Industrial Revolution. 3D printing, more professionally called additive manufacturing, moves us away from the Henry Ford era mass production line, and will bring us to a new reality of customizable, one-off production. 3D printers use a variety of very different types of additive manufacturing technologies, but they all share one core thing in common: they create a three-dimensional object by building it layer by successive layer, until the entire object is complete. It’s much like printing in two dimensions on a sheet of paper, but with an added third dimension: UP. The Z-axis. Each of these printed layers is a thinly sliced, horizontal cross-section of the eventual object. Imagine a multi-layer cake, with the baker laying down each layer one at a time until the entire cake is formed. 3D printing is somewhat similar, but just a bit more precise than 3D baking. It needs a file as well. The file, a Computer Aided Design (CAD) file is created with the use of a 3D modelling program, either from scratch or beginning with a 3D model created by a 3D scanner. Either way, the program creates a file that is sent to the 3D printer. Along the way, software slices the design into hundreds, or more likely thousands, of horizontal layers. These layers will be printed one atop the other until the 3D object is done [2].

J.ARCHITECTURE

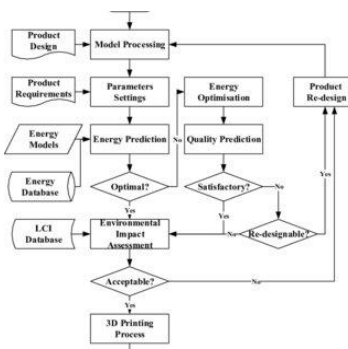


Fig 12 Schematic Diagram

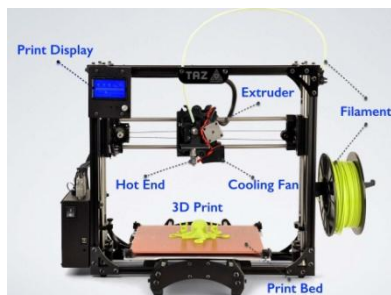


Fig 13 Architecture

The picture shows the structure of a typical 3D printer. The print table is the platform where the objects for printing has

been situated. It provides the basic support for manufacturing objects layer by layer. The extruder is the most important part of a 3D-Printer. As the extruders in the normal paper printers, this extruder is also used to pour ink for printing. The movement of extruder in various dimensions create the 3D print. For printing a 3d object, the extruder has to access X, Y and Z coordinates. For achieving this, many techniques are used according to the printer specification required for various applications. If the 3D-Printer is a desktop printer, the Z axis movement of the extruder can be avoided, and that function can be transferred to the print table. This will avoid complexity in 3D printing as well as time consumption. When the STL file is input to the printer, the microcontroller extracts each layer from it and also extracts each line segment from each layer. Then it gives controls to the movement of the extruder at required rate. The X-direction movement of extruder is made possible by the X-motor. When the X motor rotates, the shaft also rotates, and the extruder moves in X direction. The Y-direction movement of extruder is made possible by the Y-motor. When the Y motor rotates, the shaft also rotates, and the extruder moves in Y direction. The X direction movement is made by the print table. There will not be any X motor or Y motor in that case. An extruder which can pour concrete mix is fixed on the tip of a crane. The crane is programmed for the movement of extruder in X, Y and Z axis. The concept and structure of 3d printer changes according to the type, size, accuracy and material of the object that has to be printed. Generalizing the facts, the extruder needs to access all the 3 coordinates in space to print and object. The method used for that doesn't matters much [3].

K.EXTRUSION DEPOSITION

The development process technique involves heating and thermoplastic filament extrusion. When the production process kicks in, the thermoplastic is heated and transformed into a liquid state by the 3D printer.

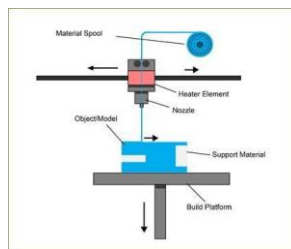


Fig 15 Extrusion Deposition.

The material is then deposited along the extrusion bath in the form of fine beads. Some of the key components in a typical FDM machine include thermal housing, extrusion nozzle, plastic filament supply coil and the X-Y-Z stage system. FDM operates following the X-Y-Z axes by drawing a layer of the model, one at a time. When undertaking thermoplastic extrusion, a plastic filament is removed from the coil in order to facilitate the movement of materials to the extrusion nozzle. When the nozzle reaches over the table surface, it releases several layers of plastic material. The nozzle features a device designed to control melted plastic. Once the plastic material cools, it hardens almost immediately. FDM also offers greater strength and is applicable to a lot more materials compared to other competing dimensional printing technologies. Laser Sintering technology works in a similar manner as FDM when it comes to the production of low-volume, functional plastic prototypes, but FDM equipment's are much more expensive [4].

L.GRANULAR MATERIAL BINDING

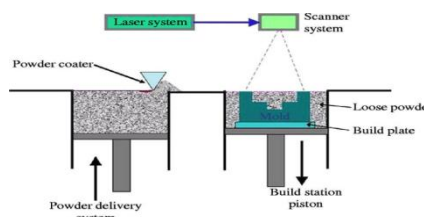


Fig 16 Granular Deposition.

Another 3D printing approach is the selective fusing of materials in a granular bed. The technique fuses parts of the layer, and then moves the working area downwards, adding another layer of granules and repeating the process until the piece has built up. This process uses the unfused media to support overhangs and thin walls in the part being produced, which reduces the need for temporary auxiliary supports for the piece. A laser is typically used to sinter the media into

a solid. Selective Laser Melting (SLM) does not use sintering for the fusion of powder granules but will completely melt the powder using a high-energy laser to create fully dense materials in a layer wise method with similar mechanical properties to conventional manufactured metals. Electron (EBM) is a similar type of additive manufacturing technology for metal parts (e.g. titanium alloys). The strength of bonded powder prints can be enhanced with wax or thermoset polymer impregnation [5].

M.STEREO LITHOGRAPHY

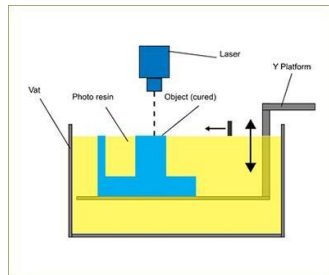


Fig 17 Stereo lithography

Stereo lithography – more commonly referred to as SLA 3D printing – is one of the most popular and widespread techniques in the world of additive manufacturing. It works by using a high-powered laser to harden liquid resin that is contained in a reservoir to create the desired 3D shape. In a nutshell, this process converts photosensitive liquid into 3D solid plastics in a layer-by-layer fashion using a low-power laser and photo polymerization. SLA is one of three primary technologies adopted in 3D printing, together with fused deposition modeling (FDM) and selective laser sintering (SLS). It belongs to the resin 3D printing category. A similar technique that is usually grouped with SLA is called digital light processing (DLP). It represents a sort of evolution of the SLA process, using a projector screen instead of a laser [6].

N.LAMINATION OBJECT MANUFACTURING

Laminated object manufacturing (LOM) is a method of 3D printing. It was developed by the California-based Helisys Inc. (now Cubic Technologies).

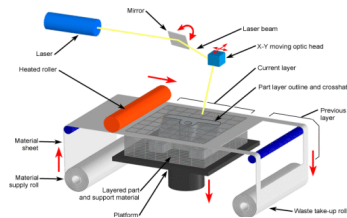


Fig 18 Laminated Object Manufacturing

During the LOM process, layers of plastic or paper are fused — or laminated — together using heat and pressure, and then cut into the desired shape with a computer-controlled laser or blade. Like all 3D- printed objects, models made with an LOM system start out as CAD files. Before a model is printed, its CAD file must be converted to a format that a 3D printer can understand — usually STL or 3DS. A LOM apparatus uses a continuous sheet of material — plastic, paper or (less commonly) metal — which is drawn across a build platform by a system of feed rollers. Plastic and paper build materials are often coated with an adhesive. A computer-controlled laser or blade then cuts the material into the desired pattern. The laser also slices up any excess material in a crosshatch pattern, making it easier to remove once the object is fully printed. New material is then pulled across the platform and the heated roller again passes over the material, binding the new layer to the one beneath it. This process is repeated until the entire object has been formed. Once an object is done "printing," it is removed from the build platform, and any excess material is cut away. Objects printed in paper take on wood-like properties and can be sanded or finished accordingly. Paper objects are usually sealed with a paint or lacquer to keep out moisture [7].

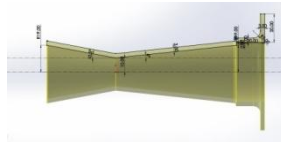
II. DESIGN

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 passes through the restrictor. The intake restrictor is a device adapting a venturi portion at its throat, for the increase of velocity of inlet air. The throat venturi diameter is

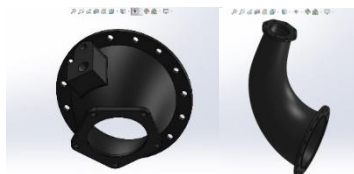


maintained at 20.0 mm (0.7874 inch) according to the rules initiated by FSAE. The restrictor is a non-movable portion of the throttle barrel. The velocity of charge in the intake system should not decrease to such limits so that fuel will start falling out of suspension. But the design should be careful so that fuel mixture is sufficient for supporting peak torque RPM.

2.1 Nozzle



2.2 Plenum



The above fig. shows the geometric model of plenum.

III. ANALYSIS AND RESULT

A. FLUENT ANALYSIS

The Iterations for various angles that were chosen for the analysis were for pressure loss considering the below angles.

ITERATION	CONVERGENCE ANGLE	DIVERGENCE ANGLE
1	10.5	6
2	12	6

Iteration 1: Angles 10.5° - 6° Pressure

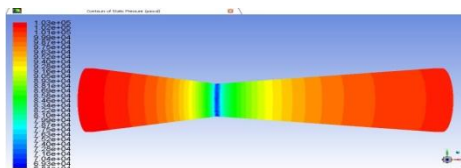
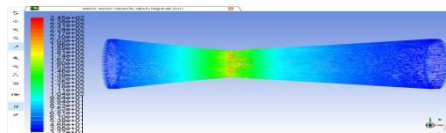


Fig.28 Pressure contours for angles 10.5 and 6.

The fig.17 shows the pressure contours for the Venturi of converging angle 10.5° and diverging 6°.



Velocity

Fig 29 Velocity vectors for angles 10.5 and 6.

The fig. 18 shows the velocity vectors of the Venturi with converging angle 10.5° and diverging angle of 6°

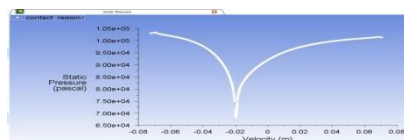


Fig 30 Static pressure vs Velocity graph.

The fig. 19 is a graph plotted for the values of static pressure and velocity of air entering.

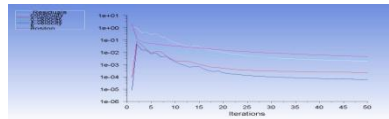


Fig 31 Residual graph.

The fig.20 shows number of errors occurred during the iterations

Mass Flow Rate	(kg/s)
outlet-ambient_pressure	-0.07314055
Mass Flow Rate	(kg/s)
contact_region-trg	0
Mass Flow Rate	(kg/s)
inlet_mass_flow_rate	0.07314

Fig 32 Final output mass flow rate.

**Iteration-2: Angles 12⁰- 6⁰.
Pressure**

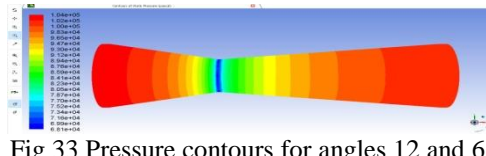


Fig 33 Pressure contours for angles 12 and 6

The Fig 22 shows the pressure contours for the Venturi of converging angle 12⁰ and diverging angle 6⁰.
Velocity

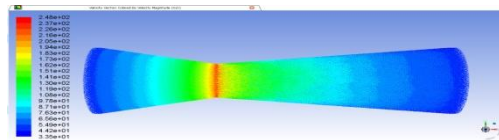


Fig 34 Velocity vectors for angles 12 and 6

The Fig 23 shows the velocity vectors of Venturi having converging angle 12⁰ and diverging angle 6⁰.

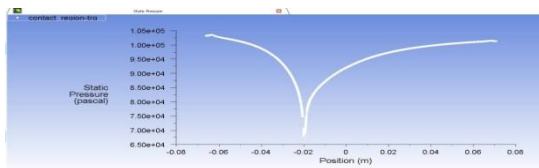


Fig 35 Static pressure vs Position graph.

The fig 24 is the graph plotted for the various values of static pressure and position.

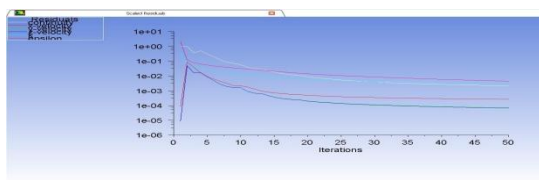


Fig 36 Residual graph.

Mass Flow Rate	(kg/s)
inlet	0.07314
Mass Flow Rate	(kg/s)
outlet	-0.073140168

Fig 37 Final output mass flow rate

RESULT

ITERATIO NS	CONG ANGLE	DIVG ANGLE	PRESSURE LOSS
1	10.5	6	1125
2	12.5	6	1225

Table 3 Pressure Loss for corresponding angles.

From the above figures it is quite clear that the pressure loss is lowest for the angles 10.5 & 6. The pressure lost is the lowest for these angles of the Venturi and therefore, these angles were selected for the manufacturing processes.

IV.ANALYSIS OF INTAKE SYSTEM

A.FLUENT ANALYSIS

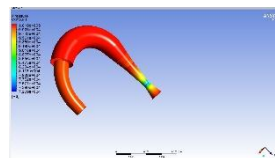


Fig 38 Pressure contours in the intake system.

The above fig. shows the pressure contour for the flow of air in the intake system. The flow should be turbulent and should have a pressure less than the atmospheric pressure so that the suction of air takes place and a required combustion occurs in the combustion chamber.

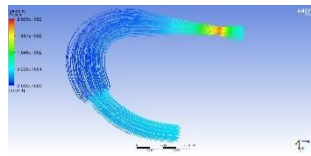


Fig 39 Velocity of air in the intake system

The above fig shows the velocity of air in the intake system. There should be high velocity of the air at the entrance of the intake system, so that more amount of air is sucked into the combustion chamber.

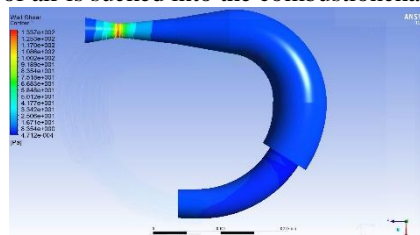


Fig.40 Wall Shear of the Intake Assembly

By conducting the wall shear analysis, can determine the shear occurs at the wall of the part due to flow of air into the intake manifold.

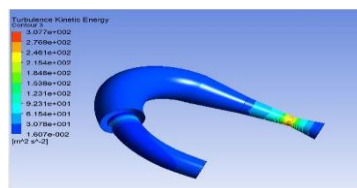


Fig.41 Turbulence Kinetic Energy Contour

Turbulence Kinetic Energy is the mean kinetic energy per unit mass associated with turbulence flow.

B.FABRICATION OF INTAKE SYSTEM

The fabrication of intake system is done using 3D printing technology by extrusion deposition method. Pictures during fabrication

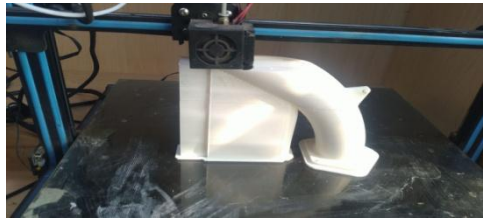


Fig.42 Fabrication of Runner.

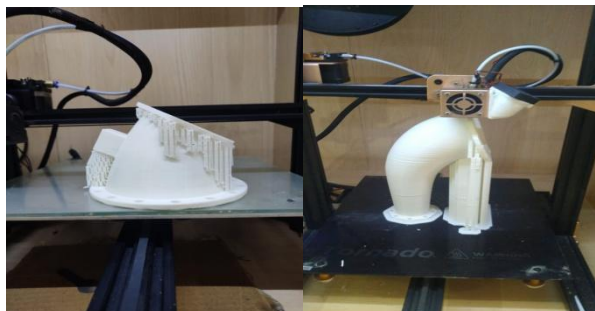


Fig.43 Fabrication of plenum part 1 and part 2



Fig 44 Top view of the intake system attached to the vehicle.

V.CONCLUSION

After reviewing work of different authors, it can be easily concluded that intake geometry makes considerable impact on engine performance. The main impact is on the volumetric efficiency of the engine which ultimately affects the torque & power produced at different engine speed. The intake manifold length is an important governing factor in deciding the peak volumetric efficiency region in the engines operating speed range. Longer intake manifolds give higher torque at lower RPMs while shorter intake manifold tends to give peak torque at high engine RPM. Author's intention is towards studying the phenomenon of intake tuning through theoretical & simulation methodologies and further validating results through`

The selection of restrictor design is also the most important factor before its application in to the intake system. The flow curves should be properly analyzed for achieving maximum volume flow at the same pressure and with controlled power output. The entire intake system should be optimized to reduce pressure loss and improve engine performance. These improvements will include flow balancing, which indicates intake runner length to optimize engine performance.

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