B. TECH. PROJECT REPORT

On

Wire Laser Additive Manufacturing of a Compressor Impeller

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DEPARTMENT OF MECHANICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY INDORE

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Wire Laser Additive Manufacturing of a Compressor Impeller

A PROJECT REPORT

Submitted in partial fulfillment of the requirements for the award of the degrees

of

BACHELOR OF TECHNOLOGY

in

MECHANICAL ENGINEERING

Submitted by:

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INDIAN INSTITUTE OF TECHNOLOGY INDORE

May 2022

CANDIDATE'S DECLARATION

We hereby declare that the project entitled **"Wire Laser Additive Manufacturing of a Compressor Impeller"** submitted in partial fulfillment for the award of the degree of Bachelor of Technology in 'Mechanical Engineering' completed under the supervision of **Dr Yuvraj Kumar Madhukar (Assistant Professor, IIT Indore),** IIT Indore is an authentic work.

Further, I/we declare that I/we have not submitted this work for the award of any other degree elsewhere.

Varinderpal Singh

Kunal Singh

CERTIFICATE by BTP Guide(s)

It is certified that the above statement made by the students is correct to the best of my/our knowledge.

23/05/22

Dr Yuvraj K Madhukar

Assitant Professor

Department of Mechanical Engineering

IIT Indore

Preface

This report on "Wire Laser Additive Manufacturing of a Compressor Impeller" is prepared under the guidance of Dr Yuvraj Kumar Madhukar(Assistant Professor, IIT Indore).

Through this report, we have tried to come up with a strategy and tried to build Compressor Impeller using Wire Laser Additive Manufacturing and discussed the challenges faced doing it.

The report contains illustrated figures of manufactured parts and steps followed in process planning methods.

We have tried to the best of our ability and knowledge to explain the content in a lucid manner.

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Acknowledgements

We would like to thank **Dr Yuvraj Kumar Madhukar** for giving us the opportunity to work on this project. We are grateful for his guidance and cooperation throughout the project. We are indebted to him for sharing his valuable knowledge and expertise in the field of Additive Manufacturing.

We are thankful to **Mr Anand Petare** for providing us required tools and workpieces for manufacturing.

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We are grateful for the love and support are given to us by our family and friends during this time.

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Abstract

Wire-laser additive manufacturing (WLAM) is a process that involves continuously feeding a wire into a melt pool created by a laser beam to create 3D components. The process dynamics, which include the laser-material interaction and wire transfer mode, have an impact on the part quality. To provide a stable deposition along the building path and predictable deposit properties, good process control is essential. The usage of support structures in metal additive manufacturing is limited, which makes manufacturing overhangs and curved structures difficult. The project creates a strategy for creating complicated geometries with an appropriate slicing technique. For the Cone and Blade, MATLAB was used to construct radial sliced layers, while Slic3r was used to make horizontally sliced layers. We need to set the Laser Power, Deposition Speed, and Wire Feed Rate to a fixed number in the beginning so that the combination does not affect the surface finishing and the bead width is as expected. To begin, we placed the cone in a vertical position perpendicular to the Laser and rotated the C-axis while keeping the Laser stationary, whereas the blade was deposited by keeping the workpiece perpendicular to the laser so that radial deposition can take place. Apart from this, in this report, we have discussed the challenges faced in the deposition of compressor impellers.

Table of Contents

List of Figures

List of Tables

Chapter 1. Introduction

Additive manufacturing (AM) has received a lot of interest in the manufacturing business in recent years. AM is a technique for creating three-dimensional objects by layering materials on top of each other. In several industries, including aerospace and automotive, additive manufacturing (AM) is a very promising approach for fabricating complicated and high-value components. Selective Laser Melting (SLM), Laser Engineered Net Shaping (LENS), Wire-Arc Additive Manufacturing (WAAM), and Wire-Laser Additive Manufacturing (WLAM) are some of the metal additive manufacturing processes available. The wire is melted with a laser beam and deposited layer-by-layer (bead-by-bead) to build a component in the WLAM technique. The use of a laser beam in conjunction with a sophisticated control system provides for effective process monitoring and control. WLAM has the advantages of virtually 100% material utilization, higher deposition rate, reduced material cost, less pollution, and so on.

Wire-Laser Additive Manufacturing (WLAM) is a versatile and promising alternative to subtractive manufacturing for rapidly fabricating big, expensive metal components with complex geometry. The laser is used to create a small melt pool on the substrate surface or a previously formed layer, after which the wire is provided. Due to the relative movement of the substrate and the laser, the clad solidifies and forms a strong bond with the original surface. A three-dimensional object emerges layer by layer. For Additive Manufacturing of metal components, using a laser beam as a heat source has several advantages, including high energy density and low heat input, small thermal deformation of the workpiece, fast heating and cooling speeds, small grain size of the formed part, no manufacturing environment requirements, no vacuum atmosphere, no electromagnetic interference, and trajectory walking. Automation and intelligence are flexible and simple to implement. The advantages of using a laser beam as a heat source for Additive Manufacturing of metal components include high energy density and low heat input, small thermal deformation of the workpiece, fast heating and cooling speeds, small grain size of the formed part, no manufacturing environment requirements, no vacuum atmosphere, no electromagnetic interference, and trajectory walking. Automation and intelligence can be implemented in a number of flexible and straightforward ways.[3]

In the Presented work, Wire-Laser additive manufacturing(WLAM) is performed using a 4-axis Fiber Laser welding machine. Various factors are involved in the WLAM process, such as part design and its orientation, welding voltage, wire feed rate, Laser Power, Deposition Speed, inert gas flow rate, ambient temperature etc which must be carefully planned in order to improve the surface quality, reduce deposition time and machining allowance. The aim of this work was to build Compressor Impeller using the WLAM process.

This Thesis is organized as follows: Chapter 2. describes the methodology taken to approach the objectives. Sections 2.1 and 2.2 detail the experimental design used which includes the WLAM setup and CAD model of the Compressor Impeller. Section 2.3 deals with the study of the process for metal deposition dimension. Section 2.4 discusses the path planning strategy adopted for the additive manufacturing of the cone and blade of the compressor impeller. Chapter 3 discusses issues faced during the deposition and purposes strategies to alleviate issues. Chapter 4 includes work done in this project and discusses the future scope of this project.

Chapter 2. Methodology

2.1 Experimental Setup

The WLAM setup used in this experiment is Mehta's Fiber Laser 4-axis Welding Machine, CWFL-2000 Industrial Chiller, Max Laser, Trishul Three Phase Servo Stabilizer and Ate Wera Wire Feeder.

2.1.1 Laser Fiber 4-axis Welding Machine

The WLAM setup consists of Laser Fiber 4-axis Welding Machine(fig.1) which has 4-axis which includes 3 linear-axis and one rotational C-axis which can be mounted separately whenever required. In this project, we used the 4-axis because we were depositing material for complex geometry. The laser and wire feeder both are attached to each other and their moment will always be the same. The wire feeder always remains in front of the laser helping in depositing the wire easily. The axis of the machine can be controlled by using CNC 2000 software. Laser Fibre Welding Machine has a torch camera via which we can see how the material is depositing and we can also see a trial run through which we can get an idea of where the material will get deposited.

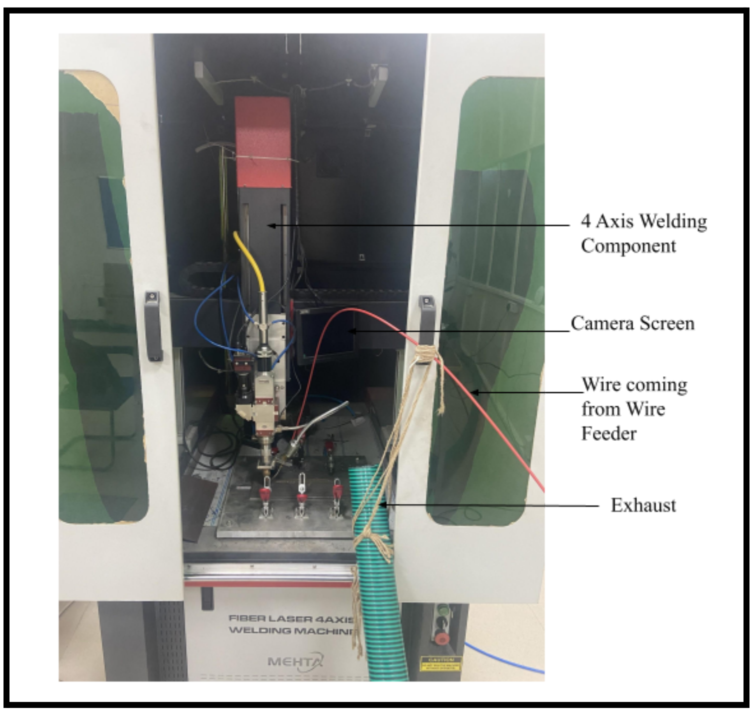

Figure 1: Fiber Laser 4Axis welding machine

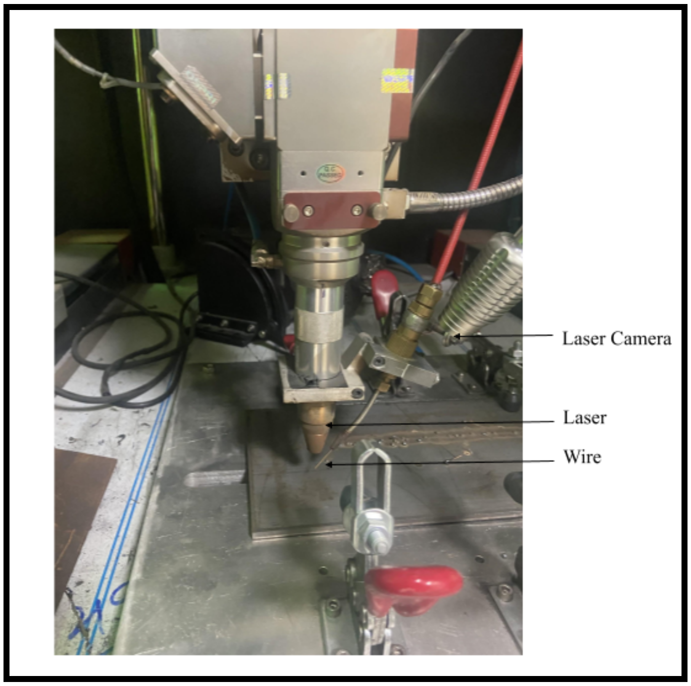

Figure 2: Laser-Wire close view

2.1.2 CNC 2000 Software

It is used to control the CNC setup. The software allows us to import G Code files and we can also create G codes for simple geometry. This software allows testing the code to know whether the code is working correctly or not. CNC 2000 also allows us to pause the code in between and we can change the Deposition Speed through the software as well.

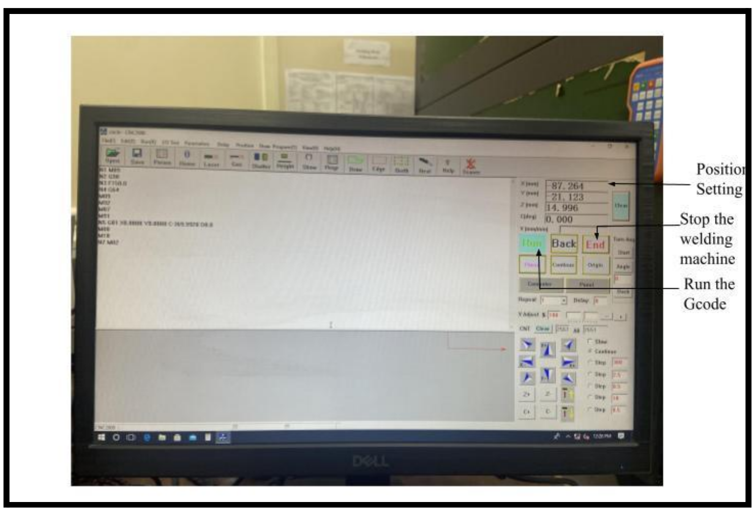

Figure 3: CNC 2000 Software

2.1.3 Maxphotonics 1000/2000W QCW FIBER LASER

MFSC 1KW single- mode continuous fiber laser with water cooling features high power, optimum beam quality, maintenance-free operation, and high electro-optical conversion efficiency, among other features. stainless steel, carbon steel, aluminium, copper, and other metals are commonly cut, welded, and drilled with this tool. Sheet metal cutting, metal processing, home appliance production, car manufacturing, and other areas are all affected[4]. The fiber laser 4 axis welding machine receives laser output from fiber laser.

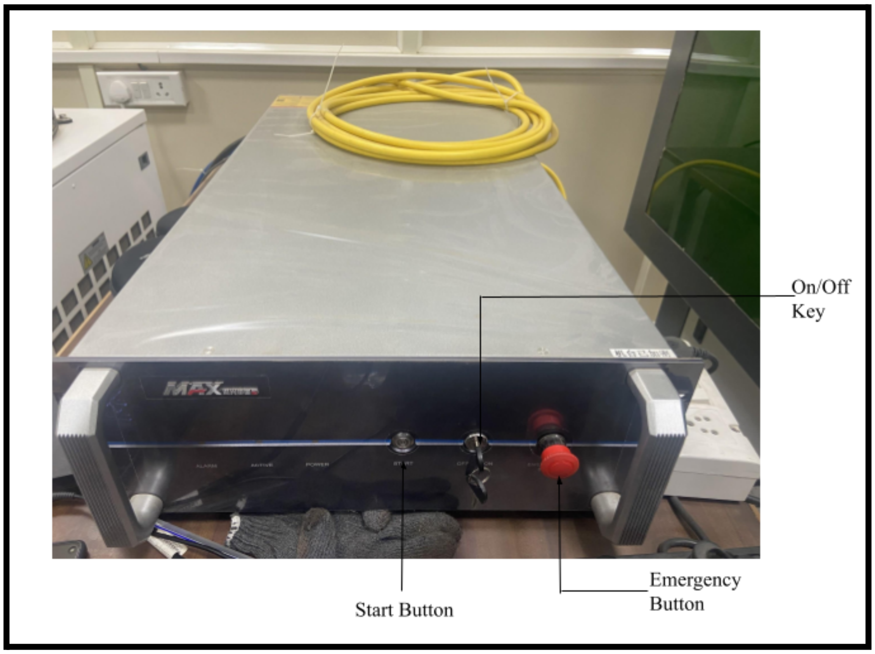

Figure 4: Maxphotonics Laser Source

2.1.4 CWFL 2000

The CWFL series water chillers are so configurable that the laser device and QBH connector/optics can both be cooled by the low-temperature control system and the high-temperature control system at the same time, considerably reducing condensed water formation. By controlling the temperature of the laser device, the chiller can prevent the laser cavity from thermal deforming, keep output power stable and ensure light beam quality to improve the working life and cutting accuracy of the laser device. It features a dual-channel design a with control accuracy of ±0.5℃. Two temperatures can be supplied from one single chiller unit for the fiber laser and the laser head, indicating up to 50% space-saving compared with the two-chiller solution.[5]

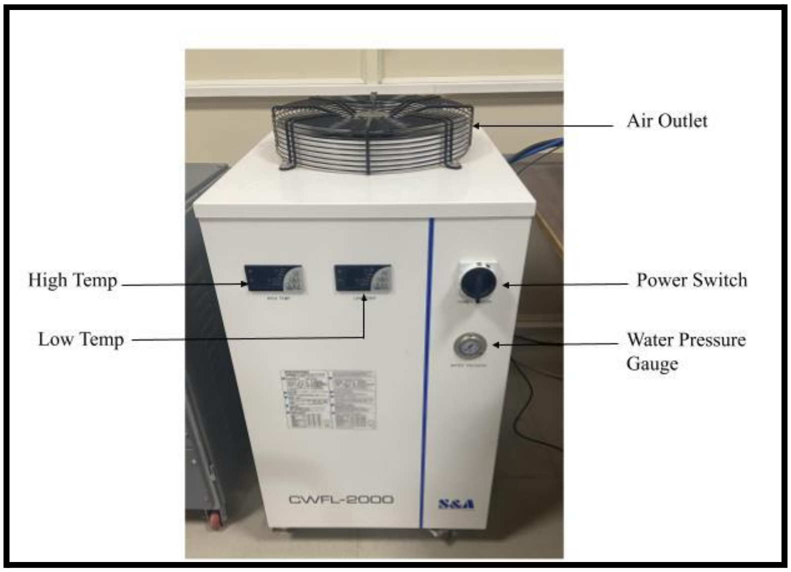

Figure 5: CWFL-2000 Industrial Chiller

2.1.5 Trishul Three Phase Servo Stablizer

Three Phase Servo Voltage Stabilizer continually monitors the output voltage and controls the input voltage variations by movements of a motor. This 3 Phase Servo Voltage Stabilizer has high efficiency, no wave distortion. Three Phase Servo Stablizer uses for short time delay and over-voltage protection. It is widely used for acquiring a constant voltage supply. It is known for its rugged design and excellent performance

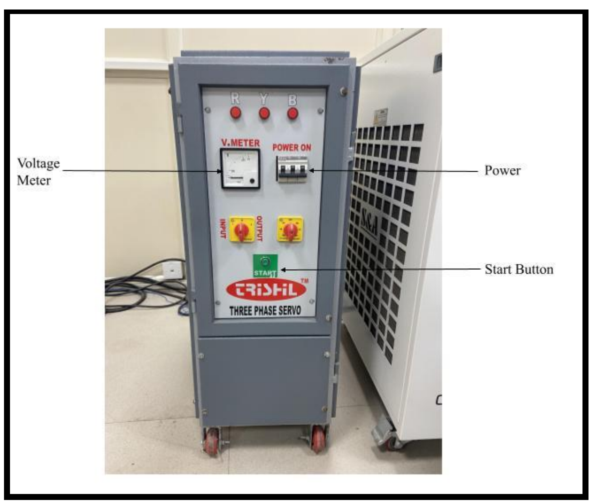

Figure 6: Three Phase Servo Motor

2.1.6 ATE Wera Cold Wire Feeder

ATE wire feeder is connected with a laser fiber 4-axis welding machine. We can set the wire feed rate(WFR) using this wire feeder. Apart from this, we can move the wire forward or backwards using the forward/backward button to align the wire in the setup. This wire feeder provides a maximum of 2m/min and a minimum of 0m/min. From the torch button, we can continuously pull out the wire when performing the deposition by just pressing the button throughout the deposition.

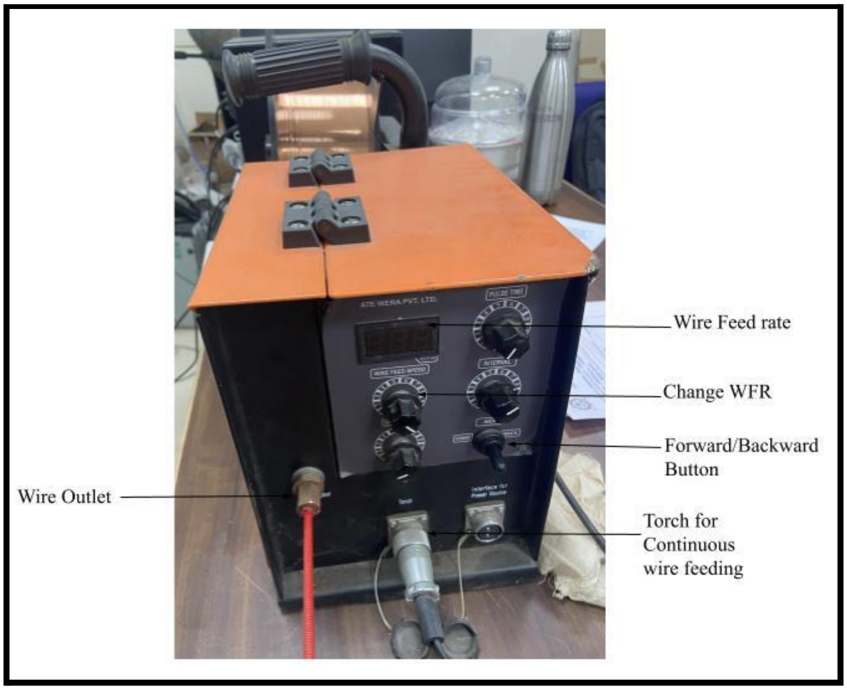

Figure 7: ATE Wera Cold Wire Feeder

2.1.6.1 Copper Coated Low Carbon Steel wire

Copper coated steel wire is used for deposition of the model. CCS is an electrical conductor composed clan inner mild steel core wire with copper coating. The diameter of the copper coated steel wire is 0.8mm. It comes in a roll of 15Kg. Copper coated low carbon steel wire is used because it has a high level of deoxidizers which makes it suitable for depositing where dirt, rust or mill-scale is present. In our case, dirt or mill-scale was present due to layer-wise deposition. Apart from this, it gives smooth wire feeding along with quality weld.

Chemical Composition of Solid Bare wire, **Wt**%:[6]

	C	**Mn**	**Si**	**S**	**P**	**Cu***
Specification	0.06-0.14	1.40-1.60	0.8-1.0	0.025 max	0.025 max	0.50 max

Table 1: Chemical composition of CCLCS

*Including Cu in the coating.

2.2 Desigining of CAD Model

For this experiment, a scaled version of the compressor impeller is used. Compressor impeller is modelled in SolidWorks with the following specifications:

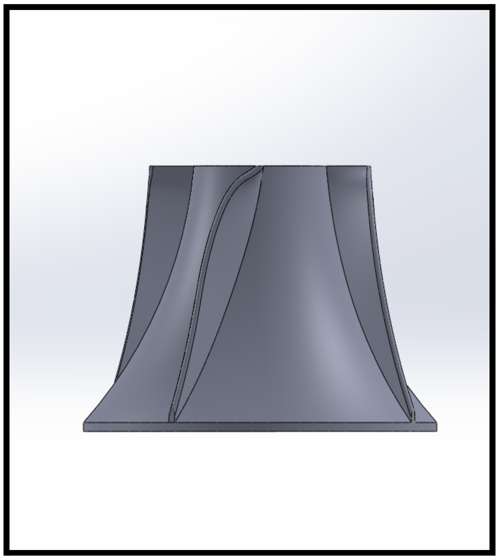

Figure 8: Compressor Impeller Side View

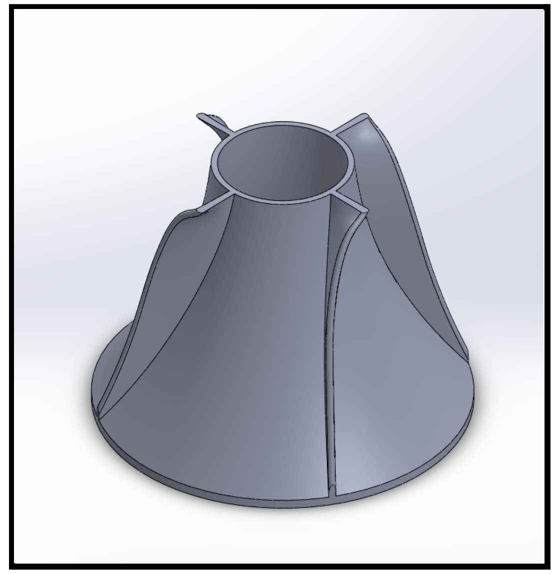

Figure 9: Compressor Impeller Isometric view

2.2.1 Specifications of Cone

Height	60mm
Base Radius	40 mm
Top Radius	15 mm
Cone Thickness	3mm
Radius of curvature of cone	100mm

Table 2: Specifications of Cone of Compressor Impeller Model

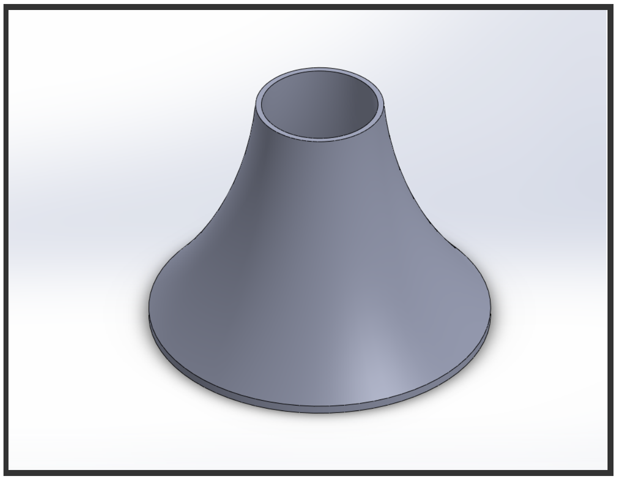

Figure 10: Cone

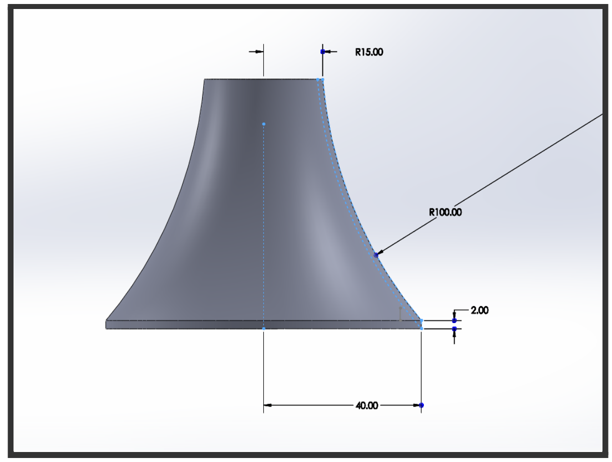

Figure 11: Cone with Dimension

2.2 Specifications of Blade

Blade Angle	30 Degree
Bottom Thickness	3mm
Top Thickness	10 mm

Table 3: Specifications of Blade of Compressor Impeller Model

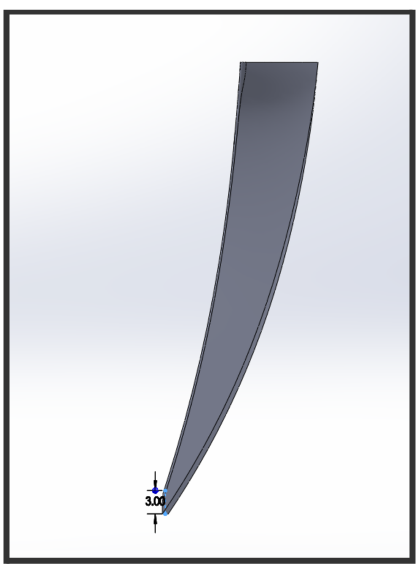

Figure 12: Blade Side View

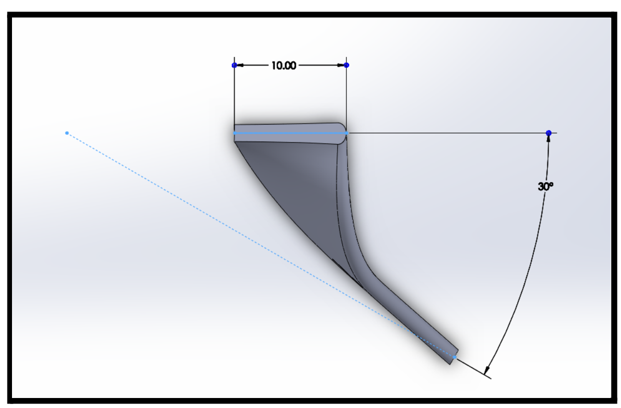

Figure 13: Blade with Isometric view

2.3 Process Parameters

The quality and dimensions of metal deposition in constant voltage WLAM are governed by three major process variables:

(i) Laser Power (P): A low laser power produces deposition with a thinner layer with low bead width and less layer height as compared to the one with high laser power. Welding with lower power produces non-uniform deposition with surface bumps, whereas with high power source gives uniform deposition but produces high spatter. In this experiment, we have assumed the Laser Power (P) to be 60% ie 1200W which gives uniform deposition with less spatter.

(ii) Deposition Speed (WS): A higher tool travel speed gives lesser time for material deposition hence high Deposition Speed results in lesser bead width and lower heights. High Deposition Speed gives desirable for lower deposition time, but we need to decrease the Wire feed rate in order to deposit the material properly otherwise defects like porosity, cutting, humping and irregularities in deposition can be noticed. The ideal operating limit of the wire speed used in this setup is between 100mm/min - 150mm/min.

(iii) Wire Feed Speed (WFS): A higher wire feed speed means a higher deposition rate of the material, thus leading to thicker bead width and vice versa. The wire feed speed is directly linked to the Deposition Speed. A higher wire feed rate will also result in more wire coming out of the wire feeder in comparison to the wire deposited. This will cause a halt in the experiment as the wire will not get deposited. The wire speed is also linked to welding current by the Lesenwich Equation (Eq. 1); an increase in one increases the other at a given electrode extension.

$$WFS=aI+b.le.I^2 \qquad (1)$$

Where:

WFS = wire feed speed in inches per minute (proportional to deposition rate)
a = constant of proportionality for anode or cathode heating (in/[min-A])
b = constant of proportionality for electrical resistance heating (min' A3)
le = electrode extension (in)
I= welding current (arc current) (A)

Apart from this we have tried to keep the volume of deposition constant using:

V = Cross-sectional area of wire*WFS/WS

V =(3.14*(.8)^2)*(.8)/100

V = 0.0160mm^3

In this experiment, wire feed rate used is between 0.7m/min - 1.2m/min for proper deposition of material.

2.3.1 Study of Metal Deposition Dimensions

The aim of this study was to get a better understanding of the variation in deposition to have better control and predictability of the layers so that we can use the best case while depositing the final model.

(i) Bead Width and Bead Height: The bead width and bead height were observed for a single line pass and thin wall deposition. Bead width and Bead Height is 1.5mm respectively for Tool Speed of 100mm/min and wire feed speed of 0.8m/min.

(ii) Overlapping: The amount of overlap between adjacent deposition lines was observed with the aim of achieving a Cone by giving offset with minimal surface waviness in the direction lateral to deposition. As, the width of each layer was around 2-3mm so, the offset for layers varied from 0.5-1.0 mm. This was done by pre-checking the overlapping as the material may go out of the previous layer. The optimal overlap between the adjacent lines was determined to be ~70-80% of the single bead width.

Deposition Speed (mm/min)	Wire feed Speed (m/min)	Bead Width (mm)	Bead Height (mm)
50	1.2	4.23	1.45
100	0.8	2.86	1.58
150	0.6	2.12	1.23

Table 4: Study of Metal deposition dimensions

As given in table 2, the thickness of the cone is around 3mm, so the combination of Deposition Speed of 100mm/min and Wire feed speed of 0.8m/min was taken into account for depositing the cone.

2.4 Path Planning for Deposition

The Process of path planning consists of slicing the CAD model and then generating G codes using those sliced layers via MatLab or we can use Slic3r to generate G codes using the STL file. The generated G codes can be verified using the Mach 3 CNC software, CNC 2000 Software or through NC viewer.

2.4.1 Slicing Methods

Zhao et. al [7] proposed a radial slicing strategy for curved parts using FDM. The radial Slicing strategy for curved parts helps to remove the support structures which are needed for overhanging parts. We can also do Horizontal Slicing as well. In this experiment, we have used both types of slicing for building the Compressor Impeller. A Matlab based program was also created to automate slicing using STL Model. Using Matlab we can also create G code against the sliced layers. Apart from this, Slice3r software can also be used for generating a Horizontal sliced layer.

A. MATLAB

Slicing is done by finding intersections between the triangulation of STL file of the Cone, Blade and triangulation of Cylindrical surfaces using Surface Intersection function based on the algorithm of triangle intersection proposed by Thomos Moller(1997).

Below are the Stepwise procedure for generating Sliced Layers using Matlab Program:

1. **Importing STL file:** First we imported STL mesh, returning Patch-Compatible face vertex structure/triangulation: STL file imported was in Binary using the in-built STL thread function in MATLAB, returning triangulation data structure consisting of vertices and faces of a triangular mesh of Cone.

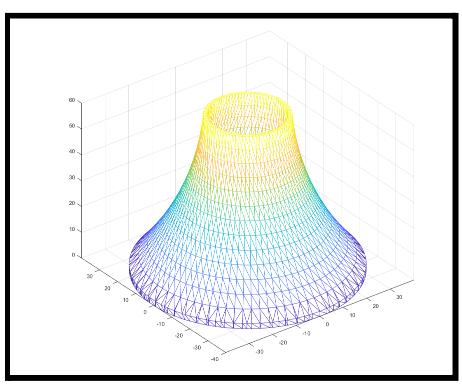

Figure 14: Triangulated mesh from STL file of Cone

2. **Generating Cylindrical Surfaces:** A set of cylinders are created with starting radius defined as the inner radius of the compressor impeller and top width of the blade and end radius as the outer radius of the compeller and bottom width of the blade. These cylinders were triangulated to obtain a triangular mesh.

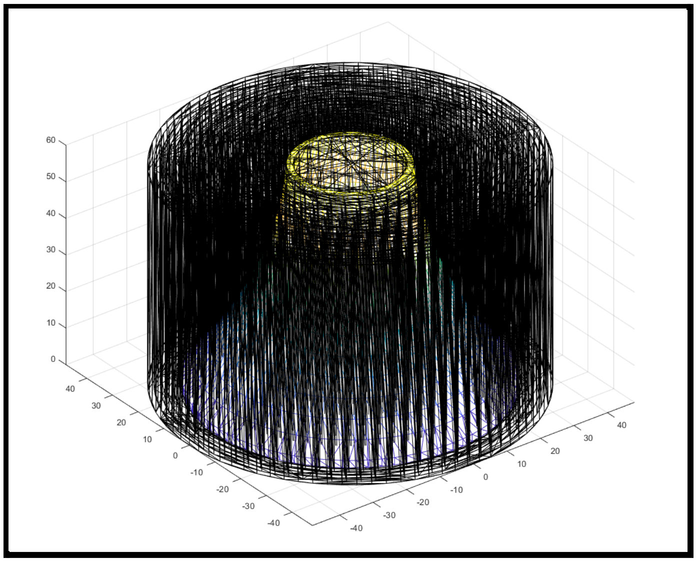

Figure 15: Intersection of many cylinders starting from radius 20mm to 80mm

3. **Intersection with Model:** The surface intersection of each cylinder mesh with the blade mesh is found using the Surface Intersection function. Boundary points of each intersection are obtained in this step.

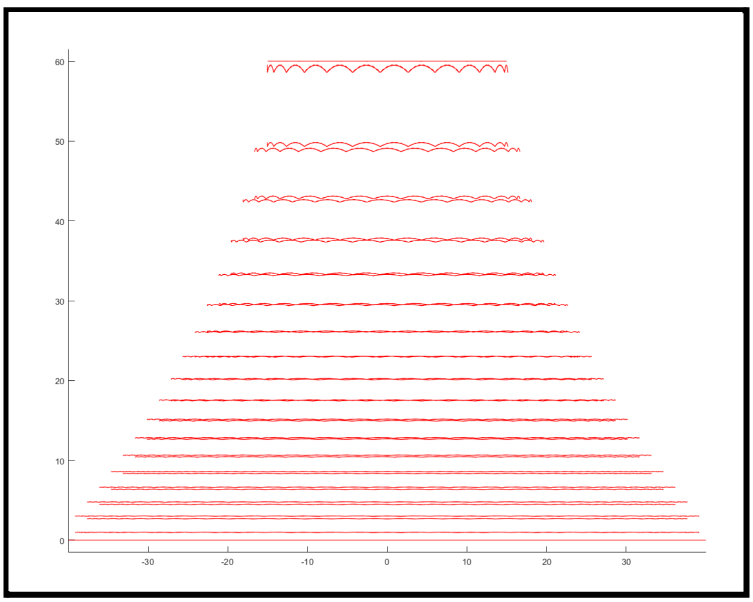

Figure 16: Side View Sliced Layers

4. **Sorting the Coordinates:** Coordinates of the boundary points is done by using the in-built boundary function of MATLAB and points are arranged to control the motion of torch starting from left edge to right edge and then coming back to the left edge of the Impeller cone.

5. **Convert to polar coordinates:** The coordinate points for each surface were converted from the cartesian coordinate system to the polar coordinate system such that the z-axis of the polar coordinates system corresponded to the X-axis of the WLAM setup. Thus, the y coordinates of the model were converted to z-axis points in the polar coordinate system, and x and z coordinates were used to find p and θ in the polar coordinate system. The z values in the polar coordinate system defined the x-axis motion of the welding torch, and θ values defined the A-axis rotation of the workpiece. The z-axis motion of the torch was given according to the layer height of each surface. This whole process was automated using a Matlab script.

6. **Export to a G-code text file:** Each Surface's coordinates are used to generate G-code which includes text files that defined the path of the Contour line of each layer.

B. SLIC3R

Below is the Stepwise procedure of generating Sliced Layers using slic3r.

1. **Set parameters:** First of all, we have to set values according to our impeller and the machines we have in our lab. Set the origin to a point on the base diameter of the cone then set the value of layer height to 1.5 mm and nozzle diameter to 3mm.

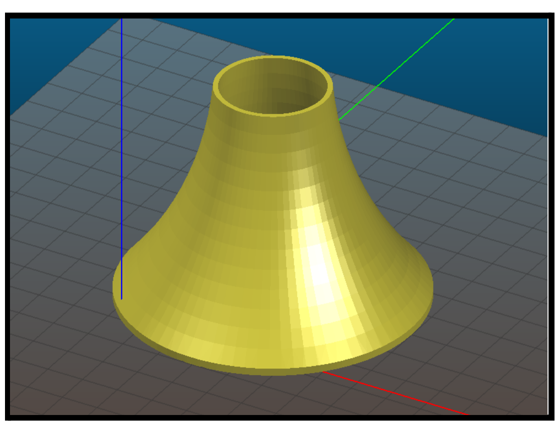

Figure 17: STL file of Cone in Slic3r

2. **Import STL file & Generate G-code:** Since the impeller is divided into 2 parts i.e. cone and blade so, we have to import both the files separately. Import STL file of cone and rotate the part if needed to keep it perpendicular to the plane of layers to be sliced.

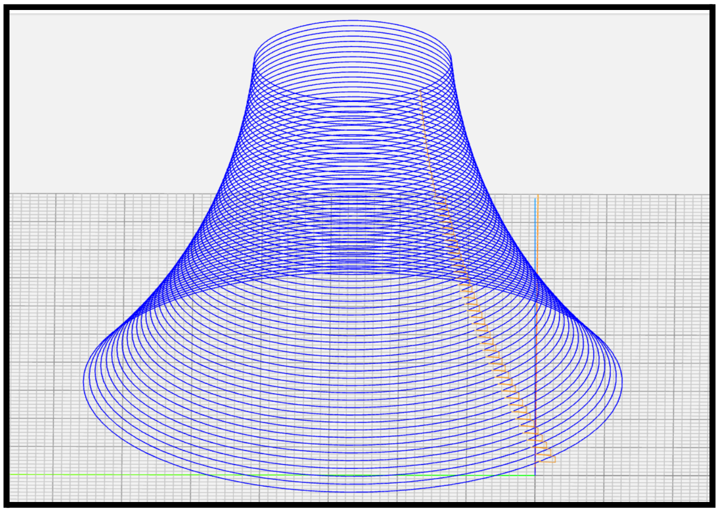

Figure 18: Sliced Layers of Cone in NC viewer from Gcode generated via Slic3r

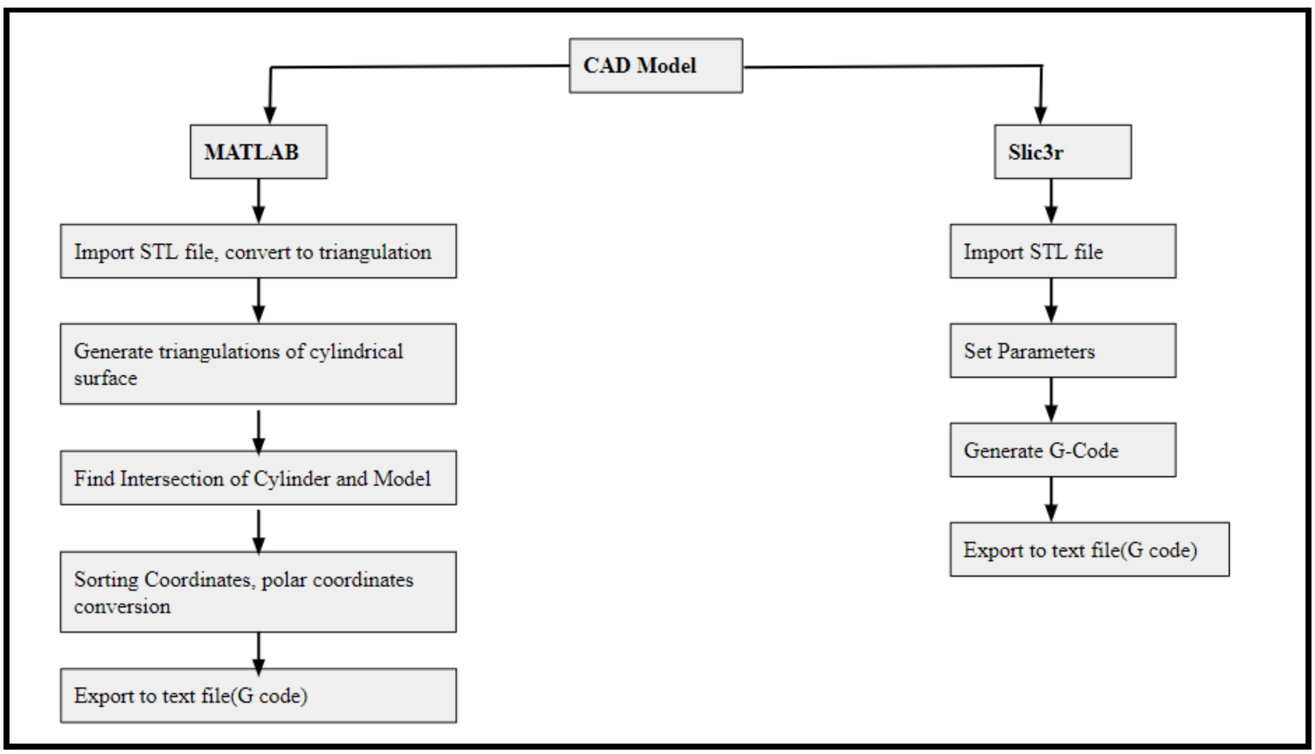

Figure 19: Flow Chart of Slicing Methods

Chapter 3. Results and Discussion

3.1 Deposition of Compressor Impeller on Flat Plate

Before deposition of the impeller cone on a Flat Plate, we first planned to deposit it on a cylindrical shaft and then we identified challenges we were facing with respect to the deposition, Wire feed speed and the bead width and height. The Slicing was done using both Horizontal and radial Slicing. The experiment failed in the initial stage due to G-code not working properly as well depositing the material over the Shaft in a Vertical direction was not possible. We just deposited a few layers on the shaft using the C-axis in the radial direction. Thereafter, we tried depositing on a Flat Plate by fixing the plate and rotating the tool. In that case, depositing layers failed as the wire was not melting. The final case we considered for deposition was fixing the tool and rotating the workpieces and depositing in the Vertical direction. Each layer was deposited in a single pass of the welding layer. The following issues were identified with the deposition of Compressor Impeller:

a. Due to Overlapping and limited precision of the process, a little gap between two adjacent layers was being created at the ending point of deposition as shown in fig 20. The buildup of this gap leads to uneven deposition and can even lead to the laser torch not being able to melt the wire and wire getting stuck, which will lead to stopping the deposition on an urgent basis as the wire will be coming out of the wire feeder. This issue was dealt with by writing the code for C-axis to 370 degrees instead of 360 degrees or by manually running the code for just that small part to cover the gap. If the gaps are not covered for each layer, this can lead to improper structure with gaps in the final build.

Figure 20: Gaps between the deposited layer

Figure 21: No Gaps in the layer

b. A bump is created at the starting point of each layer of the cone. This happened due to extra material being deposited on the starting point. This was solved by changing the starting position of deposition for each layer. This resulted in proper deposition on the top surface.

Figure 22: Bumps at the top surface

Figure 23: No Bumps on the top surface

c. Material going out the Path leads to leaving material on the external surface of the cone and creating bead bumps on the outer surface. This was due to the offset given for overlap sometimes going out of the path of the previous layer. To mitigate this, the offset given for the overlapping for each layer was checked by running the trial using CTRL + T command on the CNC 2000 software and verifying the position of deposition via the Laser Camera.

Figure 24: Material Getting deposited on the outer surface of cone

Figure 25: No material getting deposited on outer surface

d. Increasing the radius of the next layer as compared to the previous layer was a quite difficult task considering the bead width that was around 2 mm because giving offset for overlapping was not easy and maintaining the shape of the cone was quite difficult in the base layers. To overcome this, we deposited 2 layers on the base so that we can deposit the next layer on the outer surface of the second base layer. We tried to do this for at least first 3-4 layers after that, there was space for only one layer to get deposited and giving offset to them was quite easy.

Figure 27: 4- Double layers deposited to give offset

e. On the top surface layer, there were some gaps which were created due to deposition and misalignment in the axis of the Laser welding machine which resulted in improper circle. This can be corrected by machining the surface of the cones.

f. Depositing a bigger circle on the base was quite difficult because in that case, the laser needs to run for a longer time which results in uneven deposition or bead deposition. This was overcome by changing the strategy of deposition of the cone to the opposite direction with a Small diameter on the base and a larger diameter on top.

Figure 28: Uneven bead formation for circles with larger diameter

Chapter 4. Conclusion and Future Scope

4.1 Conclusion

This project work aimed at developing a systematic approach toward WLAM based Wire- Arc Additive Manufacturing using a 4-axis CNC setup, where each step controls the other. The process begins with the selection of a suitable slicing method depending on the geometry of the part that is to be additively manufactured. In this work, three radial slicing algorithms are designed using SolidWorks and Slice3r for additive manufacturing of the model. The radial slicing strategy is demonstrated on the blade of the compressor impeller.

For Path planning, the sliced layers were used for three-axis tool path generation for the compressor impeller. The three-axis considered for path generation were X, Y and C in the case of Cone, whereas Y, Z and C were considered in the deposition of Blade. The influence of deposition process variables like Welding Arc speed and Tool Travel Speed in the slicing was investigated. The bead width obtained at 1200 W laser power, 0.8 m/min and 100 mm/min was about 2.5. It was observed at this width about 75% of overlap is required to additively manufacture the cone of radius 100 mm.

The final height of the Compressor Impeller is 50mm with a Blade width of 10mm as shown in fig 29.

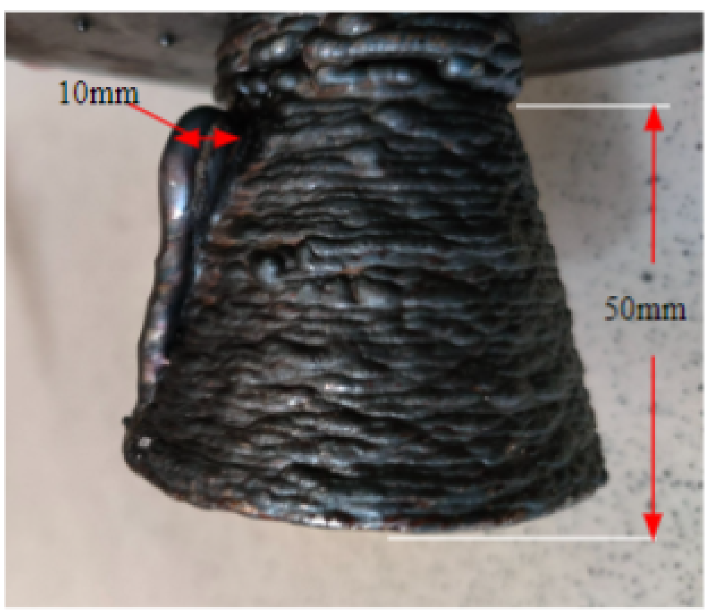

Figure 29: Final Compressor Impeller with 1 Blade

4.2 Future Scope

1. The scope of work that can be done in the future to improve the WLAM process using Fiber Laser Welding Machine setup:

    a. Radial Slicing algorithms proposed need to be tested on more curved complex geometries like helical, spherical, etc to test the robustness of the method.
    b. Increasing the Usage of CNC 2000 software for generating some complex codes.

2. The scope of work that can be done further in Compressor Impeller are:

    a. Compressor Impeller with more number of blades can be tried to build.
    b. A closed Compressor Impeller can be tried to build.

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