A Project Report

On

Development of a Computer Aided Process Planning System for Block Machining, Sheet Metal and Casting Operations

Submitted in partial fulfilment of the requirements

of the degree of

Bachelor of Engineering

By

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CERTIFICATE

This is to certify that the project entitled **“Development of a Computer Aided Process Planning System for Block Machining, Sheet Metal and Casting Operations”** is a bonafide work of **Joel Chacko Dsouza (201823)**, **Akshata Patil (201840)**, **Aaron Pereira (201846)**, **Rohan Mathew Pulimoottil (201850)** and **Prajwal Umaranikar (201862)** submitted to the **University of Mumbai** in partial fulfilment of the requirement for the award of the degree of **“Bachelor of Engineering”** in **“Mechanical Engineering”**.

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This project report entitled **"Development of a Computer Aided Process Planning System for Block Machining, Sheet Metal and Casting Operations"** is a bonafide work of **Joel Chacko Dsouza (201823)**, **Akshata Patil (201840)**, **Aaron Pereira (201846)**, **Rohan Mathew Pulimoottil (201850)** and **Prajwal Umaranikar (201862)** is approved for the degree of **Bachelor of Engineering** in **Mechanical Engineering.**

Examiners

1. ______________________________

2. ______________________________

Date:

Place:

Declaration

We declare that this written submission represents our ideas in our own words and where others ideas or words have been included, we have adequately cited and referenced the original sources. We also declare that we have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in our submission. We understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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Abstract

With the dawn of the Information Technology age came exponential growth in the field of various computer assisted systems in the industry, such as CAD, CAM, CAE, and others. In recent years, academics have focused their efforts on integrating various computer-assisted systems in order to maximise the utilisation of intellectual and other engineering resources. As a result, Computer Aided Process Planning (CAPP) systems have emerged as a link between automated design systems, such as Computer Aided Design (CAD), and automated manufacturing systems, such as Computer Aided Manufacturing (CAM). In the manufacturing industry, block machining, sheet metal & casting processes are some of the most extensively used processes.

The goal of the proposed work is to combine CAD, CAPP, and CAM to create an automated process planning solution for sheet metal components, block machining, and casting processes. In simpler words, the project aims to design a Computer Aided Process Planning GUI that will assist users in determining the best possible flow of operations for sheet metal, block machining and casting processes. The GUI will also be used to predict the time for the production of the required number of parts.

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Chapter 1

Introduction

Process planning is a pre-manufacturing phase that defines the sequence of activities or processes required to create a product or an assembly. This phase is especially crucial in work shops where one-of-a-kind goods are produced or where the identical product is produced only occasionally. The use of computer technology for process planning was initiated four decades before. Since then, there has been a large amount of research work carried out in the area of computer-aided process planning (CAPP). One of the reasons for this is the role of CAPP in reducing throughput time and improving quality. CAPP is the application of the computer to assist process planners in the planning functions. It is considered as the key technology for computer integrated manufacturing (CIM). It consists of the determination of processes and parameters required to convert a block into a finished part/product. The process planning activities includes interpretation of design data, selection, and sequencing of operations to manufacture the part/product, selection of machine and cutting tools, determination of cutting parameters, choice of jigs and fixtures, and the calculation of the machining times and costs.

It automatically synthesises process information to generate a process plan for a new part without the need for human participation. This paper explains in detail the structure, benefits and application of Generative Computer Aided Process Planning (G CAPP) in the industry.

Computer Aided Process Planning (CAPP) is considered as a bridge between CAD and CAM, which is used to describe the part design data in terms of features, part geometry, shape analyzing, tolerance, location, orientation and size. It aims to automatically convert the design into a finished process plan, economically and competitively. It depends on the part model data which is provided by CAD to perform accurate and robust process planning for manufacturing.

Why Computer Aided Process Planning (CAPP) ?

- Understand the interactions between the product, manufacturing, quality and cost.
- Diligently produce precise and consistent process plans.
- Optimize the lead time and cost of process planning.
- Reduce the requirement related to the skill of employees (process planners).
- Increase the work output and productivity of process planners.
- Easy integration with other application software for further analysis.

1.1 Background

In traditional approaches, in order to reduce the complexity of solving job shop operations and planning problems, the realistic picture of a manufacturing system was assumed as an ideal situation. Traditional approaches typically followed manual process planning in which factors such as feature reading, operation flow, order of machining, MRR, etc. were presumptuously calculated on the basis of trial and error. But, for instance, setup time of any component varies from industry and the machinery available, due to which it cannot always be neglected. This would reduce the efficacy of a company. These factors would add up and cause delay in the delivery time compared to the idle calculated time. In the present scenario, with a wide range of databases available to access these factors, the process planning method can now be modified to a more dynamic structure. Computer aided process planning can improve the efficacy and accuracy of sequencing by taking into account all factors that affect the manufacturing of a component. Automatic Feature Recognition helps to analyze the database and provide the best possible setup method. Though considering various factors will increase the complexity of the equations thus increasing time required to plan the operations, development of a software model that can handle these equations will automate the manual calculations and will save the company's time greatly.

The objective of the manufacturing process is to transform an idea into a saleable product. The common methodology used to accomplish this objective is to divide the manufacturing process into several activities, arranged serially. Usually, each activity handles a different stage of the process, each stage representing a unique discipline and training. Figure 1.1 describes the global structure of process planning in an industrial enterprise and points to the role of process planning as a part of production planning. This latter represents the general control of manufacturing activities in an enterprise. Whereas the general management of a company is concerned with long-range planning activities such as personnel policy, marketing, accounting, etc., it delegates the functions of product design and manufacture to special departments which are in charge of functions such as production planning, fabrication technologies, quality control, etc. The role of process planning itself is now explained.

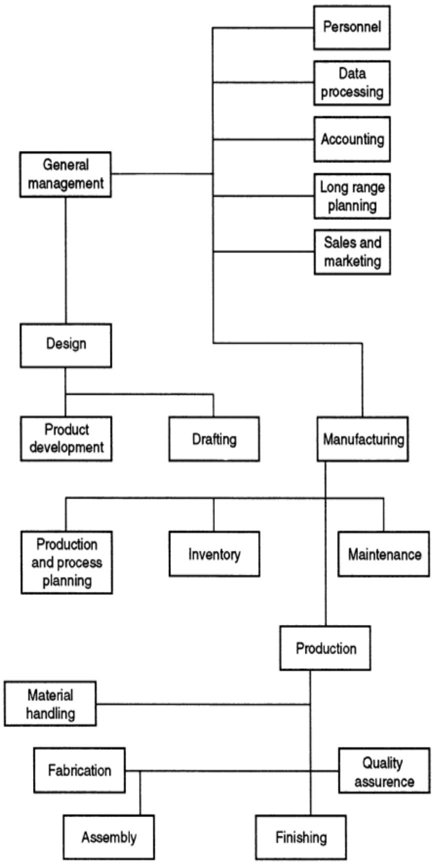


Fig 1.1: Global structure of Process planning

1.2 Motivation

Process Planning is one of the most important aspects of industrial engineering and manufacturing plants. Development of a model that can assist an operator with ease to perform process planning, will greatly improve the performance and value of an organization. Combining concepts of process planning, software development, data analysis and accurate calculations will help any industry take its leap into Industry 4.0.

1.3 Aim and Objective

1.3.1 Aim

To develop a simulation environment that can allow the user to analyze the performance measures for each of these manufacturing methods based on generative process planning.

1.3.2 Objectives

The objectives of the project are as stated below.

- The system will provide the user with the most beneficial flow of operations for manufacturing processes.
- The system will also be able to predict the tentative schedule to be followed with the time for the production of required part quantity.
- Further, this system will be able to bring the industries a step closer to Industry 4.0 with its methods to decrease human intervention.

1.4 Problem definition

It has been observed that there is scope to increase the effectiveness of the current process planning methods, using simulation as well as data to analyze and create best outcomes that make use of generative process planning.

The data required is already available through the organization's database and performing the right mathematical calculations can bring realistic results, accurate completion time and cost reduction of the company.

The present work aims to achieve this by development of a simulation model.

1.5 Scope of the project

- The system functions with the help of a GUI based on Python Programming language, using TKINTER.
- The system makes use of concepts in the GENERATIVE CAPP approach. The target of the project was to create a system for block machining, casting and sheet metal processes such that the essential parameters of process planning are recorded.
- The system helps manufacturing industries save their process planning time and resources. Further, human errors can be avoided using this method.
- The CAPP system for block machining uses automatic feature recognition to read the CAD file and obtain dimensions of the component. The parameters are calculated thereafter and the G-code is generated.
- The CAPP system for bar casting gives parameters related to material selection which is a key feature.
- The CAPP system for sheet metal is able to give an output for blanking and punching.

Chapter 2

Literature Review

Numerous individuals and institutions have undertaken extensive research projects in order to generate and integrate CAPP technology in the industry. Following are the papers and studies done along with their findings, upon which we have heavily relied for the various needs and references of our project.

***Neelesh Kumar Jain and Vijay Kumar Jain*(1).** Their research paper titled Computer Aided Process Planning Approach For Advanced Machining Processes was published in October 1999. They explained about the integration of Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) which played a key role in the development of Flexible Manufacturing System (FMS) and Computer Integrated Manufacturing Systems (CIMS).

***Omar Al- Shebeeb and Bhaskaran Gopalakrishnan*(2).** Published in September 2016, the topic of their study is Computer Aided Process Planning Approach for Cost Reduction and

Increase in Throughput. The approach presented in this paper highlights the design modifications of the product retaining functionality in order to enable the development of the most effective process plans for manufacturing for utilization in the domain of concurrent engineering.

Mariusz Deja, Mieczysław Siemiątkowski(3)**.** Machining Process Sequencing and Machine Assignment in Generative feature-based CAPP was the title of their research study published in July 2018. They put forth the feature-based reasoning approach for generating machining sequences along with the dynamic assignment of machine alternatives considering adaptability as the most essential principle.

William C. Regli, Satyandra K. Gupta and Dana S. Nau(4)**.** Their work, titled Feature Recognition for Manufacturability Analysis, was published in September 1994. This article stresses the relationship between Material Removal Shape Element Volumes (MRSEVs) and machining processes, their relevance to developing data interchange standards, and some of our approach's unique qualities that fulfil some of the objectives of manufacturability analysis. The method covers a wide range of characteristics, such as those characterizing holes, pockets, slots, and chamfering and filleting processes.

Ronald A.Walsh(5)**.** We referred to their McGraw Hill published book titled Handbook of Machining and Metalworking Calculations for all the formulae that we have utilized in our work and project for value calculation purposes. This handbook contains both the basic and advanced calculation methods required for machining applications. The formulae for all three of our operations namely, milling, drilling and turning, were referred from this book. The number of parameters and how they affect the overall process calculations was also studied and properly integrated in our study.

C. W. Ammen(6)**.** Published in 1979, The Complete Book of Sand Casting, is one of the fundamental books on sand casting. It provides all the necessary presumptions and date and theoretical side about sand casting with a wide range of metals as the casting materials. It discusses thoroughly about the various properties of ferrous and non-ferrous metals that are used in casting. It also discusses in detail the methods of making the sand mold, the molder’s tools, and patterns.

***John Campbell*(7)**. Complete Casting Handbook, Second Edition, was published in August 2015. Modern industrial methods have proved useful in taking appropriate assumptions in riser and sprue calculations. Conventional casting methods had drawbacks such as allowance of air into the mold or cavity while filling it with molten metal and the formation of bi-films on the cast metal. It also discusses the change in mechanical properties of metal, to derive critical velocity of pouring metal and to derive riser calculations.

***Hui Gao, Wenbing Zhang, Shumei Chen, Kuilong Lyu*(8).** Published in August 2019, the paper is titled Influence of Casting Temperature of Low Carbon Steel on the Interface Layer of Composite Protective Plate. Through this study, the generated oxide inclusions after the surface completely solidifies can be effectively avoided, so as to achieve the metallurgical combination of the large area of two kinds of materials.

***Daniel Galles, Jia Lu, Christoph Beckermann*(9).** Determination of Pattern Allowances for Steel Casting using the Finite Element Inverse Deformation Analysis was the title of their research study published in December 2018. By utilising this method to calculate pattern geometry in a single iteration for a plastically deformed body, an inverse deformation method can be used to determine pattern allowance in production casting.

***Mijodrag Milosevic, Miodrag Hadžistević, Dejan Lukic*(10).** Their work was published in January 2012 with the title Design of casting blanks in CAPP system for parts of piston-cylinder assembly of internal combustion engines. Specialized and integrated CAPP system, that was developed by using general user software to allow automated product design and manufacturing process planning in a system. Developed CAPP system which provides part and casting blank modelling which in turn provides basic inputs for simulation of the casting process and manufacturing process planning observed parts.

***Mikell P. Groover*(11).** Their book is titled, Fundamentals of Modern Manufacturing: Materials, Processes, and Systems, 5th Edition. This book was referred for all the formulae concerning casting processes. These helped us in defining all our calculations and making the necessary assumptions.

Chapter 3

Concepts & Procedure

3.1 Introduction

Process planning is a pre-manufacturing phase that defines the sequence of activities or processes required to create a product or an assembly.

Steps of Process Planning in Manufacturing:

- Analysis of part requirements
- Selection of raw workpiece
- Determining manufacturing operations and their sequences
- Selection of machine tools
- Selection of tools, work holding devices, and inspection equipment
- Determining machine conditions
- Manufacturing time

The whole project could be seen as the coalition of three major tasks. Each task plays an important role in the top-to-bottom working model of our work. These three tasks are as follows:

Development of a GUI which would help the user in completing the given job/work by receiving the commands and input parameters given by the user, processing all the required data and running all the necessary analysis at the back end, and producing the desired results and handing them down to the user as the output.

Automatic Feature Recognition (AFR) is the process of reading the used and implied data from a given CAD (Computer Aided Drawing) model in STEP (Standard for the Exchange of Product model data) file format. Once the CAD model is uploaded as a STEP file by the user into the GUI, it will read all the parameters that have been used to make the model, all the features and steps necessary to achieve the final form of the model, and the calculations required for the production of a physical 3D object from the CAD model. The GUI will recognise the origin, axes points, reference points, intersecting lines, faces and edges, processes like Extrusion and Revolution that the model has undergone to reach its present form.

Producing a Process Chart will help the user in foreseeing the requirements for the production of the concerned workpiece and make the necessary arrangements which would help him meet these requirements. The GUI will produce a tentative process chart, which will be based on the data collected from the user from the input end and the data received from the AFR. Thus the GUI will assist not only in the production but also in the scheduling process related to the production of the workpiece.

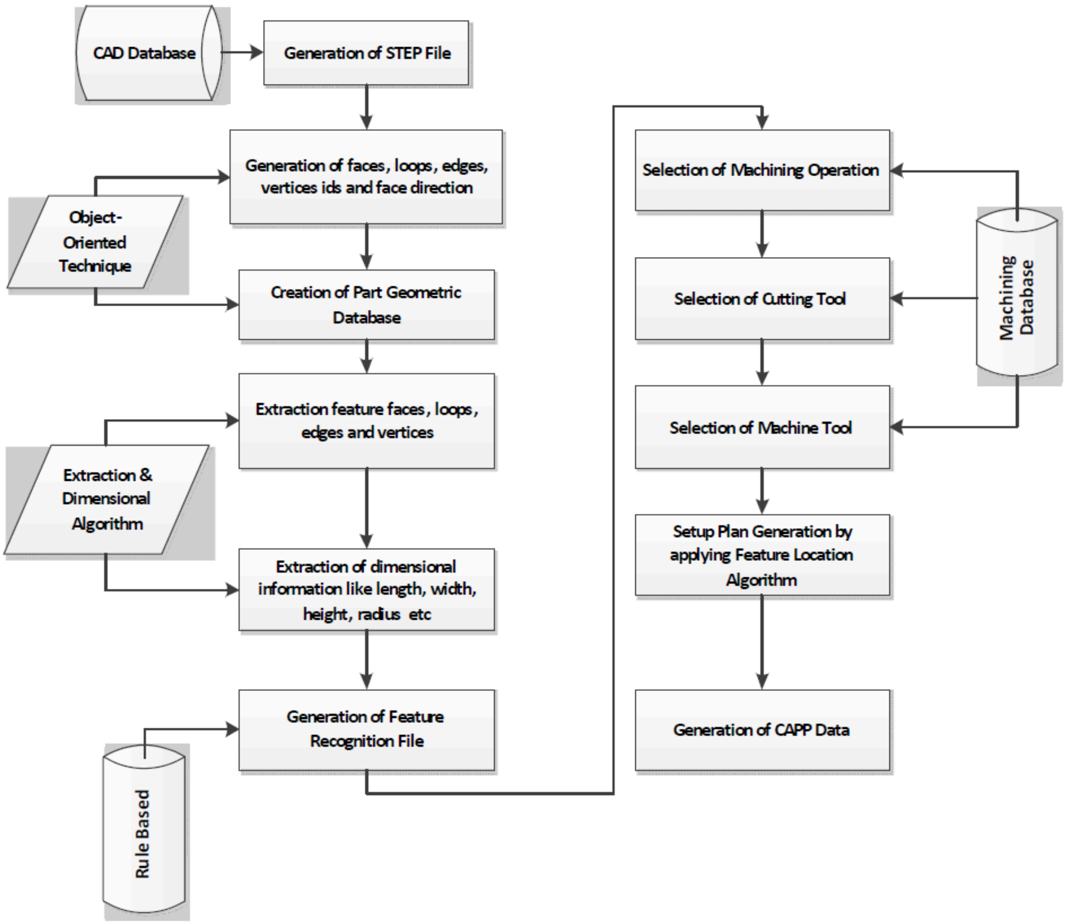


Fig 3.1: Flowchart of the CAPP system

3.2 Libraries Incorporated

Python programming language is used for this project. It is an interpreted, high-level and general-purpose programming language. Python comes with a large library of useful modules.

Few of the modules incorporated in the model are as follows:

- Pandas: - It is a software library written for the Python programming language for data manipulation and analysis. Pandas allow various data manipulation operations such as merging, reshaping, selecting, as well as data cleaning, and data wrangling features. The library is highly optimized for performance, with critical code paths written in Python or C.

- Math: - This module provides access to the mathematical functions defined by the C standard. These functions cannot be used with complex numbers. Some of the functions provided by this module are math.**ceil**(*x*), math.**comb**(*n*, *k*), math.**floor**(*x*), etc.

- NumPy: - It is a library for the Python programming language, adding support for large, multi-dimensional arrays and matrices along with a diverse collection of high - level mathematical functions to operate on these arrays.

- Tkinter: - Tkinter is Python's standard GUI library. Python, when coupled with Tkinter, provides a quick and straightforward approach to develop graphical user interface (GUI) applications. Tkinter extends the Tk GUI toolkit with a strong object-oriented interface. Tkinter is the de facto method for creating Graphical User Interfaces (GUIs) in Python, and it is included in all standard Python distributions. It is, in fact, the sole framework included in the Python standard library.

- ImageTk: - The ImageTk module contains support to create and modify Tkinter BitmapImage and PhotoImage objects from PIL images.

- Filedialog: - The Tkinter.FileDialog module provides classes and factory functions for creating file/directory selection windows.

- PIL: - Python Imaging Library is a free and open-source extension library for the Python programming language that allows you to access, manipulate, and save a variety of image file types.

- Tensorflow: - Tensorflow is an open-source library for numerical computing and large-scale machine learning that simplifies the process of obtaining data, training models, serving predictions, and refining future outcomes in Google Brain TensorFlow. Tensorflow is a framework that combines Machine Learning and Deep Learning models and algorithms.

- OS module: - This module provides a portable mechanism to access operating system-specific functions. If all you want to do is read or write a file, use open(); if you want to alter paths, use the os.path module; and if you want to read all the lines in all the files on the command line, use the fileinput module.

- DateTime: - Date and time manipulation classes are provided by the datetime module. While date and time arithmetic is provided, the implementation's primary focus is on efficient attribute extraction for output formatting and manipulation.

Apart from these libraries, there were several others used, integrated in the code to perform various tasks and simplify the code.

3.3 Automatic Feature Recognition

Automatic Feature Recognition (AFR) is often considered as the best method for automating design and production processes. Successful automation of CAD and CAM systems is a vital connection in building Computer Integrated Manufacturing (CIM) systems.[6] This is the domain of FR research that has garnered far more emphasis. Another important application of AFR is for manufacturability evaluation.[7] The AFR system should be able to interpret the design differently based on different characteristics and communicate back to the designer the manufacturability and cost of such interpretations.

There is a big stockpile of different AFR techniques that has been proposed for CAD/CAM integration and process planning. Han et al.[8] gives a critical and thorough examination of various existing techniques. According to Han et al., the most prevalent approaches span from graph-based algorithms to hint-based and volumetric decomposition techniques. A graph depicting the topology of the component (connection of faces) is generated in the graph-based feature recognition. The edges of the graph are frequently ascribed, for example, as concave or convex.[9] This graph is then processed to extract subsets of nodes and arcs that correspond to any preset template. A variety of approaches, including graph isomorphism algorithms, are used to accomplish this.[10]

Graph-based methods have been chastised for a number of flaws. Because of their dependence on topological patterns rather than geometry, they fail to account for the manufacturability of the identified characteristics. When features intersect, the number of viable feature patterns explodes, sabotaging any attempt to create feature patterns. To address these difficulties, Vandenbrande and Requicha.[11] proposed to search for "minimal indispensable portion of a feature's boundary", called hints, rather than complete feature patterns. The presence of two opposing planar faces, for example, indicates the possibility of the presence of a slot feature. Hints do not have to be limited to the geometry of the component. They can also be derived from tolerances and design characteristics. For example, "a thread attribute may be taken as a hole hint".[8] This method has proven to be more effective in detecting intersecting features. However, the approach's efficiency has been questioned, as there might be a large number of traces that do not lead to meaningful features.[8] Some writers have advocated for combining graph-based and hint-based FR to increase the effectiveness of hint-based reasoning. In the hybrid method, graph-based reasoning is employed to determine those sections of the component that, when employed by the hint-based reasoner, will undoubtedly lead to correct features.[12][13] Other existing FR approaches are volumetric decomposition,[14][15] Artificial Neural Networks,[16] and expert systems[17] Babic et al.[18] briefly introduces many of them.

However, developing feature recognition algorithms that work successfully on real-world industrial goods has proven challenging. Due to computational complexity, a genuine product with hundreds of faces and end edges puts virtually all of the aforementioned techniques to a standstill. Furthermore, the characteristics investigated in these techniques are frequently oversimplified. The majority of feature recognition literature is typically concerned with 2.5D features (those made by sweeping a 2D profile along a linear axis). For 3D and free form features, graph representations, hint definitions, and volume decompositions are significantly more complex to specify. The work done by Sundararajan[19] is centered on free form surfaces, although its applicability is restricted. Even in the case of 2.5D features, oversimplification is apparent. Feature recognition algorithms, for example, commonly assume sharp concave edges in the feature geometry. However, mostly because of manufacturing restrictions, such edges are rarely employed in the actual design of mechanical components. Some of these issues such as the presence of filleted edges and free form surfaces in the model have been studied by Rahmani and Arezoo.[12]

3.4 Design and Development of GUI

3.4.1 Block Machining

In order to develop the GUI for generative computer aided process planning for block machining, the steps mentioned below were followed to reduce error, repetitive work and ease design procedure.

1. The manual calculations were first performed, so comparison could be done once the programming was done.
2. The calculation part of the code was first written in the Jupyter Notebook and tested for errors, if any.
3. The basic code was written in Sublime Text editor and in Python Language.
4. Libraries such as math and numpy were used for arithmetical operations.
5. Automatic feature Recognition was done using Step analyzer and was run to give an output of the part details, entailing various dimensions for further process planning operation.
6. The repository of the step analyzer, which uses feature recognition, was directly linked to the GUI using the OS module library.
7. The input data, a CAD file will be taken from the user is displayed and further, using this data the Process planning code gives the required output parameters.
8. The dimensions read/generated from the AFR code is used in calculating the required output parameters by substituting them in the respective formulae.
9. The process planning code makes use of the formulae to achieve the desired output values, mentioned. (Cutting Speed, Feed Rate, Depth of Cut, Material Removal Rate, Machining Time)
10. Once the calculation code was tested and ready, the layout of the GUI was prepared in T-kinter Designer.
11. This GUI file was then converted to a programmable python file.

12. T-Kinter is a GUI interface library, in python language, where the designing of the input and output windows can be done, like drop down menu box, input text box, label, submit button etc.

13. The calculations code was then added to this GUI file and additional code was written to the input of the user to the calculations function.

14. Further code was written in the existing file to display the resulting values and table in a separate window to the user.

15. Once the user clicks on the "G-Code" button, an input from the user will be required in the format of a DXF file.

16. From the DXF file, the UI will generate a G-code for machining the object. This will be done with the help of a code run in the background.

17. The user can open the output window to obtain the values of different parameters and also perceive the G-Code necessary to machine the object.

3.4.2 Sand Casting

In order to develop the GUI for generative computer aided process planning for bar casting, the steps mentioned below were followed to reduce error, repetitive work and ease design procedure.

1. The manual calculations were first performed, so comparison could be done once the programming was done. The calculation part of the code was first written in the Jupyter Notebook and tested for errors, if any.
2. The basic code was written in Sublime Text editor and in Python Language. Libraries such as math and numpy were used for arithmetical operations.
3. The input data will be taken from the user and using this data the Process planning code gives the required output parameters for sand casting.
4. The dimensions are used in calculating the required output parameters by substituting them in the respective formulae.
5. The process planning code makes use of the formulae to achieve the desired output values, mentioned.

6. Once the calculation code was tested and ready, the layout of the GUI was prepared in T-kinter Designer. This GUI file was then converted to a programmable python file.

7. T-Kinter is a GUI interface library, in python language, where the designing of the input and output windows can be done, like drop down menu box, input text box, label, submit button etc.

8. The calculations code was then added to this GUI file and additional code was written to the input of the user to the calculations function.

9. Further code was written in the existing file to display the resulting values and table in a separate window to the user.

3.4.2 Sheet metal operations

In order to develop the GUI for generative computer aided process planning for basic sheet metal working operations, the steps mentioned below were followed to reduce error, repetitive work and ease design procedure.

1. The manual calculations were first performed, so comparison could be done once the programming was done. The calculation part of the code was first written in the Jupyter Notebook and tested for errors, if any.

2. The basic code was written in Sublime Text editor and in Python Language. Libraries such as math and numpy were used for arithmetical operations.

3. The input data will be taken from the user and using this data the Process planning code gives the required output parameters for sheet metal working.

4. The dimensions are used in calculating the required output parameters by substituting them in the respective formulae.

5. The process planning code makes use of the formulae to achieve the desired output values, mentioned.

6. Once the calculation code was tested and ready, the layout of the GUI was prepared in T-kinter Designer. This GUI file was then converted to a programmable python file.

7. T-Kinter is a GUI interface library, in python language, where the designing of the input and output windows can be done, like drop down menu box, input text box, label, submit button etc.

8. The calculations code was then added to this GUI file and additional code was written to the input of the user to the calculations function.

9. Further code was written in the existing file to display the resulting values and table in a separate window to the user.

3.5 Calculation Parameters for Process Planning

The back-end of the GUI required a vast database with a variety of formulae to obtain the necessary output. These formulae were confirmed from numerous sources such as books, sites, research papers. The parameters and formulae proved helpful to generate the codes needed to generate the output.

3.5.1 CNC Machining

Following are some of the performance measures used to quantify the effectiveness of certain parameters of the process plan. In order to apply these measures, the data required is achieved from the feature recognition software. It is desired to minimize these performance measures in order to find the optimal process plan as well as output parameters required. Although not all measures can be calculated, a few achievable parameters are considered for the output.[5]

List of figures used in the formulae for operations:

- D = Diameter of Cutter/Drill
- Do= Outer Diameter of W/P
- Df= Final Diameter of W/P (req.)
- N = Rotational Speed (RPM)
- f = Feed Rate (dist/rev)

- nt = No. of teeth on cutter
- l = Length of W/P
- lc = Extent of Cutter’s first contact with W/P
- w = Width of cut

3.5.1A Drilling

The list of formulae used in the system to measure the parameters for drilling operation are mentioned below. These parameters are integrated in the software to obtain the final results for process planning.

1. Cutting Speed (v)(SFPM) = ΠDN
2. Feed Rate (Fr)(dist/min) = Nf
3. Depth of Cut (d)(mm) = $D/2$
4. Material Removal Rate (MRR) (in3/min) = $(\Pi D^2/4)F_r$
5. Machining Time (Tm)(min) = $Volume/MRR$

3.5.1B Milling

The list of formulae used in the system to measure the parameters for milling operation are mentioned below. These parameters are integrated in the software to obtain the final results for process planning.

1. Cutting Speed (v)(SFPM) = ΠDN
2. Feed Rate (Fr)(dist/min) = $Nn_t f$
3. Depth of Cut (d)(mm) = $D/2$
4. Material Removal Rate (MRR) (in3/min) = lwd/t
5. Machining Time (Tm)(min) = $(l + 2l_c)/v$

3.5.1C Turning

The list of formulae used in the system to measure the parameters for turning operation are mentioned below. These parameters are integrated in the software to obtain the final results for process planning.

1. Cutting Speed (v)(SFPM) = $\Pi D_o N$
2. Feed Rate (Fr)(dist/min) = Nf
3. Depth of Cut (d)(mm) = $(D_o - D_f)/2$
4. Material Removal Rate (MRR) (in3/min) = $vF_r d$
5. Machining Time (Tm)(min) = L/F_r

3.5.2 Sand Casting

Following are some of the performance measures used to quantify the effectiveness of certain parameters of the process plan. In order to apply these measures, the data required is from user input and user selection. It is desired to minimize these performance measures in order to find the optimal process plan as well as output parameters required. Although not all measures can be calculated, a few achievable parameters are considered for the output. The Data for the system database has been thoroughly researched and confirmed from various sources. [25][26][27][28][29][30][31][32][33][37][38][39]

3.5.2.A Database

The data given below is the list of constants and values taken after referring to various research pacers, sites and books. These constants are in the database of our GUI that is used in the various formulae.

Ambient Temp = 30 °C

Densities: (g/cc)

Grey Cast Iron = 7.15
White Cast Iron = 7.7
Plain Carbon Steel = 7.85
Aluminum = 2.7
Brass = 8.55
Al Bronze = 7.7
Magnesium = 1.738

Specific Heat of Solid Metal: (J/gC)

Grey Cast Iron = 0.46
White Cast Iron = 0.46
Plain Carbon Steel = 0.502
Aluminum = 0.92
Brass = 0.401
Al Bronze = 0.38
Magnesium = 1.04

Melting Temperatures: (C)

Grey Cast Iron = 1165
White Cast Iron = 1260
Plain Carbon Steel = 1410
Aluminum = 660
Brass = 920
Al Bronze = 913
Magnesium = 650

Heat of Fusion: (J/g)

Grey Cast Iron = 96

White Cast Iron = 138

Plain Carbon Steel = 247

Aluminum = 321

Brass = 168

Al Bronze = 220

Magnesium = 370

Specific Heat of Liquid Metal: (J/gC)

Grey Cast Iron = 0.506

White Cast Iron = 0.540

Plain Carbon Steel = 0.6

Aluminum = 1.18

Brass = 0.5

Al Bronze = 0.48

Magnesium = 1.34

Pouring Temperatures: (C)

Grey Cast Iron = 1350

White Cast Iron = 1300

Plain Carbon Steel = 720

Aluminum = 700

Brass = 900

Al Bronze = 1150

Magnesium = 800

Mold Constant (Cm): (Unit sec/mm^2)

Grey Cast Iron = 0.6

White Cast Iron = 0.7

Plain Carbon Steel = 0.372

Aluminium = 4.2

Brass = 1.5

Al Bronze = 0.5

Magnesium = 0.4

3.5.2.B Allowances

An allowance is a planned deviation between an exact dimension and a nominal or theoretical dimension, or between an intermediate-stage dimension and an intended final dimension.

1. Liquid shrinkage: This is taken care of by a riser (liquid to liquid and liquid to solid) i.e. temperature drop. Solid to solid shrinkage high temp to room temp (volume shrinkage) is taken care of by pattern allowance. It is given to linear dimensions only (mm per mm)
For wooden pattern: Add along l/b/h Added positively for external element dimensions For hole, the dia should be reduced - core dimension Added negatively for internal element dimensions (holes).
For metal pattern: Double shrinkage allowance, i.e. for casting, Metal A (pattern) shrinkage allowance then Metal B (casting) shrinkage allowances to dimensions obtained of Metal A.

2. Draft allowance: Type of pattern affects wood / metal / plastic. External and internal surfaces (E < I) . It is given by Height × tan (angle)

3. Machining allowance: Extra material for machining to avoid rough surfaces. (For internal - reduce size (hole) For external - add size). For a better finish, size of casting should be more for larger casts and material should be more for ferrous metals Materials

4. Shake allowance: It is a Negative Allowance. Enlarged size of mould cavity while removing pattern. (Based on experience)

5. Distortion allowance: it is to accommodate for wrapping and other defects. (Based on experience)

Linear Shrinkages: (mm per mm)

Grey Cast Iron = 0.0105
White Cast Iron = 0.02

Plain Carbon Steel = 0.021

Aluminum = 0.013

Brass = 0.0155
Al Bronze = 0.021
Magnesium = 0.013

Draft Allowance: (deg)

The following table 3.1 gives data about draft allowances for internal and external angles while working on different materials like wood, plastic, metal, etc.

Table 3.1: Draft Allowance Database

Material	Internal	External
wood	0.5-3	0.25-3
Metal	0.5-3	0.35-1.5
plastic	0.35-2.25	0.25-1

Machining allowance: (mm)

The following table 3.2 gives data about machining allowances on internal and external surfaces while working on different metals.

Table 3.2: Machining Allowance Database

Material	Surface length mm	Internal	External
CI	300	3	3
	300-500	5	4
	500-900	6	5
Steel	150	3	3
	150-500	6	5.5
	500-900	7	6
Non ferrous	200	2	1.5
	200-300	2.5	1.5
	300-900	3	1.5

3.5.2.C Miscellaneous

These are the additional formulae that have been used for the development of GUI. These mostly focus on parameters of riser, sprue, pouring basin and mold cavity.

- Volume of mold = vol of pattern + 0.5x(vol of riser) + 0.5x(vol of sprue)
  Diameter of pouring basin = 25 mm
  Diameter of sprue = 10 mm
  Height of sprue = 50 mm
  Riser d/h = 1
  Increase height of riser to increase solidification time of riser
- Total heat required to raise the temperature of the metal to the pouring temperature
  $H = r V\{C_s (T_m - T_o) + H_f + C_l (T_p - T_m)\}$, where H - J (Btu);

  r density, g/cm^3 (lbm/in^3);

  C_s weight specific heat for the solid metal, J/g-C (Btu/lbm-F);

  T_m melting temperature of the metal, C (F);

  T_o starting temperature—usually ambient, C (F);

  H_f heat of fusion, J/g (Btu/ lbm);

C_l weight specific heat of the liquid metal, J/g-C (Btu/lbm-F);

T_p pouring temperature, C (F); and

V volume of metal being heated, cm^3 (in^3)

- The time required to fill a mould cavity of volume V can be estimated as

  TMF = V/Q where

  TMF mould filling time, s (sec);

  V volume of mould cavity, cm^3 (in^3); and

  Q volume flow rate,
  Q = area of base of sprue x velocity of flowing metal at base of sprue(v)
  $v = \sqrt{2gh}$
  where, h height of sprue

  g acceleration due to gravity

- TTS $= C_m (V/A)^n$

  where TTS total solidification time, min;

  V volume of the casting, cm^3 (in^3);

  A surface area of the casting, cm^2 (in^2);

  n is an exponent usually taken to have a value 2; and

  C_m is the mould constant.

- The volume of the riser is given by

  $V = \frac{\Pi D^2 h}{4}$

- The surface area is given by

  $A = \Pi D h$

3.5.3 Sheet Metal Processes

Following are some of the performance measures used to quantify the effectiveness of certain parameters of the process plan. In order to apply these measures, the data required is from user input and user selection. It is desired to minimize these performance measures in order to find the optimal process plan as well as output parameters required. Although not all measures can be calculated, a few achievable parameters are considered for the output. The Data for the system database has been thoroughly researched and confirmed from various sources. [34][35][36]

The following formulae were primarily used for sheet metal processes.

- Clearance = $0.0032 (t)\sqrt{\boldsymbol{\tau}}$

  (where $\boldsymbol{\tau}$ = shear strength of material)

- $F_1 = \boldsymbol{\Pi} D_o t\boldsymbol{\tau}$ & $F_2 = \boldsymbol{\Pi} D_i t\boldsymbol{\tau}$

  (where D_o = Outer Dia, D_i = Inner Dia, For Circular Jobs)

  $F_1 = 2(L+B)t\boldsymbol{\tau}$

  (where L = Length of Job, B = Breadth of Job, For Rectangular Jobs)

  $F_{max} = F_1 + F_2$

- Press Capacity = F_{max} x C

  (where, C = 1.2 to 1.5)

- Energy in Press Work= F_{max} x C x K x t

  (where, K = % Penetration = 80% for t < 1.6 mm)

- Power in Press Work = $\frac{E \, x \, Na}{60 \, x \, \eta}$

  (where E = Energy in Press Work, N_a = Actual No. of Strokes, η = Efficiency of Press)

- Push Through Force on Blank = 10% of F_{max}

- Horizontal Force on Punch and Die = $F_{HD} = F_{HP} = 0.15 \text{ x } 0.25 \text{ x } F_{max}$

- Diameter of Die = Punch diameter + Die Clearance,

  (where die clearance = 20% of material thickness)

- <u>For Strip layout,</u>

  a= t + (0.0015 x Outer Diameter),

b = t (t lies between 0.5 & 3.2),

c = Outer dia + b

Number of parts per strip (N) = $\frac{Stock\ Length\ (in\ mm)}{c\ (in\ mm)}$

3.5.3.A Database

The following table 3.3 gives standard gauge values for ferrous and non- ferrous metals.

Table No. 3.3: Standard Gauge Values for metals

Gauge	**Mild Steel** and other* (mm)	**Stainless Steel** (mm)	**Aluminium Alloys** and other ** (mm)
3	6.07	-	-
4	5.69	-	-
5	5.31	-	-
6	4.94	-	4.1
7	4.55	4.76	3.67
8	4.18	4.37	3.26
9	3.80	3.97	2.91
10	3.42	3.57	2.59
11	3.04	3.18	2.30
12	2.66	2.78	2.05
13	2.28	2.4	1.80
14	1.90	1.98	1.63
15	1.71	1.8	1.40
16	1.52	1.59	1.29
17	1.37	1.4	1.10

18	1.21	1.27	1.02
19	1.06	1.1	0.91
20	0.91	0.95	0.81
21	0.84	0.86	0.71
22	0.76	0.79	0.64
23	0.68	0.71	0.58
24	0.61	0.64	0.51
25	0.53	0.56	0.46
26	0.45	0.48	0.43

**includes Carbon Steels (0.1%,0.2%,0.3%), high strength low-alloy steels and silicon steels.*

***includes Copper, Bronze, Lead alloys, Magnesium alloys, Nickel alloys, Tin alloys, Titanium alloys, Zinc alloys.*

The following table 3.4 gives data about the shear strength values of different metals used in Sheet Metal Operations.

Table No. 3.4: Shear Strength Values of Metals

Metal	**τ (N/mm^2)**
0.10 % C	245 to 311
0.20 % C	308 to 385
0.30 % C	364 to 469
High strength low-alloy steels	315 to 446
Silicon Steels	420 to 490
Stainless Steels	399 to 903
Aluminium Alloys	49 to 322
Copper and Bronze	154 to 490
Lead alloys	12.8 to 41
Magnesium alloys	119 to 203

Nickel alloys	245 to 812
Tin alloys	20.5 to 77.7
Titanium alloys	420 to 490
Zinc alloys	98 to 266

3.6 Simulation Model Developed

The simulation model developed (GUI) is shown in a number of images (screenshots) from the real time working of the GUI. These images display in detail the input and output of the GUI. This section is further divided into three major subsections (Block Machining, Bar Casting and Sheet metal working operations.

3.6.1 Block Machining

The simulation model developed gives an output of the proposed parameters. User has to upload the CAD file. The uploaded CAD model after being read by the AFR module, has an output of the dimensions and features from the file. The obtained dimensions and features are then read by the program for process planning and are shown on the output page of the GUI. The images of the simulated system from the GUI design are shown below:

Fig 3.2 shows the input page of the Computer aided process planning system. This page takes the input from the user and is the preliminary design of the system.

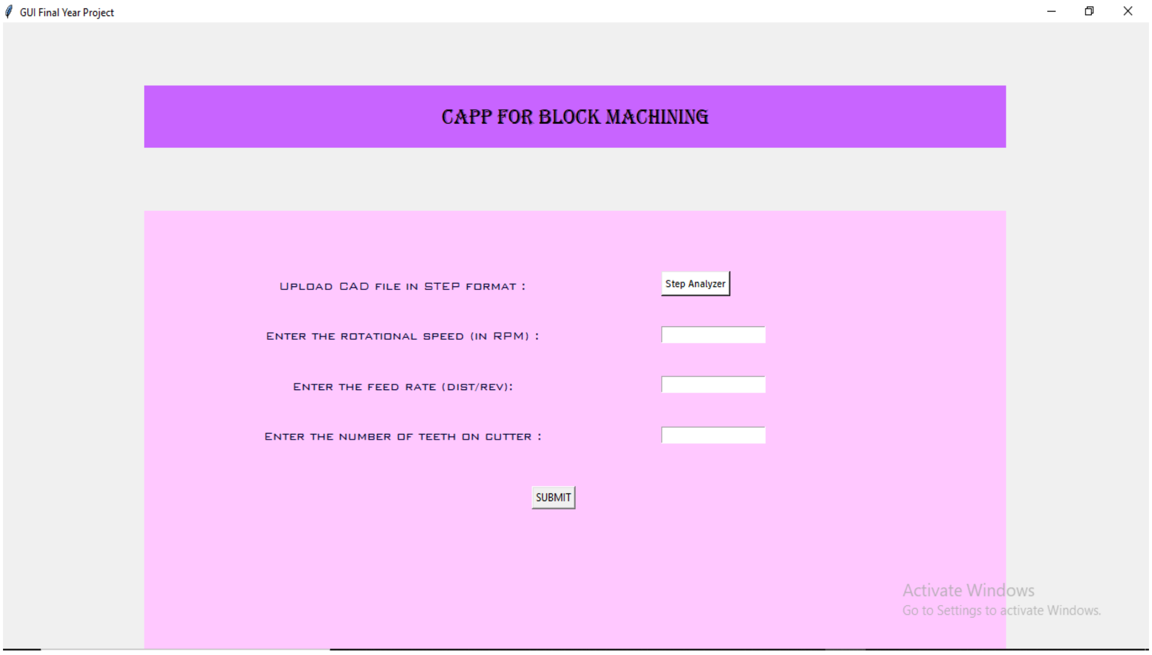


Fig 3.2: Input page

Fig 3.3 is a snapshot of the system while uploading the CAD file to conduct AFR for further analysis of the component.

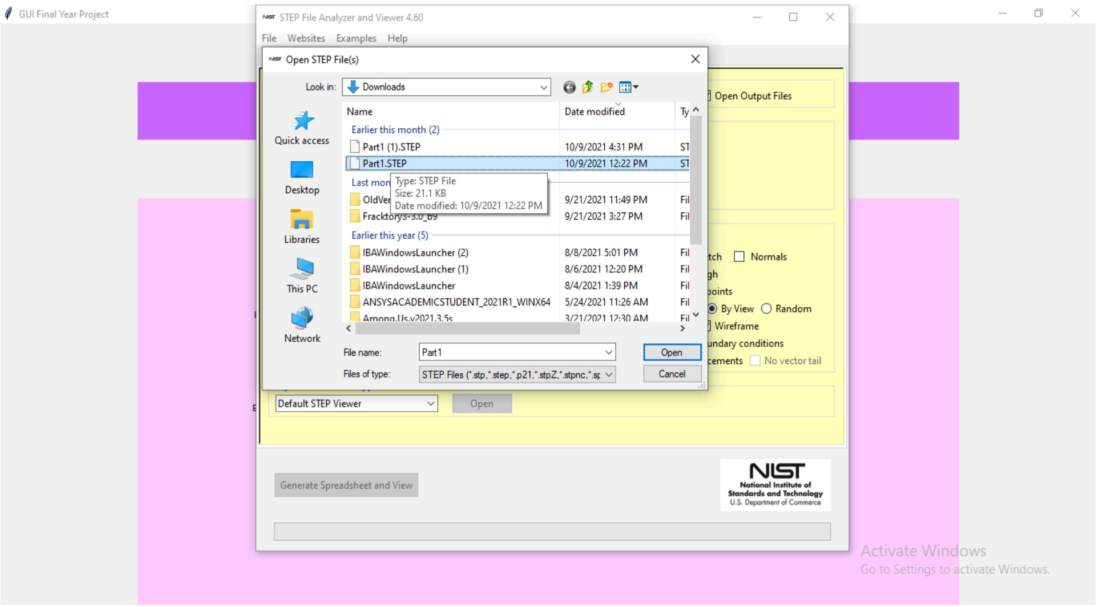
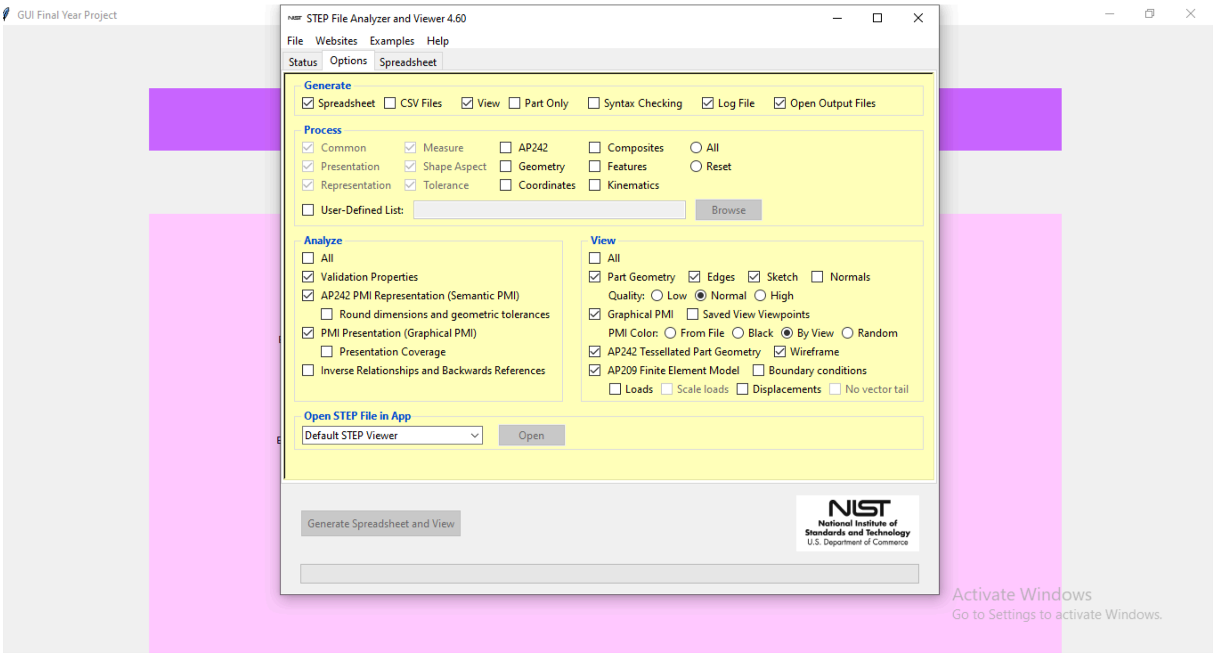


Fig 3.3: Selecting the step file

Fig 3.4 is the snapshot of the opening step analyzer after the step file has been uploaded.



Generate
☑ Spreadsheet ☐ CSV Files ☑ View ☐ Part Only ☐ Syntax Checking ☑ Log File ☑ Open Output Files

Process
☑ Common ☑ Measure ☐ AP242 ☐ Composites ○ All
☑ Presentation ☑ Shape Aspect ☐ Geometry ☐ Features ○ Reset
☑ Representation ☑ Tolerance ☐ Coordinates ☐ Kinematics
☐ User-Defined List:

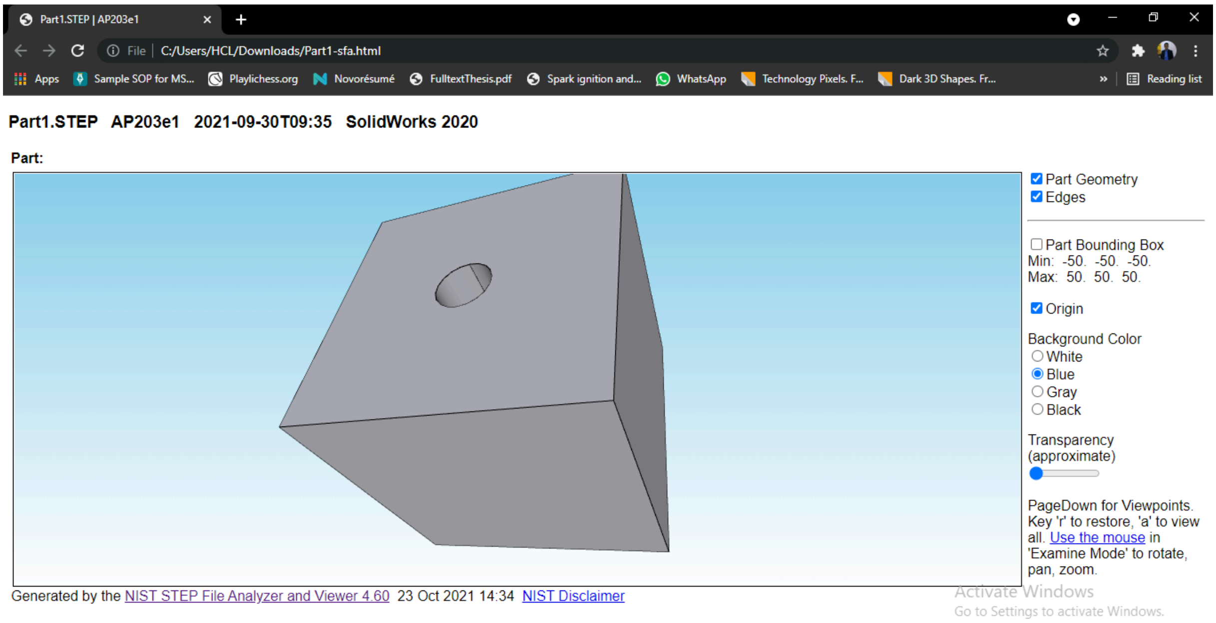
Analyze
☐ All
☑ Validation Properties
☑ AP242 PMI Representation (Semantic PMI)
☐ Round dimensions and geometric tolerances
☑ PMI Presentation (Graphical PMI)
☐ Presentation Coverage
☐ Inverse Relationships and Backwards References

View
☐ All
☑ Part Geometry ☑ Edges ☑ Sketch ☐ Normals
Quality: ○ Low ● Normal ○ High
☑ Graphical PMI ☐ Saved View Viewpoints
PMI Color: ○ From File ○ Black ● By View ○ Random
☑ AP242 Tessellated Part Geometry ☑ Wireframe
☑ AP209 Finite Element Model ☐ Boundary conditions
☐ Loads ☐ Scale loads ☐ Displacements ☐ No vector tail

Open STEP File in App
Default STEP Viewer

Fig 3.4: Opening step analyzer

After the step analyzer opens, a 3D image of the uploaded cad file can be seen (Fig 3.5). The user can change the transparency of the body, rotate and pan the view and also change the background.



Part1.STEP AP203e1 2021-09-30T09:35 SolidWorks 2020

Part:

☑ Part Geometry
☑ Edges

☐ Part Bounding Box
Min: -50. -50. -50.
Max: 50. 50. 50.

☑ Origin

Background Color
○ White
● Blue
○ Gray
○ Black

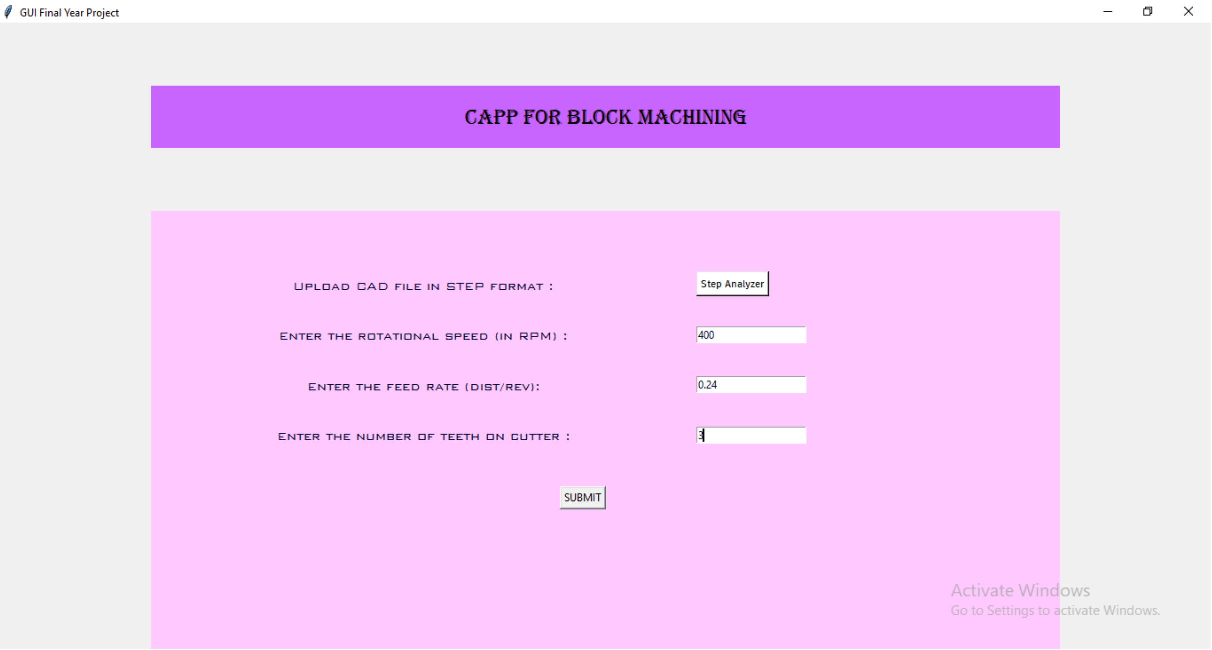
Transparency (approximate)

PageDown for Viewpoints. Key 'r' to restore, 'a' to view all. Use the mouse in 'Examine Mode' to rotate, pan, zoom.

Generated by the NIST STEP File Analyzer and Viewer 4.60 23 Oct 2021 14:34 NIST Disclaimer

Fig 3.5: Displaying image of cad file

Fig 3.6 shows the rest of the parameters which the user needs to enter.



UPLOAD CAD FILE IN STEP FORMAT :

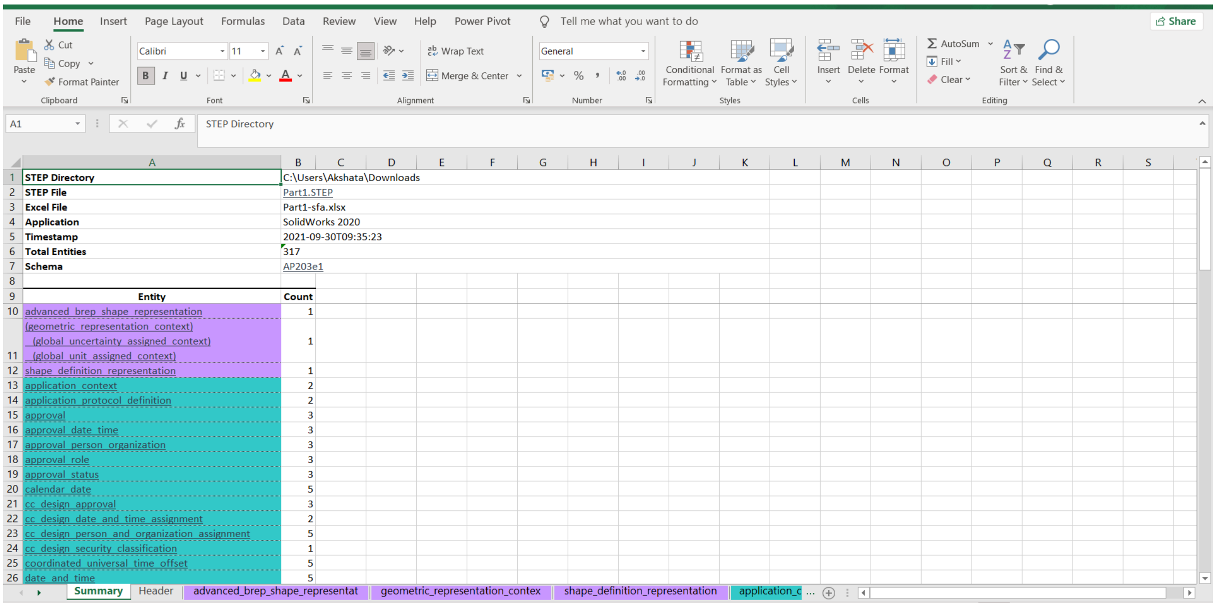
ENTER THE ROTATIONAL SPEED (IN RPM) : 400

ENTER THE FEED RATE (DIST/REV): 0.24

ENTER THE NUMBER OF TEETH ON CUTTER : 3

Fig 3.6: Entering further parameters

Fig 3.7 shows a snapshot of an excel file which is created automatically at the backend. This file contains all the features of the uploaded cad model - Date and Time on which the cad model was created, various features of the model, directory where the cad file is stored in the computer and many more.

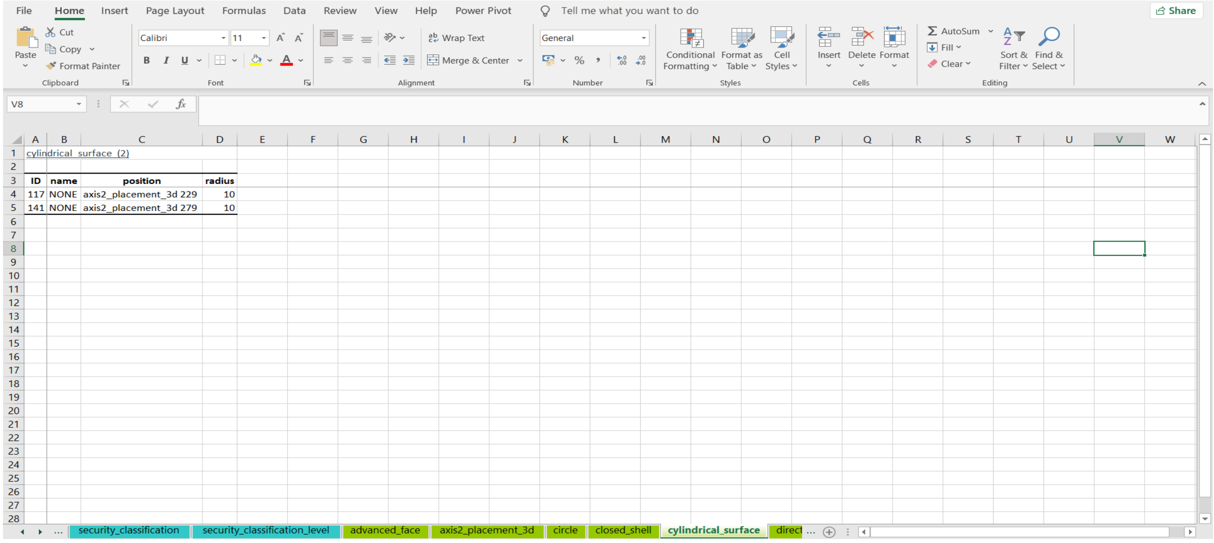


A1 STEP Directory

	A	B
1	**STEP Directory**	C:\Users\Akshata\Downloads
2	**STEP File**	Part1.STEP
3	**Excel File**	Part1-sfa.xlsx
4	**Application**	SolidWorks 2020
5	**Timestamp**	2021-09-30T09:35:23
6	**Total Entities**	317
7	**Schema**	AP203e1
8		
9	**Entity**	**Count**
10	advanced_brep_shape_representation	1
11	(geometric_representation_context) _(global_uncertainty_assigned_context) _(global_unit_assigned_context)	1
12	shape_definition_representation	1
13	application_context	2
14	application_protocol_definition	2
15	approval	3
16	approval_date_time	3
17	approval_person_organization	3
18	approval_role	3
19	approval_status	3
20	calendar_date	5
21	cc_design_approval	3
22	cc_design_date_and_time_assignment	2
23	cc_design_person_and_organization_assignment	5
24	cc_design_security_classification	1
25	coordinated_universal_time_offset	5
26	date_and_time	5

Fig 3.7: Generated Excel file

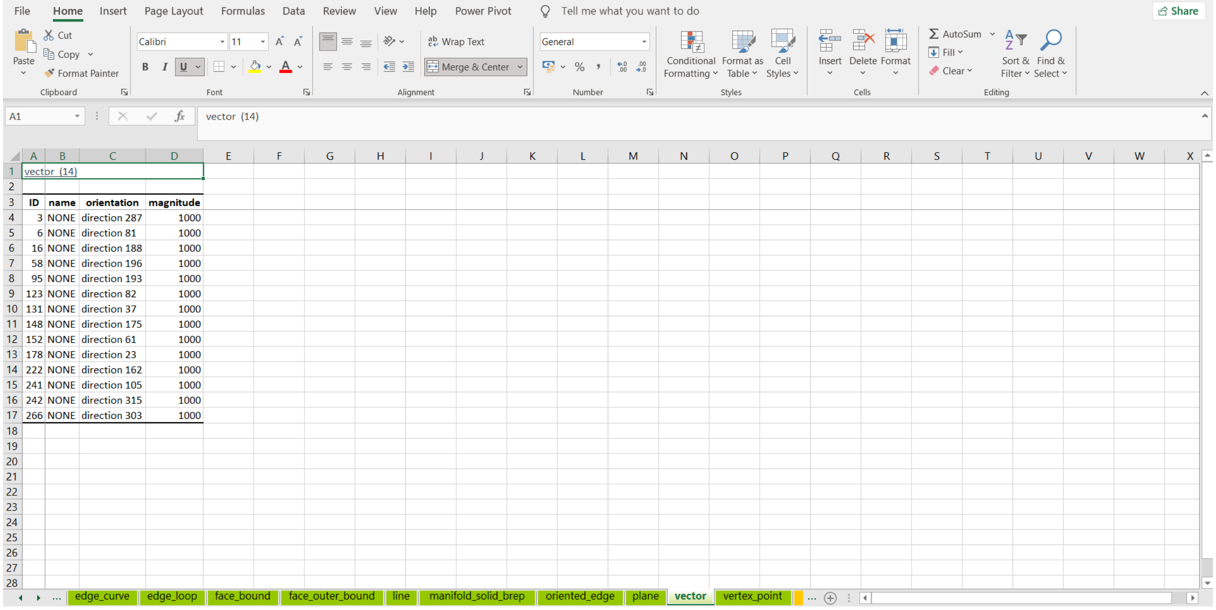
Fig 3.8 and Fig 3.9 show the hole and the block dimensions depicted on the excel file of the uploaded cad model.



cylindrical_surface (2)

ID	name	position	radius
117	NONE	axis2_placement_3d 229	10
141	NONE	axis2_placement_3d 279	10

Fig 3.8: Hole Dimensions

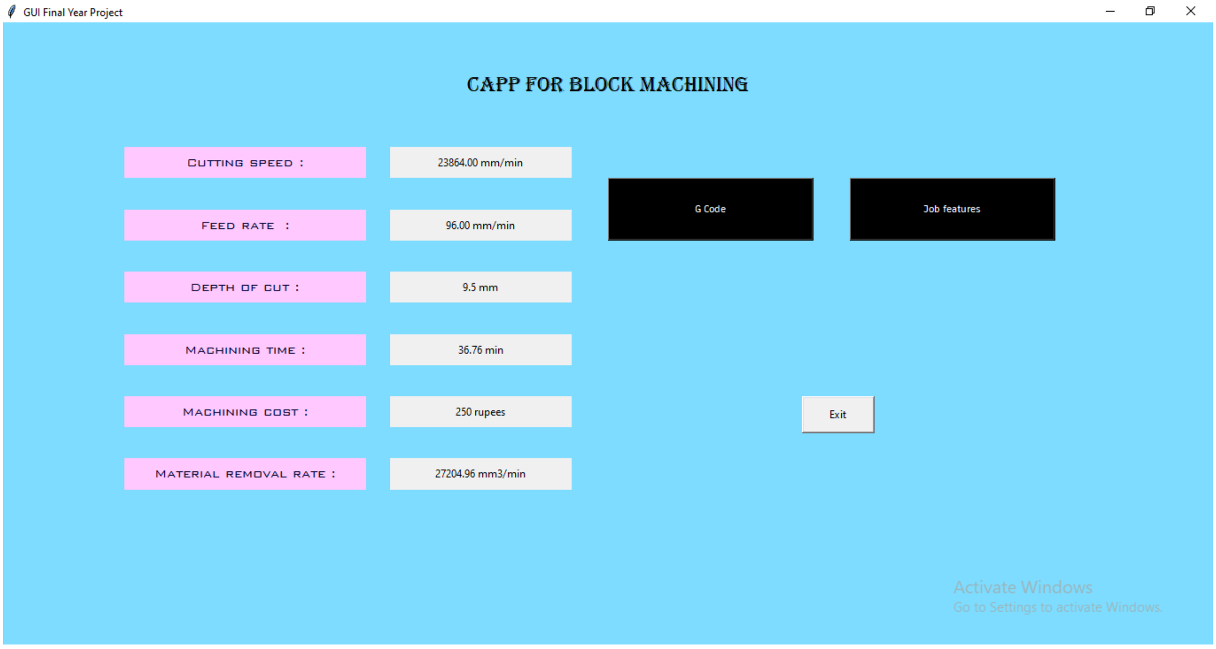


vector (14)

ID	name	orientation	magnitude
3	NONE	direction 287	1000
6	NONE	direction 81	1000
16	NONE	direction 188	1000
58	NONE	direction 196	1000
95	NONE	direction 193	1000
123	NONE	direction 82	1000
131	NONE	direction 37	1000
148	NONE	direction 175	1000
152	NONE	direction 61	1000
178	NONE	direction 23	1000
222	NONE	direction 162	1000
241	NONE	direction 105	1000
242	NONE	direction 315	1000
266	NONE	direction 303	1000

Fig 3.9: Block Dimensions

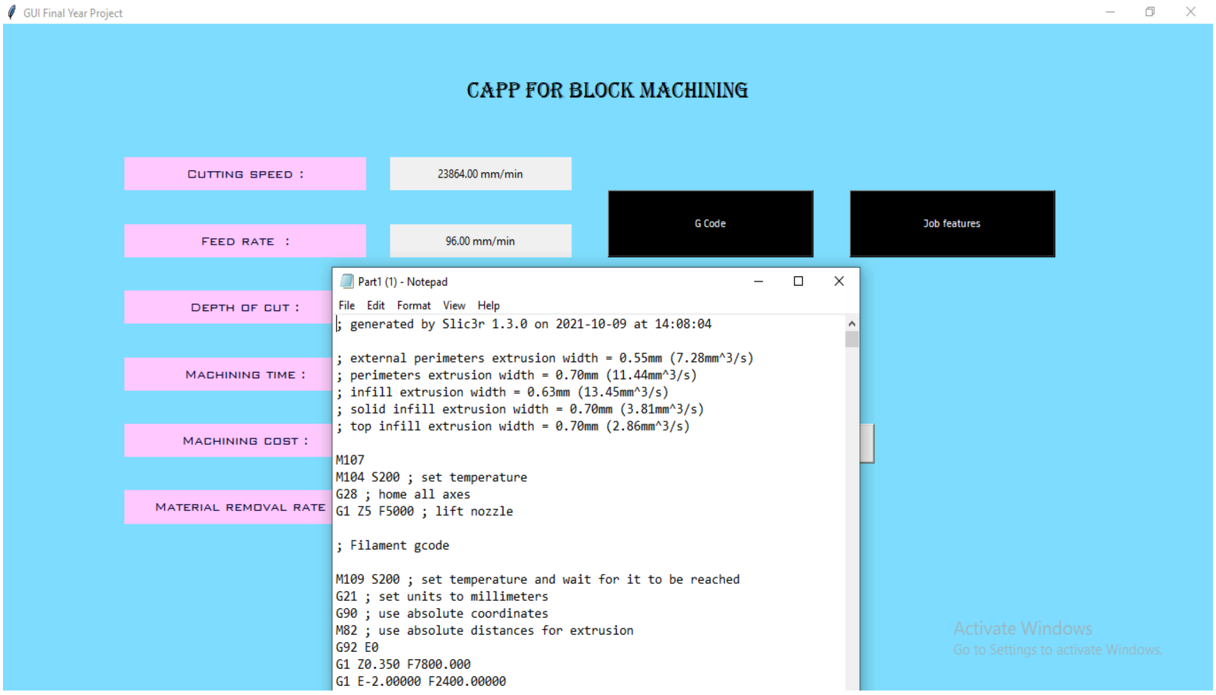
Fig 3.10 is the output page of the System seen in the GUI, with the various aforementioned parameters and their values.



CUTTING SPEED : 23864.00 mm/min
FEED RATE : 96.00 mm/min
DEPTH OF CUT : 9.5 mm
MACHINING TIME : 36.76 min
MACHINING COST : 250 rupees
MATERIAL REMOVAL RATE : 27204.96 mm3/min

Fig 3.10: Process Planning Parameter Output Page

Fig 3.11 is the snapshot of the G code which is directly generated when the user clicks the " G Code" tab on the output page.

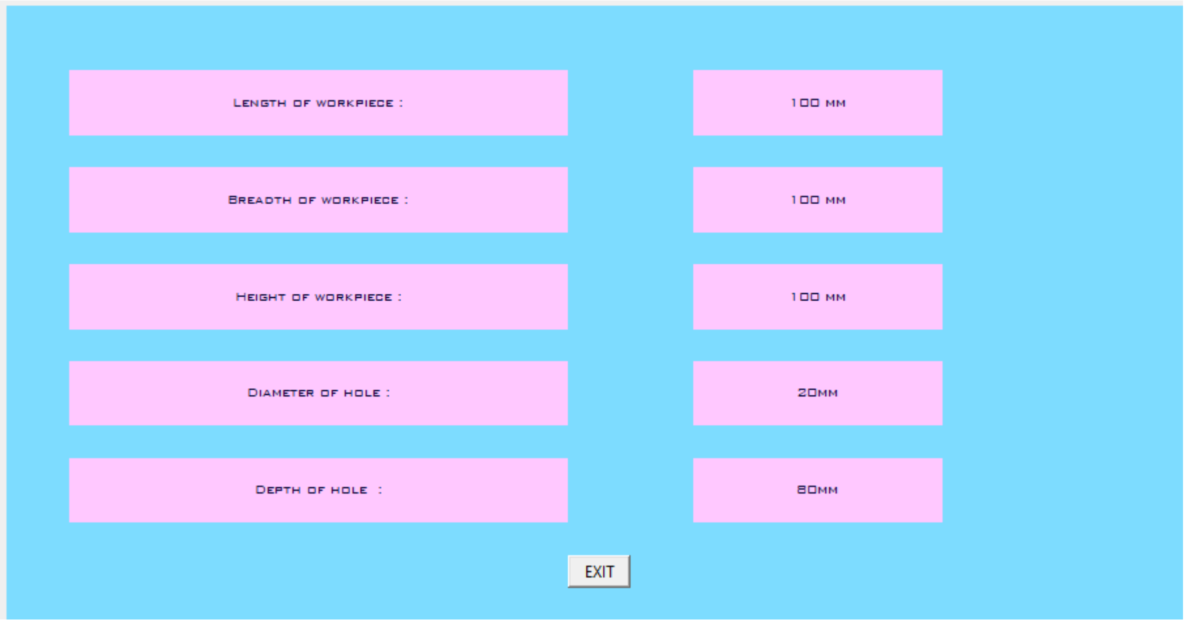


CUTTING SPEED : 23864.00 mm/min
FEED RATE : 96.00 mm/min

```
; generated by Slic3r 1.3.0 on 2021-10-09 at 14:08:04

; external perimeters extrusion width = 0.55mm (7.28mm^3/s)
; perimeters extrusion width = 0.70mm (11.44mm^3/s)
; infill extrusion width = 0.63mm (13.45mm^3/s)
; solid infill extrusion width = 0.70mm (3.81mm^3/s)
; top infill extrusion width = 0.70mm (2.86mm^3/s)

M107
M104 S200 ; set temperature
G28 ; home all axes
G1 Z5 F5000 ; lift nozzle

; Filament gcode

M109 S200 ; set temperature and wait for it to be reached
G21 ; set units to millimeters
G90 ; use absolute coordinates
M82 ; use absolute distances for extrusion
G92 E0
G1 Z0.350 F7800.000
G1 E-2.00000 F2400.00000
```

Fig 3.11: G-Code Output Page

Fig 3.12 is the output of the features and dimensions read by the Automatic Feature Recognition algorithm. The values can be seen alongside the parameters. This can be viewed by clicking the "Job Features" tab on the output page.



Length of workpiece : 100 mm

Breadth of workpiece : 100 mm

Height of workpiece : 100 mm

Diameter of hole : 20mm

Depth of hole : 80mm

Fig 3.12: Job features derived from the step file

3.6.2 Bar Casting

The GUI for bar casting gives us parameters related to the part, patter, mold volume and well as related parameters for pre-pouring such as heating the metal. The GUI is a helpful tool to determine all related answers to the processes involved in Sand Casting. Major research was conducted for material parameters. In this process, major research was focused on optimization of sand casting a bar by varying the material. The related output parameters have been calculated using the formulae from noteworthy research papers and books, thus increasing the credibility. Sand Casting can be labelled as one of the most dynamic and widely used forms of manufacturing. Its wide scope and number of approaches make it complex. The focus of our project is a step towards development and integration of computer aided process planning.

Casting of hollow bars is also given as an option as it saves material. In that case, a core made of wood will be used as a constant.

Fig 3.13 shows the user input parameters are necessary to obtain the required output. User input parameters: Length, Breadth, Height and/or Radius and the height of riser.

Select Material: Grey Cast Iron

Select the Bar Cross section: Rectangular

Select the Pattern Material: Metal(Grey Cast Iron)

Length: 200

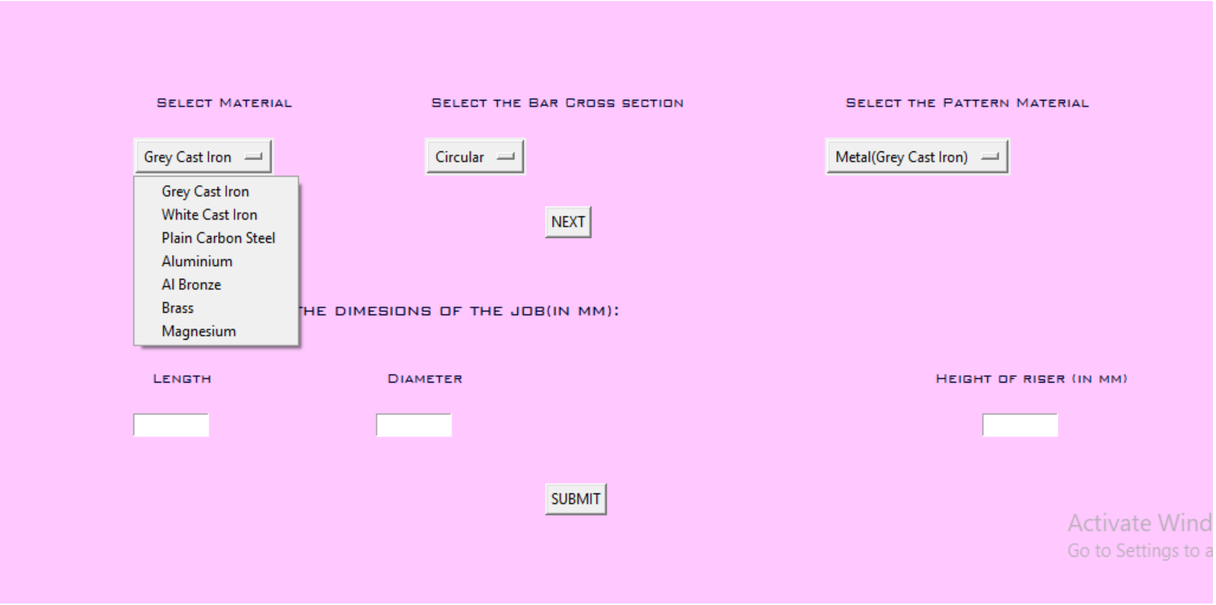
Breadth: 20

Height: 10

Height of riser (in mm):

Fig 3.13: Input page of bar casting

Fig 3.14 is a snapshot of casting material selection. It includes the following material options: Grey Cast Iron, White Cast Iron, Plain Carbon Steel, Aluminium, Brass, Al Bronze and Magnesium.



Select Material: Grey Cast Iron

Select the Bar Cross section: Circular

Select the Pattern Material: Metal(Grey Cast Iron)

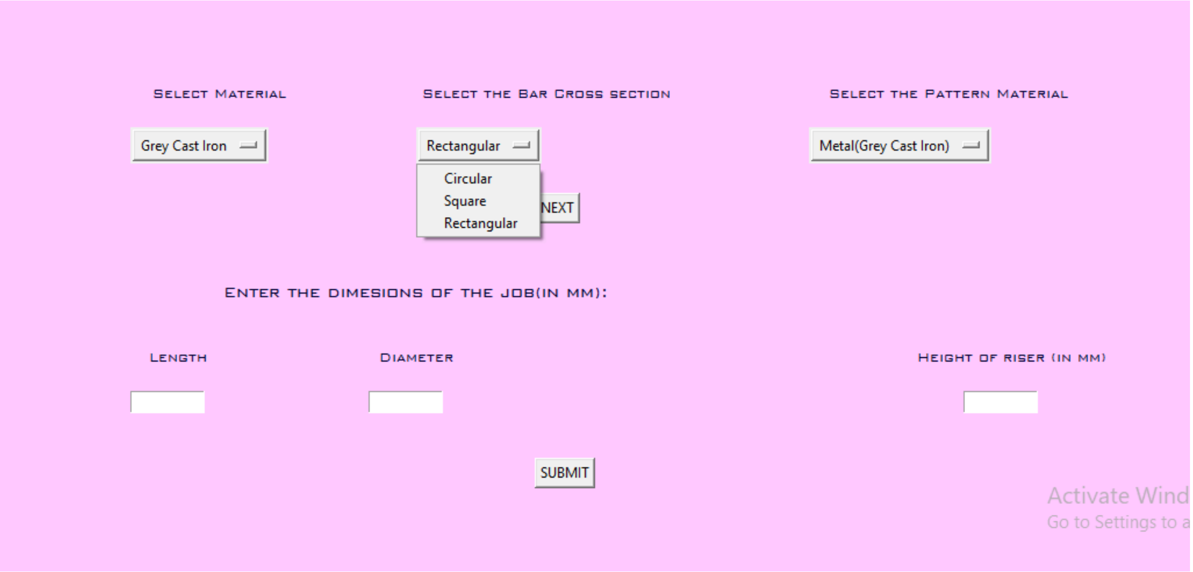
Length:

Diameter:

Height of riser (in mm):

Fig 3.14: Input page - casting material selection

Fig 3.15 is a snapshot of cross section type selection. The user will select the type of cross section for the required part from the dropdown menu. The provided options are: Rectangle, Square, Circular.



Select Material: Grey Cast Iron

Select the Bar Cross section: Rectangular

Select the Pattern Material: Metal(Grey Cast Iron)

Enter the dimesions of the job(in mm):

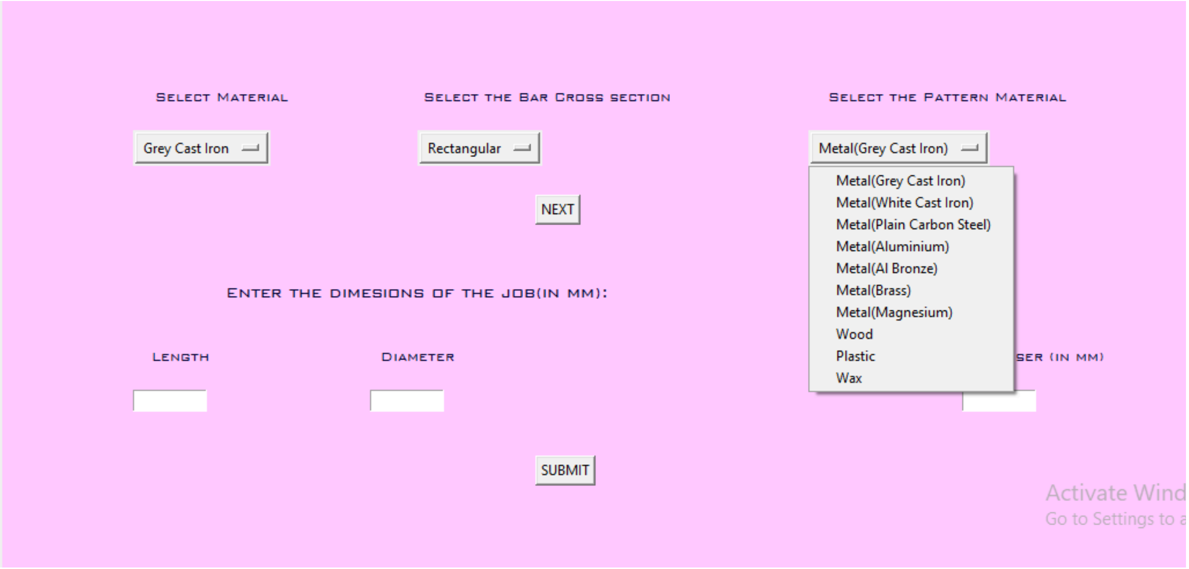
Length

Diameter

Height of riser (in mm)

Fig 3.15: Input page - cross section type selection

Fig 3.16 is a snapshot of the selection of the pattern material. This will also be through a dropdown menu. The user can choose from a list of varied options for his/her pattern material. Pattern material selection list is as follows: Metal (Grey Cast Iron, White Cast Iron, Plain Carbon Steel, Aluminium, Brass, Al Bronze, Magnesium), Wood, Plastic and Wax.



Select Material: Grey Cast Iron

Select the Bar Cross section: Rectangular

Select the Pattern Material: Metal(Grey Cast Iron)

Enter the dimesions of the job(in mm):

Length

Diameter

Fig 3.16: Input page - pattern material selection

Fig 3.17 is a snapshot of the output page. This page entails all vital information related to the sand casting process based on the parameters we've set. This process is helpful to generate a process plan in casting industries.

CAPP FOR CASTING

Part material : Grey Cast Iron
Part length : 200
Part breadth : 20
Part height : 10
Part volume (in cubic mm): 40000
Part surface area (in sq mm): 12400
Pattern length (in mm): 203.011
Pattern breadth (in mm): 23.359
Pattern height (in mm): 13.011
Pattern volume (in cubic mm): 61700
Pattern surface area (in sq mm): 15374

Riser volume (in cubic mm): 98174.77

Mold volume (in cubic mm): 85261.944
Mold surface area (in sq mm): 24798.777

Heat required to reach pouring temp (in kJ) : 314.989
Volumetric flow rate (in cubic mm / sec) : 6024.003
Time required to fill the mold cavity (in secs) : 14.154
Solidification time of riser(in secs) : 93.75
Solidification time of cavity (in secs) : 9.66

Fig 3.17: Output page - parameters obtained

The output parameters are as follows:

- Part Material
- Part Dimension
- Part Volume
- Part Surface Area
- Pattern Volume
- Pattern Surface Area
- Riser Volume
- Mould Volume
- Mould Surface Area
- Heat Required to reach pouring temperature of the metal
- Volumetric Flow Rate

- Time required to fill the mould cavity
- Solidification Time

It is also known that the solidification time of the riser should be greater than the solidification time of the cavity. By reducing the height of the riser, the solidification time can be reduced. However, beyond a certain limit, if the height of the riser is reduced, the solidification time of the riser will be lesser than the solidification time of the metal in the mold cavity. This is an undesirable phenomenon in any casting process as it drastically affects the atomic arrangement and strength of the solidified metal, due to the formation of cracks and/or bubbles. [20]

Figure 3.18 is a flowchart of the detailed steps of bar casting. This is a simplified format to understand the backend functioning of the GUI for the bar casting process.

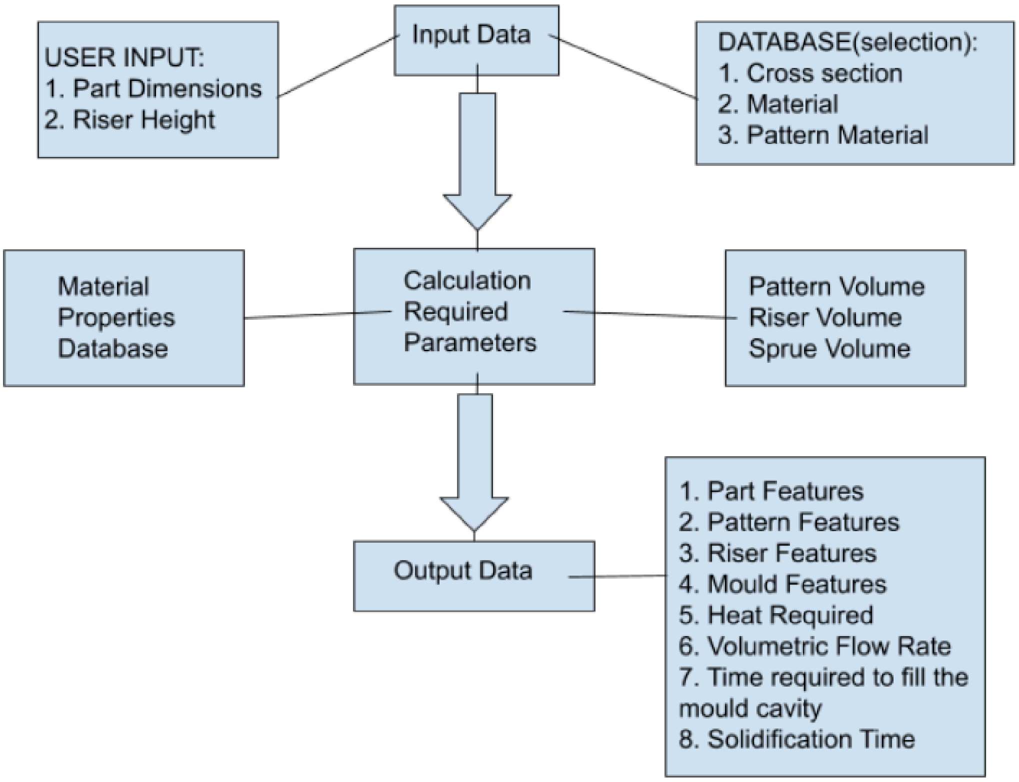


Fig 3.18: Process Flowchart for Sand Casting a Bar

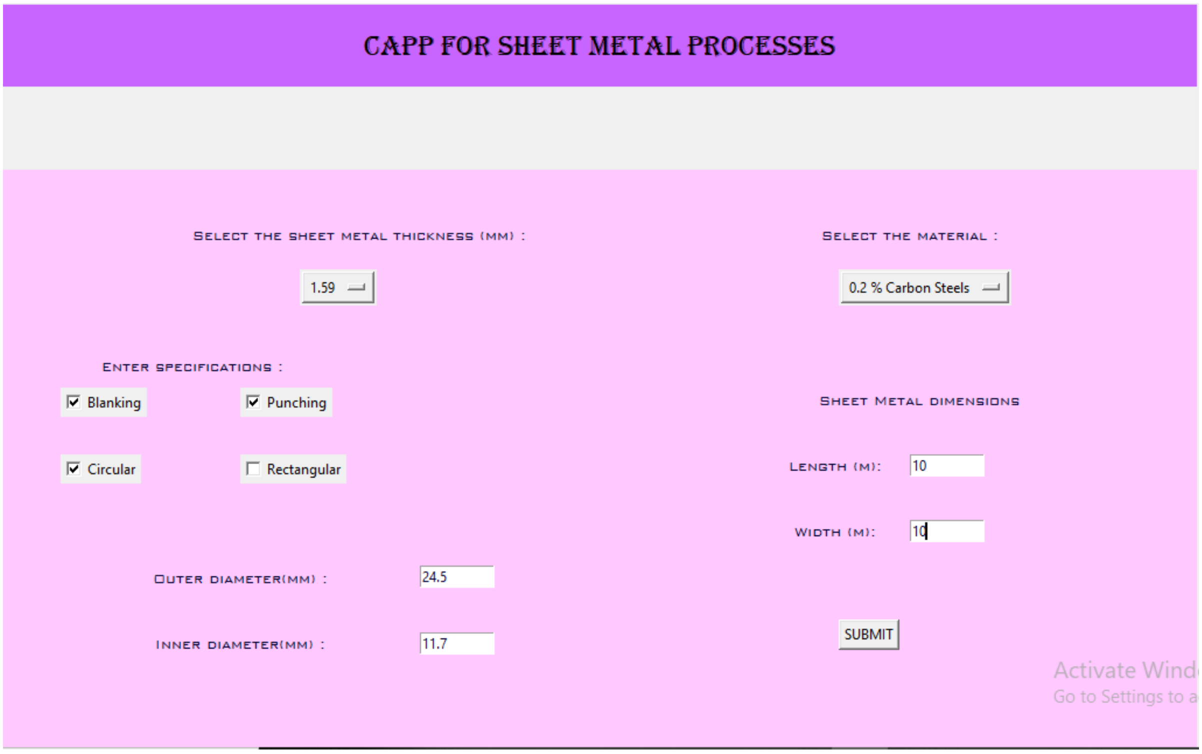
3.6.3 Sheet Metal Working

In the Sheet Metal Process, the user can choose the thickness of sheet metal by selecting a standard gauge length value. Gauge is a common term used to denote the thickness of the sheet metal. The larger the gauge number, the thinner the metal. Commonly used steel sheet metal ranges from 26 gauge to about 3 gauge. Gauge differs between ferrous (iron-based) metals and nonferrous metals such as aluminum or copper. Cutting changes the size of the sheet and can also be used to cut the metal into different shapes. Comparatively, punches perforate the sheet and cut specific shapes out of the metal.

List of Parameters:

- Thickness of sheet metal
- Material of sheet metal
- Dimensions of the job
- Batch dimensions of the sheet metal

Fig 3.19 Is the input page of sheet metal working. Here, the user is required to select the material and the thickness from the database (drop-down menu). The user is also given the option of selecting among operations, blanking, punching or both. The user can select the shape of the hole or blank to be cut. The user has to input certain dimensions as well before executing the program.



CAPP FOR SHEET METAL PROCESSES

SELECT THE SHEET METAL THICKNESS (MM) : 1.59

SELECT THE MATERIAL : 0.2 % Carbon Steels

ENTER SPECIFICATIONS :

☑ Blanking ☑ Punching

☑ Circular ☐ Rectangular

OUTER DIAMETER(MM) : 24.5

INNER DIAMETER(MM) : 11.7

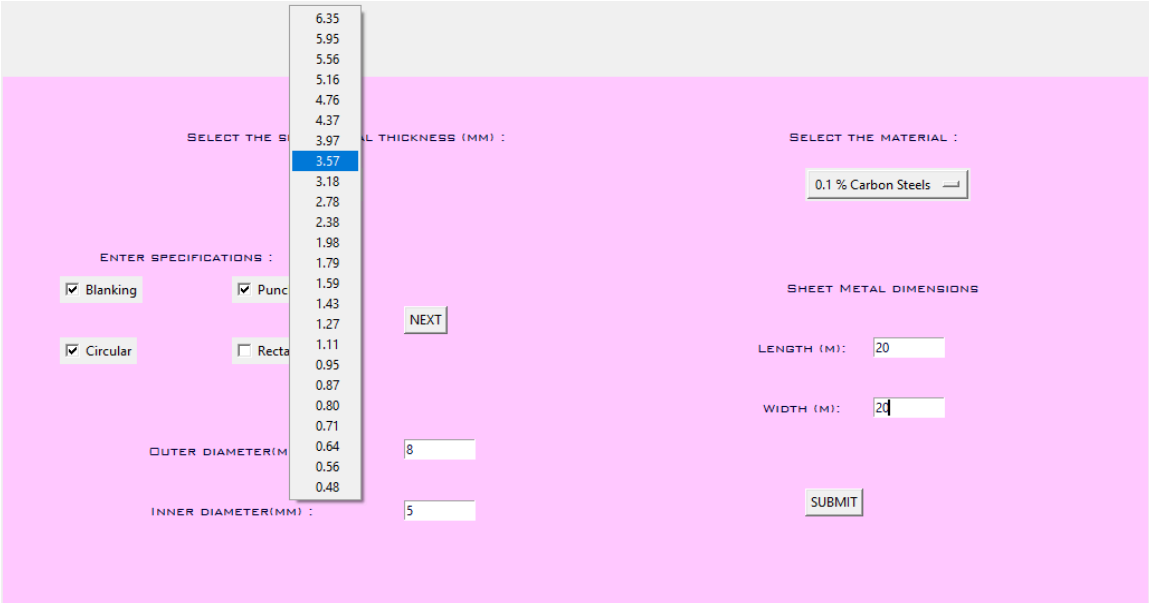
SHEET METAL DIMENSIONS

LENGTH (M): 10

WIDTH (M): 10

Fig 3.19: Input page of sheet metal operations

Fig 3.20 shows the drop down menu for selection of sheet metal thickness. The range varies from 0.48 mm to 6.35 mm. Anything below 0.48mm is a foil whereas anything above 6.35mm is a plate.



SELECT THE S L THICKNESS (MM) :

SELECT THE MATERIAL : 0.1 % Carbon Steels

ENTER SPECIFICATIONS :

☑ Blanking ☑ Punc

☑ Circular ☐ Recta

SHEET METAL DIMENSIONS

LENGTH (M): 20

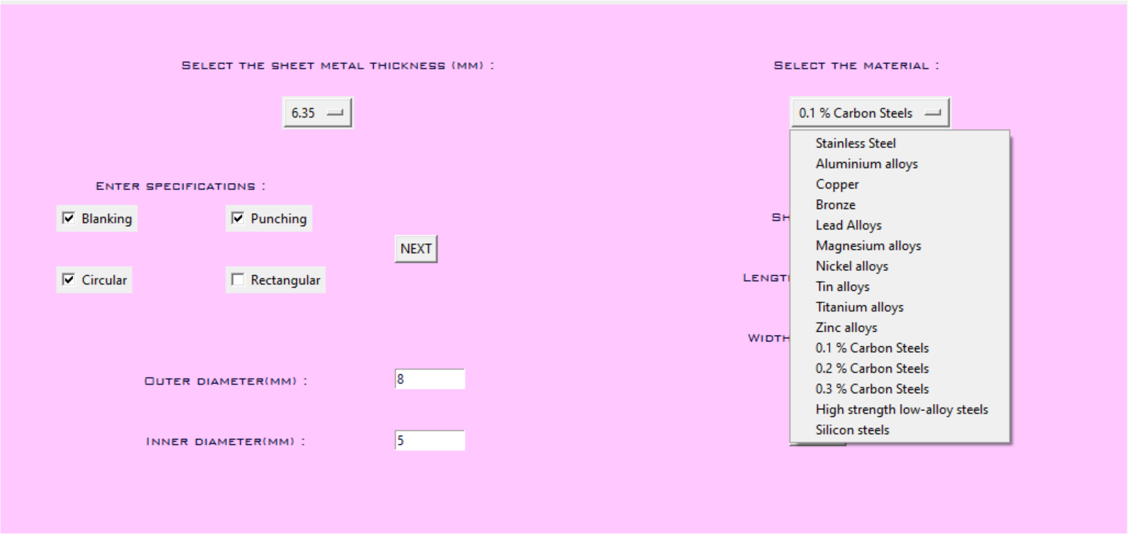
WIDTH (M): 20

OUTER DIAMETER(M 8

INNER DIAMETER(MM) : 5

Fig 3.20: Input page - selecting thickness

Fig 3.21 is the input page that shows the drop-down menu for material selection. There is a list of materials in the database defined based on the uses in the industry. The user can select from the list below. The variety in material selection will help the user get more defined values and suit his/her needs.



SELECT THE SHEET METAL THICKNESS (MM) : 6.35

SELECT THE MATERIAL : 0.1 % Carbon Steels

ENTER SPECIFICATIONS :

☑ Blanking ☑ Punching

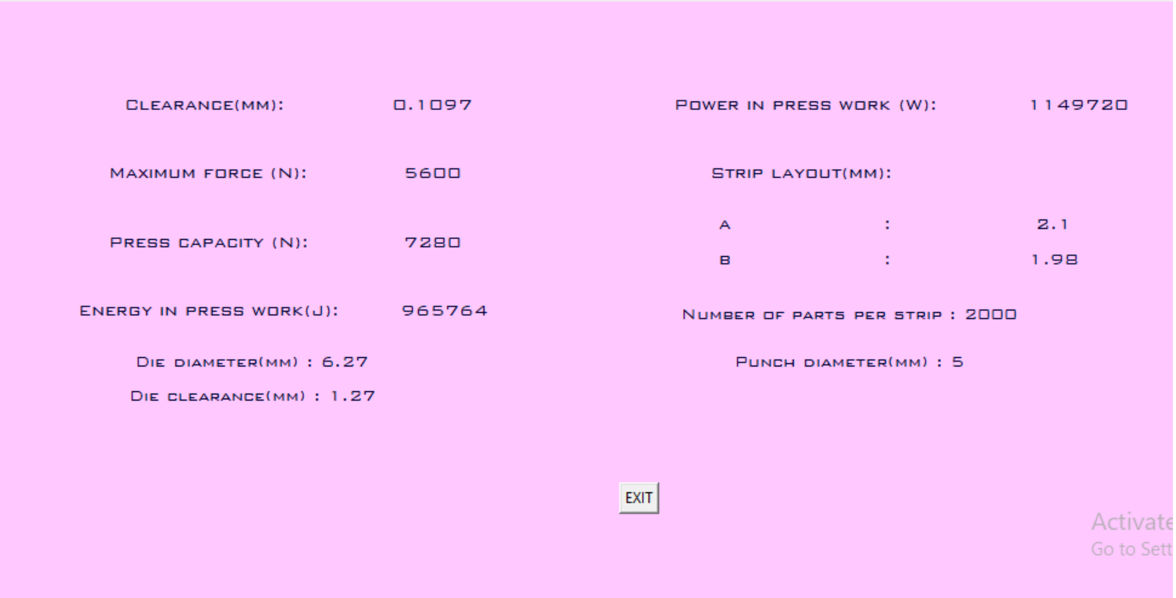
☑ Circular ☐ Rectangular

OUTER DIAMETER(MM) : 8

INNER DIAMETER(MM) : 5

Fig 3.21: Input page - selecting metal

Fig 3.22 shows us the output for sheet metal working. The user can use the obtained values for further study and process planning. The output obtained will assist the user to improve his/her process plan by creating a model, thus the accuracy is improved.



Clearance(mm): 0.1097

Maximum force (N): 5600

Press capacity (N): 7280

Energy in press work(J): 965764

Die diameter(mm) : 6.27

Die clearance(mm) : 1.27

Power in press work (W): 1149720

Strip layout(mm):

A : 2.1

B : 1.98

Number of parts per strip : 2000

Punch diameter(mm) : 5

Fig 3.22: Output page of sheet metal operation

Fig 3.23 summarises the entire methodology for sheet metal operations in the form of a flowchart.

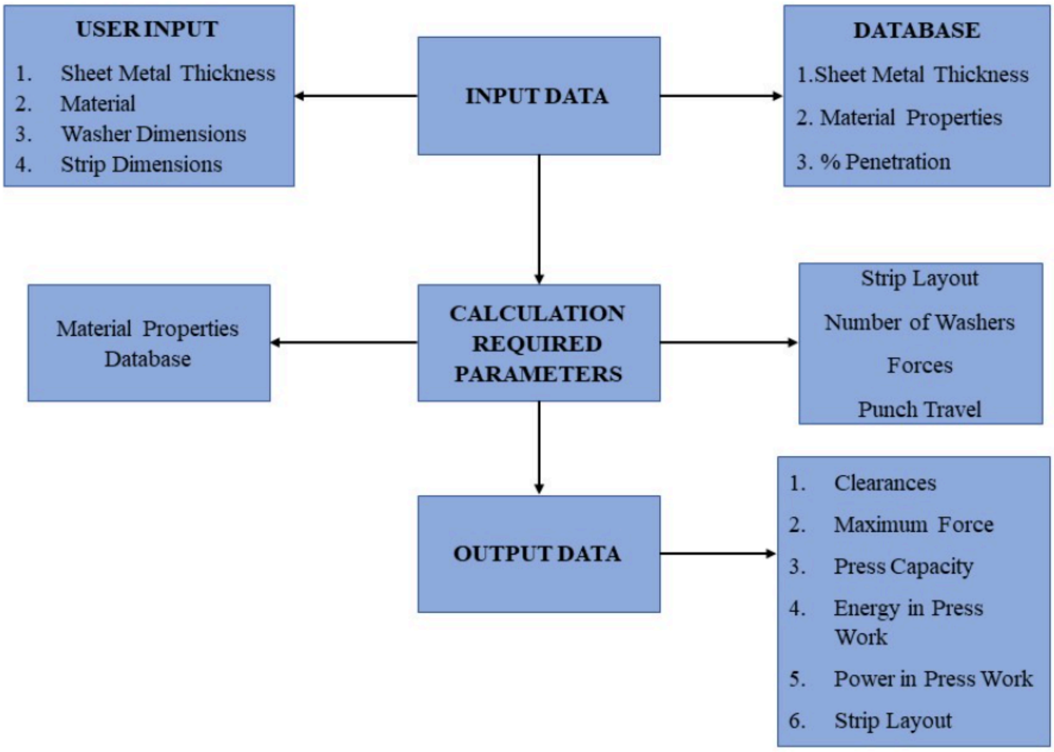


Fig 3.23: Process Flow Chart for Sheet metal working (punching and/or blanking)

Chapter 4

Case Study

To understand the working of our GUI in the real world, various industry applications, for each of the operations, were referred to and then simulated in our GUI. The values and comparative study of the same can be seen in this chapter.

4.1 Case Study Of Block Machining

This chapter entails the case study related to block machining. A real world application is referred to and the output of real data is compared with the data obtained from output GUI. The results can be seen below.

4.1.1 Industry Standards

A research paper titled "Computer Aided Process Planning Approach for Cost Reduction and Increase in Throughput" was referred in order to get the values for specific operations according to industry standards.

4.1.2 The Case

This section focuses on the utilization of GUI to determine process planning attributes.

Figure 4.1 (a) shows the initial stock dimensions of the part that has to be machined by using process planning and figure 4.1 (b) explains the final dimensions of the part after applying process planning by using machining processes. The product is a fixture that is used to hold parts prior to machining.

<u>Part Specifications:</u>

- Material: Gray Cast Iron.
- Heat treatment condition: annealed.
- Hardness: 150 Bhn.
- Melting point: 2,200 ºF

The part is a fixture used to drill axial holes in hollow cylinders with significant lengths. The details for the stock and produced part are illustrated below:

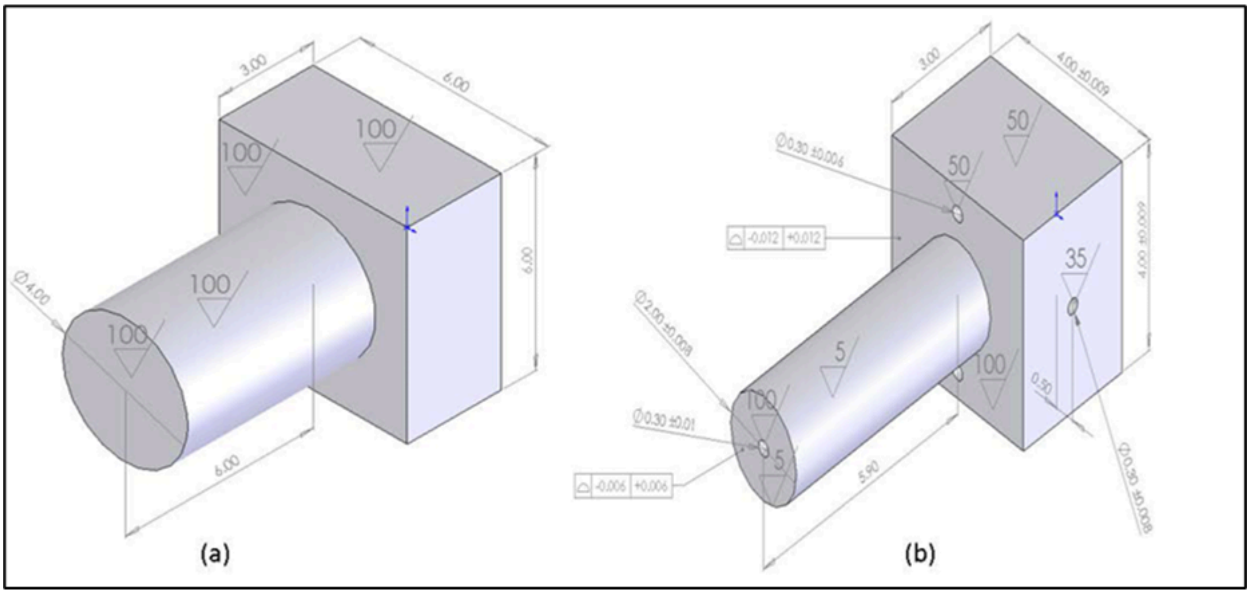


Fig 4.1: Dimensions of stock (a) without hole (b) with hole

Details about features to be machined (Drilling)

- Axial hole in the cylinder. Diameter = 0.3 inch. Length = 0.5 inch.
- Two non-axial holes in the side of the block. Diameter = 0.3 inch. Length = 0.5 inch.
- Two holes on the surface G. Diameter = 0.3 inch. Length = 0.5 inch.

Input Parameters: (For 1 hole)

- Feed Rate: 0.035 distance/rev
- Rotational Speed: 400 rpm
- Number of teeth on cutter: 3

Output Parameters: (For 1 hole)

- Cutting Speed: 9,570.72 mm/min
- Feed Rate: 14 mm/min
- Depth of Cut: 12.7 mm
- Material Removal Rate: 0.0388 inch^3/min
- Machining Time: 0.91 minute for 1 hole.
- Machining Cost: Rs 25

Table No. 4.1 is the comparison between industry based practical values and values obtained from GUI for block machining.

Table No. 4.1 : Comparison of Industry and GUI values for Block machining

Parameters	Industry Values	GUI Output
Cutting Speed	9,570.72 mm/minute	9,570.72 mm/minute
Feed Rate	14 mm/minute	14 mm/minute
Depth of Cut	12.7 mm	12.7 mm
Material Removal Rate	0.0388 inch^3/minute	0.0388 inch^3/minute
Machining Time	0.91 minute per hole	0.91 minute per hole

4.2 Case Study Of Bar Casting

This chapter entails the case study related to bar casting. A real world application is referred to and the output of real data is compared with the data obtained from output GUI. The results can be seen below.

4.2.1 Industry Standards

A report titled "A Final Report for the American Metalcasting Consortium (AMC) Research Program: Casting Solutions for Readiness (CSR) - Modeling of Steel Casting Performance: Dimensions and Distortion " was referred in order to get the values for specific operations according to industry standards.

4.2.2 The Case

This section focuses on the utilization of GUI to determine process planning attributes for the following job through the bar casting process of ASTM A216 grade WCB carbon steel, prepared in an induction furnace at 250 lb heat at 1873 K, performed at University of Northern Iowa's Metal Casting Centre.

Part specifications:

1. Material = Low Carbon Steel
2. Type of cross section of bar = Square
3. Length of bar = 305 mm
4. Area of cross section = 25 mm x 25 mm
5. Height of riser = 50 mm

Output

- Part Volume = 190,625 mm^3
- Part Surface Area = 30,500 mm^2
- Pattern Volume = 247,154.65 mm^3
- Pattern Surface Area = 34,933.5 mm^2
- Riser Volume = 290,564.4 mm^3
- Mold Volume = 260,554.6 mm^3

- Mold Surface Area = 55,682.4 mm^2
- Heat required to reach pouring Temperature = 450.35 kJ
- Volumetric Flow Rate = 6,030 mm^3/s
- Time required to fill the Mold Cavity = 21 seconds
- Solidification Time of Riser = 124.5 seconds
- Solidification Time of Cavity = 36.4 seconds

Table No. 4.2 is the comparison between industry based practical values and values obtained from GUI for bar casting.

Table No. 4.2: Comparison of Industry and GUI values for Bar Casting

Parameters	**Industry Values**	**GUI Output**
Part Volume	190,625 mm^3	190,625 mm^3
Part Surface Area	30,500 mm^2	30,500 mm^2
Pattern Volume	247,154.6 mm^3	247,464.5 mm^3
Pattern Surface Area	34,933.5 mm^2	35,072.4 mm^2
Riser Volume	290,564.4 mm^3	290,892.4 mm^3
Mould Volume	260,554.6 mm^3	263,675.6 mm^3
Mould Surface Area	55,682.4 mm^2	56,824.84 mm^2
Heat required to reach Pouring Temperature	450.3 kJ	469.84 kJ
Volumetric Flow Rate	6,030 mm^3/s	6,367 mm^3/s
Time required to fill Mould Cavity	21 seconds	48 seconds
Solidification time of Riser	164 seconds	124.5 seconds
Solidification time of Cavity	56 seconds	36.4 seconds

4.3 Case Study Of Sheet Metal Operations

This chapter entails the case study related to sheet metal working. A real world application is referred to and the output of real data is compared with the data obtained from output GUI. The results can be seen below.

4.3.1 Industry Standards

A research paper titled "Integrated CAD/CAPP/CAM and ANN in Sheet Metal Punching and Nibbling Operations" was referenced in order to get the values for specific operations according to industry standards.

4.3.2 The Case

This section focuses on the utilization of GUI to determine process planning attributes for the following job through sheet metal operations.

Part Specifications:

1. Inner Dia = 12.7 mm
2. Outer Dia = 25.4 mm
3. Thickness = 1.5 mm
4. Material = 0.2% Carbon Steel (τ = 3,08-385 N/mm2)
5. Number of strokes per min = 20,
6. Stock Dimensions = 10 m x 10 m

Output:

- Clearance = $0.0032 (t)\sqrt{\tau}$

  = 0.0893 mm

- $F_1 = \Pi D_o t \tau$

  = 41.474 kN

  $F_2 = \Pi D_i t \tau$

  = 20.737 kN

$F_t = F_1 + F_2$

= 62.211 kN

- Press Capacity = F_{max} x C …… (where, C = 1.2-1.5)

  = 83.98 kN

- Energy in Press Work = Press Capacity x K x t ….. (where, K = % Penetration = 80% for t < 1.6 mm)

  E = 100.781 kJ

- Power in Press Work = E x na60 x = 44.7914 kW
- Push Through Force on Blank = 10% of F_{max} = 6.22 kN
- Horizontal Force on Punch and Die = $F_{HD} = F_{HP} = 0.15 \times 0.25 \times F_{max}$

  = 2.33 kN

- Strip Layout

  a= t + 0.0015 x Outer Dia.

  a= 1.5381 mm

  b = 1.5 mm (t lies between 0.5 & 3.2, hence b = t)

  c = Outer dia + b = 26.9 mm

  Number of parts per strip (N) = Stock Length in mm / c in mm

  N = 37 parts

Table No. 4.3 is the comparison between industry based practical values and values obtained from GUI for sheet metal.

Table No. 4.3: Comparison of Industry and GUI values for Sheet Metal Operations

Parameters	**Industry Values**	**GUI Output**
Clearance	0.0893 mm	0.09107 mm
Maximum Force (F_{max})	62.2 kN	64.635 kN
Press Capacity	83.9 kN	84.025 kN
Energy in Press Work	100.7 kJ	100.83 kJ
Power in Press Work	44.7 kW	42.012 kW
Push through force on Blank	6.2 kN	6.46 kN
Horizontal force on Punch and Die	2.3 kN	2.43 kN
Strip Layout		

Back Scrap (a)	1.5381	1.5381
Scrap Bridge (b)	1.5	1.5
c	26.9	26.9
Number of parts per strip (N)	37	37

Thus, separate and independent case studies were successfully carried out for the operations of block machining, bar casting and sheet metal operations. The results from the GUI were in conformity with the values from the industry, barring the differences caused due to practical reasons. The positive results from the case studies confirm the efficiency of the GUI and proves the software to be reliable and be used as a tool in the industry, for automating process planning systems.

Chapter 5

Conclusion

The objective of this project was to develop a GUI which would automate process planning systems for the operations of block machining, bar casting and sheet metal processes, which was duly accomplished by the end of the project. A GUI was developed using Python programming language and an extensive database was prepared for the same, which renders the GUI as a working software. After the successful completion of the GUI for a CAPP system for block machining, sheet metal operation and casting operation, separate case studies were carried out for each of the operations to verify our calculations and to determine the efficiency of our software.

Since block machining is the operation that has been more explored in the recent past years out of the three operations concerned in this project, it was decided to start with the CAPP system for block machining. This helped get accustomed to the tasks and get a hint of the challenges involved.

With this momentum, the second leg of the project, casting process, was started. Sand casting process was incorporated as it is commonly used in the industry and can be used with a variety of metals. Sand Casting parameters were thoroughly researched upon and included in the project. Using AFR software was not feasible as the project would delve deep into AI & DL, although a step has been taken towards automation in process planning.

The next phase of the project was sheet metal operations, which was done after casting. The operations of blanking, punching in sheet metal operations software, were incorporated for a wide range of metals that are used in the industry for sheet metal operations.

After the completion of the GUI, case studies were carried out separately for each of the operations to verify the calculations and to determine the efficiency of the software. The results were positive and favourable and proved the reliability of the project outcome.

For future development of this software/GUI, the number of operations coming under the three main operations can be increased. The number of major operations can be increased as well. If extensive work is done with the help of neural networks and artificial intelligence, AFR can be heavily and accurately used in the GUI, which would further automate process planning systems and would aid workers in the industry to produce more accurate products at a faster rate. The database of the GUI can be vastly expanded according to the demands of the industry. Individual companies can personalise the GUI according to their requirements and areas of service.

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