Manufacturing of 3 D Shrouded Impeller of a Centrifugal Compressor on 3D-Printing machine using FDM Technology

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Abstract. Blades of impellers are intricate and are having complex profiles which are difficult to be manufactured by convectional milling processes. To produce such multifaceted precise dimensional functional components, expertise combined with new technology machining such as 5-Axis CNC machining is required which is costly and tedious task. The impellers components have maximum diameters of 200mm and thickness of blades are less than 1.5mm. A rapid manufacturing technique aids in manufacture of blade profiles which are robust in design and prototypes can be easily made for testing and analysis this aid in design validation. In particular, the investigation was focused on shrouded and unshrouded 3D impeller of centrifugal compressors. The present paper describes about the basic functioning of FDM based 3D printer while printing open and shrouded impeller and various steps involved in it and finally advantages and disadvantages associated with 3D printing technology.

Keywords: Shrouded 3D impeller, FDM, Rapid manufacturing, Centrifugal Compressors

1. Introduction
Additive manufacturing (AM) technology has been considered a breakthrough for future product development and production. There has been tremendous effort in recent years to introduce technology advancements to reorganize and establish businesses and its allied fields globally. One of the studies indicates that usage of AM technology is restricted to only few sectors but soon will become a future, integrating all sectors of manufacturing. Prototyping components from AM based rapid technology can create and build models based on CAD files and computer data. This technology detects and constructs layers which befall one by one thus representing and building the replica or idea of original product. This process doesn’t require tooling or fixture set ups as in convectional machining. This delivers successful commodities in shorter times with add on replacement facilities unlike regular machining process which involves cutting or removal of material example milling. Now days, large number of materials like plastics, metals, ceramics, etc, can be used for 3D printing technologies. Rapid prototyping covers different fields in its application point of view such as health care, research investigations, armed forces, structural engineering, fashion and jewellery industry, design and prototype making, CAE etc.
1.1. Manufacturing of impeller

Shang Liangchen et al[1] applied latest and advanced CAD/CAM methods to manufacture blades of centrifugal compressor impeller. Reverse engineering, Unigraphics NX (CAD/CAM) software, coordinate measuring machines (CMM) technologies are discussed in this paper. Finally they concluded that cavity milling in conjunction with five axis milling technology adapted could increase efficiency and accuracy in manufacturing impeller blades. Aruna prabha et al[13] used 5-Axis machines in conjunction with UNIGRAPHICS software to optimize tool paths for manufacturing steam turbine blades. Klaus bodden berg [2] discussed about the manufacturing methods of impeller and how the casting and forging manufacturing processes are useful for impeller blank. Moreover, they discussed about what are the methods for joining of blades and hub in industries. Those methods are welding, brazing and riveted methods. Selection of materials and heat treatment operations are discussed. Finally, in this paper they have explained on entire view of manufacturing system of impeller for turbo compressors. Toru kaino[3] discussed and dealt about machining large size impellers used in centrifugal compressors which require 5-axis machining set ups. This improved efficiency and accuracy of products by retaining its shape. By introducing the contour machining in line with cutting resistance-levelling arrangement the machining time was reduced and can also chatter was easily detected. This paper depicts the use of new technology methods applied to efficiently machine large impellers with ease. B.Sajjan, et al[4] designed and analysed impeller type centrifugal pump on ANSYS work bench. The initial objective is to test for deflections and stresses in impeller as well as centrifugal pump housing by applying load onto the belt. Various materials are selected for pump assembly and their corresponding induced stresses are individually evaluated ensuring that it does not exceed its elastic limit. This gave various factors as results to determine how different materials vary and which material is best for pump building. These include natural frequency, stress, strain, deformation factors and modal values. Modelling is done in design modeller and analysis in work bench both available in ANSYS. This FEM analytical tool can be used to solve many structural, static and dynamic problems and also can find deformations, stresses in impellers throughout its profile. Syam Prasad el al[5] analyzed static and dynamic factors in centrifugal pump impeller. They used CATIA software for modeling of impeller. They did analysis on impeller using ANSYS software to find out the stress, strain, deformation, deflection and mode shapes of impeller. They used three types of alloy materials to estimate the impeller performance. Those alloy materials are Inconel 740, Inconel 830, and Warpaloy. Finally, they concluded that comparing the results of three alloys, Inconel alloy 740 is best for impeller making. Dinesh Tare al[6] investigated static and dynamic analysis of impeller of centrifugal blower. They used CATIA Software for modeling of blower. They did analysis on blower by using ANSYS software to find out the stress, strain, deformation, deflection and mode shapes of impeller. In this paper, meshing of blower is done by
using hyper mesh software. They used three types of alloy materials to estimate the impeller performance. Those alloy materials are MS, SS, and SS316L Steel. Finally they concluded that comparing the results of three alloys, SS316L STEEL is best for blower design. Tao Wu, Yan long Cao, Jiangxi Yang[7] investigated about the core part in centrifugal compressor impeller and found that quality of blade effects its function as in structural potential and its aerodynamic characteristics in compressor. Numerical analysis is performed on different impeller profiles and dimensions and simulation is done on NUMECA software where centrifugal impeller 3-dimensional viscous force is analysed. This checks profile inaccuracies on various size and design impellers. A comparative study of designed impeller determines its aerodynamic behaviour and analysis result will validate the design process. This showed that machining errors effects impeller’s functional performance, in terms of pressure ratio and its effectiveness. Determining the S-type profile error on blade surface is the important factor which affects the performance aspects hence the design can be made accordingly. Min-Ho Cho-al[8] discussed about the case based impeller machining strategies (CBIMS). CBIMS support system replaces efficient machining strategies with the existing machine strategies. It creates impeller strategies in machining following a stepwise reasoning procedure. Finally, this paper concluded that through CBIMS, latest machining strategies are promptly developed making use of both cooperation base and E-manufacturing work of CBIMS. Rech al[9] analyzed the sound levels during the operation of milling. In his paper identified that during milling operation, sound pressure levels cross more than 100 DBA compared to drilling, tapping and reaming. They arranged anechoic chamber and microphones to analyze the sounds in different levels. After the experimental work the evaluation of sound levels, noise signals in milling, 92 DBA level of sound waves are obtained. Finally concluded that air leakages, damped noises and depth of cut has little effect on noise emission. Mill wills having less diameter provide good stability and reduce turbulence which are main contributing factor for producing undue noise. Francis quail et al[10] presented a rapid manufacturing technique for prototype building of a regenerative pump impeller. They found that intricate, multifaceted blade profiles of impellers built by RP technology can be used for analysis, testing and in developing optimized design. Vinod G. Gokhare et al[11] in their literature review mentioned and presented different 3-D printing techniques, characteristics and its significance and selection of the best materials suitable for 3 D printing machine. Ana Pavlovic et al[12] in their paper adopted polymers based additive manufacturing technique in prototyping water pump impeller. This assessed the functional requirement and facilitated in manufacturing of original parts. The polymer-based technology is very helpful in manufacturing and prototyping water pump impellers.

2. Methodology
TECHB Weaver 3D Printer using Fused Filament Fabrication or Fused deposition modelling method for manufacturing a light weight and high strength 3D Shrouded Impeller for centrifugal Compressors with Industrial Grade thermoplastics are used. This equipment has a wire made of plastic substance coiled in form of a spool and the material ejects from nozzle whenever needed and deposited onto layers during printing. The heat is supplied which melts the substance used for printing and with the help of machine it can be moved in horizontal and vertical direction via controller-controlled mechanism. The entity is formed by extracting melted material and layered until it solidifies and hardens due to cooling action taking after it is being released from nozzle. This technology is mainly used to print materials having low melting temperatures, plastics like Polylactic Acid (PLA) and Acrylonitrile Butadiene Styrene (ABS).

3. Processes
Fused Deposition Modeling (FDM) fabrication process works in this fashion as shown in figure 2. Thermoplastic material in thin film form called spool which is fed or inserted into the 3D-printer. As
the required temperature is attained by the nozzle the filament it is supplied onto top for extrusion called head and in the nozzle it liquefies. The head of extrusion can travel in three directions where they follow in x, y, z axis. The liquefied substance extrudes out in the form of thin filament layers which are built on to predefined positions where it hardens due to cooling. Additional cooling facility is provided by fixing fans onto the extrusion head. For the region to be covered numerous passes are needed as in colouring a rectangle with colour pencils. When a layer is finished, the build platform descends and a fresh layer is deposited but in some cases extrusion head lifts up to deposit the layer. This procedure continues till the component printing is finished. Acrylonitrile Butadiene Styrene [ABS] the material used in 3-D printing is very resilient, elastic, stretchy and lightweight making the extrusion process very simple and easier for making small parts. To print ABS materials the temperature should reach about 210 - 250°C and during this there are hazardous gases produced which cause respiratory problems in humans and hence this material usage is limited. The alternative to it is Poly lactic acid (PLA) material, a biodegradable thermoplastic that is derived from corn. PLA is biocompatible, tougher when solidified and melts at lower temperature compared to ABS material.

4. Experimentation/Design & Modeling

Modelling for part generation are done in CAD software’s such as CATIA, UNIGRAPHICS etc or by using 3D scanners. The geometric data collected for 3D modelling in computer graphics is like mould preparation in manufacturing. In 3D modelling, analysis and shape data are collected as in the look of the object. Scanners can also provide data relevant to 3D models. Prior to model printing in 3D .STL file, it is pre-processed by "slicer" software (figure 6) in which the 3D model is sliced into layers of millimetre thickness aided by a G-code file then .STL file sends commands to the printer. The open source softwares available for slicing are Slic3r, KISSlicer, and Cura. A set of G-code commands as shown in figure 4 are given to printer to place layer after layer either for sintering, liquid material deposition or in form of sheets which represent the cross sections of original model. When they are placed accordingly and combining all layered fused is the exact and finished model.
Most FDM systems are flexible and allow the adjustment of various parameters, such as temperature of nozzle, build platform, raster speed, the rate of cooling, layer thickness which can differ around 50 to 400 µm [3]. The less thick layers can be used to produce curved, smooth, finer and dimensionally accurate components whereas thicker layers can rapidly print parts which are economical. Generally FDM uses layers upto 200 µm and generally not used for complete solid printing. Alternatively it used concepts of outer and inner filling concepts where in outer area the shell is printed and inner layers are infilled as seen in figure 5 with low density type structures. This reduces long hours of printing and lessen material use. A twenty-five percentage in fill density is set for a shell thickness of 1 millimeter which ensures tough structure and rapid print. The fill percentage is 20% and printing time is about 18 hours.

**Figure 3.** 3D-Models of Open and Shrouded Impeller

**Figure 4.** Sample of G-Code
Support structure in Fused Deposition Modelling aids in developing geometries which require overhangs. Structures cannot be built in air and hence in 3D printing also liquid layer can’t be deposited without a support structure. Hence supports play a major role in 3D printing as these can be easily removed and object is printed. In impeller printing by FDM each and every layer is deposited using heated filaments which hold and remain onto other layers either below or surrounding it. Every layer is printed with some offset to subsequent layer. This facilitates 45° angle building in models making prints flexible so that it could spread afar from before layers width. As the component is printed having an overhang further than 45°, it hangs down and necessitates support material underneath to clutch up which is used in impellers building. By using the above mentioned FDM based 3D Printer an open Impeller of 150 mm diameter is printed and closed or shrouded impeller of 150 mm diameter and 45 mm height is printed. This prototype built allows in verifying, validation and test the impeller helping in design improvisation whenever required. This ensures time to market idea projection, reduces expensive investments but with limitations such as unable to produce large components, post processing damage evaluation etc. But overall, the complex and intricate designs of impeller blades of centrifugal compressors are easily modelled by CAD software and printed using Fused Deposition Modelling method.

5. Conclusions and Future Scope
Complex 3-D impeller blade profiles are easily printed by FDM technique unlike 5- Axis machining which are expensive and requires large set ups. By using the above mentioned FDM based 3D Printer an open Impeller of 150 mm and closed or shrouded impeller of 150 mm diameter and 45 mm height is printed. This prototype built allows in verifying, validation and test the impeller helping in design improvisation whenever required. This ensures time to market idea projection, reduces expensive investments but with limitations such as unable to produce large components, post processing damage evaluation etc. But overall, the complex and intricate designs of impeller blades of centrifugal compressors are easily modelled by CAD software and printed using Fused Deposition Modelling method.

Present method of 3D printing plastic patterns can be used for making shells for investment casting of actual impeller by choosing suitable plastic material such as PMMA, which can be heated up and
removed from the ceramic shells. In future direct metal 3D printing will be the process to be adopted for printing of actual impeller using 17-4PH material powder using powder bet LASER sintering process.

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