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SELECTION OF ADDITIVE MANUFACTURING TECHNOLOGY FOR OPTIMIZED INTAKE MANIFOLD: A REVIEW

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ABSTRACT

Additive Manufacturing (AM) is on the path of becoming the next big thing that will possess the capability of printing almost any object. It involves printing objects from a digital template to a physical 3-dimensional physical structure. A relatively newer field, where AM finds its application, is in the Automobile industry for manufacturing the various automotive components. One example of the same is the intake manifold. This research makes an attempt to look into the potential methods of AM available to us and proposes one of them to be the best AM technology for printing a functional intake manifold with optimized geometric design which would yield maximum volumetric efficiency for the engine

1. Introduction

The scope of this paper is to study and compare additive manufacturing technologies and to draw a conclusion on which additive manufacturing technology would be best suited to manufacture an intake manifold with increased volumetric efficiency. Intake manifold is a component of an engine that is responsible for supplying air fuel mixture to all the cylinders of the engine.[1]. Air filter, intake plenum and runners are its major parts. It is the link between the throttle body and the cylinder heads via intake ports. (Seshadri,2015). The most significant design criteria of the intake manifold are that it should supply equal quantity of air to all the cylinders. Improper distribution leads to poor efficiency of the engine.[2]. The design geometry of the I.M plays a crucial role in increasing the engine's V.E. Therefore it is necessary to analyse the pattern of flow of air in the intake manifold and modify the geometry of the intake manifold to achieve finer outcomes for volumetric efficiency of the engine.[3].

Literature survey of how researchers have adopted several techniques and methods to optimize and better the intake manifold geometry for volumetric efficiency were studied. Computational fluid dynamics (CFD) being one of them. It was used to study the air flow inside the intake manifold which helped to improve the design geometry and customise it further.

Computational Fluid Dynamics is a great tool for problem solving wherein the different techniques aim to solve Navier Stokes equation to satisfy conservation of mass , energy , momentum and predict the fluid behaviour [4]**.** The CFD analysis not only helps in studying fluid behaviour but consequently leads to certain geometric changes to achieve the goal of better output aimed through CFD[5]**.** CFD is not used unilaterally but compared with the experimental results if feasible and it helps in determining accuracy of the design[6]The most highlighted point as to why CFD is used is because it prevents drastic geometric changes which may prove costly if found inefficient , hence saving huge unnecessary expenditure.[7]

Looking at the geometric flexibility needed by the intake manifold to improve the volumetric efficiency, additive manufacturing was seen assisting and meeting our requirement. The origin of 3D printing goes right back to the 1960's where an attempt to make a three-dimensional object was made by using two light sources (Laser) of different wavelength with the aim to polymerise resin. However, it was Charles Hull in the 1980's to come up with the first 3D printing machine which used the process of stereolithography. Thus Charles Hull brought in a revolution to manufacturing which is now called additive manufacturing.[8]. In the early days this technology was used in the making of prototypes which resulted in it being called rapid prototyping, however over the years it has changed to being called 3D printing at the desktop level and additive manufacturing at the industry level. [9].AM is a technology in which joining and adding of materials one above the other takes place to make a product.

Three steps involved in the making of the final product are: -

- Using a design software for making the design geometry of the product to be printed and converting it to the file format as required by the AM machine.
- This file obtained requires pre-processing steps like setting up the orientation of geometry, setting up support structures, scaling of the model in order to achieve maximum benefits.
- The printing starts in the printer. Post processing of the final product in order to improve surface features, porosity and overall completeness.[10]

AM gets an edge over conventional manufacturing because of its features of customization, printing of complex parts, freedom in design geometry, lack of material wastage, customers become creator's moto and uses varying from desktop to the industry level.[11][9]

Different 3D printing processes were studied and a comparison was made between the most widely used. An in-depth study of the literature of each of these processes along with the material which would be able to sustain the engine variations was done. This helped us conclude which AM technologies can be used in the fabrication of intake manifold for improved volumetric efficiency.

Rapid Prototyping > Additive Manufacturing > 3-D Printing: A brief history (Table 1)

3-D Printing Technology	Founder	Year of foundation	Company they started
Stereolithography (SLA)	Charles (Chuck) Hull	Year of invention – 1989 Year of issuing patent - 1986	3D Systems
Selective Laser Sintering (SLS)	Carl Deckard	Year of invention – Mid 1980's Year of issuing patent – Mid 1980's	Desktop Manufacturing Corporation (DTM Corp) Later acquired by 3D Systems
Fused Deposition Modelling (FDM)	S. Scott and Lisa Crump	Year of issuing patent - 1989	Stratasys
Direct Metal Laser Sintering	Hans Langer	Year of invention – Late 1989	Electro Optical System (EOS)
Laminated Object Manufacturing (LOM)	Michael Feygin	Year of invention - 1995	Helisys Inc.

Table 1 : *Brief history of 3D printing technologies [8]*

Although it was Hideo Kodama from Japan who invented the 3D printing technique using a laser beam, his patent was rejected. He published papers on how laser beam can be used on photopolymers to fabricate 3D models. In 1984, it was Charles Hull who invented Stereolithography which used the impact of UV on liquid polymers to form three dimensional models. Charles Hull went on to win many awards from the year 1996 – 2014 for the invention and the beginning of a new manufacturing sector called additive manufacturing. He is currently the co-founder, chief technology officer and the executive vice president of 3D Systems which offers 3D printing services. [8]

2. Additive Manufacturing Vs Subtractive Manufacturing

This research is aimed at increasing the volumetric efficiency and the power output of the engine. This can be achieved by making changes in the design geometry of the already existing intake manifold plus further optimizing it by making flow analysis. Now to customize the design according to our requirements and to fabricate this complex shape 3D printing edged over traditional manufacturing techniques.

Additive Manufacturing is also popularly called as 3D printing. As the name suggests is a process of manufacturing or building a complex part layer over layer. Now this is completely different from conventional manufacturing techniques which makes use of CNC machines where operations like drilling, grinding, milling etc. are performed or parts to be built are casted into moulds. This as we can interpret are subtractive manufacturing techniques where material is cut from the parent material in order to produce a part. [12]

Additive manufacturing as seen by experts have a major role to play in the fourth industrial revolution. The advantages and benefits it provides not only allows growth and development in the industrial level but has led to consumers becoming creators or developers, because of its massive growth on the desktop level. Key benefits of 3D printing over conventional manufacturing techniques can be seen in its efficiency in the industry, mass customization, on-demand manufacturing, decentralized manufacturing, manufacturing of components, printing systems, improvement in quality, modifying and re-designing without penalties, increased supply chain advantages and continuous manufacturing initiatives. [11]

Advantages of additive manufacturing technology

- The advantage of using additive manufacturing over subtractive manufacturing is that its design phase allows wide number of iterations and prototyping thus reducing the financial investments and the development time in the design phase of the product. [13]
- Manufacturing can be classified into three parts depending upon the complexity of their products or the complexity advantage that it provides, customization available and the volume i.e. the quantity of products being manufactured. High Production volume-based mass manufacturing technique has never suited additive manufacturing because of the high investment that goes in setting up of an 3D printing manufacturing line. However, if we explore the region of low production volume-based mass complexity and mass customization it suits additive manufacturing because of the complexity in shapes that 3D printing gives plus the freedom to make changes in the design and suit customers need that it provides. Thus a conclusion can be drawn that if a product is to be manufactured which includes complexity in it or needs to be customized according to the customers need additive manufacturing gets an edge over traditional manufacturing.[12]

[14] made use of 3D printing (MakerBot Replicator 2X) and CNC machine (Roland 3D CNC Milling Machine) to fabricate a product and hence used the results to compare the two methods that is additive and subtractive manufacturing and also on the product quality obtained. Process parameters like the number of steps, the time taken to produce the part, software ease of use, machining/ printing speed, material wastage, accuracy of the final part and the surface finish were considered. MakerBot Replicator 2X edged over every process parameter except the surface finish which was better in Roland 3D CNC Milling Machine.

- Additive manufacturing has provided flexibility to designers which has led to optimization in lean production. Supply chain has been simplified as by incorporating AM technology only the design needs to be transferred which can be then printed and not the final product. AM is a boom in single or low volume production sectors also the clear advantage is that it is environment friendly because of less or no wastage of material in comparison to subtractive manufacturing and hence increase in resource efficiency. [11]

Our project is a single volume production, involves the making of a complex product and needs customization to improve the working and efficiency hence Additive manufacturing best suits our requirements.

Overview on different additive manufacturing processes

One of the first 3D printing process to be developed was Stereolithography (SLA) is the early 1980's followed by the invention of selective laser sintering (SLS) in the mid 1980's. Fused Deposition modelling another 3D printing technology came into picture in the late 1980's. These technologies had the same goal of manufacturing a product in the additive way but were completely different in functioning. These three processes continue to be widely used and some of the most popular processes incorporated my 3D printing organizations worldwide.[8]

ASTM has divided additive manufacturing technologies into seven groups which include vat photopolymerization, powder bed fusion, material extrusion, material jetting, binder jetting, directed energy deposition and sheet lamination. [15]

Overview of all 3D printing technologies and the different processes under them as shown in Table 2.

3D printing technology	Basic Idea and Materials Used	Different Processes
Vat Photopolymerization	Laser or ultraviolet light (UV) is focused on liquid photopolymer resin. Upon contact chemical reaction takes place between the materials to become cured. Layers keep stacking above each other which leads to the final product	Stereolithography (SLA) Digital light processing (DLP) Continuous liquid interface production

	Material Used - UV Curable Photopolymers	(CLIP)
Powder Bed Fusion	Heat in the form of an electron beam or laser is focused on the powdered bed which leads to fusion between the powder particles. Layers are added upon each other which leads to the final product. Material Used – Polymer and Composites Metal and Composites Ceramic and Composites	Selective Laser Sintering (SLS) Electron Beam Method (EBM) Selective Laser Melting (SLM) Direct Laser Metal Sintering
Material Extrusion	The material in the form of a filament passes through an extrusion head which consists of heating coils which in turn heats the filament and the liquified material is extruded out of the nozzle. Layers are formed according to the design and the product is obtained. Material Used – ABS, PLA etc.	Fused Deposition Modelling (FDM)
Material Jetting	It is similar to 2D printing where the ink is jetted on to the surface using piezoelectric or thermal methods and allowed to solidify on the surface in the presence of UV light. The layer gets added one above the other and the product is formed. Material Used – Metal, Polymers, Ceramics and solution and dispersed based deposition	Continuous Material Jetting Drop on demand Material Jetting PolyJet by Objet Nanoparticle jetting by Xjet
Binder Jetting	In this process a powder is spread on the	Binder Jetting

	surface and an ink jet in the form of a liquid binder is injected on to the surface. This leads to curing and fusion of the powder. Layers of powder are renewed after every jetting by a mechanism and a 3D printed product is obtained. Material in the powder form – Polymer, Metal, Ceramics and Biomaterials.	
Sheet Lamination	It involves layer by layer lamination of sheets using a carbon dioxide laser. Each layer representing a cross section of the design model. These sheets are bonded together by gluing or adhesives, thermal bonding, clamping or ultrasonic welding. Materials Used – Metals, Ceramics, Polymer and Paper	Laminated object manufacturing (LOM) Selective Lamination Composite Object Manufacturing (SLCOM) Plastic Sheet Lamination (PSL)
Direct Energy Deposition	Similar to Material Extrusion however in this method there are 4-5 nozzles that can move in multi axis direction. The nozzle extrudes the material on to the surface of the object and then the material is heated and melted using a electron beam, laser or plasma arc. The layers are added one by one and the product is either repaired or some additional feature is added. Material used in powder form: - Metals, Ceramics	LENS Technology by Optomec. Electron Beam Additive Manufacturing (EBAM) Laser Deposition Welding (LDW)

Table 2 : *Overview of all 3D printing technologies and the different processes under them.[16][17][18]*

Setup of different additive manufacturing technologies is shown in the Fig 1

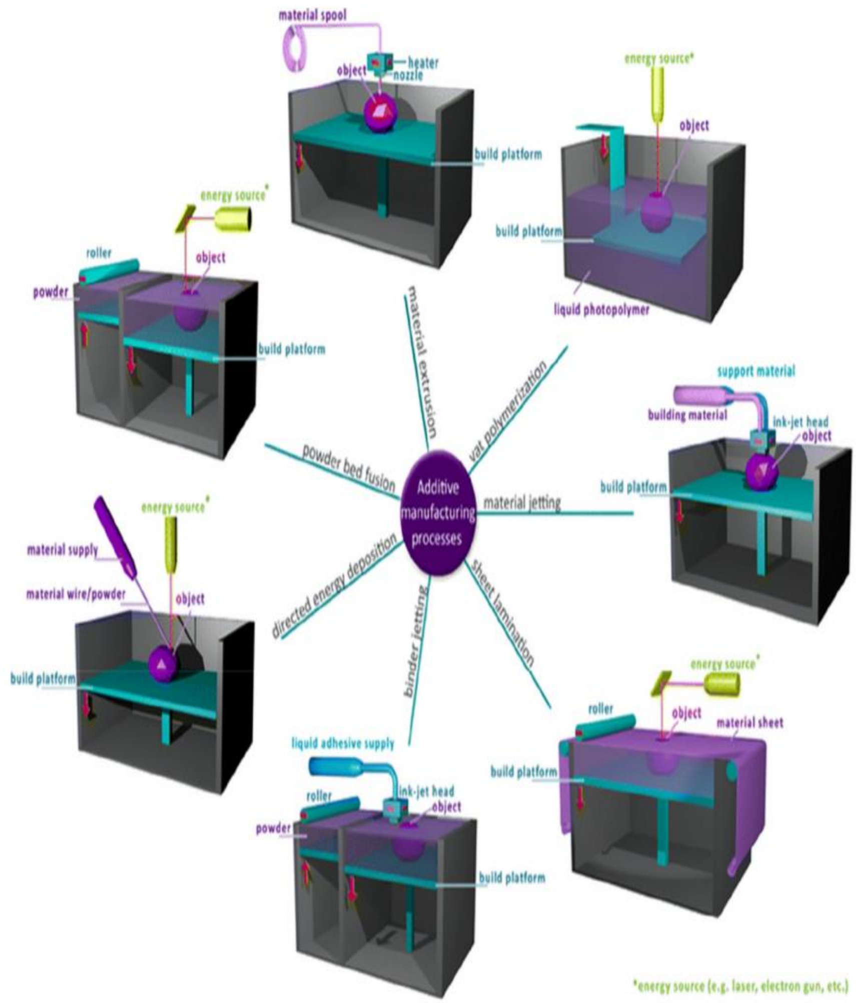


Fig1: *Setup of different additive manufacturing technologies [18]*

3. Comparison of widely used rapid manufacturing technologies

The 3D printing technologies that are incorporated by majority of the 3D printing organizations and are most widely used are stereolithography (SLA), selective laser sintering (SLS) and fused deposition modelling (FDM). These are one of the firsts and oldest 3D printing technologies. Significant research have been done on these technologies which has led to considerable growth in the field of additive manufacturing.[19]. These 3D printing processes have been compared with each other on the basis of various process parameters, the final product analysis, advantages and disadvantages over each other in a particular manner. Now which 3D printing technology to be used depends mostly on the product that you need to manufacture. Analysing and studying these 3D printing technologies one can easily find out which technology would suit its product the best and give optimum results and efficiency.[20]
Comparison of Stereolithography (SLA), Selective Laser Sintering (SLS) and Fused Deposition Modelling (FDM) on the basis of different parameters is shown in Table 3.

	Stereolithography (SLA)	Selective Laser Sintering (SLS)	Fused Deposition Modelling (FDM)
Basic idea	Photopolymer resin cured by Laser.	Polymer powder fused by resins.	Melting and extruding thermoplastic filament.
Accuracy and resolution	High accuracy and resolution. Shrinkage percentage is minimum.	Good accuracy and resolution. Shrinkage percentage is somewhere between SLA and FDM.	Low accuracy and resolution. High shrinkage percentage is observed in FDM.
Surface Finish	Good surface finish is obtained that is the measured surface roughness is low.	Surface finish obtained is inferior to that obtained in Stereolithography.	Measured surface roughness is high and therefore surface finish obtained is not so good.
Ease of handling	Difficult to handle because of the use of laser or ultraviolet light (UV) and photopolymer resin.	Handling of the powder becomes really difficult, requires the presence of an inert environment for the process to take place.	Easy to handle as the material used is in the form of a filament wire. Less supervision is required and can be carried at room temperatures.
Material Used	Photopolymer Liquid Resins	Metals, amorphous polymers and ceramics. Number of different materials can be used.	Thermoplastics like ABS, PLA and a blend of the two.

Need of supports and post processing	Support structure is required to support the overhangs. This leads to wastage of the material and power of the laser in building of the support structure. It also increases the post processing time.	Support structures are not required. Powder is used as the material which gives support to the overhangs. This powder in turn can be recycled and used for the next batch. Since there are no support structures to be removed post processing time is less.	Support structured are required in fused deposition modelling to support the overhangs. Post processing is required.
Initial Machine Costs	Costs of industrial stereolithography printers are quite high.	Industrial SLS 3D printers cost more than industrial SLA printers.	FDM printers are cheap both at the desktop level and the industrial level.

Table3: *Comparison of Stereolithography (SLA), Selective Laser Sintering (SLS) and Fused Deposition Modelling (FDM) on the basis of different parameters. [19], [20], [21] , [22], [23].*

A lot of process parameters go on to affect the density, porosity, tensile strength, hardness and shrinkage of the final product which accounts to the accuracy of the product and the surface finish. In the SLA process choosing proper process parameters like thickness of layer, orientation of the final product, time taken to build the product, speed of the laser and scan velocity which accounts to the pre-processing steps will lead to good physical properties of the final product. Considering the FDM technology, optimizing the process parameters like thickness of layer, air gap, orientation of the final product, number of contours and raster width will lead to better output of the final product. Moving on to SLS technology, the process parameters power of the laser, thickness of the layer, scan speed, temperature, cure depth and hatch spacing will decide the properties of the product. It was also seen that power of the laser and the speed of scanning had a major effect on the final product whereas power of the laser and temperature had an effect on the surface quality [20][19].

In their research they carried out an experiment to find out the dimensional accuracy, shrink percentage, surface roughness, time taken to build, machine setup time and industrial component cost. The component is a fluid premixture which was redesigned and reconstructed for optimum results using CAD software. The fluid premixture was 3D printed using three different technologies which were stereolithography (SLA), selective laser sintering (SLS) and fused deposition modelling (FDM). The final product was compared for the above-mentioned parameters. The material used in SLA was Accuracy 25, in SLS was a polyamide and in FDM was ABS. When compared for the shrinkage percentage, the least shrinkage was found to be in part produced by SLA process. Surface roughness was measured at the top surface and the rib surface i.e. the periphery. SLA produced part has a smooth surface finish. FDM on the other hand lacked surface finish and had high surface roughness. The build time, machine setup time and cost were least for FDM and comparatively high for SLA produced part. Selective laser sintering produced part had a shrinkage percentage, surface roughness, build time, machine setup time and cost incurred somewhere in between SLA process and FDM process [19].

SLA, SLS and FDM when compared with each other have their own advantages and disadvantages. Which process to be applied where and will best suit which application becomes a matter of knowledge in each 3D printing technology. Experimental results show that in order to have negligible shrinkage, good accuracy, density and surface finish, stereolithography (SLA) and selective laser sintering (SLS) best suits these parameters. However, they have their own disadvantages, handling of powder in selective laser sintering is a major task. Several kilograms of powder get loaded on to the bed and a lot of it goes unused which can be recycled however it losses some of its properties because of the temperature inside the machine that it is exposed to. This powder is highly reactive when it comes in contact with the atmosphere, therefore an inert environment is required to avoid the same. SLA makes the use of highly powered beam of light in the form of Laser or ultraviolet light (UV) which requires high amount of power and again a controlled environment to make the process take place. FDM on the other hand makes use of an ABS filament or a metal filament at room temperature without any controlled environment requirements in contrast to the SLA and SLS process. This reduces the lead time in between the printing of two products like machine cleaning, recycling of materials, chamber preparation and hence reduces the cost incurred in it. Hence it can be concluded that FDM is a choice if you are certainly not looking for surface finish and accuracy. It can be incorporated in small business and university laboratories in order to produce 3D printed parts.[23]

4. Materials

Materials used in stereolithography (SLA)

Photopolymerization measures utilize fluid, radiation-reparable gums, or photopolymers, as essential materials. The resins utilized in stereolithography are epoxy based furthermore, are birefringent, which makes the procedure especially appealing for the creation of photo-elastic models.[24].

Study of SL750 resin

The behaviour of photopolymers directly affects the dimensional exactness and physical properties of the components produced. So, investigation of properties of SL7560 is significant and important. In this study parameters like photosensitivity, viscosity, optical property and mechanical property of SL7560 resin were evaluated. After studying the viscosity vs temperature graph of this resin, it was observed that it is a non-Newtonian fluid. Its viscosity at 86˚F was 197mP_a.S, and the thickness was moderate with utilizing the resin to manufacture a component at 86˚F.The critical exposure and the penetration depth of the resin were found out to be 5.9mJ/cm2 and 0.14mm respectively. For Mechanical strength 5 specimen were selected and testing was done using a Universal Testing Machine. The mean tensile strength of the 5 components selected was 43.7 MPa, the mean tensile modulus was in the range 2500-2600 MPa, and the mean break elongation rate was 10.6%, which proved that the UV-cured components of SL7560 possessed strong physical properties, and the manufactured components had reasonable strength.[25].

Materials used in selective laser sintering (SLS)

Different powders are used in Powder bed fusion additive manufacturing like metals, polymers and ceramics. Nylon, ceramics, wax, Polycarbonate (PC), glass/nylon composite, elastomeric, true form (TM) and polymer-metal powders are materials that can be produced in SLS. At regular intervals, new materials are included to this lot.[26].Most widely used materials are metals and polymers. A comparative study between these indicates that melting point of metal powders(1600^{o}C) is much higher as compared to polymer powders (63^{o}C -372^{o}C). But the impact strength for polymers is greater than metal powders.

SLS materials used in automobile industry

The material suited for automobile application should be light weight which will cause better fuel efficiency and minimization of greenhouse gases. Other than this, great strength, stiffness, chemical resistance, hardness, fatigue resistance, impact resistance and less friction are qualities are required for using materials in automobile industry. Thus the materials suggested are (ABS),(PC), Alumide®, PEEK, nylon 11 and 12, Al-SiC composites etc.[27].

Materials used in fused deposition modelling (FDM)

Materials like metals, ceramics and Plastic/polymers are used in additive manufacturing by fused deposition modelling. Some of these include ABS, PC, ABS-PC, PPSF (polyphenylsulfone), and ULTEM 9085.[28] The most widely used materials in additive manufacturing by fused deposition modelling are ABS and PLA. Tensile strength of PLA lies in the range of 61-66 MPa whereas that of ABS lies in the range of 42-45 MPa. The shrink rate of PLA is 0.37 - 0.41% and for ABS is 0.33-0.36.[29]. It was observed that melting temperature of ABS (205^{o}C) is than that of PLA (175^{o}C). Density of ABS (1.04g/cm^3) is lower than that of PLA (1.25g/cm^3). ABS (75.84 MPa) has a higher flexural strength as compared to PLA(55.3 MPa). PLA has a better surface finish than ABS so it can be used in applications where more precision is needed.[30].

Study of optimizing intake manifold design for improved volumetric efficiency by methods adopted by researchers and CFD software.

The aim of this study is to select a 3D printing technology which will best suit the manufacturing of a customized intake manifold with an increased volumetric efficiency. We have gained sufficient knowledge on the various

AM technologies and the materials that are widely used in them. In order to go ahead with the study and achieve the aim, the following methodology was adopted.

- A complete in-depth study of the intake manifold, its function in the engine and how it affects the volumetric efficiency was made. This helped us understand various techniques that several researches have adopted and alterations that have been made in the design geometry using these techniques.
- Further studying the process, it was seen that optimization in the design geometry was possible by studying the flow pattern of air inside the manifold. This study helped in recognizing the restriction to air flow and further assisted the researchers to make use of flow analysing software's to analyse the flow and make further improvement in the design geometry to achieve maximum results.

Intake Manifold – A brief introduction

The most crucial part of an automobile is the engine. Over several years a lot of research has went behind on how to optimize and improve the engine efficiency as it leads to the overall betterment in an automobile. Number of factors affect the working of the engine, engine breathing being one of them. Engine breathing is a process in which air is taken inside the engine which mixes with the fuel to form the air fuel mixture which is responsible for the combustion process which takes place in the combustion chamber and in turn helps in the working of the engine. The part which plays the role of breathing in the air and distributing it to the combustion chamber where it leads to the formation of the air fuel mixture (direct fuel injection) or directly distributing the mixture of air and fuel to the cylinder is the intake manifold. The design or the geometry of the intake manifold plays a very crucial part to determine the volumetric efficiency of the engine and hence the performance and power output of the automobile. [31]

An intake manifold is a mix of two components a plenum and the runners. The plenum takes in air via the throttle body and distributes it to the runners. The runners are directly attached to the engine cylinder where the air fuel mixture is formed. [32]. The main aim for the intake is to dispense equal amount of air and fuel mixture to each and every cylinders of the engine. The intake manifold geometry however restricts equal amount of air to flow through each runner thus leading to poor mixture of air and fuel in different cylinders. Researchers over the years have come up with a lot of research and study on how the geometry and a lot of other engine parameters can be improved to obtain even distribution of air in each runner leading to equal distribution of air-fuel mixture in the cylinder and thus improving the overall efficiency of the engine. [2]

The performance of an intake manifold can be improved in several ways. Necessary requirements for an optimum intake manifold are

- Equal distribution of air to all cylinders
- Resistance to air should be minimum in Intake manifold runners.
- Appropriately designed Intake manifold geometry helps in enhancing induction process through pressure waves.

- Remove excessive turbulence and eddies from the Intake manifold
- Appropriate positioning of the throttle body.

5. Enhancing volumetric efficiency by varying intake system parameters

1. Tuning of the Intake System

As the piston in the cylinder moves away from the engine head (suction stroke), the volume in the cylinder gets expanded and leads to the creation of vacuum. The air which is present inside the runner because of the vacuum created inside the cylinder moves with a high velocity towards the cylinder. The cylinder vacuum leads to the formation of a negative pressure wave which moves towards the start of the runner. This leads to a rarefaction at the mouth of the runner inlet which makes the air from the plenum of the intake manifold to fill the vacancy, thus sending a compression wave towards the cylinder. At a certain RPN, the compression wave will reach the mouth of the cylinder just before the intake valve has closed. This phenomenon will allow excess air to enter the cylinder before the intake valve gets closed. This will allow maximum air to enter the cylinder and hence an increase of efficiency of engine performance. On the other side of the intake valve, the momentum of the fast-moving air from the runner of the intake manifold will come to a stop. The kinetic energy (K.E.) of the air will get converted to pressure energy leading to the formation of another pressure wave. Now again at a certain RPM these pressure waves will be used to maximize the intake manifold of the engine. This is a repetitive process. [33]

Intake manifold tuning involve two major theories

- Helmholtz Theory
- Reflective Wave Theory

Helmholtz theory was applied into the intake manifold by Engelman to make an analogy between changes in the resonator chamber and volume of the cylinder when piston is at mid stroke. This resulted in the formulation of a formula which showed a relation between engine spend and runner length. [34]

$$N = \frac{13.5c}{k} \times \sqrt{\frac{A}{LVd}} \times \sqrt{\frac{rc-1}{rc+1}}$$

c = acoustic speed k = constant (value between 2.5 to 2.8) A = Area of the intake

L = Intake length; Vd = displacement volume; rc= compression ratio of the engine;

The Reflective Wave Theory can be defined as the time that the time that the wave takes to move downwards with the speed equal to the acoustic speed through the runner pipe and then be reflected back so that it gets benefited by the reflected wave. [34]

$$N = \frac{c\Delta\theta}{12L}$$

c = acoustic speed $\Delta\theta$ = wave travel period in crank angle degree

L = length of the intake pipe

A lot of ways have been researched and studied about for the betterment of the intake manifold tuning. One method which has been most widely used is making use of the Helmholtz theory or the Helmholtz resonator. Noise reduction in the intake as well as exhaust is possible with the use of a Helmholtz resonator. However, it has widely been used to increase the amount of air entering the cylinder intake system. This would automatically lead to an increase in the volumetric efficiency of the engine. An experiment was performed by making use of a Helmholtz resonator inside an intake system.

- An increase of 17.8 % was observed in the amount of air entering the cylinder when the volume was kept constant. 24.7 % increase in the amount of air entering was seen when the valve timings were optimized with the cylinder volume.
- The best results were obtained when,

Frequency of intake system = Frequency of Helmholtz resonator[35]

2. By using variable length intake manifold

One effective and widely used way of optimizing Intake manifold design is by adopting variable length/variable plenum methodology. Several studies have been carried out in this field and better results for engine performance via optimized volumetric efficiency have been achieved. The design factors that influence the intake performance are length of the intake manifold runner, runner size of intake manifold and the plenum size of the intake manifold.[36].

A study by M.A Ceviz and M.Akin shows that an addition in intake plenum length yields better results than conventional plenum length. According to the experiments conducted on Ford-MVH-418 4 Cylinder engine, it was observed that for lesser engine speeds the length of plenum must be increased and vice versa. Highest engine thermal efficiency and was achieved when the length of plenum was increased by 64mm.Also better results for engine brake torque, specific fuel consumption characteristics and also brake power characteristics were observed.[37].So it is advised to use continuously varying intake plenum length to improve the performance of Intake manifold.

Conventional vs Variable length intake manifold

For more precise computation of the intake manifold length, calculations were carried out using Helmholtz resonator theory and Chryslers ram theory. This study was performed on a single cylinder 4-S CI Engine. The aim is to maximize parameters like volumetric efficiency and torque by making use of different intake lengths at different engine speeds. Fig 4 and 5 show the results for volumetric efficiency and torque benefit at different engine speeds with different intake lengths.

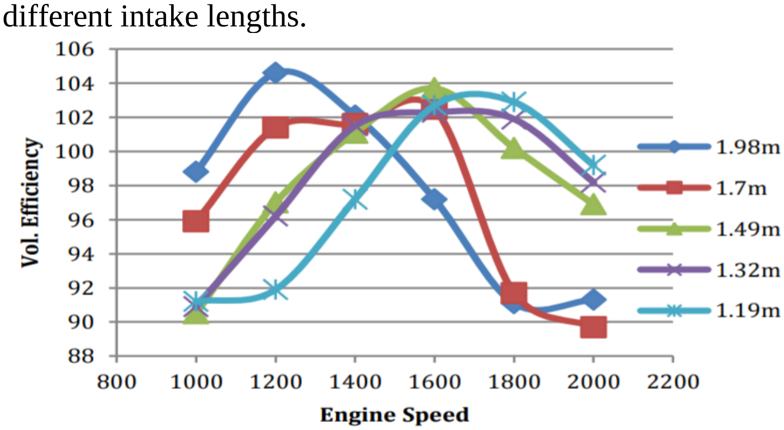


Fig 4

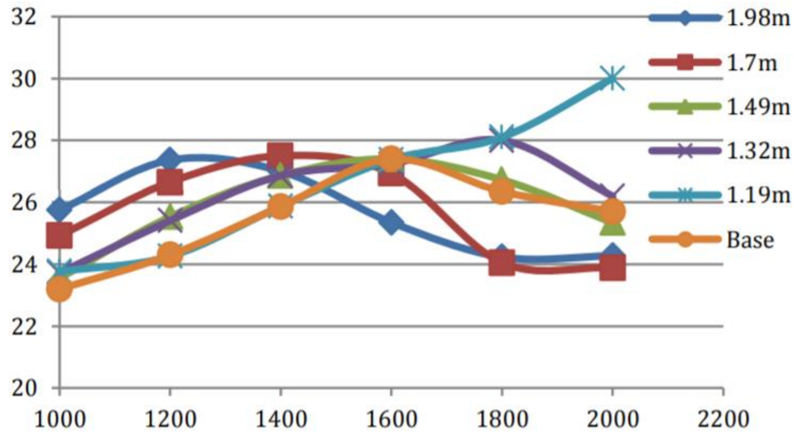


Fig 5

The results of these Variable length intake manifold by Chrysler ram theory is compared with conventional intake in fig 6. Better results for Brake Power, Brake Torque & Vol. Efficiency were achieved.[38].

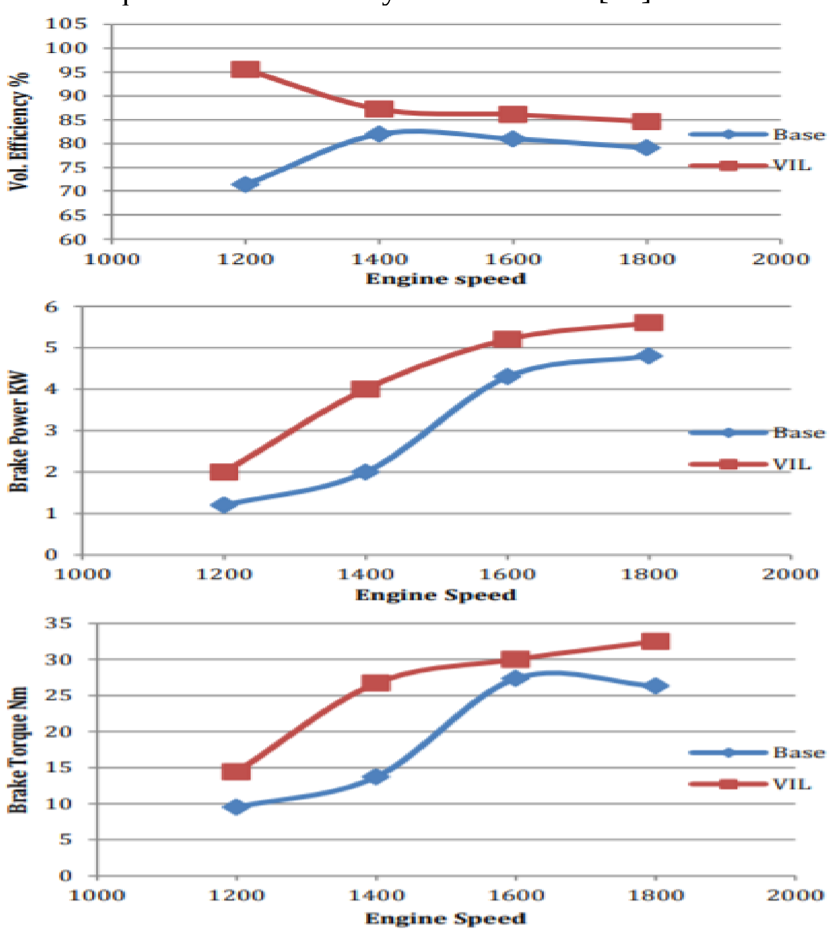


Fig 6

3. By varying intake manifold angles

conducted experiment on a 4 stroke 125cc port fuel injection (PFI) system engine using an asynchronous dynamometer and a mass flow meter. The

experiment was carried out to study the changes in the engine parameters and emissions for different angles of an intake manifold. The intake manifold angles that were taken into consideration were 90^0 and 150^0. The aim of this experiment was to improve the working conditions of the engine and hence which angle of the intake manifold would assist in doing that. The results showed that higher brake power was obtained for intake manifold with a 150^0 angle at all the load conditions of the dynamometer. Brake mean effective pressure is related to high power production per cylinder pressure. The 150^0 angle intake manifold obtained high brake mean effective pressure (BMEP) at all loading conditions of the dynamometer. It was seen through results that the brake specific fuel consumption was high for the intake manifold with 90^0 angle which means that fuel was not effectively used to produce work. On the other hand, the brake specific fuel consumption for the 150^0 angle intake manifold was quite low hence it provided good volumetric efficiency[39].
Experimented on six different angles of the intake manifold making use of CFD software. The six angles of the intake taken were 30^0, 60^0, 90^0, 120^0, 150^0 and 180^0. CFD air flow simulations were performed on each one of them. The engine which was taken into consideration was a 4 stroke, 125cc with PFI system. Velocity contours and pressure contours were studied for each angle and results were obtained. Smooth velocity contours were seen for the straight intake manifold or manifold with less bend to it. It is obvious that with the increase in bend there will be greater restriction to air flow. This restriction would make the power of the engine to fall. For intake manifolds as shown in Fig 7 with bends high velocities were seen at the inner wall of the intake manifold and low velocities were obtained at outer wall[40].

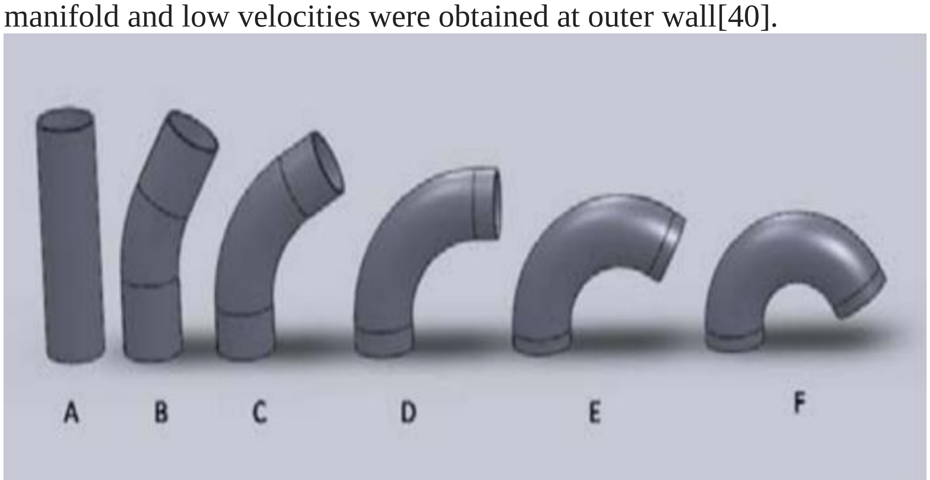


***Fig7** : Different angles of the intake manifold.[40]*

Pressure contours were studied and for the straight intake manifold high pressure was observed at the start of the intake and it gradually started to reduce down the pipe. Whereas for bent intake manifold, the pressure was high at the outer bend walls of the intake manifold and were low at the inner bend wall. This was inversely proportional to the velocity contours. Maximum efficiency is obtained when proper air-fuel mixture enter the engine cylinder. For straight intake manifolds, it was seen that no major disturbances were seen in both velocity and pressure contours at the walls. The velocity was quite high at the centre of the straight intake manifold which led to good air fuel mixture and because of almost no bends there was no fuel film formation which would tamper the efficiency of the engine.

The fuel injection system would be mounted on the wall of the intake manifold after the bend. This area should not have high pressure since when the fuel is injected it would result in improper mixing of the air and fuel and will affect the performance of the engine. This is the reason why manifolds with higher angle of bend which have high pressure contours near the region where the fuel is injected are not ideal when compared with manifold with no bend or minimum bend to it which have no turbulences where the fuel gets injected.

By using variable valve timing

Another way of amplifying the engine's efficiency is by using continuously changing the valve timing. By previous studies, it is known that intake valve timing that is intake valve closing time is a very crucial factor in Variable valve timing. This is because it is very convenient in construction and cost effective.[41].It is also known that a properly designed Variable valve timing systems may directly or indirectly result in minimization of pumping losses ,reduction of exhaust pollutions and higher volumetric efficiency.[42]

This paper shows that for the optimum Intake manifold performance depends both on variable length of runners and on opening timings of valve. Both have to function in a synchronized manner in order to achieve higher efficiency of the intake manifold. Variable valve timing allows us to exercise more control pressure waves. So, when this is integrated together with variable intake lengths, better results for intake performance are achieved. If both these parameters are varied individually, it would have been difficult to accommodate both into the same assembly. But combined variations of these two parameters namely variable intake length and variable valve timing has caused a reduction in span and number of alternatives needed thus helping us exercise more command over pressure waves overall operating speeds of the engine and in turn yielding better results for engine performance. Fig 8 shows a comparative study of engine's output of the two cases.[43].

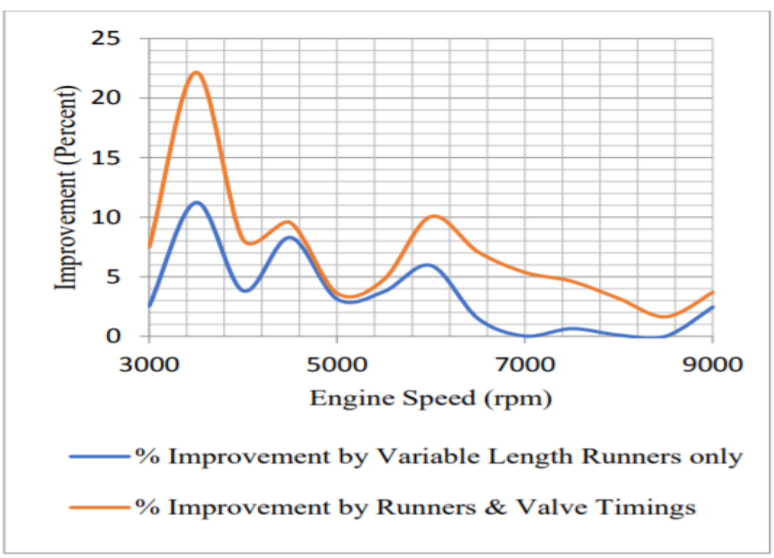


Fig 8

Several researchers have studied and experimented to improve either the geometry or the working conditions of the intake manifold. Research on how to optimize the geometry by making variations in the length and volume of the runner and plenum concluded the requirement of a variable runner length intake manifold which would give best results at different speeds. Intake manifold tuning (tuning of pressure waves with valve timing) helped in excess charge of air fuel mixture to enter the intake valve which led to increase in engine output. Use of a Helmholtz resonator led to increase in mass flow rate of air which led to improving the efficiency. Choosing proper intake manifold angles further helped in optimizing the intake manifold geometry to give a good air fuel mixture to the cylinder.

All these methods are quite useful in improving the engine output, however the increase when each of this method is used individually is much less. In order to develop the design geometry, further researchers have used CFD which helps to study the even distribution of air, detect restrictions to the air flow and reduce turbulences from the results obtained. This improvement in geometry design will optimize air flow and will lead to better engine output.

6. Introduction to computational fluid dynamics (CFD)

It is the science which helps us understand the flow patterns of fluids inside a body. With the advancement in technology, there a number of software's that are used to understand the flow pattern and help analyse them according to the application required. It helps in testing the flow without physical experiments, thus saving time and money.

The intake manifold of an engine in similar fashion, has the flow of air inside which when understood and analysed can help optimize the geometry of the intake manifold which will further help in better efficiency and output.

Various research papers have been studied wherein the intake manifold geometry has been optimized by various researchers and has been published. A detailed study and analysis have been done of these papers with reference to the optimization of flow with respect to various parameters (like pressure and velocity) and how CFD has helped in giving better results.

Use of CFD in intake manifold to improve engine output

The function of intake manifold of an engine to maximize the air inflow to maximize efficiency and output. [5] aims to optimize both intake system geometry and the filter utilization area by analysis results.

An air filter cleans the dirt particles entering the intake and supplying clean air to engine. Optimum utilization of filter leads to better functioning and lesser replacements.

The solid geometric model of the intake was obtained and for obtaining 3D flow, multi-block structured hexagonal mesh was generated. High Reynold's number was taken and equations of mass and momentum were solved by using SIMPLE algorithm to get velocity and pressure in the fluid domain. Filter of intake and air sensor were taken as porous media using coefficients. Various governing equations and boundary conditions were applied. A baffle was introduced in the air filter for uniform flow of air so that the cleaning is effective.

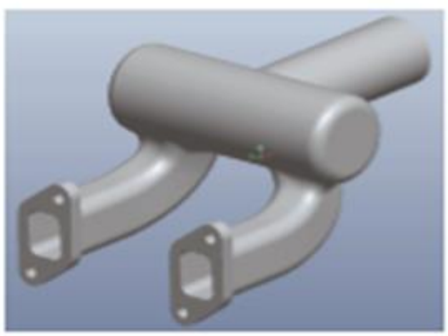
Introduction of baffle below the filter showed improved efficiency and reduced the pressure drop significantly. The flow became relaxed and had better distribution.

All the changes made above improved the overall pressure drop by 22%.

"Emphasis is more on increasing the volumetric efficiency of a diesel engine which is formerly giving an efficiency of 84% at 2400 rpm" [44].

Here the variables are primary runner length, plenum volume and secondary runner length. The optimization is carried out at 2400 rpm.

Pro-E software is used in this research to obtain the geometry of the intake manifold.GT-Power software is used to obtain dimensions. The geometry of the first manifold is such that the axis of primary and secondary pipes lies on the same plane and that of the second geometry constructed otherwise. This helps in comparing both these results. After applying the governing equations and boundary conditions, the results had various observations regarding the 2 geometries and their individual results. As a result manifold 2 as shown in fig 9 which gave better velocities and space reduction was preferred over manifold 1.



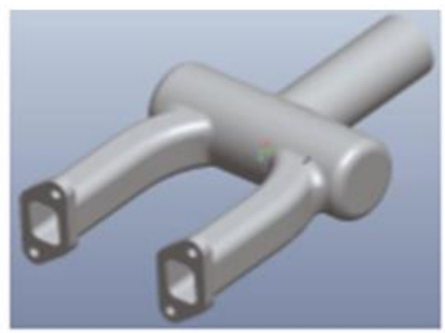


Fig 9: *Intake manifold geometry -1* *Intake manifold geometry-2 [44]*

Throttle body is located between the air filter and intake manifold. Its main function is to control the amount of air entering the intake. The butterfly valve varies the flow area to control the air flow.

This research paper aims to calculate the best possible conditions for optimum air flow through throttle to intake in single cylinder engine.

The throttle body consists of -bypass screw, throttle valve, bypass and main passage. When the throttle valve is opened, the air flow is mainly in the main passage. Whereas during idling, the throttle vale remains closed, and thus the air flow is increased in bypass passage.

After applying various governing equations and boundary conditions at the inlet, outlet and wall analysis has been done. The study started with the idling conditions of the engine and then at various throttling positions.Two types of shaft have been used viz. rectangular and circular. It was found out that there is more loss of energy with circular throttle and hence less velocity at outlet.

The CFD results show that the air flow increment with increase in throttle opening. It also shows the results for main and bypass air passages. It showed that at 12% throttle opening, air flow is equal in both passages. Further increase leads to increase in main passage air flow.

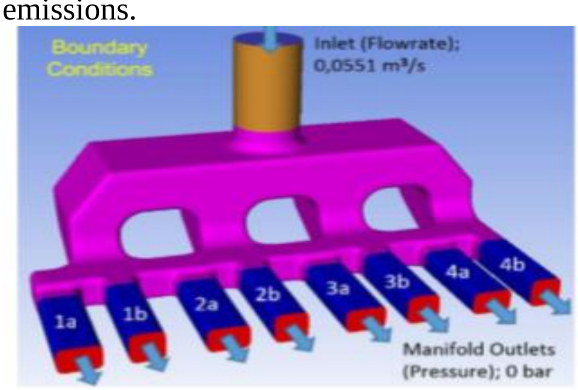
Further, effect of bore diameter was seen after 60% throttle opening. For every 2mm increase in diameter,7% air flow rate increases and 6% engine power increases [6]**.**

In this research paper aims to optimize the intake manifold geometry through Ansys software where 2 different models were generated to test their efficiency. One in which narrow throat is enlarged by removing bolt cavity and the other one wherein the inlet pipe has been raised by 10mm [7].

The inlet volume of air flowing in the cylinder is calculated theoretically and is defined as inlet boundary condition whereas the atmospheric pressure is taken as the outlet boundary condition. The pressure loss is determined by CFD.

Tetrahedral mesh was applied at the intake body. Extended inlet and outlets had sweep mesh.

After getting the simulation results as shown in Fig 10 it was found out that the pressure loss increases from 1st to 4th cylinder. So, the results of the simulation show that due to the enlargement in narrow throat, the pressure difference is considerably reduced. Also, for the second case where the manifold surface which is connected to the inlet pipe is raised by 10mm also showed considerable pressure difference reduction. But still the flow was double in the first cylinder compared to second, and third and fourth cylinders had more pressure drop. Due to this unsatisfactory result which can impact engine performance, a new intake geometry was designed keeping flow consideration in mind. This intake showed better results; it had lower pressure losses, good flowrate distribution, improved swirl values in cylinder and lower exhaust emissions.



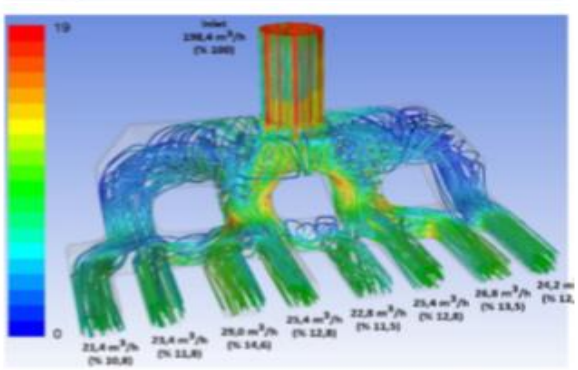


Fig 10: *New and final geometry- [7]*

in this paper uses 1D modelling along with 3D modelling of the intake manifold. GT-Power software was used to prepare the 1D model whereas the 3D modelling was done using CFD with the help of ANSYS Fluent.

The first simulation run was to verify gas flow inside the intake. The 3D simulation was done first. The runner to cylinder 1 was opened and the mixture of gases taken were air(main) and CO_2 (secondary fluid). Intake inlet had a mixer installed to force the gases to merge with each other. The Exhaust Gas Recirculation mixer was found out to be effective in combining air and burned gases [45].

The next simulation was aimed at transient calculations, to verify distribution of EGR gases inside intake and runners. In this, 3D simulation is conducted along with 1D simulation. Just one engine speed i.e. 1687 rpm is considered. The fluid properties used in ANSYS were the same as the model generated using GT-Power. The software GT-SUITE is used to exchange boundary values to each CFD step through special connection.

The results at the outlet of the runners of the model was obtained was obtained and was found out that each time certain amount of EGR(exhaust gas recirculation-16%) flows to the runners .The results showed fairly even distribution of gases in each runner and the coupling of 3D and 1D simulations proved useful in determining that there are no concerns related to EGR and verified that EGR fraction assumed a constant amount inside plenum for certain specific engine conditions.

in this research paper aims to change the geometry of intake manifold and obtain the reduced pressure losses, equal flow of velocities in runner and improve overall performance.

A prototype is created using Pro-E software and stress analysis is done using CD. The proposed model is then compared with the new prototype and then considerable modifications are made.

The main aim of stress analysis is to check the material suitability and thickness of intake manifold against bursting pressure in bad conditions, and the analysis is done on one of the runners.

It was seen that the thickness of intake was better than normal to bear a pressure of 3-5 bar. Then 3 models each with small modifications have been made to compare their results and the best possible results have been incorporated.

Many points were noted from the results: depth cuts at extreme side of plenum is carefully designed, curvy design is good for equal flow in runners and geometry should be free from projection of nuts, stiffeners and depth cut at plenum extremity. These points were noted which gave better results. Velocity of air in runner 1 increases by 16% and in other runner outlets by 5-7% [46].

Lessons learned

The above studied research papers used various techniques with different software’s to study the flow analysis but, with a common objective of obtaining the best efficiency and output of the intake manifold that can be achieved by design modifications.

Now since flow of air within an intake manifold have been studied above, it is now possible to use CFD analysis as a tool to implement the Intake manifold optimization techniques for maximizing the volumetric efficiency of the Intake manifold. Design modifications have been done to the geometry of the intake manifold using CFD analysis to assure equal distribution of air to all cylinders. Now to manufacture this optimized intake manifold with complex geometry, use of additive manufacturing has been used since there is no restriction on no. of design iterations. The major advantage of additive manufacturing over subtractive manufacturing is that it reduces material wastage and helps in customization of product as per customer's need.

Decision Theory

Variations that the material of the intake manifold should be able to sustain

The material of the intake manifold should be such that it should be able to withstand high temperatures and pressures along with good mechanical properties like tensile strength and creep resistance. The minimum temperature requirement within an intake manifold is at least 121^{o} C, with peak value of up to 150°C to 160°C. The tensile strength required for Intake manifold material is at least 50-60 N/mm^2 at room temperature. Stiffness measures how an air intake manifold is going to perform under higher stresses. Stiffer part results in lesser movement/vibration during the functioning of the component.[47].Moreover the material of Intake manifold should have high thermal conductivity and low specific heat capacity. It should allow decent resistance to thermal loads and greater value of chemical resistance against fuels, oils, and additives.[48].

7. Fabrication of Intake Manifold using Additive Manufacturing

The most widely used additive manufacturing techniques were studied and compared with each other. Stereolithography (SLA), selective laser sintering (SLS) and fused deposition modelling (FDM) had a certain amount of advantages and drawbacks of its own. The 3D printing technology to be used as discussed earlier always depends upon the application which it is used for keeping the cost, volume of production, build time, accuracy, surface finish and the advantages and disadvantages of each process in picture.

Conventional intake manifolds are manufactured when a number of aluminium components (mostly either bent aluminium tubing or casted aluminium parts) are bonded together via welding. The use of aluminium gives the intake manifold good strength and also provides a low mass functional part to the engine however there are a lot of design restriction because of the manufacturing method used. This leads to lowering the output of the engine as the intake design is restricted to obtain optimal results. Hence it becomes difficult to design an inlet system which provides equal distribution of air in all the runners of the intake manifold and one with least pressure losses. Additive manufacturing provides design freedom to the user which gives it an edge over conventional manufacturing as the design can be customized according to the user requirement thus leading to optimum results of the engine performance.[13]

One of the first used additive manufacturing technique to be used in prototyping of an intake manifold was stereolithography (SLA). In 1996 the team of Ecole de technologiesuperieure (ETS) manufactured an intake manifold prototype using SLA 3D printing process. [49]

Additive manufacturing techniques like fused deposition modelling (FDM), selective laser sintering (SLS) and stereolithography (SLA) have been used in the manufacturing of the intake manifold. [13] used fused deposition modelling process for the manufacturing of their intake manifold using FDM's most commonly used material acrylonitrile butadiene styrene (ABS). Research on the engine operating conditions made them realise that FDM printed intake manifold cannot withstand the high temperature environment surrounding the engine. Further the parts produced by FDM printers have high porosity and poor finish. They decided to provide a layer of composite material in the form of carbon fibre fabric by making use of strongly heated resin via curing and vacuum bagging. This layer of composite material provided improves the part density of the intake manifold thus reducing the porosity and making it air tight. Thus, allowing the manifold to be light weight, strong and resistant to heat. In order to further protect the 3D printed intake, manifold the end of the runners were attached to aluminium mounts. Further gaskets with high temperature resistance were provided to avoid heat transfer from engine to the manifold.

developed a log shaped intake manifold by making use of selective laser sintering (SLS) technology. Support structures are not required to support the overhangs unlike all other 3D printing processes. The capital invested is less than traditional manufacturing giving excellent strength and a good surface finish. Since SLS process provides wide range of materials, the author had to choose which material would give best functionality inside the operating conditions of the engine. The material to be chosen should be able to withstand high amount of pressure and should have high resistance to heat. Material analysis of the materials available and which would best suit the engine environment was PA-12 material. PA 12 has low water absorption property, high resistance to hydraulic fluids, abrasion and stress cracking. PA 12 also had high melting M.P. of 180^0 C [50].

3-D printed intake systems

For the fabrication of an intake manifold as we saw various parameters are to be taken into account like it should withstand high temperature and high pressure, should have excellent mechanical properties like creep resistance and tensile strength. In addition to this stiffness plays an important role in reducing vibrations within an intake manifold. Further it should have high thermal conductivity, low specific heat capacity and should be highly resistance to chemical action. The material and the additive manufacturing process that will best suit the above-mentioned parameters was chosen.

Fused deposition modelling (FDM) is considered as the most cost-effective method to be used in additive manufacturing technology. Not only is it cost effective but the lead time taken to manufacture a product is also low. FDM has been used widely at desktop level to produce prototypes because of its easy to handle functionality however industrial FDM machines are also popular in the building of functional end products. On the other hand, it lacks surface finish and resolution when compared with other technologies. Further it also produces products which are weak in the Z direction. However, this can be overcome by improving the part orientation during the design phase and putting the less important part of the intake manifold in the Z direction. FDM uses thermoplastics like ABS and PLA. Studies on if they could sustain the engine parameters and if they can be used in making of the intake manifold. Results showed that ABS alone cannot sustain the engine temperature, another composite material needs to be added in order to sustain the engine temperature. Further the composite would go on to improve the part density of the intake manifold making it more engine ready. PLA on the other hand have the tensile strength and is also temperature resistant to sustain engine working parameters. The manifolds manufactured by these materials can only be used in open environment application like in FSAE cars as it becomes difficult to sustain the high temperatures of the closed engine conditions. However, in order to provide additional safety, aluminium gaskets can be provided at the interval where the intake manifold is connected to the cylinder head in order to give stability and protect from high temperatures.

Thus, it can be concluded that an intake manifold can be fabricated using fused deposition modelling as it can sustain the variations provided by the engine. Surface finish, shrinkage, low resolution and weakness in part in the Z direction are some of the disadvantages of this process however they can be overcome by optimizing the design phase and using optimum post processing techniques. Further FDM can be used in high volume production of parts because of its low cost and minimum lead time advantage. This leads to obtaining a complex, customized and volume production by this additive manufacturing technology.

The advantages of the stereolithography (SLA) process is its excellent surface finish and part accuracy which is obtained in the final product. However, the major disadvantage lies with the materials used in this process. Photopolymers used in stereolithography do not have impact strength and are not durable. The final products obtained are brittle. Thus, SLA process cannot be used in the making of functional products. They have been used in the making of visual prototypes because of the smooth surface finish and dimensional accuracy. Functional intake manifold cannot be produced by using SLA technique because of the restrictions provided by the material. Visual prototypes of intake manifold can be produced by this technique for educational or lab purposes.

The major advantage of selective laser sintering is that it requires no support structure like other 3D printing techniques. The powder itself provides the part with all necessary supports and hence this technology can be used in making any design geometries with any number of overhangs which are difficult to manufacture under other additive techniques. The products obtained have excellent mechanical properties and can be used in the making of functional prototypes. The only disadvantage of this process is that the surface finish obtained is grainy and the porosity of the parts obtained is also high. However, this can be reduced my making use of post processing techniques. This will result in a good surface finish and air tight product. The most common material used in selective laser sintering is PA – 12. PA -12 properties were studied to see whether they would be able to sustain the engine conditions. The tensile strength of PA 12 was seen to match the requirements of tensile strength of the intake manifold. Further when temperature conditions were to be studied, it was found that the temperature at which PA 12 melts is much higher that the highest temperatures reached in the engine. PA 12 was also found to be chemical resistant. These ideal properties of PA 12 and the advantages provided by selective laser sintering technology made it most suitable to fabricate a functional intake manifold.

8. conclusion

The aim of this paper was to study which additive manufacturing technology would be best suited to use for the fabrication of the intake manifold. This intake manifold was fabricated for obtaining maximum volumetric efficiency in the engine. In order to achieve this, aim the following methodology of study was followed and several conclusions were drawn based on the literature study done.

- Literature study on how to improve the volumetric efficiency by making changes in the intake manifold geometry or the intake manifold parameters was done. Intake manifold tuning, using a variable length intake manifold, using more straighter angles of the intake manifold i.e. manifolds with less bends and using variable valve timing to assist the pressure wave so that maximum charge could flow inside the cylinder were some ways adopted by the researchers to obtain a good engine output and volumetric efficiency.
- However, the increase obtained by each of these techniques were found out to be quite small. This led to the study where researchers made use CFD to obtain improvement in the design. Researchers studied the air flow inside the intake manifold from which velocity and pressure plots were obtained. Turbulences inside the manifold were studied and geometry was modified so that the air gets minimum restriction and maximum air fuel mixture flows into the cylinder. This approach helped researchers to get an increase in the volumetric efficiency by optimizing the flow.
- In order to achieve best volumetric efficiency results a huge amount of flexibility in geometry is required. Additive manufacturing provides this geometric flexibility along with providing the complexity advantage i.e. manufacturing of complex parts like the intake manifold.
- Literature study of different 3D printing technologies enabled the knowledge of the major advantages and disadvantages of different technologies and the material used by them. Comparative study between the most widely technologies plus studying the conditions of temperature, pressure and various other parameters inside the engine further gave a clear idea on which would best suit to fabricate a functional intake manifold.

- The study of stereolithography (SLA) which makes use of photosensitive resins gave final 3D printed products with had excellent surface finish, high resolution and low shrinkage. However, it lacked good mechanical strength and was brittle. Conclusions were drawn that stereolithography cannot be used in the fabrication of the intake manifold because of the lack in mechanical strength which cannot sustain the engine conditions.
- ABS and PLA material are used in FDM. The product obtained by FDM technique have poor surface finish, low resolution and high shrinkage. However, these drawbacks can be brought down to minimum by adopting good pre-processing and post processing techniques. Moreover, ABS and PLA have good strength and properties which can withstand the harsh engine conditions. ABS require another composite material in combination in order to sustain engine conditions and also improve porosity of the final product. Provision of aluminium gaskets at the joining of the manifold and cylinder will provide further protection. This study concluded that FDM can be used in the fabrication of the intake manifold in vehicles which used open environment engines like the FSAE cars. High volume production of intake manifold could also be obtained by this process because of the low cost and low lead time features.

The study of selective laser sintering by using PA 12 material was found out to be the best fit for fabrication of an intake manifold. No support structures are required in this process thus there can be any number of overhangs or complexity that can be provided as there is no restriction in design geometry, the powder used will act as the support. The surface finish obtained is not as desired however it can be fixed by using suitable post processing techniques. PA 12 material fulfil each and every conditions and variations provided by the engine like it has high melting point than the maximum temperature reached, provides tensile strength that can withstand various forces and is also chemical resistant. Studies concluded that selective laser sintering was found out to be the best technology in order to obtain a functional intake manifold

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