T.C.
ISTANBUL GEDİK UNIVERSITY
INSTITUTE OF GRADUATE STUDIES

MANAGING THE PROCESS PLANNING AND MANUFACTURING AUTOMATION

MASTER'S THESIS

Sarah ALAMEEN

Engineering Management Department

Engineering Management Master in English Program

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İSTANBUL GEDİK ÜNİVERSİTESİ
LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ MÜDÜRLÜĞÜ

Yüksek Lisans Tez Onay Belgesi

Enstitümüz, Engineering Management Department İngilizce Tezli Yüksek Lisans Programı (201281002) Sarah Alameen'nin "Managing the Process Planning and Manufacturing Automation" adlı tez çalışması Enstitümüz Yönetim Kurulunun 02.08.2022 tarihinde oluşturulan jüri tarafından *Oy Birliği* ile Yüksek Lisans tezi olarak *Kabul* edilmiştir.

Öğretim Üyesi Adı Soyadı

Tez Savunma Tarihi: (02/08/2022)

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3) Jüri Üyesi: Dr. Öğr. Üyesi Murat SAĞBAŞ

DECLARATION

I, Sarah ALAMEEN, do hereby declare that this thesis titled "Managing the Process Planning and Manufacturing Automation" is original work done by me for the award of the master's degree in the Faculty of Engineering Management. I also declare that this thesis or any part of it has not been submitted and presented for any other degree or research paper in any other university or institution. (02/08/2022)

Sarah ALAMEEN

DEDICATION

To my dear father who was an example of the ideal supportive father for his daughter, my mother who surrounded me all the time with her prayers and love, my sisters and brothers who shared with me every happy or sad moment, to my friends who were the best support in my life.

To everyone who passed through my life leaving a good impact, I am nothing but the outcome of what I have gone through, and perhaps I was not able to express my thanks before in an adequate way, this is a good time to express my gratitude for everything that has happened to me in my life to make me who I am today

This work was done with a little effort from me and great support from everyone around me

PREFACE

I will start this thesis in the name of Allah with my full feeling of gratitude and thanks for His unlimited gifts and success, without whom I would not have reached what I have reached. Thank you, O God, for every time I thought that I would not be able to overcome the difficulties, but He gives me enough strength, patience, and wisdom to continue.

To my teacher, who guided me through this long journey and made it full of knowledge and benefit, during which he spent a lot of effort and time without getting bored, thank you to Dr. Mazin Alwswasi at the University Of Technology in Baghdad (UOT).

A special thanks to Dr. Tuğbay Burçin GÜMÜŞ who helped me constantly without waiting for anything in return as he was a symbol of giving and I was fortunate enough to choose him as my supervisor from the beginning.

Thanks are due to the wonderful Prof. Dr. Gözde Ulutagay and to every teacher who has passed in my life. I owe them a lot of gratitude you are the lights in our lives.

To my lovely parents and all my family, who were always in my back, helping and supporting me unconditionally, and to all my friends thanks a lot for being part of my success. While I cannot express enough thanks to my companion in my path, Sara Omair, you were with me in every step I took, you were the friend and guide to all the hardships I faced.

I cannot forget to thank my boss and all my co-workers. This is for reminding me that I would never have succeeded without their support and patience for my shortcomings at work. You were my second family, Thank you.

July 2022 Sarah ALAMEEN

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LIST OF ABBREVIATIONS

2D	: Two Dimensions
3D	: Three Dimensions
ACAPP	: Automated Computer Aided Process Planning
AFR	: Automatic Feature Recognition
CAD	: Computer-Aided Design
CAM	: Computer-Aided Manufacturing
CAPP	: Computer Aided Process Planning
GD&T	: Geometric dimensioning and tolerancing
IGES	: Initial Graphic Exchange Specification
NC	: Numerical Control
CNC	: Computer Numerical Control
PDE	: Product Data Exchange
DXF	: Drawing Exchange Format
STEP	: Standard for the Exchange of Product

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MANAGING THE PROCESS PLANNING AND MANUFACTURING AUTOMATION

ABSTRACT

This work depends on the principle of automation of manufacturing processes to keep pace with the rapid development in the field of manufacturing, and the field of manufacturing rotary parts through CNC (Computer Numerical Control) machines is one of the important areas that enter almost any industrial manufacturing line. Both the CAD (computer aided design) and CAM (computer aided manufacturing) stages got abundant efforts to advance them to advanced stages, and on the contrary, the CAPP (computer aided process planning) stage remained late. This research is to develop this stage and make as much as possible from it automatic to reduce human intervention to ensure speed and low cost, while avoiding all possible errors.

STEP (Standard for the Exchange of Product) File is the method that will be used to transfer information from the designer to the CAPP stage to plan the manufacturing process, by developing an AFR (Automatic Feature Recognition) system that can analyze all the information that the STEP file provides and recognize the intermediate and final features of the design and extract all their data automatically to be presented to the user.

Keywords: *ACAPP system, Smart manufacturing, Step file, Intermediate features, Automation*

SÜREÇ PLANLAMA YÖNETİMİ VE ÜRETİM OTOMASYONU

ÖZET

Üretim süreçlerinin otomasyonu ilkesine dayanmaktadır ve CNC Bilgisayarlı Sayısal Kontrol makineleri ile döner parça üretimi alanı hemen hemen her endüstriyel üretim hattına giren önemli alanlardan biridir. Hem CAD bilgisayar destekli tasarım hem de CAM bilgisayar destekli üretim aşamaları, onları ileri aşamalara taşımak için bolca çaba harcadı ve tam tersine, CAPP (bilgisayar destekli süreç planlama) aşaması geç kaldı. Bu araştırma, bu aşamayı geliştirmek ve olası tüm hatalardan kaçınırken, hız ve düşük maliyet sağlamak için insan müdahalesini azaltmak için mümkün olduğunca otomatik hale getirmektir.

STEP Ürün Dosyası Değişimi Standardı, STEP'in tüm bilgilerini analiz edebilen bir AFR (Otomatik Özellik Tanıma) sistemi geliştirerek, imalat sürecini planlamak için tasarımcıdan CAPP aşamasına bilgi aktarmak için kullanılacak yöntemdir. dosya tasarımın ara ve son özelliklerini sağlar ve tanır ve tüm verilerini otomatik olarak çıkararak kullanıcıya sunar.

Anahtar Kelimeler: *ACAPP sistemi, Akıllı imalat, STEP dosyası, Ara özellikler, Otomasyon*

1. INTRODUCTION

1.1 Introduction

The competition in the global markets has become at a high level and new requirements appeared, that brings us to an important question;

What are the most important requirements to compete in the global or local market?

A fundamental question that leads to different supply chains consists of several factors that complement each other, starting from sources (suppliers) and ending with marketing and consumer (end-user).

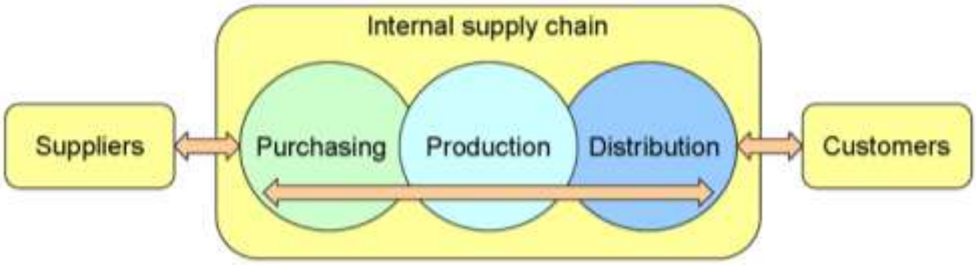


Figure 1.1: Supply Chain

Source: (Felea & Albastroiu Nastase, 2013)

The main controller of all supply chains, which determines their superiority over similar ones, is how to manage each of (time, efforts, cost, and quality) for this chain, and from here the idea of automating the largest possible number of stages of the chain to overcome other competitors began.

This thesis will search the automation of the manufacturing stage of this chain and the creation of a new system for manufacturing circular parts through CNC machines, which is an extension of the thesis of my colleague Sarah Omair (*preparing for part management based on feature recognition technology(afr) and step file*, n.d.-a)

Under the supervision of Dr. Mazin Al-Wswasi and Dr. Redvan Ghasemlounia.

The automated manufacturing system is the new era of global industry, where it made a great leap in the field of production and manufacturing, while the old manufacturing methods required effort and a great time for traditional calculations and can't dispense the human intervention in every step of its steps, and above that, it is prone to error, which leads to wastage in cost time and effort threaten the quality of the resulting product, Ivanov, and Makatsoris 2018), so the new system which consists of

1. Computer-Aided Design (CAD)
2. Computer-Aided Process Planning (CAPP)
3. Computer-Aided Manufacturing (CAM)

came to move manufacturing to a new level in which the production process is managed best possible way. This system if it is used correctly, will allow the company to stay and grow in the market at a time when the competition among all those existing companies is very fierce, it will turn from additional costs for the company to a strong strategic weapon (Engelke, 1987).

The Computer-Aided Design (CAD) system is a 3D drawing system on the computer with unlimited possibilities to reach the desired shape in the design, which is a replacement for the old manual drawing system and all its obstacles and challenges that were facing the engineer (Sarcar et al., 2008; Verroust et al., 1992). Also, the design is not limited to dimensions and shape but goes beyond them to include all the physical properties of the material (Mazin Ghazi Al-wswasi Supervisor & Ivanov, 2019a) to be manufactured so that the designer can apply full simulations to the final product before it is manufactured on the ground. After the design is completed, the information must be transferred to the planning stage of the production process (Computer Aided Process Planning (CAPP)) which is also done via the computer, where different systems have been designed to transfer information between the CAD and the CAPP, such as Standard for the Exchange of Product (STEP), Drawing Exchange Format (DXF), Initial Graphic Exchange Specification (IGES) (Qin et al., 2017).

Computer-Aided Process Planning (CAPP) is a process in which the planner of the production process uses a computer to come up with the best manufacturing plan, taking into account the cost of manufacturing, the time required, and competition among other companies (Engelke, 1987). Many efforts are being made to upgrade the CAPP system to a level equivalent to CAD and CAM systems, but it is still far behind them in many stages due to the difficulty and complexity of the nature of the process as well as the dynamic aspects of this process. In 1989 Sutton said, “there is no fully automated CAPP system and almost all of them still require extensive manual operations” (Sutton, 1989) It is a fact that is still true to this day. In order to simplify the process better, the required inputs to the ACAPP system must be defined and what outputs should we expect?

The required inputs for the ACAPP system are (Feature technology, dimensions, and measurements, the material, surface finish, and manufacturing process) (Mazin Ghazi Al-wswasi Supervisor & Ivanov, 2019a).

This thesis analyze and study these inputs to reach the best production plan based on the information available to us to form the outputs of the system as follows (choosing the manufacturing process, the process sequence, choosing the required tool, choosing the appropriate cutting conditions, choosing a tool path for the tool, cutting depth and feed, calculating the cost and time of the process) (Marri et al., 1998b).

1.2 Background

As mentioned earlier that this work is built on and complements a previous work that concerned with taking the STEP file for the rotary designed part and sorting it to get the information needed to manufacture the designed part, after getting this information, an (AFR) feature recognition technology used which is a system using C# (C sharp) programing language and several algorithms to get the final features of the designed part. The step file has been chosen as an input for this system despite the problem of its random information, enduring the hardship of sorting it, because of the advantages it has that other available file formats do not have, one of these advantages that the step file transfer the geometrical and non-geometrical information for the rotary part (Marjudi et al., 2010a). The output of this system is the “Final Features” of the part. The limitation of this system is that it deals with only the rotational parts and with only pre-defined final features ("Square Groove", "Left square groove", "Right square groove", "Wide Groove", "Facing", "Cylindrical", "Right Taper", "Left Taper"), but it can be developed to include more final features.

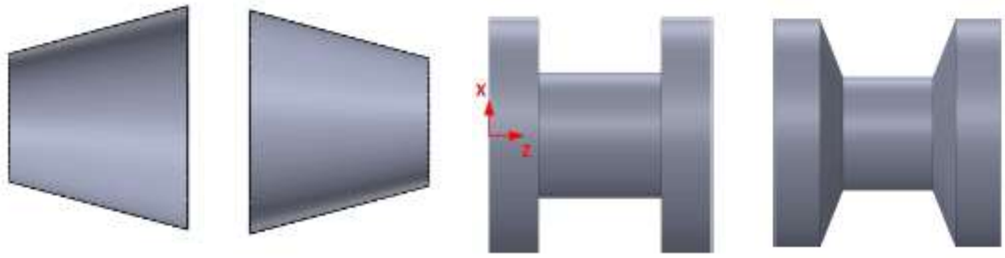


Figure 1.2: Examples of pr-defined final features (Drawn by the author)

This process is mainly obtained to reduce the work time and all unnecessary paper calculations which need the expertise to make while anyone with no much expertise can use this system. Also, this work adds Mathematical equations to calculate the time required for the part manufacturing.

For more details and information you can review the thesis of my colleague Sara Omair “preparing for part management based on feature recognition technology(afr) and step file” Under the supervision of Dr. Mazin Al-Wswasi and Dr. Redvan Ghasemlounia.

1.3 Aim of the work

Now the final features that came from previous work are ready, but in the manufacturing workshop, the cylindrical block can not just convert into a final shape. The tool path that the tool will take while converting this block to the final shape first needs to be defined, the intermediate features that will get before reaching the final features, The tool that can cut this part of the block and provide the specific shape need to be selected, Cutting conditions must also be specified. It is necessary to take into account all these factors before extracting the final G-Gode that will operate the CNC machine (Mazin Ghazi Al-wswasi Supervisor & Ivanov, 2019a).

The importance of the presented work is:

1. First of all it will upgrade the old (CAPP) system and take it to a new automatic level (ACAPP), which lead us to minimize as much as possible the human interference in the planning process.
2. The output of this system can be saved as a document file including all the information on process planning and used as an input for the manufacturing machine.

3. Add new pre-defined features to the feature recognition system (AFR) to increase the ability of the system in covering more shapes.
4. Extract the intermediate features that the process planning should go through before reaching the final features.
5. Using C sharp (#C) language to develop a methodology of feature subtracting system to solve the issues that may be encountered during the manufacture of rotary parts.

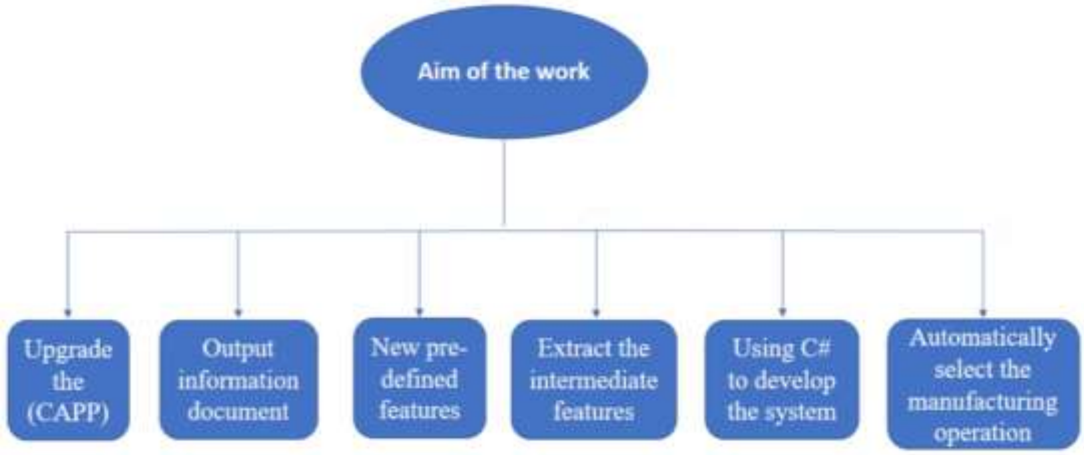


Figure 1.3: Aim of the presented work (Drawn by the author)

1.5 Outline of the Thesis

Chapter one in this thesis presents the introduction to the automation system and its importance in production and supply chain management, the background of this work and what was their results, and finally, the aim of this work and points tried to achieve, also the outline of this thesis. Chapter two is a literature review of all previous work in this field and their result, the process planning which contains (the CAPP system, feature technology, tool selection, and tool path), Chapter three contain STEP file structure, background about it, what he consists of, how to follow and understand its data to use it in AFR systems, Chapter four present the AFR system and feature subtracting explain what AFR means and how it works what are the pre-defined features that already exist and the features that have been added in this work, also feature subtracting methodology is explained in the same chapter and a case study on it to see the result of this program, conclusion and limited of the work with feature work advice are all presented in the same chapter.

2. PROCESS PLANNING

2.1 Introduction

In recent decade, (CAPP) computer-aided process planning has obtained lots of attentiveness from practitioners and researchers. One of the motives for this is the Function of CAPP in lowering productivity time and improving exceptional.

The interest in determining which manufacturing methods and equipment must be employed to carry out the multiple operations required to produce an issue, as well as the sequence in which the procedures must be carried out, is referred to as process planning (Marri, Gunasekaran, and Grieve 1998a). It may also be described as the methodical use of one-of-a-kind procedures for producing elements from raw materials to finished goods. Computer-aided process planning (CAPP) has become well-known in recent years as a critical component of a computer-assisted manufacturing (CIM). Regardless of the fact that a lot of work has gone into establishing CAPP systems, the advantages of capp in actual-existence production environments are yet to be seen because of the rapid growth of computer-aided techniques, the design and execution of CAPP have been modified substantially considering the fact that its improvement. More than 300 papers have been published in this region during the last three decades maximum of the publications appear to introduce the most effective precise capp structures even though some papers give a trendy survey (Steudel 1984, ElMaraghy 1993).

With contemporary speedy development in technological know-how and generation, it's far more important than ever to keep the information up to date so that study and improvement goals may be met. Throughout the previous 30 years, many CAPP structures advanced had been based totally on the variation approach, however currently the generative and semi-generative methods are widely used. Artificial intelligence (AI) techniques were introduced into CAPP in the early 1980s. Many CAPP structures were implemented using AI techniques, which are sometimes referred to as "knowledge-based" systems or "expert" structures. Each one has advantages and cons (Marri, Gunasekaran, and Grieve 1998a). A loss of professional procedure planners in a few industrialised nations, together with in the America (Emerson and Ham 1982) and the united kingdom (Davies et al. 1986), provides a boost to progress. CAPP structures have been acquired by a wide range of commercial organizations for the integration of layout and production, as well as to compensate for the scarcity of expert procedure planners. Despite the fact that numerous CAPP structures have developed, their efficiency is still far from ideal, and many large agencies have had to set up their own research firms in order to expand their CAPP structures. Small and medium-sized enterprises can raise funds for the most readily available CAPP structures, which have been established by research organizations or universities.

2.2 CAPP System

The path, machine, machine tool, methods, and procedure parameters are frequently included in the process plan. Due to the fact that machining procedures for the same machined surface can be done in a variety of ways, more than one device equipment to be had to carry out the identical operation, distinct machining sequences, and many others process planning allows for opportunity selections. Although most current CAPP structures are built in such a way that only one technique plan is created for a machined piece, there are usually numerous viable method plans for manufacturing the component. usually, those CAPP systems work at the side of CAD and other computer systems. CAPP is a method for deciding which options to pursue and determines a set of commands and machining parameters required to manufacture a component. Input, output, database, and manufacturing decision-making rules are the four essential components of a CAPP machine (Henderson & Chang, 1988).

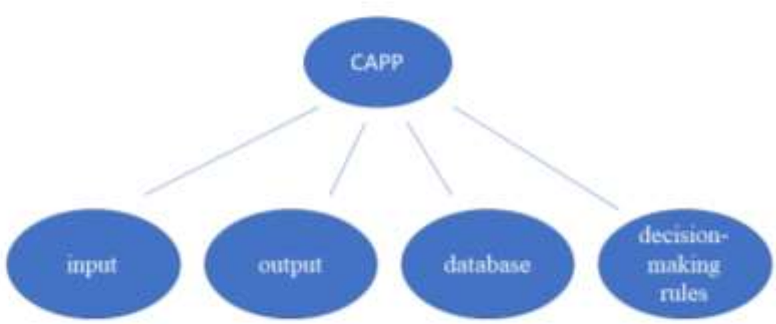


Figure 2.1: Essential Components of a CAPP (Drawn by the author)

In the CAPP scheme, information education is an important step to acquiring right definations of the product in CAPP system which is finished after the CAD machine is finished. After the completion of information preparation, this information is entered into the CAPP system and is supported by way of knowledge and physical rules. When the CAPP operation is finished, the next step is output. From this output, the following operation is publish processing which prepares facts for manufacturing planning and scheduling activities. Sooner or later, the production planning and scheduling operations are executed. Those additives within the dashed-line container are impartial to CAD and manufacturing planning/scheduling (Marri et al., 1998a).

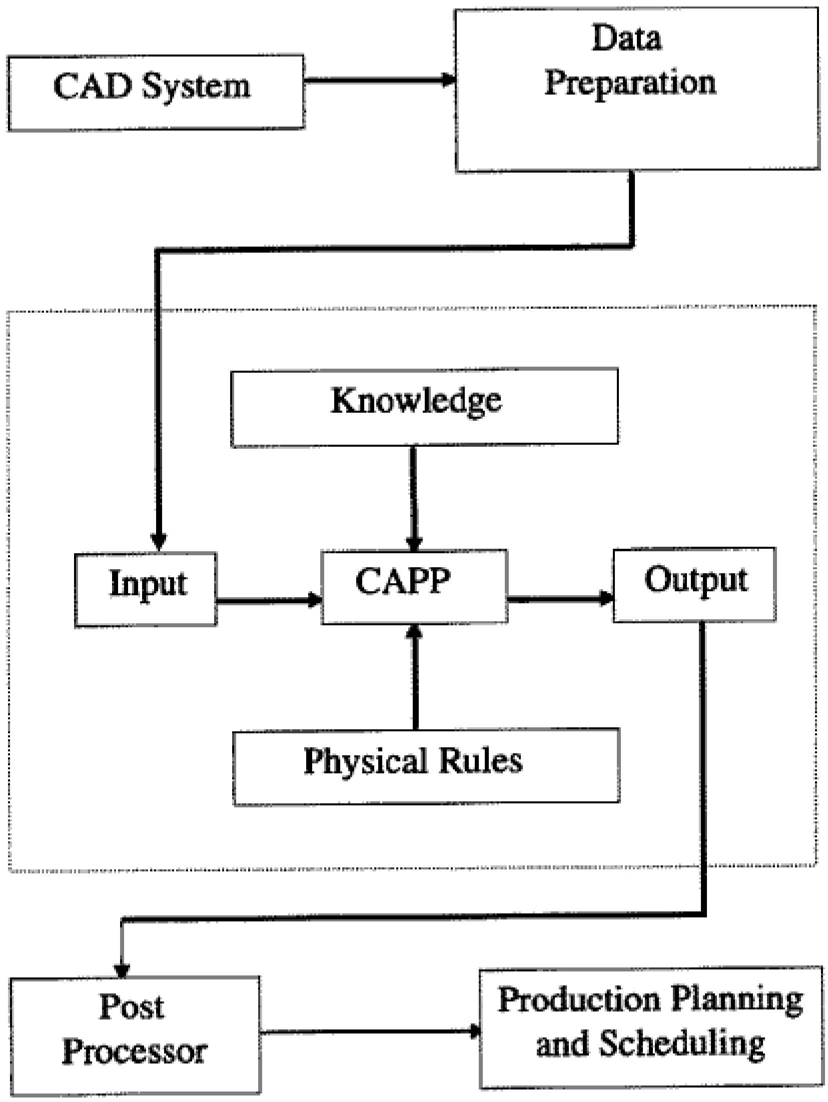


Figure 2.2: CAPP Model

Source: (ElMaraghy, 1993)

A number of surveys were finished within the final thirty years on the development of CAPP structures. Many keynote papers have addressed problems for the development of CAPP. Weill et al (Weill et al., 1982) Surveyed CAPP structures and addressed the technical issues within the development of CAPP, from procedure choice to the editing of manner sheets. The survey also mentioned the structure of CAPP structures for technology processing in the form of bar diagrams. Extra than 15 specific structures were suggested, the subsequent survey paintings changed into mentioned 3 years later by using Eversheim and Schulz (Eversheim & Schulz, 1985) who reviewed extra than 50 CAPP systems. Inside the same year, some other comprehensive survey became suggested via Wysk et al (Wysk, 1985) Wherein greater than 25 systems are reviewed. The review turned into further prolonged through Chang and Wysk (Chang et al., 1985) any other extensively used survey become achieved by means of Alting and Zhang (Alting & Zhang, 1989)

The significance of CAPP in a current manufacturing facility can not be underestimated, CAPP provides a direct hyperlink between design and manufacturing. It reduces the time spent among part design and actual manufacture. The CAPP systems of the destiny need to be dynamic, flexible and clever. The successors to smart structures can be "learning systems" which could display production and feed statistics returned to the device. This remarks wilt become the instructor. The systems could be capable of learn from manufacturing mistakes and therefore enhance their overall performance. The blessings of a learning and self-adapting gadget have to include greater correct time and price estimates, improve productivity, the ability to reveal strategies, less variability, more reliability, and decreased human involvement. The CAPP vicinity has been substantially developed within the remaining many years and lots of strategies had been involved (Marri et al., 1998a).

2.3 Feature Technology

Since 1960, computer-aided manufacturing has been in place to assist with complex graphics and modern designs. All CAD packages encompass geometric or modelling capabilities which describe a part the usage of low stage entities, which includes points, lines, and curves. At the same time as the CAD packages store the data of their very own databases, every package has a distinctive database shape, for there's no one fashionable that has been advanced to be used by all (Hu et al., 2015) also, the geometrical functions of a part are not appropriate to be used directly in CAPP structures; hence, they need to be transformed to excessive-degree production features, inclusive of grooves, holes, and pockets. The integration of CAD and CAM has two main techniques (Hu et al., 2015)

1. Feature recognition.
2. Feature-based design.

2.3.1 Feature-based

CAD data may be represented as features in a feature-based model. Designers don't forget features to be practical factors. Layout functions are often distinct from production features (Ou-Yang & Lin, 1997) Offer an estimator for the fabrication value of a design, based on the shapes and precision of its features, on the way to assist a designer with little information of the fabrication method to estimate the fabrication value early within the design method so as to keep away from immoderate fees afterward within the manufacturing procedure. It become proposed by means of (Yepez et al., 2021) to create an intelligent system that automatically can provide renovation commands on the product and element levels through using feature-based product identification. A framework for expertise-based decision-making, sturdy reverse engineering, CAD model feature detection, product identity, and protection plan era became advanced as a part of the studies. A wise plan for the renovation operation is generated while the identified product is related to the knowledge-based totally system given.

2.3.2 Feature recognition

In order to link CAD with CAM, feature recognition is basic. It helped designers to spotlight product capability and make the maximum of it. This option can identify the product's manufacturing functions (Regli et al., 1995) Most feature recognition systems rely on solid model information, and although solid models contain geometric and topological information, they lack accuracy and measurements, and as a result, the results of the process will be disappointing (Wang, 1990). In another hand, recognizing information like holes or curves in the 2D dimension model is very difficult.

Later a new system capable of recognizing features in the rotational part was developed by (Owusu-Ofori & Chen, 1990), (Dong & Wozny, 1991) continue from their result to be the first in using frame-based reasoning technique to extract features to the CAPP system. using this technique, they were capable of assemble volumetric traits from surface functions and carry out a tool accessibility study. For non-rotational part (MEERAN, 1992) was the first how present a study in this felid, three organizations of characteristics were utilized in his work: As an end result, there are three unique styles of functionalities: simple features, interacting functions, and standard functionalities.

Another type of files that came as an output from CAD/CAM (IGES) were analyzid by (Basu & Kumar, 1995), it was totally depend on the element and nodes in the mesh entites that developed in this work. the use of a easy code, a general-motive IGES translator for preprocessing in a finite detail or boundary detail primarily based analytic surroundings can be fast created with minimum attempt. (Perng, 1988) Cautioned a two-level method for reconstructing the solid model the usage of orthographic perspectives and spotting capabilities within the initial solid model. (Gao et al., 2004) Study the usage of constraints to outline the hole-collection feature version from information retrieved from a design database. Similarly, feature interactivity was tested, and a feature-based method for generating hole-collection machining features was offered (Lau et al., 2005) Made a smart computer-integrated system for reliable layout feature recognition so as to obtain automated procedure planning. Properties of plastic products may be divided into 3 hierarchical stages: primitive characteristics; complicated characteristics; and excessive-degree complex characteristics. Graph-theoretic and logic-based methodologies are mixed inside the recommended method. For automated extraction of primitive and sophisticated characteristics of plastic elements, the authors offer improved multi-attributed adjacency graph (EMAAG) and feature-interaction feature graph (FIFG) strategies. That’s what (Mok & Wong, 2006) reached for (Farsi & Arezoo, 2009) made a study about the sheet-metal element, a design adviser system and feature identification module presented. On this technique, the functions of sheet metal additives are retrieved automatically from a 3-D model, these are object-oriented information. visual primary was used to assemble the system in SolidWorks 2008. (Sunil et al., 2010) Delivered a hybrid method for figuring out interacting functions in prismatic machined components the usage of B-Rep CAD models (graph + rule-based method). he created a feature identity system for prismatic elements that detected all variations of easy orthogonal functions. (Niu et al., 2015) Proven the way to leverage a database engine and CAD modeler to find times of entities that fulfill the predicates that make up features, in addition to how to show a declarative feature description right into a SQL. query. (Tarsitano et al., 2015) Made a database with a definition of the capabilities and connected it to a CAD modeler with out specifying how they must be located. This database optimization substantially reduces the time complexity of feature locating, ensuing in an appropriate time. The reserchers found that the feature recognation will take more time asa well as the shape size and complexety.

2.4 Tool Selection

To fabricate a product with the specified shape, length and properties, this depends not only at the design, but additionally on the selection of the suitable process planing (Jain & Jain, 2003). Process selection in CAPP is making the decision of which part apply to manufacture first, even as taking into account the existence of alternative ways which might be capable of obtain the identical task. Consequently, a part that is planned to be manufactured on a specific condition, will be additionally manufactured on another manufacture plan and cutting conditions . However, the usage of different tools and conditions approach considerably different production procedures and therefore, different system planning (Mazin Ghazi Al-wswasi Supervisor & Ivanov, 2019b).

A machining method consists of the material removing from a workpiece as swarf or chips using single or multi-point cutting equipment with a precise geometry (Cheng, 2008) Regardless of the cutting tools selection being only a sub-feature of system planning, it's far a complicated challenge that requires huge experience and information. (Arezoo et al., 2000; Oral & Cakir, 2004) Historically, the quality set of cutting equipment is chosen by people based totally on their previous experience, however, this technique is gradual as well as results in mistakes and inconsistencies (Oral & Cakir, 2004). As a consequence truely, it is inconvenient to select the cutting equipment primarily based on the familiarity, experience, and reminiscence of operators. To triumph over this difficulty, a system is needed to examine element geometry and specifications, in the end figuring out the right equipment automatically. Sadly, in spite of the improvement of CAPP structures, automatic cutting equipment selection for machining operations remains in its infancy.

The tool selection impacts many different parameters in production along with the choice of fixtures, manufacturing price, machining accuracy and the final value of the product (Fernandes & Raja, 2000). The perfect selection of cutting equipment and its related cutting conditions may want to extensively reduce the manufacturing cost. Therefore, any CAPP system that doesn't take into account those parameters may have extreme limitations (Ribeiro & Coppini, 1999). Despite the fact that maximum modules use "minimal cost" standards in the tools choice mission, this standards does not always constitute the appropriate solution because it does not constantly take into account different technological constraints. In such conditions, it's far tough to encompass machinists' experience of selection making, as those systems are constructed up primarily based on "low value" standards. Thus far, there's no wellknown appropriate solution for tools selection that would be utilized in all workshops (Arezoo et al., 2000).

Ribeiro & Coppini provided a new set of rules to enhance the computer aided technical help (CATA) system (Ribeiro & Coppini, 1999). formerly, this turned into used to decide operational expenses of machining techniques. Through including the development, the system is capable of pick cutting tools and cutting conditions, this is primarily based on a database to decide most manufacturing.

(Arezoo et al., 2000) Evolved an professional computer aided tool selection machine (EXCATS) with the aid of the usage of the Prolog language. The goal is to choose tool-holder, insert and cutting situations in turning operations. The system has many functions, as an instance, it permits the consumer to regulate the end result via feeding his or her personal store ground experience. similarly, it has an interface that allows equipment producers to feature their tooling machine to the bundle. The desired inputs to the system are the component illustration and tools document.

Later, (Zhao et al., 2002) offered a unique technique to combine a CAD system with EXCATS in turning operations. The CADEXCATS machine begins with using an IGES impartial layout to store product inf-ormation. Thereafter, a function popularity technique is carried out to generate a factor illustration document for EXCATS.

(Fernandes & Raja, 2000) Suggest included tool selection systems (ITSS) in a CIM surroundings. There are 5 steps performed in ITSS to pick out a fixed of equipment for every function within the product, as processed on a selected system. Step one is to outline viable opportunity equipment for every feature. Then, the system excludes a number of the tools from step one which isn’t like-minded to the chosen machines. The following step consists of in addition getting rid of the tools that aren't well matched with the task, component material, or characteristic attributes. The fourth step is, the dedication of tooling parameters for each type is done by the use of the available data about the element. Eventually, a tooling fit is decided while the system searches via an object-oriented database. This system is fast and provides continuous updates to the user about updates to the tools.

A new system by (Edalew et al., 2001) It relied mainly on the use of mathematical units and exploratory data, evolved a dynamic programming-primarily based system to choose cutting tools and calculate overall element cost. that is to provide customers guidelines and answers to lessen cost and time of machining. The system was evolved using Kappa-computer software program with 5 modules: information acquisition, information base, inference engine, consumer interface, and database. The system become designed to cowl specific machining strategies, wherein it can examine cylindrical and prismatic parts. All of the calculations are primarily based at the product material, functions attributes, machining time and price, tool existence and material elimination price.

While (Oral & Cakir, 2004) presented the tool selection system for the generation strategy of CAPP for (GPPS-RotP) rotational parts. On this method, the automated tools choice mission is based totally on numerous elements: component features, component machinability, set-up number, component holding tool, and machine tool information. There are standards which have been carried out to acquire tool series that minimise each the range of the tool tour time and tool modifications.

2.5 Tool Path

The process planner prepares technical processing information as an essential part of his task. This technical information includes:

1. Numerical control NC program

2. Tool sets
3. Design of jigs and fixtures

NC numerical control includes tool path determination (cutting tool location), machine path operation commands and cutting conditions (Boogert et al., 1996). The tool path is encrypted codes and instructions and is presented in a numerical way and codes to process the part to be run from the work piece. Once the characteristics of the shape and all its geometrical information are known, the tool path for cutting can be determined, manual tool path generation is an intensive process that is time-consuming and prone to costly errors, which is why automatic tool path creation is an essential task of the planning process (Bala & Chang, 1991).

In turning or milling process, there are many stages of operation like (rough cycle, single-pass cycle, multi-pass cycle, and finish cycle). In rough cycle material is removed in layers from the workpiece in order to keep the workpiece and the machine away from damage, that's how most of the material is removed from the original workpiece to reach the desired shape and size. This operation directly affects the total manufacture time and less effect to the final accuracy of the workpiece (Bala & Chang, 1991; Wu et al., 2016).

Whilst in the finishing cycle, the surface of the workpiece is processing genital and smoothly to reach the final dimensions and accuracy for the product. The finishing cycle directly affects the accuracy, dimensions and the finishing surface of the product (Bala & Chang, 1991).

Anyway, to generate an automatic tool path for both rough and finishing cycles, we must take in consideration these factors:

- Relevant for popular feature kinds;
- Relevant for popular surfaces;
- Whilst cutting a selected part of the workpiece, the cutter does not have an effect on every other part ;
- Cutting performance, which refers to saving time whilst the cutter repeats traversals within the rough-cycle and at the end achieves the specified accuracy (marshall & griffiths, 1994) this is done via decreasing the range of movements in which no cutting happens.

(Sadilek et al., 2013) Recommend a new technique in turning operation for the tool path in rough-cycle, In reverse to the traditional roughing cycles, while the tool machines has a steady depth of cutting, he applayed a variable depth of cut, which will growth the life of the tool. 3 paths of roughing cycles are covered in this studies: regularly reducing the depth of cut, making conical paths of cut, and using nonlinear techniques. With this new method using a sintered-carbide tool note the following results: growing the sturdiness of the cutting tool for 44%, decreasing the whole cost for the cutting equipment, and lowering the load on the spindle for 10%. This technique needs complex programming to generate an automatic variable-depth tool path.

(Francis et al., 2014) Suggest automatic tool path technology for finishing cycle machining of freeform surfaces. The free shape surfaces include scallops, which can be the quantities of material deliberately left in the workpiece. Scallop height techniques were used on this studies as a way to examine the finest tool path technique. First one is the minimal scallop height (MSH), which incorporates more tool passes and outcomes in smoother surfaces with decrease machining performance, second one is most scallop height (CSH), whilst the cutter sweeps in fewer passes in comparison with the MSH technique, consequently less smoothness of the final surface could be received. but, the cutter touch (CC) points and the tool orientation at those factors are recognized, hence it's far viable to decide whether or not a collision will arise among the tool and the neighboring surface.

2.6 Summery

Process planning is an essential process to integrate CAD with CAM to transfer the design from a data on cumputer to final product, it has to main function: first the input for the system and the expected output from it. Many efforts have been made to develop the CAPP system so they could reduce the time and cost of production, but these systems still limited and can’t present all the output needed, which leave the user with uncomplete manufacturing information, and can’t dispensing the human intervention.

3. STEP FILE

3.1 Introduction

In all the computer aided process planning (CAPP) system, an automatic feature recognition (AFR) system is needed, this system linked between Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) and convert the low level geometric data like the lines, pointes, and curves into high level geometric data like holes, pockets, and grooves which make the final features of the shape (Babic et al., 2008; Zhang et al., 2014) That's why the CAD files are exported in one of the international PDE standards to facilitate the transportation process between CAD/ CAPP/ CAM, and the most common file extensions are (STEP, IGES, and DXF) files (Marjudi et al., 2010b) these files are analysed and translate to Intelligible form for the features recognation by program made with some coding language like C#, C++, JAVA, or any other chosen language. With the same coding language in this program, a set of pre-defined features are being prepared and saved so the program can compare it with the analysed part to recognize its features. Different AFR systems used different PDE files, but the STEP file got the greatest area; that's because it's specific that allowed him to transfer both the geometric and non-geometric data of the design, the geometric data represent in vertices, curves, edges, relations, and surface, whilst the non-geometric data represent in materials, witness line, view, leader, general note, and associativity entities, also the STEP file organize the mechanical data in a special way (Marjudi et al., 2010b) The complex structure of the STEP file leads to misunderstanding for most of the researchers that based on the STEP file to develop an AFR system, that's why this chapter pays attention to explaining the STEP file structure in detail.

3.2. Background

The STEP file is a worldwide preferred (ISO 10303) which is computer-readable, it represents the product information throughout the whole product lifecycle, it consists of: production, inspection, design, quality management, and support (Qin et al., 2017) a lot of software Protocols (APs) were evolved in STEP to specify the representation of product information for one or extra commercial programs (Mazin Ghazi Al-wswasi Supervisor & Ivanov, 2019b) With AP203 being extensively referred to as a CAD model's information exchange document. The element of AP 203 is to explain the product information in a manner that satisfies production filed desires, on the way to change configuration-controlled 3D product design information of mechanical components or assemblies (Mazin Ghazi Al-wswasi Supervisor & Ivanov, 2019b) maximum of those APs use the specific language to explain the representation of the information, that is converted right into a physical text document (Qin et al., 2017).

3.3 (AP-203) STEP File Structure

The document of STEP AP203 is a language-primarily based text document, containing strings and entities describing a product's representation (Jaider et al., 2014) being divided into two essential sections: "HEADER" and "DATA" as shown in figure (3.1).

The HEADER segment offers standard product data, which includes the document name, generating date, organization name, programmer name, and so forth. The data segment includes strains of entities, which constitute the primary geometrical and topological product information. Every entity instance within the data segment begins with "#" observed by an unparalleled integer, entity name, and related information. The related information may be numbers, strings, Boolean, or maybe a connection with some other entity instance in the document.

```
ISO-10303-21;
HEADER;
FILE_DESCRIPTION (( 'STEP AP203' ),
    '1' );
FILE_NAME ('step ap 203.STEP',
    '2022-06-11T20:00:05',
    ( '' ),
    ( '' ),
    'SwSTEP 2.0',
    'SolidWorks 2020',
    '' );
FILE_SCHEMA (( 'CONFIG_CONTROL_DESIGN' ));
ENDSEC;

DATA;
#1 = FACE_OUTER_BOUND ( 'NONE', #149, .T. ) ;
#2 = DIRECTION ( 'NONE',  ( 1.000000000000000000,
0.000000000000000000, 0.000000000000000000 ) ) ;
#3 = COORDINATED_UNIVERSAL_TIME_OFFSET ( 3, 0, .AHEAD. ) ;
#4 = DATE_AND_TIME ( #87, #116 ) ;
#5 = CC_DESIGN_PERSON_AND_ORGANIZATION_ASSIGNMENT ( #120, #54,
( #98 ) ) ;
#6 = ORGANIZATION ( 'UNSPECIFIED', 'UNSPECIFIED', '' ) ;
#7 = CARTESIAN_POINT ( 'NONE',  ( 0.000000000000000000,
0.000000000000000000, 80.00000000000005684 ) ) ;
#8 = ADVANCED_FACE ( 'NONE', ( #140 ), #173, .T. ) ;
#9 = UNCERTAINTY_MEASURE_WITH_UNIT
(LENGTH_MEASURE( 1.000000000000000082E-05 ), #47,
'distance_accuracy_value', 'NONE');
#10 = EDGE_LOOP ( 'NONE', ( #46, #151 ) ) ;
#11 = CC_DESIGN_PERSON_AND_ORGANIZATION_ASSIGNMENT ( #58, #59,
```

Figure 3.1: Part of STEP file text (from STEP file Drawn by the author)

STEP file information is organized hierarchically starting from the “CLOSED SHELL” at the top of the pyramid and ending with the “Cartesian Point X,Y,Z” as shown *in* the figure (3.2).

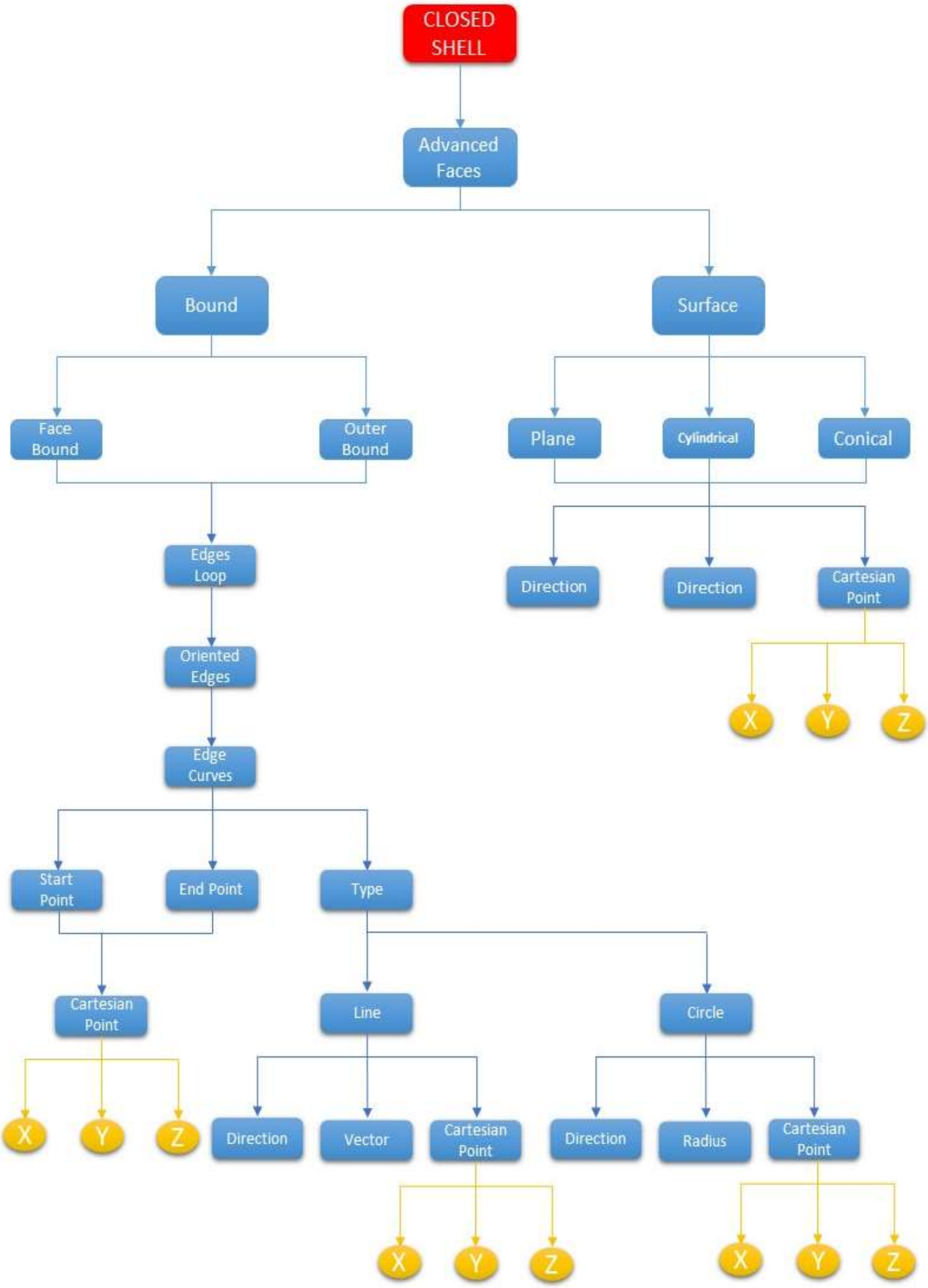


Figure 3.2: Hierarchically structure of STEP file

Source: (Mazin Ghazi Al-wswasi Supervisor & Ivanov, 2019b)

The closed shell is a topological object that bounds a space in 3D-area by connection some of faces along edges. The figure (3.3) showes a conical object which consider a "closed shell" and it's STEP file data has #175 line of data .

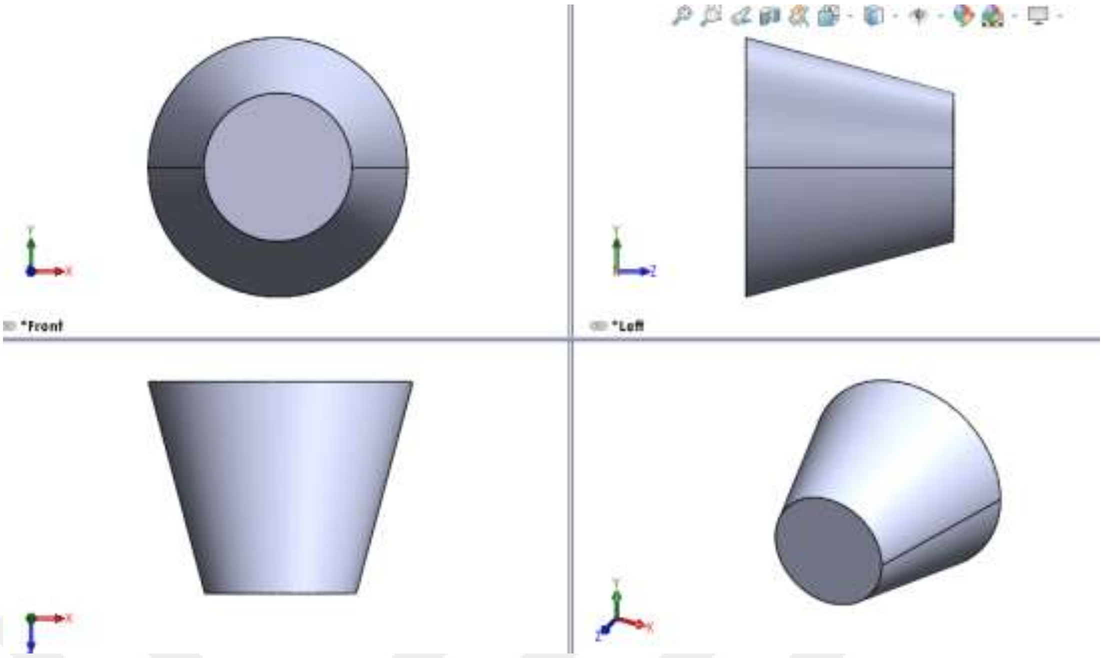


Figure 3.3: Conical " CLOSED SHELL" (Drawn by the author)

The information configuration in the DATA text document does not appear in a hierarchical series, regardless of the fact that the STEP document has a hierarchical shape and represents the entity lines in a scientific way. As a outcome, the top-degree of the hierarchy, the "CLOSED SHELL" node, is not constantly present in the first line of entities. In fact, it is probably anywhere within the data element between the start and the end. This assertion is real for all degrees of information. like, the Conical in figure (3.3) has a closed shell in the line #138

#138 = CLOSED_SHELL ('NONE', (#127, #103, #8, #77);

The second level in the STEP structure is the Advanced Faces, Faces are topological entities that represent a surface with a bounded edge and share these edges with other faces to make the CLOSED SHELL (Mazin Ghazi Al-wswasi Supervisor & Ivanov, 2019b) figure (3.4) shows the 4 faces of the conical.

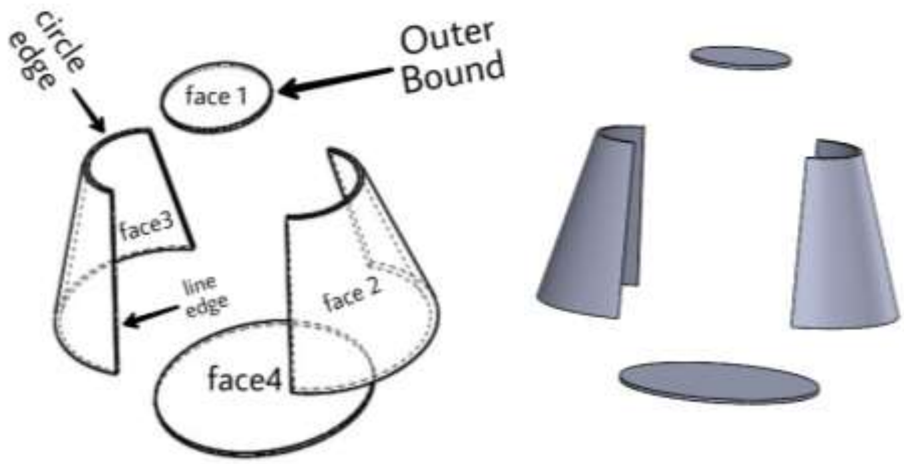


Figure 3.4: Faces of a conical shape (Drawn by the author)

Each face has two factors, the Bound and the Surface as we see in first fase in the Conical which is represent in Line #127, while #93 in the line refers to the bound of the face and #71 to the surface.

#127 = ADVANCED_FACE ('NONE', (#93), #71, .T.) ;

3.3.1 Bound

The bound is edges orginezed in a loop surrounding a surface, there is two type of bound, the OUTER-BOUND which is an external loop-edges surrounding the surface from the outline, and the FACE BOUND which make an internal loop-edges inside a surface as shown in figure (3.5).

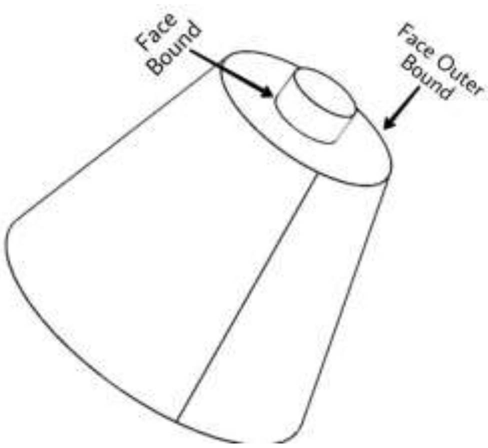


Figure 3.5: Outer Bound and Face Bound (Drawn by the author)

Number #93 in ADVANCES_FACE refers directly to the Bound line,

#93 = FACE_OUTER_BOUND ('NONE', #170, .T.) ;

In this line, the Bound type is shown as “FACE_OUTER_BOUND” and no matter the type of the bound is, the number in the line #170 reffers to the Edge bound

#170 = EDGE_LOOP ('NONE', (#171, #148, #30, #90)) ;

The numbers #171, #148, #30, #90 present the oriented-edges, the Edge Loop is a closed path from the oriented edges, the start point and end point of them are the same.

Oriented edge is generate by another original edge, it has a boolean flag’s direction that holds data in, the edge may be in different shapes (circle, line, or B-spline curve with ellipse Knots, the result is the orientation of this boolean flag may be reversed between the start and the end vertex.

#171 = ORIENTED_EDGE ('NONE', *, *, #29, .F.) ;

#148 = ORIENTED_EDGE ('NONE', *, *, #143, .T.) ;

#30 = ORIENTED_EDGE ('NONE', *, *, #62, .T.) ;

#90 = ORIENTED_EDGE ('NONE', *, *, #115, .F.) ;

Now #29, #143, #62, and #115 refer to the Edge Curve, the Edge Curves are topological elements that has a start and end point, the edge curves are:

#29 = EDGE_CURVE ('NONE', #150, #76, #104, .T.) ;

#143 = EDGE_CURVE ('NONE', #150, #44, #91, .T.) ;

#62 = EDGE_CURVE ('NONE', #44, #128, #21, .T.) ;

#115 = EDGE_CURVE ('NONE', #76, #128, #174, .T.) ;

Every Edge Curve has a geometrical and topological definition, it has a start and end points, and a definition of the type if it is a line or circle and its directions, #150 and #76 in #29 Edge Curve refers to the start and end points.

#150 = VERTEX_POINT ('NONE', #119) ;

#76 = VERTEX_POINT ('NONE', #70) ;

While #104 refers to the Edge Curve type,

#104 = CIRCLE ('NONE', #17, 28) ;

#119, #70, and #17 are the cartesian points of the edge curve while 28 refers to the radiuse of the circle, the cartesian point is the lowest level in the hierarchy of STEP file, which represents the X, Y, and Z

#119 = CARTESIAN_POINT ('NONE', (-28.564, -4.810-15, 80.000)) ;

#70 = CARTESIAN_POINT ('NONE', (28.564, 0.00, 80.000)) ;

These values are the cartesian point X, Y, and Z respectively, #17 in the circle line refers to the Axis placement which have cartesian point and directions,

#17 = AXIS2_PLACEMENT_3D ('NONE', #92, #34, #36) ;

#92 = CARTESIAN_POINT ('NONE', (0.000, 0.000, 80.000)) ;

#34 = DIRECTION ('NONE', (0.000, 0.000, 1.000)) ;

#36 = DIRECTION ('NONE', (1.000, 0.000, 0.000)) ;

3.3.2 Surface

Back to the Advanced Face in line #127,

#127 = ADVANCED_FACE ('NONE', (#93), #71, .T.) ;

#71 refers to the surface type (plane, cylindeical, and conical) in this face the type is Conical as shown in line #71

#71 = CONICAL_SURFACE ('NONE', #159, 50.000, 0.261) ;

The number #159 refers to the Axis placement of the surface, and the value (50.00, 0.261) refers to the radius and the slant height of the conical.

#159 = AXIS2_PLACEMENT_3D ('NONE', #81, #65, #66) ;

Line #81 is the cartesian point and #65, #66 refers to the directions

#81 = CARTESIAN_POINT ('NONE', (0.000, 0.000, 0.000)) ;

#65 = DIRECTION ('NONE', (-0.000, -0.000, -1.000)) ;

#66 = DIRECTION ('NONE', (1.000, 0.000, 0.000)) ;

And so on the same procedure can be follwed to contiune following the four faces of the conical in the STEP file.

3.4. Summery

The STEP file is one of the most important files type in international PDE standerds, a lot of AFR systemes and CAPP devloped based on STEP file, that's because the loaded data that can transfer about the design. researchers may make a small mistake in understanding the STEP structure that leads to a big problem in production. STEP file has different APs like AP203, AP214, and AP242, they all using to transfer information between CAD and CAM systems and having the same hierarchical structure, each one is used in a specific filed in manufacturing and its return to the AFR developer to chose which kind of the STEP APs will used as an input to the system, Noting that is no more than one type can be used.

Among all the benefits of the STEP file, it still has limitations in recognizing the pre-defined features and the ability to recognize new features.

4. AFR SYSTEM AND FEATURE SUBTRACTING

4.1 AFR System

4.1.1 Introduction

The Automatic Feature Recognition (AFR) system is a means of transferring information between CAD and CAPP system using one of the PDE standards files as explained before. The importance of this link appears due to the fact that the CAD system is a geometry-based, while the CAPP system is feature-based system. All subsequent efforts to develop a feature recognition system were the result of this difference.

The principle of its work is by pre-defining the potential features and storing them in the program so that the program will later compare it with the new designs to recognize the features, this system is still limited by the number of preset features and cannot identify a new feature other than those included in its system .

The AFR system in this work is developed by a previous work from my colleague “Sara Omair” and her thesis (*preparing for part management based on feature recognition technology(afr) and step file*, n.d.-b)

4.1.2 The Pre-defined features

The system first needs to analyze all the information of the feature in the STEP file including; the number of the faces in the feature, feature direction, and variations among the coordinates of every face (*preparing for part management based on feature recognition technology(afr) and step file*, n.d.-b)

This system has eight pre-defined features that will be clarified in this section

The first feature is the “Facing” shown in figure (4.1 – a)

It consists of only one face (plane) and it could be in any size or direction.

The second feature in the system is the “Cylindrical” shown in figure (4.1 – b)

It also consists of one face (cylinder)

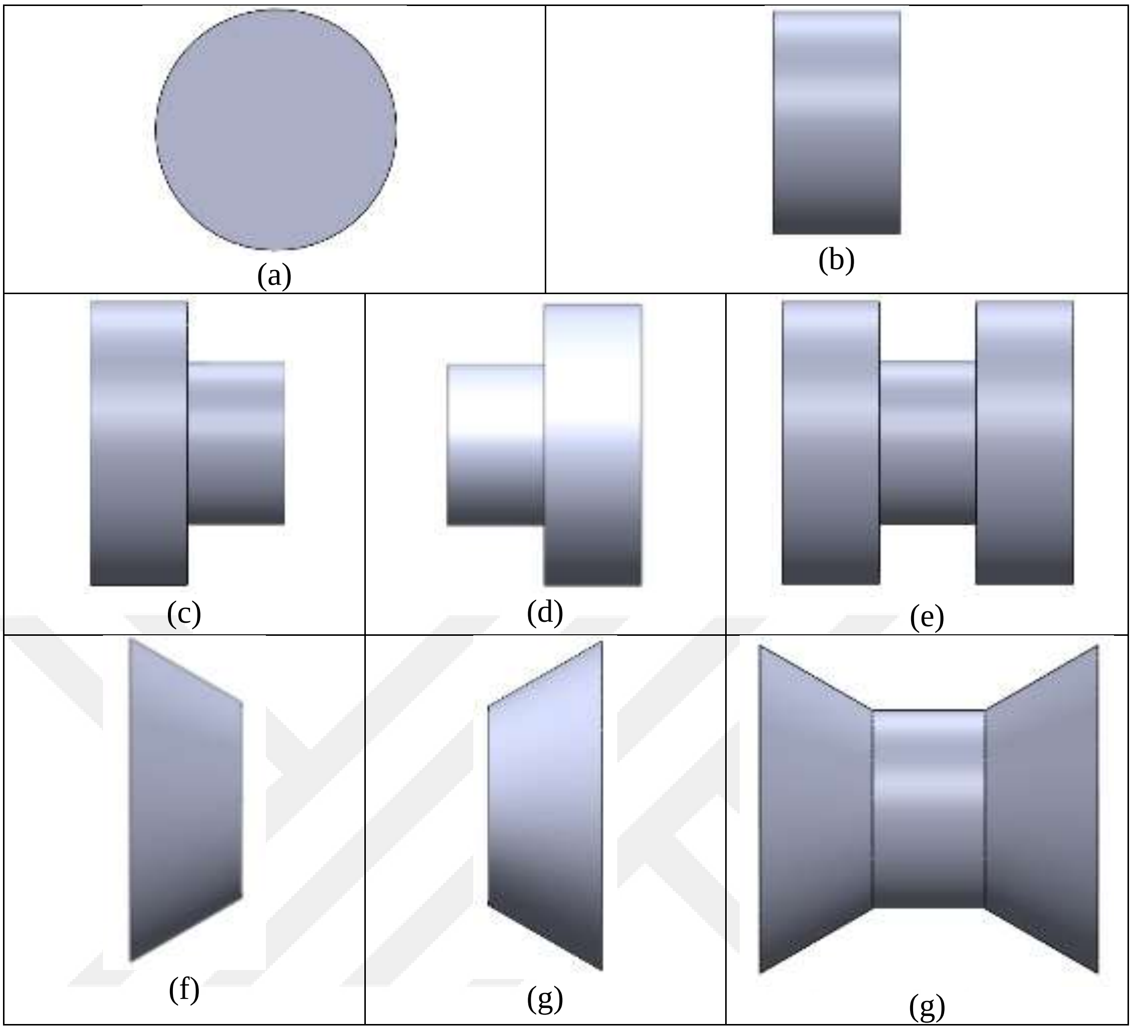


Figure 4.1: The pre-defined features in the AFR system (Drawn by the author)

The third feature is the “Right Step” as in figure (4.1 – c)

It consists of two faces, a cylinder, and a plane and its direction is to the right of the design

The fourth feature is the “Left Step” in figure (4.1 – d)

It also consists of two faces, cylinder, and plane but in the reverse direction of the right step.

The Fifth feature is the “Square Groove” shown in figure (4.1 – e)

It consists of three faces, two planes, and one cylinder between them, and the two planes must be equal in hight

The Sixth feature is the “Right Taper” shown in figure (4.1 – f)

It consists of one face (conical) to the right direction of the design

The seventh one is the “Left Taper” shown in figure (4.1 – g)

Consists of one face (Conical) in the opposite direction from the “Right Taper”

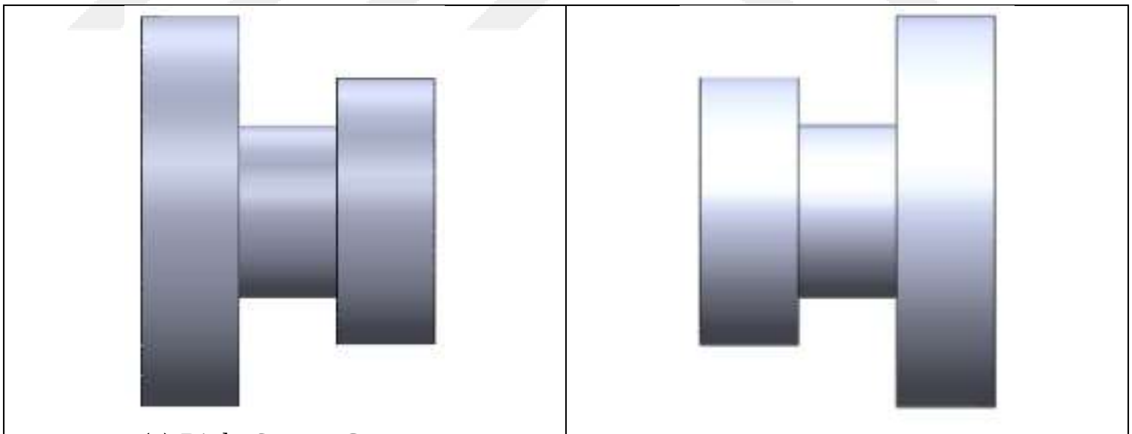
The final feature in the system is “Wide Groove” in figure (4.1 – h)

It consists of three faces, two opposite conical and one cylinder between them, and the conical should be in the same hight.

4.1.3 Adding new pre-defined features

As mentioned before, the previous 8 pre-defined features in the AFR system was the result from (*preparing for part management based on feature recognition technology(afr) and step file*, n.d.-b).

The more pre-defined features are added, the more efficient the system will be, that’s why this research has developed the system by adding two more features. The “Right Square Groove” and the “Left Square Groove”. They are close to the “Square Groove” in the shape but one of their sides is higher than the other. Figure (4.2) shows the add pre-defined features. With these new features, the total pre-defined features in this system are ten.



(a) Right Square Groove

(b) Left Square Groove

Figure 4.2: The Add New pre-defined features to the system (Drawn by the author)

4.2 Feature Subtracting

4.2.1 Introduction

The AFR system that was developed identifies the final features of the design compared to previously known features, but in the manufacturing workshops, generally, it’s not possible to just convert the workpiece from a cylindrical block shape to the final designed shape figure (4.1 a) shows the first cylinder block and (4.1 b) the final designed features. It has to go over sequential steps that must be calculated accurately to manage time, and cost and to ensure that no collateral damage to the piece or machine occurs. These steps may result in intersecting features, and the AFR system must recognize these resulting new features, from here the idea of developing a new methodology that can recognize the subtraction features and manage its operation.

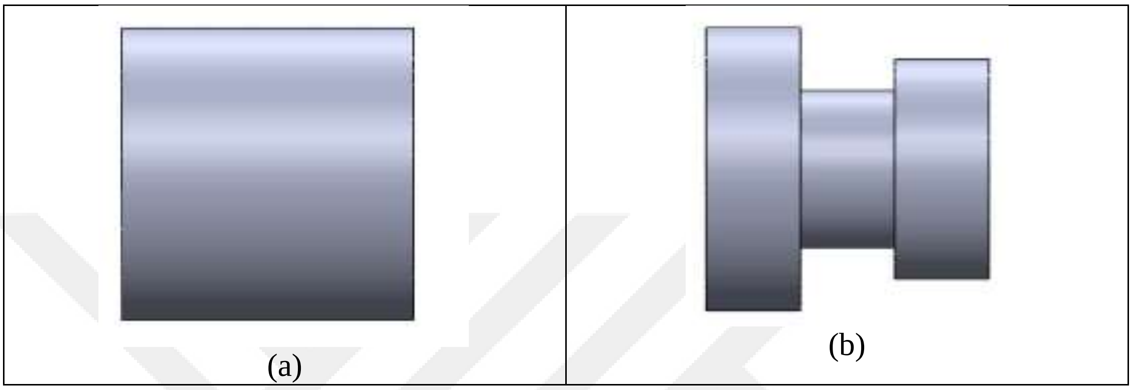


Figure 4.3: The first and final shape of the workpiece (Drawn by the author)

4.2.2 Explain the problem

In simple designs, when there is only one feature as in the example in figure (4.2) there is only one feature (right step) in a case like this, No need to feature Subtracting, the machine tool will just process this feature and the mission is done. Probably most of the missions won't be that easy, and on the opposite, the AFR systems are used mostly when the desigin is complex and hard to extract G-God manually.

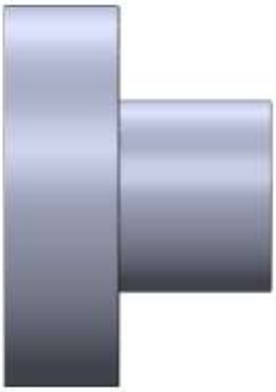


Figure 4.4: Right step as a simple design (Drawn by the author)

When designs get more complex, the extracting of features get more complex and the process plan had to go over more steps to reach the final shape.

To make this clear, figure (4.3) showes an example of a designe and all the possible way to process it and then explain which one is the best, and why.

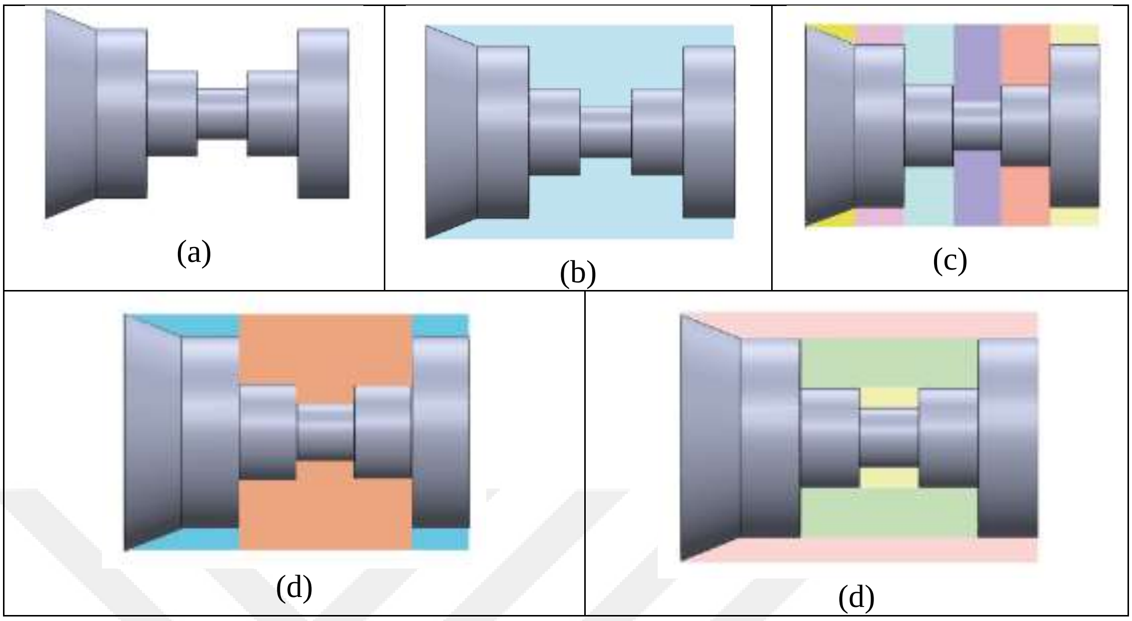


Figure 4.5: The different ways to process the feature intersecting (Drawn by the author)

Figure (4.3) (a) is the original design and that's how the final shape should be. Here is a ways to do that; figure (b) represent the entire extracted material from the cylinder, but there is no possible way to remove it in one step. Figure (c) considering to opperate each feature in the design seperatly. This procedure is a waste of time and increases the cost, in addition, it can cause technical problems and cause damage to the tool and work piece, therefore, a deep vision and particular processing are required to take into account all features' intersections of the design, in a manner that considers all of the procedures of regenerating intermediate features, that are occurs at intersections of original features, and select the right procedure. Figure (4.3) (d) shows another procedure to remove the material, it suggests operating the first feature (the cylindrical) first in blue color, then the area with brown color which represents three features (left step, square groove, and right step). This procedure is somewhat better than the previous one but it is still far from the optimal solution. The last figure (e) shows the perfect procedure to operate the required design, it divides the area into three layers, the first layer in pink color operates the first feature (the cylinder), and the last two features (cylinder and conical). The next layer in green color will make a Feature Subtracting and make a big square groove rather than (left step, square groove, right step). Here the AFR system has to recognize this subtracted feature and define its dimensions to operate it rightly. The final layer in yellow color will extract the lowest square groove to present all the final features in the design. The last strategy is considered the most reasonable one because it decreases the path of the cutting tool and presents one or more features in one step, it also decreases the cost of the manufacturing, helping in increas the tool life and protecting the workpiece surface from damage. This is one example and there are more complex cases that have more features interacting and many possibilities of material removing strategy that produces intermediate features therefore an efficient technique need to be evolved for these cases. the following section produces a technique for fixing features intersections troubles based on volume subtraction method.

4.2.3 Feature subtracting methodology

While the manufacturing is moving on, final features cross over to produce “intermediate features”. That’s because the tool goes over several paths to reach to the final shape. The intermediate features could be in many shapes, depending on the process planer decisions. As mentioned earlier in section 4.2, many strategies could be available to operate the workpiece, it goes between unacceptable, acceptable and the ideal strategy. To ensure getting the ideal strategy for each intersection feature, a new system has been developed in this thesis. This system worked by scanning all the features based on the X and Z axis, dividing these features into groups then arranging the suitable cutting strategy.

First of all, the system determines the radius and length of the required cylindrical workpiece. This is done by scanning all the (x , z) coordinates points in the design and defining the max X and Z values required. Figure (4.6) is an example of the max X and Z in the design.

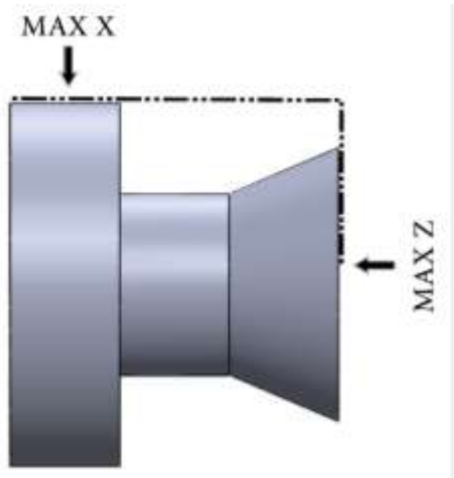


Figure 4.6: Example of the max X and Z in the design (Drawn by the author)

After defining the max X and Z in the shape, the system start a sequential steps to find the intermediate features and will be explained in this chapter in detail.

4.2.3.1 Step one in subtracting feature system

First step in this system is scanning all the final features and there faces to define which features has the value of max X, this could be the same previeuse max X value for the design and it also could take another value, depending on the design it could be one or more final features that share the same max X value.

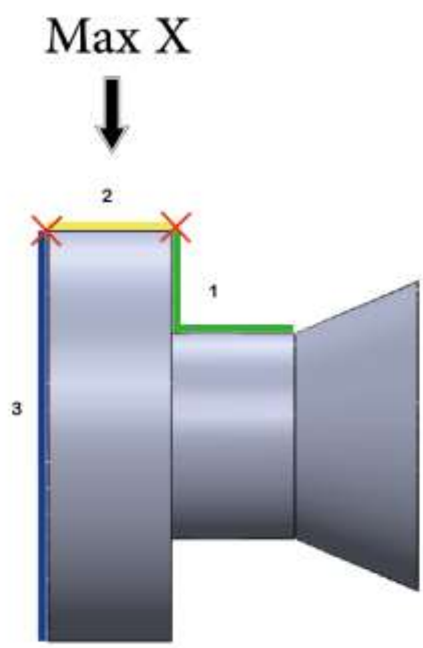


Figure 4.7: Three features share the same max X value (Drawn by the author)

Figure (4.7) shows three features with the same max X, the right step feature in green color toch the Max X in the endpoint of plane face, and the cylinder feature in yellow color has the same Max X in all its points, the third feature is the “facing” feature in blue color toch the Max X in his start point.

4.2.3.2 Step two in subtracting feature system

After detecting the features with the Max X, they might be all connected to each other as in figure (4.8) where the right step feature, the cylinder, and the facing are all connected. In other cases it could be separated as figure (4.9) there are two groups of features that share the max X and are connected together. Group one contains three features, the “right step”, “cylinder”, and the “facing” features. The second group contains “conical”, “cylinder”, and “left step”. The system in this step is checking the features with the same Max X and sorting them into groups depending on the start and end point of each face in the features and if it connected or not.

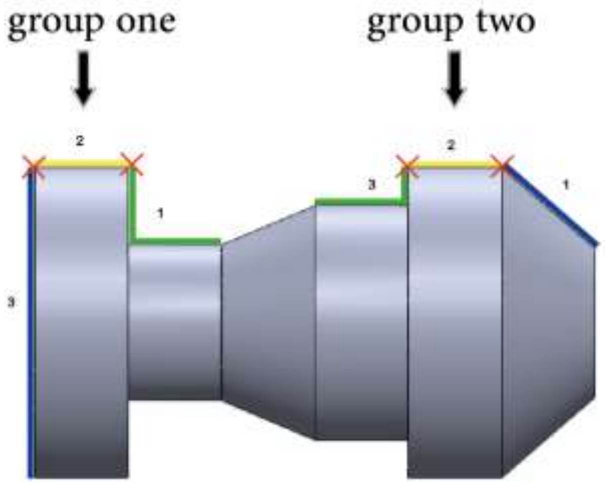


Figure 4.8: Groups of features with the same Max X (Drawn by the author)

4.2.3.3 Step three in subtracting feature system

In this step, the system starts by taking the groups one by one, for each group it checks every feature within this group, scan to the right and left side of each feature in the group starting from the neighboring features and keep contiune untill one of two conditions is met; Either it collides with a feature that has the same or bigger max X value of the relevant feature, or it reaches the last end of the design. Figure (4.9) shows an example of these two cases.

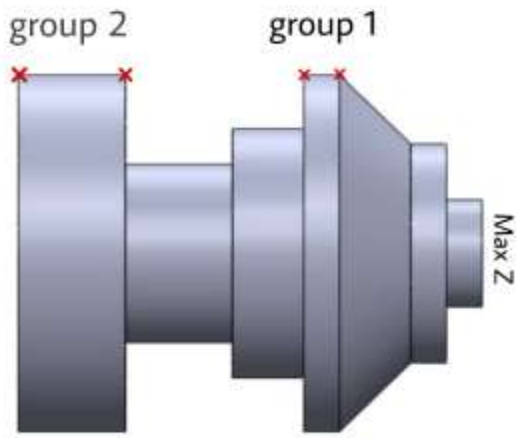


Figure 4.9: Example of two conditions of the system in step three (Drawn by the author)

This design consists of the following features in order from right to left: (Facing, Right step, Cylindrical, Right taper, Cylindrical, Left step, Right square groove, Cylindrical, Facing), Group one of the features that have the same Max X value and connected to each other consist of: (Right taper, Cylindrical, Left step) the system will start scanning to the right of the right taper reading the cylinder and right step then stop by reaching the far end of the shape (the Max Z), then when the system scan to the left of the right taper it will face immediately the cylindrical with the same Max X value of the Right taper feature and stop without reading any feature; and so on for the rest of the features of group one, the same procedure will be applied to the second group. The scaned features from the right and left sides are exported to the next step in the system.

In some cases an independent final feature appears, that's when there is a final feature located between two features with the Max X value, in these cases the independent final feature doesn't export to the next step. The system calculates them and keeps them for later.

4.2.3.4 Step four in subtracting feature system

The scanned features come in bunches of features from the previous step. Each bunch consists of the respective feature with the Max value of X and the scanned features by his side, there is a different bunch for both the right and left side of the respective feature. Based on the two conditions that were set in the previous step to stop scanning, this results in each package containing one feature (the respective feature) with a max value of X. Now the system analyzes these bunches and finds the

Second Max X in each bunch, which could be anywhere in the features in this bunch depending on the design.

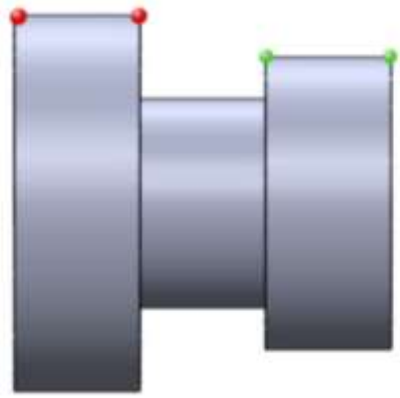


Figure 4.10: Example of Max X and Second Max X (Drawn by the author)

Figure(4.10) show a case where the Max X in red points in the (endpoint of the left square groove, the start and end points of the cylindrical, and the start point of the facing), while the Second Max X in green points in (endpoint of the facing, start and end points of the cylindrical and the start point of the left square groove). This step will affect directly the decision of the system about which part should be removed first from the workpiece and which features or intermediate features will appear first.

4.2.3.5 Step five in subtracting feature system

This step can be considered the basis for which this system was built, defining the sequence that must be followed to remove the material from the workpiece, and if this sequence will produce final features or intermediate features. The final features are already defined in the AFR system and all its data are available. The problem is with intermediate features, they are features that the system doesn't have their data, the faces of the intermediate features, their start and end points, their Max X and Z value, and so on. This is what all this section is about, a system that can recognize the intermediate features and extract their data.

The new intermediate features data depends on three factors:

1. The Max X value of the design from step number one
2. The faces of the first and very last features in the bunches from step number 3
3. The Second Max X from step number four

With these factors, the system can extract the faces of the intermediate feature with their start and end points.

To explain the methodology of this system, figure (4.10) shows an example of a rotary design with two intermediate features. Firstly the system starts by scanning the design to set the Max X and Max Z values. Now as a step one; the system will define which features contain the concerned x value, in this case, the features are; (Right step, Cylindrical, Facing). Step two is checking which of these features are connected to each other, in this case; they are all connected in one group. Step three is start scanning to the right and left of each feature in the group until one of two conditions is met, either collide with another feature with the same or bigger value of the concerned X or reach the end of the design (Max Z or Z = 0). In this case, the system will start with the Right step feature, by scanning its right side the system start fıllıng the fırst bunch by readıng the features starting from the feature itself: (Right step, Square groove, Left step, Cylindrical, and Facing) then stop by meeting one of the conditions which is reaching the last end of the design (Max Z). Now the left side of the Right step and here the system will immediately collide with a feature with the same concerned X value (the cylinder) and stop without making any bunch.

The next feature in the group is the Cylinder, it is located between two features with the concerned X value so no scanning occurs and it defines as an independent final feature.

The same for the final feature in the group (Facing), it is located between the start of the design where Z = 0, and the cylinder with the concerned X value, no scanning occurs and defines as an independent final feature.

One bunch is exported to the next step which contains the features (Right step, Square groove, Left step, Cylindrical, and Facing). The system analyzes the bunch to define where the Second Max X is located. All the required data is ready and extracting the faces of the intermediate feature is all what it left.

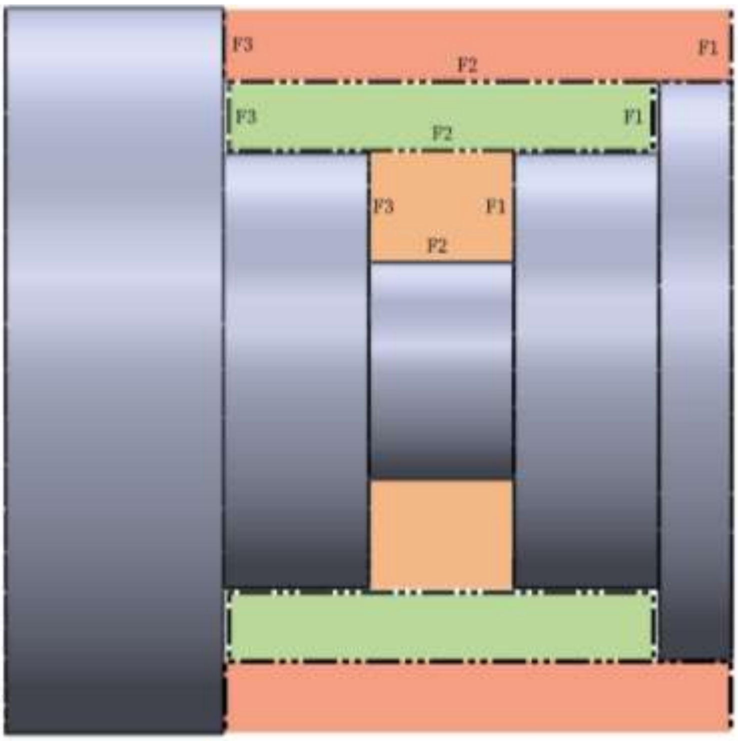


Figure 4.11: Example of a rotary design with two intermediate features (Drawn by the author)

The red zone in figure (4.11) is represented the first intermediate feature. The first face of the intermediate feature is indicated in "F1". F1 consists of; (start point of X, start point of Z, end point of X, and end point of Z).

These points will be determined as follows:

F1 Start Point X = The concerned X value (Max X)

F1 Start Point Z = The Max Z value

F1 End Point X = The Seconed Max X

F1 End Point Z = F1 Start Point Z (Max Z)

The first face data are totally determined, in this case, the face is vertical where its start and end points of Z are equal, in other cases, it might be not.

The second face in the intermediate feature is indicated in "F2" in the figure (4.11), and the points of this face are determines as follows:

F2 Start Point X = The Second Max X

F2 Start Point Z = Max Z value

F2 End Point X = The Second Max X

F2 End Point Z = The Min Z value of the last feature in the bunch

This face is constantly horizontal, the start and end points of X are always equal.

The third face of the intermediate feature is indicated in "F3" in the figure (4.11). The points of this face are determined as follows:

F3 Start Point X = The Second Max X

F3 Start Point Z = The End Point Z of F2

F3 End Point X = The concerned value of X (Max X)

F3 End Point Z = F3 Start Point Z

In this case, the face is vertical where its start and end points of Z are equal, in other cases, it might be not.

Figure (4.12) shows another example, in this case, the first and third faces of the intermediate features are not vertical. The red points represent the Max Z values of the features, while the green points represent the Min Z values.

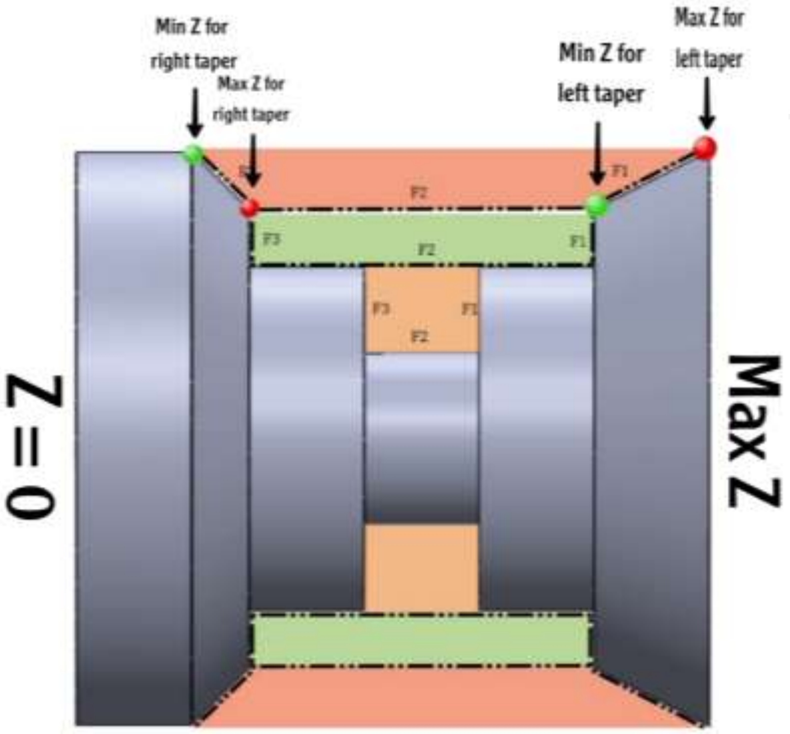


Figure 4.12: Example of the conical intermediate feature (Drawn by the author)

For conical shape, this procedure is followed:

First face points are:

F1 Start Point X = The concerned X value (Max X)

F1 Start Point Z = Max Z value for the left taper feature

F1 End Point X = The Seconed Max X

F1 End Point Z = Min Z value for the left taper feature

The second face in this case is still horizontal (that's constant)

Second face points are:

F2 Start Point X = Second Max X in the bunch

F2 Start Point Z = F1 End Point Z

F2 End Point X = Second Max X in the bunch

F2 End Point Z = Max Z value for the right taper

And the third face points are:

F3 Start Point X = Second Max X in the bunch

F3 Start Point Z = F2 End Point Z

F3 End Point X = Max X value in the bunch

F3 End Point Z = Min Z value for the right taper

By this procedure, we can extract the intermediate feature for the conical features, but that still doesn't cover all the cases. Figure (4.12) shows another case of a conical intermediate feature but this time the second Max X is reaching only the half of the taper feature (it could also be anywhere in between Max X and Min X of the taper).

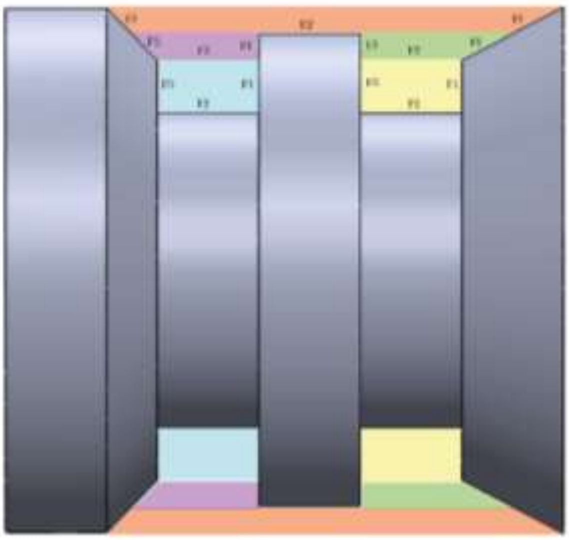


Figure 4.13: Another case of a conical intermediate feature (Drawn by the author)

In this case the first intermediate feature with read color, it cover only the half of the conical from both sides.

The procedure for this first intermediate feature to extract its data is:

First face points are:

F1 Start Point X = The concerned X value (Max X)

F1 Start Point Z = Max Z value for the left taper feature

F1 End Point X = The Seconed Max X

F1 End Point Z = Max Z value for left taper – (tan(ϴ) * (Max X – Min X))

ϴ is the angel of the taper .

Max X is the value of the max X for the left taper feature.

Min X is the value of the min X for the left taper feature.

Second face points are:

F2 Start Point X = Second Max X in the bunch

F2 Start Point Z = F1 End Point Z

F2 End Point X = Second Max X in the bunch

F2 End Point Z = Min Z value for the right taper + (tan (ϴ) * (Max X – Min X))

ϴ here is the angle for the right taper

Max X is the value for the maximum x in the right taper

Min X is the value of minimum X in the right taper

The third face points are:

F3 Start Point X = Second Max X in the bunch

F3 Start Point Z = F2 End Point Z

F3 End Point X = Max X value in the bunch

F3 End Point Z = Min Z value for the right taper

By this procedure, the program covered as many as possible of the cases that might be faced in the design.

4.2.3.6 Step six in subtracting feature system

In this step a loop of the same procedure is applied, the work area will be divided into layers depending on the design and each layer represent an intermediate or final feature, these layers are removed sequentially until all the final features from the design appear. For example the design in figure (4.14) will start by removing the material from the first intermediate feature in red color, the next layer will be the intermediate feature in green color, here the second Max X vakue will update to be the Max X value and the program will check the other features in this bunch to define the second Max X which will be represented in the end point of the left taper and so on. Figure (4.14) explains these steps in sequence.

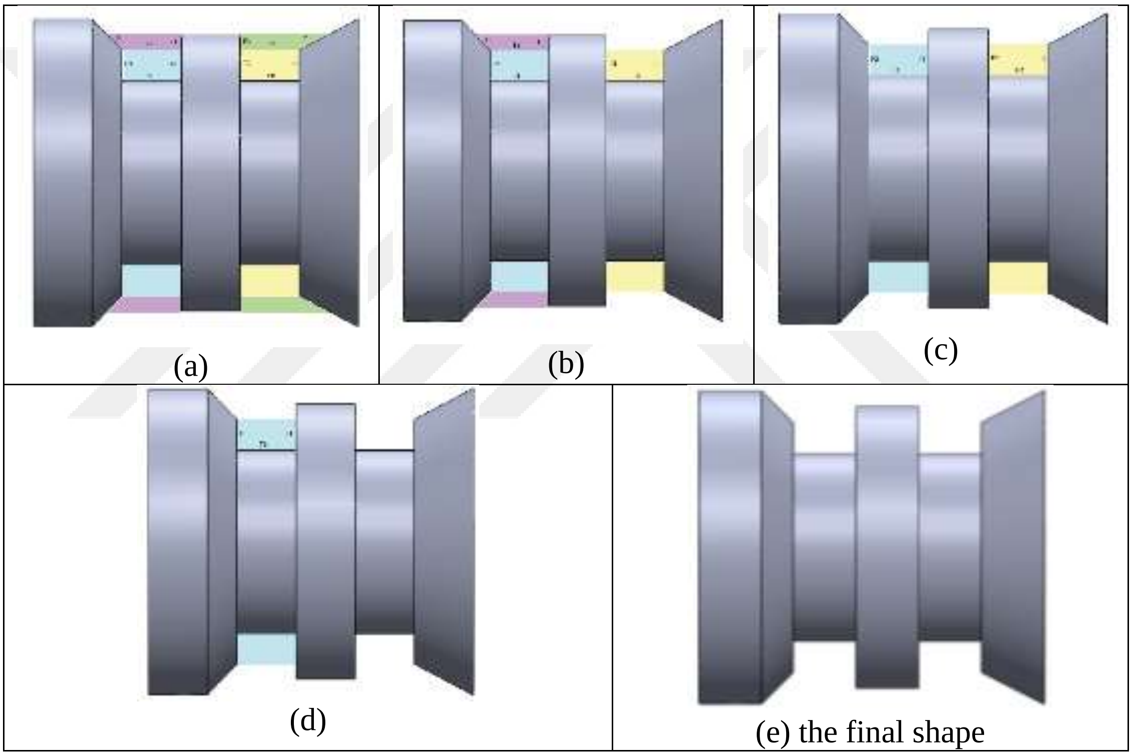


Figure 4.14: The steps of removing the material from the workpiece (Drawn by the author)

4.2.3.7 Step seven in subtracting feature system

This step is to ensure that no repeating will happen, as a result of the fact that the system is scanning the features to the right and left sides, it's wide possible that the same intermediate feature may be detected twice, and to avoid that every detecting intermediate feature is temporarily stored in the memory to compare with other dedicated ones and delete the duplicate.

4.3 Case Study

To explain the previous work, this is a case study of a rotary design that needs to extract its intermediate features. Figure (4.15) showes the Case study design.

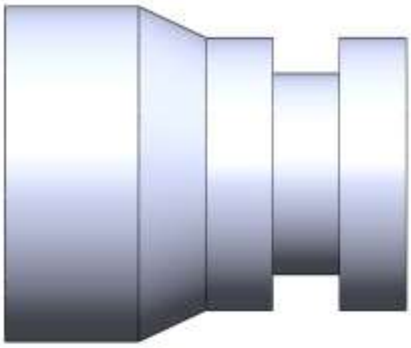


Figure 4.15: Case Study for the intermediate and final features

For this design, one intermediate feature appears and four final features as shown in figure (4.16).

The first one is the intermediate feature in the yellow area

The second feature is Facing the green line

Then the Square Groove in the red area

The fourth feature is the Cylindrical in the red line

And the final feature is the Facing in the yellow line

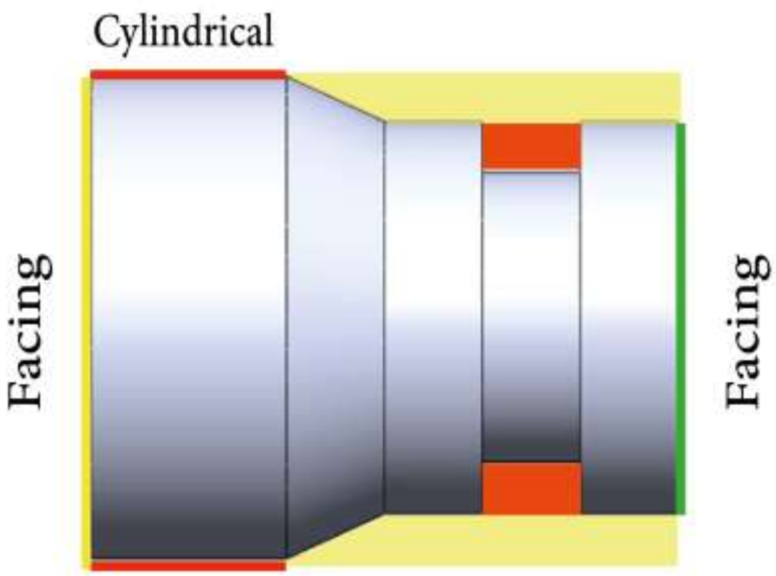


Figure 4.16: Explain the intermediate and final features

The developed program automatically extracts these features in the right sequence of operation and analyse the data of each face in the features.

The data that comes out from the program for this design are clarify in table (4.1):

Table 4.1: The result of the case study (made by the author)

Features	Faces	Start Point X	Start Point Z	End Point X	Ene Point Z
Intermediate Feature	1	50	120	40.674	120
	2	40.674	120	40.674	60
	3	40.674	60	50	40
Facing	1	0	120	40.674	120
Square Groove	1	40.674	100	30	100
	2	30	100	30	80
	3	40.674	80	30	80
Cylindrical	1	50	40	50	0
Facing	1	50	0	0	0

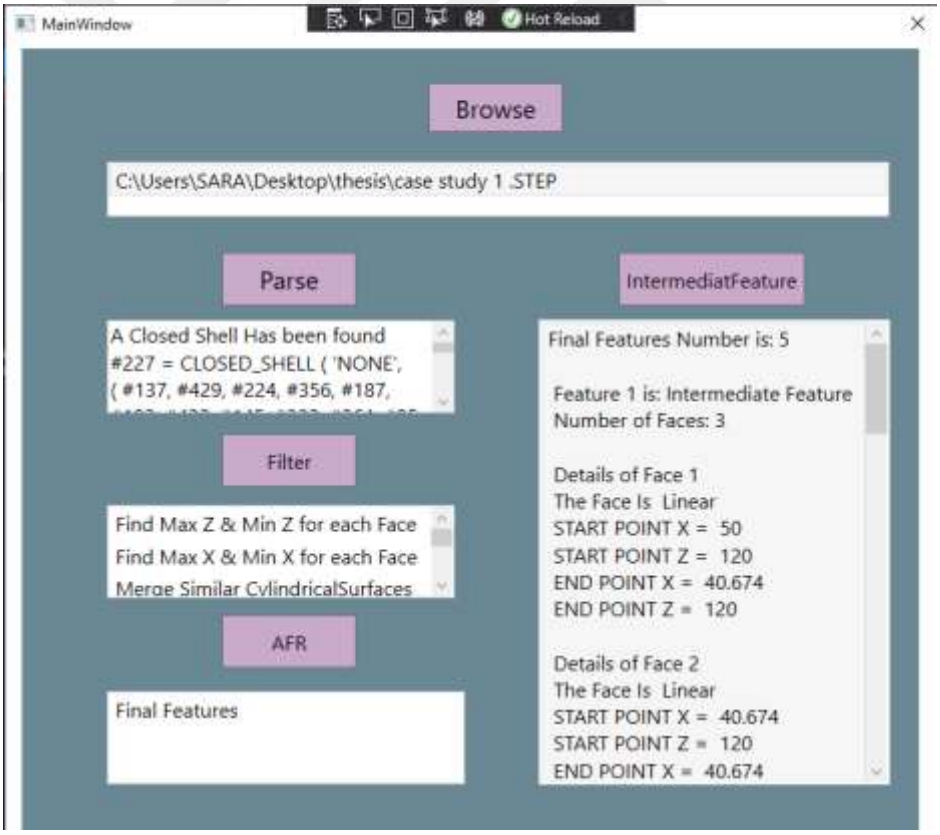


Figure 4.17: The result in the program

Figure (4.17) shows the program interface and the result in the Intermediate Feature section. These results will help the operator to know which area should be removed first to reach the final required shape.

4.5 Conclusion

This research is about automating the production of rotary parts with CNC machines, developing a program that can analyze the STEP files that comes from the designer, and producing a plan to manufacture this design. The STEP file has been chosen in this work because of all its benefits and its ability to provide all of the geometrical and non-geometrical information of the design. By analyzing design features by the Feature recognition system AFR system that developed using C sharp C# programing language and comparing them with ten pre-defined features that are already saved in the memory of the program, after recognizing all the final features the intermediate features must be defined because in real life work it's almost impossible to transfer the workpiece from cylindrical block to the final shape in one step, the removing area needs to divided to layers and with these layers, an intermediate features will appear before reaching the final required shape. The result of the program directs the user to which part should be removed first and the data of each face in the intermediate or final features (start and ends point of each face) it could be one face, two or three faces depending on the feature geometry. the user can easily use the result from this program to operate the workpiece in minimum time and cost, this is done by avoiding possible errors or useless operating paths that damage the cutting tool and the workpiece. This program also reduces the cost of the wages of an engineering expert to extract this information.

4.6 Limitations of the work

this work also has limitations because of the pre-defined features. The more pre-defined features are added, the more effective the program will be, that’s why it has been developed in this research by adding two new features but it still follows the designer’s imagination if any new feature comes out of these pre-defined features the program will not be able to analyze it.

4.7 Future work

There is ample room for development in this research, more pre-defined features can be added, or more over a smart feature recognition system can be developed to recognize any new feature that may appear.

Automating tool selection can be added to the work whereas there is a special tool for each feature and the user might not be familiar with the suitable tool for each part.

The automating tool path selection is another step forward, part of it is already done in this research by defining the right sequence of the part that should be operated first. the path of the tool for each part can be extracted too.

The final step in this field can be done by extracting the G-code for operating the required design whereas all the data of the intermediate and final features with their start and end points of each face are ready.

There can be some other additions, such as adding mathematical equations to calculate the expected time and cost for each operational process, to shorten the need to do it on paper each time.

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APPENDIX

Appendix A: The Step File of the Conical Shape

The step file of the conical shape:
ISO-10303-21;
HEADER;
FILE_DESCRIPTION (('STEP AP203'),
'1');
FILE_NAME ('conical.STEP',
'2021-12-21T13:50:21',
(''),
(''),
'SwSTEP 2.0',
'SolidWorks 2020',
'');
FILE_SCHEMA (('CONFIG_CONTROL_DESIGN'));
ENDSEC;

DATA;
#1 = APPROVAL_ROLE ('') ;
#2 = PRODUCT_DEFINITION_FORMATION_WITH_SPECIFIED_SOURCE ('ANY', '',
#105, .NOT_KNOWN.) ;
#3 = CC_DESIGN_APPROVAL (#69, (#109)) ;
#4 = DIRECTION ('NONE', (0.000000000000000000, 0.000000000000000000,
1.000000000000000000)) ;
#5 = ORIENTED_EDGE ('NONE', *, *, #19, .T.) ;
#6 = CARTESIAN_POINT ('NONE', (-40.97909924655443348, -
5.018492272423459991E-15, 0.000000000000000000)) ;
#7 = DIRECTION ('NONE', (0.000000000000000000, 0.000000000000000000,
1.000000000000000000)) ;
#8 = ORIENTED_EDGE ('NONE', *, *, #24, .F.) ;
#9 = ADVANCED_FACE ('NONE', (#99), #36, .T.) ;
#10 =(NAMED_UNIT (*) SI_UNIT ($, .STERADIAN.) SOLID_ANGLE_UNIT ( ));
#11 = CC_DESIGN_DATE_AND_TIME_ASSIGNMENT (#49, #102, (#109)) ;
#12 = DATE_AND_TIME (#37, #65) ;
#13 = LOCAL_TIME (16, 50, 21.00000000000000000, #162) ;
#14 = SECURITY_CLASSIFICATION_LEVEL ('unclassified') ;
#15 = ORIENTED_EDGE ('NONE', *, *, #133, .F.) ;
#16 = CARTESIAN_POINT ('NONE', (-29.31628069829131888, -
4.304350602215118770E-15, 60.00000000000002132)) ;
#17 = ORIENTED_EDGE ('NONE', *, *, #56, .T.) ;
#18 = CARTESIAN_POINT ('NONE', (0.000000000000000000, 0.000000000000000000,
0.000000000000000000)) ;
#19 = EDGE_CURVE ('NONE', #135, #137, #77, .T.) ;
#20 = DIRECTION ('NONE', (-0.000000000000000000, -0.000000000000000000, -
1.000000000000000000)) ;
#21 = PERSON_AND_ORGANIZATION (#96, #60) ;

#22 = PERSON_AND_ORGANIZATION_ROLE ('creator') ;
#23 = MANIFOLD_SOLID_BREP ('Boss-Extrude1', #71) ;
#24 = EDGE_CURVE ('NONE', #169, #57, #26, .T.) ;
#25 = CONICAL_SURFACE ('NONE', #93, 40.97909924655443348, 0.1919862177193762676) ;
#26 = CIRCLE ('NONE', #150, 29.31628069829131888) ;
#27 = PERSON_AND_ORGANIZATION_ROLE ('creator') ;
#28 = AXIS2_PLACEMENT_3D ('NONE', #108, #120, #174) ;
#29 = ORIENTED_EDGE ('NONE', *, *, #24, .T.) ;
#30 = ORIENTED_EDGE ('NONE', *, *, #149, .F.) ;
#31 = LINE ('NONE', #85, #100) ;
#32 = DIRECTION ('NONE', (1.000000000000000000, 0.000000000000000000, -0.000000000000000000)) ;
#33 = FACE_OUTER_BOUND ('NONE', #66, .T.) ;
#34 = CARTESIAN_POINT ('NONE', (0.000000000000000000, 0.000000000000000000, 0.000000000000000000)) ;
#35 = APPROVAL_DATE_TIME (#74, #69) ;
#36 = CONICAL_SURFACE ('NONE', #157, 40.97909924655443348, 0.1919862177193762676) ;
#37 = CALENDAR_DATE (2021, 21, 12) ;
#38 = APPLICATION_PROTOCOL_DEFINITION ('international standard', 'config_control_design', 1994, #75) ;
#39 = DESIGN_CONTEXT ('detailed design', #75, 'design') ;
#40 = DIRECTION ('NONE', (0.000000000000000000, 0.000000000000000000, 1.000000000000000000)) ;
#41 =(GEOMETRIC_REPRESENTATION_CONTEXT (3) GLOBAL_UNCERTAINTY_ASSIGNED_CONTEXT ((#143)) GLOBAL_UNIT_ASSIGNED_CONTEXT ((#160, #88, #10)) REPRESENTATION_CONTEXT ('NONE', 'WORKASPACE'));
#42 = DATE_AND_TIME (#62, #95) ;
#43 = DIRECTION ('NONE', (0.000000000000000000, 0.000000000000000000, 1.000000000000000000)) ;
#44 = FACE_OUTER_BOUND ('NONE', #128, .T.) ;
#45 = ORIENTED_EDGE ('NONE', *, *, #79, .T.) ;
#46 = PLANE ('NONE', #110) ;
#47 = CARTESIAN_POINT ('NONE', (0.000000000000000000, 0.000000000000000000, 0.000000000000000000)) ;
#48 = DIRECTION ('NONE', (1.000000000000000000, 0.000000000000000000, 0.000000000000000000)) ;
#49 = DATE_AND_TIME (#159, #73) ;
#50 = PERSON_AND_ORGANIZATION_ROLE ('design_owner') ;
#51 = PERSON_AND_ORGANIZATION (#96, #60) ;
#52 = LOCAL_TIME (16, 50, 21.00000000000000000, #158) ;
#53 = CALENDAR_DATE (2021, 21, 12) ;
#54 = APPROVAL (#156, 'UNSPECIFIED') ;
#55 = PERSON_AND_ORGANIZATION_ROLE ('design_supplier') ;
#56 = EDGE_CURVE ('NONE', #169, #137, #31, .T.) ;
#57 = VERTEX_POINT ('NONE', #16) ;
#58 = EDGE_LOOP ('NONE', (#15, #45, #5, #80)) ;
#59 = DIRECTION ('NONE', (0.000000000000000000, 0.000000000000000000, 1.000000000000000000)) ;
#60 = ORGANIZATION ('UNSPECIFIED', 'UNSPECIFIED', '') ;
#61 = DATE_AND_TIME (#53, #13) ;
#62 = CALENDAR_DATE (2021, 21, 12) ;
#63 = PERSON_AND_ORGANIZATION (#96, #60) ;

#64 = AXIS2_PLACEMENT_3D ('NONE', #166, #7, #32) ;
#65 = LOCAL_TIME (16, 50, 21.00000000000000000, #131) ;
#66 = EDGE_LOOP ('NONE', (#30, #113)) ;
#67 = CC_DESIGN_PERSON_AND_ORGANIZATION_ASSIGNMENT (#126, #81, (#87)) ;
#68 = LINE ('NONE', #6, #118) ;
#69 = APPROVAL (#142, 'UNSPECIFIED') ;
#70 = PERSON_AND_ORGANIZATION (#96, #60) ;
#71 = CLOSED_SHELL ('NONE', (#115, #9, #86, #122)) ;
#72 = CARTESIAN_POINT ('NONE', (-40.97909924655443348, -5.018492272423459991E-15, 0.000000000000000000)) ;
#73 = LOCAL_TIME (16, 50, 21.00000000000000000, #171) ;
#74 = DATE_AND_TIME (#90, #52) ;
#75 = APPLICATION_CONTEXT ('configuration controlled 3d designs of mechanical parts and assemblies') ;
#76 = APPROVAL_PERSON_ORGANIZATION (#91, #54, #144) ;
#77 = CIRCLE ('NONE', #103, 40.97909924655443348) ;
#78 = APPROVAL_DATE_TIME (#42, #167) ;
#79 = EDGE_CURVE ('NONE', #57, #135, #68, .T.) ;
#80 = ORIENTED_EDGE ('NONE', *, *, #56, .F.) ;
#81 = PERSON_AND_ORGANIZATION_ROLE ('classification_officer') ;
#82 = ORIENTED_EDGE ('NONE', *, *, #133, .T.) ;
#83 = CC_DESIGN_PERSON_AND_ORGANIZATION_ASSIGNMENT (#148, #55, (#2)) ;
#84 = EDGE_LOOP ('NONE', (#168, #8, #17, #152)) ;
#85 = CARTESIAN_POINT ('NONE', (40.97909924655443348, 0.000000000000000000, 0.000000000000000000)) ;
#86 = ADVANCED_FACE ('NONE', (#44), #116, .T.) ;
#87 = SECURITY_CLASSIFICATION ('', '', #14) ;
#88 =(NAMED_UNIT (*) PLANE_ANGLE_UNIT ( ) SI_UNIT ($, .RADIAN.));
#89 = PRODUCT_DEFINITION_SHAPE ('NONE', 'NONE', #109) ;
#90 = CALENDAR_DATE (2021, 21, 12) ;
#91 = PERSON_AND_ORGANIZATION (#96, #60) ;
#92 = DIRECTION ('NONE', (1.000000000000000000, 0.000000000000000000, 0.000000000000000000)) ;
#93 = AXIS2_PLACEMENT_3D ('NONE', #47, #20, #112) ;
#94 = SHAPE_DEFINITION_REPRESENTATION (#89, #170) ;
#95 = LOCAL_TIME (16, 50, 21.00000000000000000, #123) ;
#96 = PERSON ('UNSPECIFIED', 'UNSPECIFIED', 'UNSPECIFIED', ('UNSPECIFIED'), ('UNSPECIFIED'), ('UNSPECIFIED')) ;
#97 = DIRECTION ('NONE', (0.000000000000000000, 0.000000000000000000, 1.000000000000000000)) ;
#98 = DIRECTION ('NONE', (1.000000000000000000, 0.000000000000000000, -0.000000000000000000)) ;
#99 = FACE_OUTER_BOUND ('NONE', #84, .T.) ;
#100 = VECTOR ('NONE', #136, 1000.000000000000000) ;
#101 = CC_DESIGN_SECURITY_CLASSIFICATION (#87, (#2)) ;
#102 = DATE_TIME_ROLE ('creation_date') ;
#103 = AXIS2_PLACEMENT_3D ('NONE', #34, #97, #139) ;
#104 = MECHANICAL_CONTEXT ('NONE', #119, 'mechanical') ;
#105 = PRODUCT ('conical', 'conical', '', (#104)) ;
#106 = APPROVAL_ROLE ('') ;
#107 = CC_DESIGN_DATE_AND_TIME_ASSIGNMENT (#61, #111, (#87)) ;
#108 = CARTESIAN_POINT ('NONE', (0.000000000000000000, 0.000000000000000000, 0.000000000000000000)) ;

#109 = PRODUCT_DEFINITION ('UNKNOWN', '', #2, #39) ;
#110 = AXIS2_PLACEMENT_3D ('NONE', #18, #43, #98) ;
#111 = DATE_TIME_ROLE ('classification_date') ;
#112 = DIRECTION ('NONE', (1.000000000000000000, 0.0000000000000000000, 0.0000000000000000000)) ;
#113 = ORIENTED_EDGE ('NONE', *, *, #19, .F.) ;
#114 = DIRECTION ('NONE', (-0.1908089953765448321, -2.336736254364077596E-17, -0.9816271834476639757)) ;
#115 = ADVANCED_FACE ('NONE', (#154), #25, .T.) ;
#116 = PLANE ('NONE', #64) ;
#117 = CARTESIAN_POINT ('NONE', (0.0000000000000000000, 0.0000000000000000000, 0.0000000000000000000)) ;
#118 = VECTOR ('NONE', #114, 1000.000000000000000) ;
#119 = APPLICATION_CONTEXT ('configuration controlled 3d designs of mechanical parts and assemblies') ;
#120 = DIRECTION ('NONE', (0.0000000000000000000, 0.0000000000000000000, 1.000000000000000000)) ;
#121 = APPROVAL_DATE_TIME (#12, #54) ;
#122 = ADVANCED_FACE ('NONE', (#33), #46, .F.) ;
#123 = COORDINATED_UNIVERSAL_TIME_OFFSET (3, 0, .AHEAD.) ;
#124 = CARTESIAN_POINT ('NONE', (0.0000000000000000000, 0.0000000000000000000, 60.00000000000002132)) ;
#125 = CC_DESIGN_PERSON_AND_ORGANIZATION_ASSIGNMENT (#175, #27, (#2)) ;
#126 = PERSON_AND_ORGANIZATION (#96, #60) ;
#127 = CIRCLE ('NONE', #146, 29.31628069829131888) ;
#128 = EDGE_LOOP ('NONE', (#29, #82)) ;
#129 = CARTESIAN_POINT ('NONE', (29.31628069829131888, 0.0000000000000000000, 60.00000000000002132)) ;
#130 = CARTESIAN_POINT ('NONE', (0.0000000000000000000, 0.0000000000000000000, 0.0000000000000000000)) ;
#131 = COORDINATED_UNIVERSAL_TIME_OFFSET (3, 0, .AHEAD.) ;
#132 = PRODUCT_RELATED_PRODUCT_CATEGORY ('detail', '', (#105)) ;
#133 = EDGE_CURVE ('NONE', #57, #169, #127, .T.) ;
#134 = AXIS2_PLACEMENT_3D ('NONE', #130, #59, #92) ;
#135 = VERTEX_POINT ('NONE', #72) ;
#136 = DIRECTION ('NONE', (0.1908089953765448321, 0.0000000000000000000, -0.9816271834476639757)) ;
#137 = VERTEX_POINT ('NONE', #141) ;
#138 = CC_DESIGN_APPROVAL (#167, (#87)) ;
#139 = DIRECTION ('NONE', (1.000000000000000000, 0.0000000000000000000, 0.0000000000000000000)) ;
#140 = APPLICATION_PROTOCOL_DEFINITION ('international standard', 'config_control_design', 1994, #119) ;
#141 = CARTESIAN_POINT ('NONE', (40.97909924655443348, 0.0000000000000000000, 0.0000000000000000000)) ;
#142 = APPROVAL_STATUS ('not_yet_approved') ;
#143 = UNCERTAINTY_MEASURE_WITH_UNIT (LENGTH_MEASURE(1.000000000000000082E-05), #160, 'distance_accuracy_value', 'NONE');
#144 = APPROVAL_ROLE ('') ;
#145 = CC_DESIGN_PERSON_AND_ORGANIZATION_ASSIGNMENT (#21, #50, (#105)) ;
#146 = AXIS2_PLACEMENT_3D ('NONE', #124, #40, #173) ;
#147 = APPROVAL_STATUS ('not_yet_approved') ;
#148 = PERSON_AND_ORGANIZATION (#96, #60) ;

#149 = EDGE_CURVE ('NONE', #137, #135, #172, .T.) ;
#150 = AXIS2_PLACEMENT_3D ('NONE', #151, #4, #165) ;
#151 = CARTESIAN_POINT ('NONE', (0.000000000000000000, 0.000000000000000000, 60.00000000000002132)) ;
#152 = ORIENTED_EDGE ('NONE', *, *, #149, .T.) ;
#153 = DIRECTION ('NONE', (-0.000000000000000000, -0.000000000000000000, -1.000000000000000000)) ;
#154 = FACE_OUTER_BOUND ('NONE', #58, .T.) ;
#155 = APPROVAL_PERSON_ORGANIZATION (#63, #167, #1) ;
#156 = APPROVAL_STATUS ('not_yet_approved') ;
#157 = AXIS2_PLACEMENT_3D ('NONE', #117, #153, #48) ;
#158 = COORDINATED_UNIVERSAL_TIME_OFFSET (3, 0, .AHEAD.) ;
#159 = CALENDAR_DATE (2021, 21, 12) ;
#160 =(LENGTH_UNIT ( ) NAMED_UNIT (*) SI_UNIT (.MILLI., .METRE.));
#161 = APPROVAL_PERSON_ORGANIZATION (#51, #69, #106) ;
#162 = COORDINATED_UNIVERSAL_TIME_OFFSET (3, 0, .AHEAD.) ;
#163 = CC_DESIGN_PERSON_AND_ORGANIZATION_ASSIGNMENT (#70, #22, (#109)) ;
#164 = CC_DESIGN_APPROVAL (#54, (#2)) ;
#165 = DIRECTION ('NONE', (1.000000000000000000, 0.000000000000000000, 0.000000000000000000)) ;
#166 = CARTESIAN_POINT ('NONE', (0.000000000000000000, 0.000000000000000000, 60.00000000000002132)) ;
#167 = APPROVAL (#147, 'UNSPECIFIED') ;
#168 = ORIENTED_EDGE ('NONE', *, *, #79, .F.) ;
#169 = VERTEX_POINT ('NONE', #129) ;
#170 = ADVANCED_BREP_SHAPE_REPRESENTATION ('conical', (#23, #134), #41) ;
#171 = COORDINATED_UNIVERSAL_TIME_OFFSET (3, 0, .AHEAD.) ;
#172 = CIRCLE ('NONE', #28, 40.97909924655443348) ;
#173 = DIRECTION ('NONE', (1.000000000000000000, 0.000000000000000000, 0.000000000000000000)) ;
#174 = DIRECTION ('NONE', (1.000000000000000000, 0.000000000000000000, 0.000000000000000000)) ;
#175 = PERSON_AND_ORGANIZATION (#96, #60) ;
ENDSEC;
END-ISO-10303-21;

Appendix B: The Step File of the Case Study Design

The step file of the case study design:

```
ISO-10303-21;
HEADER;
FILE_DESCRIPTION (( 'STEP AP203' ),
   '1' );
FILE_NAME ('case study 1 .STEP',
   '2022-07-04T21:28:42',
   ( '' ),
   ( '' ),
   'SwSTEP 2.0',
   'SolidWorks 2020',
   '' );
FILE_SCHEMA (( 'CONFIG_CONTROL_DESIGN' ));
ENDSEC;

DATA;
#1 = PRODUCT ( 'case study 1 ', 'case study 1 ', '', ( #246 ) ) ;
#2 = EDGE_CURVE ( 'NONE', #343, #185, #388, .T. ) ;
#3 = CYLINDRICAL_SURFACE ( 'NONE', #157, 50.00000000000000000 ) ;
#4 = DIRECTION ( 'NONE', ( 1.000000000000000000, 0.000000000000000000, 0.000000000000000000 ) ) ;
#5 = CARTESIAN_POINT ( 'NONE', ( 0.000000000000000000, 0.000000000000000000, 119.9999999999999716 ) ) ;
#6 = CARTESIAN_POINT ( 'NONE', ( 50.00000000000000000, 6.123233995736766085E-15, 40.00000000000000000 ) ) ;
#7 = APPROVAL_STATUS ( 'not_yet_approved' ) ;
#8 = DIRECTION ( 'NONE', ( 0.000000000000000000, 0.000000000000000000, 1.000000000000000000 ) ) ;
#9 = ORIENTED_EDGE ( 'NONE', *, *, #163, .F. ) ;
#10 = ORIENTED_EDGE ( 'NONE', *, *, #392, .F. ) ;
#11 = CARTESIAN_POINT ( 'NONE', ( -40.67384683690001879, 0.000000000000000000, 119.9999999999999716 ) ) ;
#12 = CARTESIAN_POINT ( 'NONE', ( 0.000000000000000000, 0.000000000000000000, 60.00000000000000000 ) ) ;
#13 = ORIENTED_EDGE ( 'NONE', *, *, #163, .T. ) ;
#14 = EDGE_CURVE ( 'NONE', #70, #185, #290, .T. ) ;
#15 = CARTESIAN_POINT ( 'NONE', ( 0.000000000000000000, 0.000000000000000000, 79.99999999999998579 ) ) ;
#16 = VERTEX_POINT ( 'NONE', #207 ) ;
#17 = ORIENTED_EDGE ( 'NONE', *, *, #298, .T. ) ;
#18 = CARTESIAN_POINT ( 'NONE', ( 0.000000000000000000, 0.000000000000000000, 0.000000000000000000 ) ) ;
#19 = CC_DESIGN_SECURITY_CLASSIFICATION ( #90, ( #296 ) ) ;
#20 = CIRCLE ( 'NONE', #259, 50.00000000000000000 ) ;
#21 = EDGE_LOOP ( 'NONE', ( #376, #188, #273, #214 ) ) ;
#22 = DIRECTION ( 'NONE', ( -1.000000000000000000, 0.000000000000000000, 0.000000000000000000 ) ) ;
#23 = APPROVAL_STATUS ( 'not_yet_approved' ) ;
#24 = EDGE_LOOP ( 'NONE', ( #9, #17, #144, #186 ) ) ;
#25 = PERSON_AND_ORGANIZATION_ROLE ( 'creator' ) ;
#26 = ORIENTED_EDGE ( 'NONE', *, *, #50, .T. ) ;
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#27 = ORIENTED_EDGE ('NONE', *, *, #382, .T.) ;
#28 = VECTOR ('NONE', #37, 1000.000000000000227) ;
#29 = AXIS2_PLACEMENT_3D ('NONE', #60, #265, #406) ;
#30 = CARTESIAN_POINT ('NONE', (0.000000000000000000, 0.000000000000000000, 40.00000000000000000)) ;
#31 = EDGE_CURVE ('NONE', #100, #294, #97, .T.) ;
#32 = CARTESIAN_POINT ('NONE', (50.00000000000000000, 6.123233995736766085E-15, 0.000000000000000000)) ;
#33 = AXIS2_PLACEMENT_3D ('NONE', #341, #310, #346) ;
#34 = LINE ('NONE', #43, #279) ;
#35 = CYLINDRICAL_SURFACE ('NONE', #126, 40.67384683690001879) ;
#36 = DIRECTION ('NONE', (1.000000000000000000, 0.000000000000000000, 0.000000000000000000)) ;
#37 = DIRECTION ('NONE', (-0.4226182617406996078, -5.175581015019661243E-17, -0.9063077870366499367)) ;
#38 = ORIENTED_EDGE ('NONE', *, *, #398, .T.) ;
#39 = PERSON_AND_ORGANIZATION (#96, #358) ;
#40 = DIRECTION ('NONE', (1.000000000000000000, 0.000000000000000000, 0.000000000000000000)) ;
#41 = VERTEX_POINT ('NONE', #175) ;
#42 = DIRECTION ('NONE', (-0.000000000000000000, -0.000000000000000000, -1.000000000000000000)) ;
#43 = CARTESIAN_POINT ('NONE', (40.67384683690001879, 4.981109633781930391E-15, 79.99999999999998579)) ;
#44 = CC_DESIGN_DATE_AND_TIME_ASSIGNMENT (#152, #123, (#395)) ;
#45 = ORIENTED_EDGE ('NONE', *, *, #373, .F.) ;
#46 = DIRECTION ('NONE', (0.000000000000000000, 0.000000000000000000, 1.000000000000000000)) ;
#47 = DIRECTION ('NONE', (0.000000000000000000, 0.000000000000000000, 1.000000000000000000)) ;
#48 = DIRECTION ('NONE', (1.000000000000000000, 0.000000000000000000, 0.000000000000000000)) ;
#49 = LOCAL_TIME (0, 28, 42.00000000000000000, #291) ;
#50 = EDGE_CURVE ('NONE', #294, #342, #313, .T.) ;
#51 = CALENDAR_DATE (2022, 5, 7) ;
#52 = AXIS2_PLACEMENT_3D ('NONE', #74, #410, #112) ;
#53 = AXIS2_PLACEMENT_3D ('NONE', #80, #381, #73) ;
#54 = EDGE_LOOP ('NONE', (#116, #236, #166, #58)) ;
#55 = EDGE_LOOP ('NONE', (#399, #13)) ;
#56 = EDGE_CURVE ('NONE', #41, #92, #119, .T.) ;
#57 = ORIENTED_EDGE ('NONE', *, *, #61, .F.) ;
#58 = ORIENTED_EDGE ('NONE', *, *, #2, .F.) ;
#59 = CIRCLE ('NONE', #189, 30.00000000000000000) ;
#60 = CARTESIAN_POINT ('NONE', (0.000000000000000000, 0.000000000000000000, 99.99999999999997158)) ;
#61 = EDGE_CURVE ('NONE', #343, #92, #20, .T.) ;
#62 = CIRCLE ('NONE', #314, 40.67384683690001879) ;
#63 = DIRECTION ('NONE', (1.000000000000000000, 0.000000000000000000, 0.000000000000000000)) ;
#64 = CARTESIAN_POINT ('NONE', (0.000000000000000000, 0.000000000000000000, 99.99999999999997158)) ;
#65 = CYLINDRICAL_SURFACE ('NONE', #222, 40.67384683690001879) ;
#66 = CARTESIAN_POINT ('NONE', (0.000000000000000000, 0.000000000000000000, 79.99999999999998579)) ;

#67 = APPLICATION_PROTOCOL_DEFINITION ('international standard', 'config_control_design', 1994, #400) ;
#68 = CIRCLE ('NONE', #386, 30.00000000000000000) ;
#69 = CARTESIAN_POINT ('NONE', (0.000000000000000000, 0.000000000000000000, 79.99999999999998579)) ;
#70 = VERTEX_POINT ('NONE', #32) ;
#71 = DIRECTION ('NONE', (0.4226182617406996078, 0.000000000000000000, -0.9063077870366499367)) ;
#72 = VECTOR ('NONE', #306, 1000.000000000000000) ;
#73 = DIRECTION ('NONE', (1.000000000000000000, 0.000000000000000000, -0.000000000000000000)) ;
#74 = CARTESIAN_POINT ('NONE', (0.000000000000000000, 0.000000000000000000, 79.99999999999998579)) ;
#75 = CARTESIAN_POINT ('NONE', (-50.00000000000000000, 0.000000000000000000, 40.00000000000000000)) ;
#76 = ADVANCED_FACE ('NONE', (#101), #200, .T.) ;
#77 = DIRECTION ('NONE', (0.000000000000000000, 0.000000000000000000, 1.000000000000000000)) ;
#78 = DIRECTION ('NONE', (0.000000000000000000, 0.000000000000000000, 1.000000000000000000)) ;
#79 = VERTEX_POINT ('NONE', #176) ;
#80 = CARTESIAN_POINT ('NONE', (0.000000000000000000, 0.000000000000000000, 0.000000000000000000)) ;
#81 = CARTESIAN_POINT ('NONE', (-50.00000000000000000, -6.123233995736766085E-15, 40.00000000000000000)) ;
#82 = ORIENTED_EDGE ('NONE', *, *, #347, .T.) ;
#83 = CARTESIAN_POINT ('NONE', (50.00000000000000000, 0.000000000000000000, 40.00000000000000000)) ;
#84 = FACE_OUTER_BOUND ('NONE', #249, .T.) ;
#85 = PERSON_AND_ORGANIZATION (#96, #358) ;
#86 = EDGE_LOOP ('NONE', (#228, #45)) ;
#87 = CALENDAR_DATE (2022, 5, 7) ;
#88 = COORDINATED_UNIVERSAL_TIME_OFFSET (3, 0, .AHEAD.) ;
#89 = AXIS2_PLACEMENT_3D ('NONE', #168, #206, #115) ;
#90 = SECURITY_CLASSIFICATION ('', '', #150) ;
#91 = VECTOR ('NONE', #71, 1000.000000000000227) ;
#92 = VERTEX_POINT ('NONE', #120) ;
#93 =(GEOMETRIC_REPRESENTATION_CONTEXT (3) GLOBAL_UNCERTAINTY_ASSIGNED_CONTEXT ((#385)) GLOBAL_UNIT_ASSIGNED_CONTEXT ((#340, #205, #231)) REPRESENTATION_CONTEXT ('NONE', 'WORKASPACE'));
#94 = ORIENTED_EDGE ('NONE', *, *, #289, .F.) ;
#95 = ADVANCED_FACE ('NONE', (#149), #403, .T.) ;
#96 = PERSON ('UNSPECIFIED', 'UNSPECIFIED', 'UNSPECIFIED', ('UNSPECIFIED'), ('UNSPECIFIED'), ('UNSPECIFIED')) ;
#97 = CIRCLE ('NONE', #424, 40.67384683690001879) ;
#98 = ORIENTED_EDGE ('NONE', *, *, #289, .T.) ;
#99 = CC_DESIGN_PERSON_AND_ORGANIZATION_ASSIGNMENT (#419, #25, (#395)) ;
#100 = VERTEX_POINT ('NONE', #103) ;
#101 = FACE_OUTER_BOUND ('NONE', #225, .T.) ;
#102 = FACE_OUTER_BOUND ('NONE', #305, .T.) ;
#103 = CARTESIAN_POINT ('NONE', (40.67384683690001879, 4.981109633781930391E-15, 79.99999999999998579)) ;
#104 = LINE ('NONE', #81, #28) ;

#105 = EDGE_LOOP ('NONE', (#282, #308, #26, #237)) ;
#106 = DIRECTION ('NONE', (1.000000000000000000, 0.000000000000000000, 0.000000000000000000)) ;
#107 = CARTESIAN_POINT ('NONE', (-30.00000000000000000, 0.000000000000000000, 99.99999999999997158)) ;
#108 = CARTESIAN_POINT ('NONE', (-40.67384683690001879, -5.552171814759348633E-15, 60.00000000000000000)) ;
#109 = DIRECTION ('NONE', (1.000000000000000000, 0.000000000000000000, 0.000000000000000000)) ;
#110 = PRODUCT_RELATED_PRODUCT_CATEGORY ('detail', '', (#1)) ;
#111 = CIRCLE ('NONE', #325, 40.67384683690001879) ;
#112 = DIRECTION ('NONE', (1.000000000000000000, 0.000000000000000000, 0.000000000000000000)) ;
#113 = DIRECTION ('NONE', (-0.000000000000000000, -0.000000000000000000, -1.000000000000000000)) ;
#114 = DIRECTION ('NONE', (1.000000000000000000, 0.000000000000000000, 0.000000000000000000)) ;
#115 = DIRECTION ('NONE', (1.000000000000000000, 0.000000000000000000, 0.000000000000000000)) ;
#116 = ORIENTED_EDGE ('NONE', *, *, #382, .F.) ;
#117 = PERSON_AND_ORGANIZATION (#96, #358) ;
#118 = CC_DESIGN_PERSON_AND_ORGANIZATION_ASSIGNMENT (#39, #344, (#1)) ;
#119 = LINE ('NONE', #83, #91) ;
#120 = CARTESIAN_POINT ('NONE', (50.00000000000000000, 6.123233995736766085E-15, 40.00000000000000000)) ;
#121 = COORDINATED_UNIVERSAL_TIME_OFFSET (3, 0, .AHEAD.) ;
#122 = PERSON_AND_ORGANIZATION_ROLE ('creator') ;
#123 = DATE_TIME_ROLE ('creation_date') ;
#124 = EDGE_CURVE ('NONE', #92, #70, #352, .T.) ;
#125 = APPROVAL_PERSON_ORGANIZATION (#85, #405, #391) ;
#126 = AXIS2_PLACEMENT_3D ('NONE', #230, #365, #215) ;
#127 = EDGE_CURVE ('NONE', #148, #197, #62, .T.) ;
#128 = AXIS2_PLACEMENT_3D ('NONE', #309, #46, #114) ;
#129 = AXIS2_PLACEMENT_3D ('NONE', #66, #135, #106) ;
#130 = CARTESIAN_POINT ('NONE', (-40.67384683690001879, 0.000000000000000000, 99.99999999999997158)) ;
#131 = ORIENTED_EDGE ('NONE', *, *, #127, .F.) ;
#132 = CARTESIAN_POINT ('NONE', (0.000000000000000000, 0.000000000000000000, 40.00000000000000000)) ;
#133 = DIRECTION ('NONE', (1.000000000000000000, 0.000000000000000000, -0.000000000000000000)) ;
#134 = FACE_OUTER_BOUND ('NONE', #193, .T.) ;
#135 = DIRECTION ('NONE', (0.000000000000000000, 0.000000000000000000, 1.000000000000000000)) ;
#136 = DIRECTION ('NONE', (-1.000000000000000000, 0.000000000000000000, 0.000000000000000000)) ;
#137 = ADVANCED_FACE ('NONE', (#190), #35, .T.) ;
#138 = ORIENTED_EDGE ('NONE', *, *, #229, .T.) ;
#139 = CARTESIAN_POINT ('NONE', (40.67384683690001879, 4.981109633781930391E-15, 119.9999999999999716)) ;
#140 = ORIENTED_EDGE ('NONE', *, *, #298, .F.) ;
#141 = CIRCLE ('NONE', #319, 50.00000000000000000) ;
#142 = DIRECTION ('NONE', (0.000000000000000000, 0.000000000000000000, 1.000000000000000000)) ;

#143 = DIRECTION ('NONE', (1.000000000000000000, 0.000000000000000000, 0.000000000000000000)) ;
#144 = ORIENTED_EDGE ('NONE', *, *, #392, .T.) ;
#145 = ADVANCED_FACE ('NONE', (#84), #364, .T.) ;
#146 = CIRCLE ('NONE', #223, 40.67384683690001879) ;
#147 = LINE ('NONE', #11, #288) ;
#148 = VERTEX_POINT ('NONE', #130) ;
#149 = FACE_OUTER_BOUND ('NONE', #21, .T.) ;
#150 = SECURITY_CLASSIFICATION_LEVEL ('unclassified') ;
#151 = VECTOR ('NONE', #170, 1000.000000000000000) ;
#152 = DATE_AND_TIME (#87, #397) ;
#153 = EDGE_CURVE ('NONE', #79, #203, #433, .T.) ;
#154 = CC_DESIGN_APPROVAL (#293, (#296)) ;
#155 = ORIENTED_EDGE ('NONE', *, *, #307, .F.) ;
#156 = CONICAL_SURFACE ('NONE', #33, 50.00000000000000000, 0.4363323129985826054) ;
#157 = AXIS2_PLACEMENT_3D ('NONE', #132, #266, #22) ;
#158 = CARTESIAN_POINT ('NONE', (0.000000000000000000, 0.000000000000000000, 119.9999999999999716)) ;
#159 = AXIS2_PLACEMENT_3D ('NONE', #18, #366, #4) ;
#160 = DIRECTION ('NONE', (1.000000000000000000, 0.000000000000000000, 0.000000000000000000)) ;
#161 = FACE_BOUND ('NONE', #86, .T.) ;
#162 = VECTOR ('NONE', #113, 1000.000000000000000) ;
#163 = EDGE_CURVE ('NONE', #384, #324, #146, .T.) ;
#164 = CARTESIAN_POINT ('NONE', (0.000000000000000000, 0.000000000000000000, 99.99999999999997158)) ;
#165 = DIRECTION ('NONE', (1.000000000000000000, 0.000000000000000000, 0.000000000000000000)) ;
#166 = ORIENTED_EDGE ('NONE', *, *, #14, .T.) ;
#167 = CARTESIAN_POINT ('NONE', (0.000000000000000000, 0.000000000000000000, 79.99999999999998579)) ;
#168 = CARTESIAN_POINT ('NONE', (0.000000000000000000, 0.000000000000000000, 60.00000000000000000)) ;
#169 = EDGE_LOOP ('NONE', (#371, #38, #428, #335)) ;
#170 = DIRECTION ('NONE', (-0.000000000000000000, -0.000000000000000000, -1.000000000000000000)) ;
#171 = CARTESIAN_POINT ('NONE', (0.000000000000000000, 0.000000000000000000, 99.99999999999997158)) ;
#172 = EDGE_LOOP ('NONE', (#138, #277)) ;
#173 = EDGE_LOOP ('NONE', (#348, #312, #226, #418)) ;
#174 = PERSON_AND_ORGANIZATION (#96, #358) ;
#175 = CARTESIAN_POINT ('NONE', (40.67384683690001879, 0.000000000000000000, 60.00000000000000000)) ;
#176 = CARTESIAN_POINT ('NONE', (30.00000000000000000, 3.673940397442059178E-15, 99.99999999999997158)) ;
#177 = AXIS2_PLACEMENT_3D ('NONE', #299, #217, #253) ;
#178 = DATE_AND_TIME (#179, #421) ;
#179 = CALENDAR_DATE (2022, 5, 7) ;
#180 = AXIS2_PLACEMENT_3D ('NONE', #275, #77, #133) ;
#181 = SHAPE_DEFINITION_REPRESENTATION (#353, #269) ;
#182 = ADVANCED_FACE ('NONE', (#238), #302, .T.) ;
#183 = AXIS2_PLACEMENT_3D ('NONE', #247, #375, #136) ;
#184 = AXIS2_PLACEMENT_3D ('NONE', #374, #270, #63) ;
#185 = VERTEX_POINT ('NONE', #315) ;

#186 = ORIENTED_EDGE ('NONE', *, *, #413, .F.) ;
#187 = ADVANCED_FACE ('NONE', (#328), #3, .T.) ;
#188 = ORIENTED_EDGE ('NONE', *, *, #229, .F.) ;
#189 = AXIS2_PLACEMENT_3D ('NONE', #171, #196, #143) ;
#190 = FACE_OUTER_BOUND ('NONE', #24, .T.) ;
#191 = LOCAL_TIME (0, 28, 42.00000000000000000, #317) ;
#192 = VECTOR ('NONE', #434, 1000.000000000000000) ;
#193 = EDGE_LOOP ('NONE', (#82, #211)) ;
#194 = DIRECTION ('NONE', (0.000000000000000000, 0.000000000000000000, 1.000000000000000000)) ;
#195 = PLANE ('NONE', #53) ;
#196 = DIRECTION ('NONE', (0.000000000000000000, 0.000000000000000000, 1.000000000000000000)) ;
#197 = VERTEX_POINT ('NONE', #368) ;
#198 = EDGE_CURVE ('NONE', #241, #16, #357, .T.) ;
#199 = AXIS2_PLACEMENT_3D ('NONE', #64, #378, #36) ;
#200 = CYLINDRICAL_SURFACE ('NONE', #327, 40.67384683690001879) ;
#201 = LINE ('NONE', #107, #151) ;
#202 = DIRECTION ('NONE', (-0.000000000000000000, -0.000000000000000000, -1.000000000000000000)) ;
#203 = VERTEX_POINT ('NONE', #349) ;
#204 = AXIS2_PLACEMENT_3D ('NONE', #408, #47, #109) ;
#205 =(NAMED_UNIT (*) PLANE_ANGLE_UNIT ( ) SI_UNIT ($, .RADIAN.));
#206 = DIRECTION ('NONE', (0.000000000000000000, 0.000000000000000000, 1.000000000000000000)) ;
#207 = CARTESIAN_POINT ('NONE', (30.00000000000000000, 3.673940397442059178E-15, 79.99999999999998579)) ;
#208 = FACE_OUTER_BOUND ('NONE', #169, .T.) ;
#209 = FACE_OUTER_BOUND ('NONE', #430, .T.) ;
#210 = EDGE_LOOP ('NONE', (#284, #57, #420, #361)) ;
#211 = ORIENTED_EDGE ('NONE', *, *, #31, .T.) ;
#212 = DIRECTION ('NONE', (-0.000000000000000000, -0.000000000000000000, -1.000000000000000000)) ;
#213 = DIRECTION ('NONE', (-1.000000000000000000, 0.000000000000000000, 0.000000000000000000)) ;
#214 = ORIENTED_EDGE ('NONE', *, *, #198, .T.) ;
#215 = DIRECTION ('NONE', (-1.000000000000000000, 0.000000000000000000, 0.000000000000000000)) ;
#216 = PERSON_AND_ORGANIZATION (#96, #358) ;
#217 = DIRECTION ('NONE', (-0.000000000000000000, -0.000000000000000000, -1.000000000000000000)) ;
#218 = CALENDAR_DATE (2022, 5, 7) ;
#219 = ADVANCED_FACE ('NONE', (#379), #367, .T.) ;
#220 = COORDINATED_UNIVERSAL_TIME_OFFSET (3, 0, .AHEAD.) ;
#221 = DATE_TIME_ROLE ('classification_date') ;
#222 = AXIS2_PLACEMENT_3D ('NONE', #15, #345, #213) ;
#223 = AXIS2_PLACEMENT_3D ('NONE', #329, #233, #160) ;
#224 = ADVANCED_FACE ('NONE', (#338), #65, .T.) ;
#225 = EDGE_LOOP ('NONE', (#140, #411, #232, #274)) ;
#226 = ORIENTED_EDGE ('NONE', *, *, #295, .T.) ;
#227 = CLOSED_SHELL ('NONE', (#137, #429, #224, #356, #187, #182, #432, #145, #322, #264, #95, #76, #219, #359)) ;
#228 = ORIENTED_EDGE ('NONE', *, *, #198, .F.) ;
#229 = EDGE_CURVE ('NONE', #203, #79, #59, .T.) ;

#230 = CARTESIAN_POINT ('NONE', (0.000000000000000000, 0.000000000000000000, 119.9999999999999716)) ;
#231 =(NAMED_UNIT (*) SI_UNIT ($, .STERADIAN.) SOLID_ANGLE_UNIT ( ));
#232 = ORIENTED_EDGE ('NONE', *, *, #413, .T.) ;
#233 = DIRECTION ('NONE', (0.000000000000000000, 0.000000000000000000, 1.000000000000000000)) ;
#234 = CARTESIAN_POINT ('NONE', (40.67384683690001879, 4.981109633781930391E-15, 119.9999999999999716)) ;
#236 = ORIENTED_EDGE ('NONE', *, *, #124, .T.) ;
#235 = DIRECTION ('NONE', (0.000000000000000000, 0.000000000000000000, 1.000000000000000000)) ;
#237 = ORIENTED_EDGE ('NONE', *, *, #320, .T.) ;
#238 = FACE_OUTER_BOUND ('NONE', #210, .T.) ;
#239 = CARTESIAN_POINT ('NONE', (0.000000000000000000, 0.000000000000000000, 99.99999999999997158)) ;
#240 = CARTESIAN_POINT ('NONE', (0.000000000000000000, 0.000000000000000000, 0.000000000000000000)) ;
#241 = VERTEX_POINT ('NONE', #268) ;
#242 = AXIS2_PLACEMENT_3D ('NONE', #69, #244, #331) ;
#243 = CYLINDRICAL_SURFACE ('NONE', #435, 30.00000000000000000) ;
#244 = DIRECTION ('NONE', (0.000000000000000000, 0.000000000000000000, 1.000000000000000000)) ;
#245 = DIRECTION ('NONE', (0.000000000000000000, 0.000000000000000000, 1.000000000000000000)) ;
#246 = MECHANICAL_CONTEXT ('NONE', #400, 'mechanical') ;
#247 = CARTESIAN_POINT ('NONE', (0.000000000000000000, 0.000000000000000000, 79.99999999999998579)) ;
#248 = DIRECTION ('NONE', (1.000000000000000000, 0.000000000000000000, 0.000000000000000000)) ;
#249 = EDGE_LOOP ('NONE', (#94, #311, #336, #27)) ;
#250 = VECTOR ('NONE', #212, 1000.000000000000000) ;
#251 = DATE_AND_TIME (#51, #351) ;
#252 = ORIENTED_EDGE ('NONE', *, *, #61, .T.) ;
#253 = DIRECTION ('NONE', (-1.000000000000000000, 0.000000000000000000, 0.000000000000000000)) ;
#254 = APPROVAL_ROLE ('') ;
#255 = EDGE_CURVE ('NONE', #324, #384, #111, .T.) ;
#256 = DATE_AND_TIME (#390, #191) ;
#257 = APPROVAL_DATE_TIME (#178, #316) ;
#258 = AXIS2_PLACEMENT_3D ('NONE', #5, #8, #301) ;
#259 = AXIS2_PLACEMENT_3D ('NONE', #30, #422, #287) ;
#260 = APPROVAL_PERSON_ORGANIZATION (#174, #316, #350) ;
#261 = ORIENTED_EDGE ('NONE', *, *, #320, .F.) ;
#262 = CIRCLE ('NONE', #89, 40.67384683690001879) ;
#263 = CC_DESIGN_DATE_AND_TIME_ASSIGNMENT (#256, #221, (#90)) ;
#264 = ADVANCED_FACE ('NONE', (#161, #134), #304, .T.) ;
#265 = DIRECTION ('NONE', (0.000000000000000000, 0.000000000000000000, 1.000000000000000000)) ;
#266 = DIRECTION ('NONE', (-0.000000000000000000, -0.000000000000000000, -1.000000000000000000)) ;
#267 = LINE ('NONE', #402, #250) ;
#268 = CARTESIAN_POINT ('NONE', (-30.00000000000000000, 0.000000000000000000, 79.99999999999998579)) ;
#269 = ADVANCED_BREP_SHAPE_REPRESENTATION ('case study 1 ', (#396, #159), #93) ;

#270 = DIRECTION ('NONE', (-0.000000000000000000, -0.000000000000000000, -1.000000000000000000)) ;
#271 = FACE_OUTER_BOUND ('NONE', #380, .T.) ;
#272 = FACE_OUTER_BOUND ('NONE', #105, .T.) ;
#273 = ORIENTED_EDGE ('NONE', *, *, #360, .T.) ;
#274 = ORIENTED_EDGE ('NONE', *, *, #127, .T.) ;
#275 = CARTESIAN_POINT ('NONE', (0.000000000000000000, 0.000000000000000000, 99.99999999999997158)) ;
#276 = CYLINDRICAL_SURFACE ('NONE', #183, 40.67384683690001879) ;
#277 = ORIENTED_EDGE ('NONE', *, *, #153, .T.) ;
#278 = EDGE_CURVE ('NONE', #100, #41, #34, .T.) ;
#279 = VECTOR ('NONE', #202, 1000.000000000000000) ;
#280 = FACE_BOUND ('NONE', #172, .T.) ;
#281 = CARTESIAN_POINT ('NONE', (-40.67384683690001879, 0.000000000000000000, 79.99999999999998579)) ;
#282 = ORIENTED_EDGE ('NONE', *, *, #278, .F.) ;
#283 = DESIGN_CONTEXT ('detailed design', #321, 'design') ;
#284 = ORIENTED_EDGE ('NONE', *, *, #124, .F.) ;
#285 = PERSON_AND_ORGANIZATION (#96, #358) ;
#286 = CARTESIAN_POINT ('NONE', (-40.67384683690001879, 0.000000000000000000, 79.99999999999998579)) ;
#287 = DIRECTION ('NONE', (1.000000000000000000, 0.000000000000000000, 0.000000000000000000)) ;
#288 = VECTOR ('NONE', #42, 1000.000000000000000) ;
#289 = EDGE_CURVE ('NONE', #342, #343, #104, .T.) ;
#290 = CIRCLE ('NONE', #204, 50.00000000000000000) ;
#291 = COORDINATED_UNIVERSAL_TIME_OFFSET (3, 0, .AHEAD.) ;
#292 = PERSON_AND_ORGANIZATION (#96, #358) ;
#293 = APPROVAL (#23, 'UNSPECIFIED') ;
#294 = VERTEX_POINT ('NONE', #281) ;
#295 = EDGE_CURVE ('NONE', #41, #342, #262, .T.) ;
#296 = PRODUCT_DEFINITION_FORMATION_WITH_SPECIFIED_SOURCE ('ANY', '', #1, .NOT_KNOWN.) ;
#297 = AXIS2_PLACEMENT_3D ('NONE', #362, #389, #300) ;
#298 = EDGE_CURVE ('NONE', #384, #197, #404, .T.) ;
#299 = CARTESIAN_POINT ('NONE', (0.000000000000000000, 0.000000000000000000, 99.99999999999997158)) ;
#300 = DIRECTION ('NONE', (-1.000000000000000000, 0.000000000000000000, 0.000000000000000000)) ;
#301 = DIRECTION ('NONE', (1.000000000000000000, 0.000000000000000000, -0.000000000000000000)) ;
#302 = CYLINDRICAL_SURFACE ('NONE', #297, 50.00000000000000000) ;
#303 = APPLICATION_PROTOCOL_DEFINITION ('international standard', 'config_control_design', 1994, #321) ;
#304 = PLANE ('NONE', #242) ;
#305 = EDGE_LOOP ('NONE', (#155, #394)) ;
#306 = DIRECTION ('NONE', (-0.000000000000000000, -0.000000000000000000, -1.000000000000000000)) ;
#307 = EDGE_CURVE ('NONE', #185, #70, #141, .T.) ;
#308 = ORIENTED_EDGE ('NONE', *, *, #347, .F.) ;
#309 = CARTESIAN_POINT ('NONE', (0.000000000000000000, 0.000000000000000000, 40.00000000000000000)) ;
#310 = DIRECTION ('NONE', (-0.000000000000000000, -0.000000000000000000, -1.000000000000000000)) ;
#311 = ORIENTED_EDGE ('NONE', *, *, #295, .F.) ;

#312 = ORIENTED_EDGE ('NONE', *, *, #278, .T.) ;
#313 = LINE ('NONE', #286, #415) ;
#314 = AXIS2_PLACEMENT_3D ('NONE', #164, #194, #48) ;
#315 = CARTESIAN_POINT ('NONE', (-50.00000000000000000, 0.000000000000000000, 0.000000000000000000)) ;
#316 = APPROVAL (#7, 'UNSPECIFIED') ;
#317 = COORDINATED_UNIVERSAL_TIME_OFFSET (3, 0, .AHEAD.) ;
#318 = CIRCLE ('NONE', #199, 40.67384683690001879) ;
#319 = AXIS2_PLACEMENT_3D ('NONE', #240, #235, #165) ;
#320 = EDGE_CURVE ('NONE', #342, #41, #377, .T.) ;
#321 = APPLICATION_CONTEXT ('configuration controlled 3d designs of mechanical parts and assemblies') ;
#322 = ADVANCED_FACE ('NONE', (#272), #276, .T.) ;
#323 = ORIENTED_EDGE ('NONE', *, *, #56, .F.) ;
#324 = VERTEX_POINT ('NONE', #407) ;
#325 = AXIS2_PLACEMENT_3D ('NONE', #334, #370, #40) ;
#326 = CC_DESIGN_PERSON_AND_ORGANIZATION_ASSIGNMENT (#285, #387, (#90)) ;
#327 = AXIS2_PLACEMENT_3D ('NONE', #158, #333, #401) ;
#328 = FACE_OUTER_BOUND ('NONE', #54, .T.) ;
#329 = CARTESIAN_POINT ('NONE', (0.000000000000000000, 0.000000000000000000, 119.9999999999999716)) ;
#330 = DIRECTION ('NONE', (1.000000000000000000, 0.000000000000000000, 0.000000000000000000)) ;
#331 = DIRECTION ('NONE', (1.000000000000000000, 0.000000000000000000, -0.000000000000000000)) ;
#332 = CC_DESIGN_APPROVAL (#316, (#395)) ;
#333 = DIRECTION ('NONE', (-0.000000000000000000, -0.000000000000000000, -1.000000000000000000)) ;
#334 = CARTESIAN_POINT ('NONE', (0.000000000000000000, 0.000000000000000000, 119.9999999999999716)) ;
#335 = ORIENTED_EDGE ('NONE', *, *, #360, .F.) ;
#336 = ORIENTED_EDGE ('NONE', *, *, #56, .T.) ;
#337 = CC_DESIGN_PERSON_AND_ORGANIZATION_ASSIGNMENT (#117, #122, (#296)) ;
#338 = FACE_OUTER_BOUND ('NONE', #173, .T.) ;
#339 = DIRECTION ('NONE', (-0.000000000000000000, -0.000000000000000000, -1.000000000000000000)) ;
#340 =(LENGTH_UNIT ( ) NAMED_UNIT (*) SI_UNIT (.MILLI., .METRE.));
#341 = CARTESIAN_POINT ('NONE', (0.000000000000000000, 0.000000000000000000, 40.00000000000000000)) ;
#342 = VERTEX_POINT ('NONE', #108) ;
#343 = VERTEX_POINT ('NONE', #383) ;
#344 = PERSON_AND_ORGANIZATION_ROLE ('design_owner') ;
#345 = DIRECTION ('NONE', (-0.000000000000000000, -0.000000000000000000, -1.000000000000000000)) ;
#346 = DIRECTION ('NONE', (1.000000000000000000, 0.000000000000000000, 0.000000000000000000)) ;
#347 = EDGE_CURVE ('NONE', #294, #100, #431, .T.) ;
#348 = ORIENTED_EDGE ('NONE', *, *, #31, .F.) ;
#349 = CARTESIAN_POINT ('NONE', (-30.00000000000000000, 0.000000000000000000, 99.99999999999997158)) ;
#350 = APPROVAL_ROLE ('') ;
#351 = LOCAL_TIME (0, 28, 42.00000000000000000, #121) ;
#352 = LINE ('NONE', #6, #192) ;

#353 = PRODUCT_DEFINITION_SHAPE ('NONE', 'NONE', #395) ;
#354 = APPROVAL_STATUS ('not_yet_approved') ;
#355 = APPROVAL_DATE_TIME (#251, #293) ;
#356 = ADVANCED_FACE ('NONE', (#209), #156, .T.) ;
#357 = CIRCLE ('NONE', #129, 30.00000000000000000) ;
#358 = ORGANIZATION ('UNSPECIFIED', 'UNSPECIFIED', '') ;
#359 = ADVANCED_FACE ('NONE', (#280, #271), #414, .F.) ;
#360 = EDGE_CURVE ('NONE', #203, #241, #201, .T.) ;
#361 = ORIENTED_EDGE ('NONE', *, *, #307, .T.) ;
#362 = CARTESIAN_POINT ('NONE', (0.000000000000000000, 0.000000000000000000, 40.00000000000000000)) ;
#363 = CC_DESIGN_APPROVAL (#405, (#90)) ;
#364 = CONICAL_SURFACE ('NONE', #184, 50.00000000000000000, 0.4363323129985826054) ;
#365 = DIRECTION ('NONE', (-0.000000000000000000, -0.000000000000000000, -1.000000000000000000)) ;
#366 = DIRECTION ('NONE', (0.000000000000000000, 0.000000000000000000, 1.000000000000000000)) ;
#367 = PLANE ('NONE', #258) ;
#368 = CARTESIAN_POINT ('NONE', (40.67384683690001879, 4.981109633781930391E-15, 99.99999999999997158)) ;
#369 = DIRECTION ('NONE', (-0.000000000000000000, -0.000000000000000000, -1.000000000000000000)) ;
#370 = DIRECTION ('NONE', (0.000000000000000000, 0.000000000000000000, 1.000000000000000000)) ;
#371 = ORIENTED_EDGE ('NONE', *, *, #153, .F.) ;
#372 = CIRCLE ('NONE', #128, 50.00000000000000000) ;
#373 = EDGE_CURVE ('NONE', #16, #241, #68, .T.) ;
#374 = CARTESIAN_POINT ('NONE', (0.000000000000000000, 0.000000000000000000, 40.00000000000000000)) ;
#375 = DIRECTION ('NONE', (-0.000000000000000000, -0.000000000000000000, -1.000000000000000000)) ;
#376 = ORIENTED_EDGE ('NONE', *, *, #398, .F.) ;
#377 = CIRCLE ('NONE', #412, 40.67384683690001879) ;
#378 = DIRECTION ('NONE', (0.000000000000000000, 0.000000000000000000, 1.000000000000000000)) ;
#379 = FACE_OUTER_BOUND ('NONE', #55, .T.) ;
#380 = EDGE_LOOP ('NONE', (#131, #10)) ;
#381 = DIRECTION ('NONE', (0.000000000000000000, 0.000000000000000000, 1.000000000000000000)) ;
#382 = EDGE_CURVE ('NONE', #92, #343, #372, .T.) ;
#383 = CARTESIAN_POINT ('NONE', (-50.00000000000000000, 0.000000000000000000, 40.00000000000000000)) ;
#384 = VERTEX_POINT ('NONE', #234) ;
#385 = UNCERTAINTY_MEASURE_WITH_UNIT (LENGTH_MEASURE(1.000000000000000082E-05), #340, 'distance_accuracy_value', 'NONE');
#386 = AXIS2_PLACEMENT_3D ('NONE', #167, #142, #330) ;
#387 = PERSON_AND_ORGANIZATION_ROLE ('classification_officer') ;
#388 = LINE ('NONE', #75, #162) ;
#389 = DIRECTION ('NONE', (-0.000000000000000000, -0.000000000000000000, -1.000000000000000000)) ;
#390 = CALENDAR_DATE (2022, 5, 7) ;
#391 = APPROVAL_ROLE ('') ;
#392 = EDGE_CURVE ('NONE', #197, #148, #318, .T.) ;
#393 = APPROVAL_PERSON_ORGANIZATION (#292, #293, #254) ;

#394 = ORIENTED_EDGE ('NONE', *, *, #14, .F.) ;
#395 = PRODUCT_DEFINITION ('UNKNOWN', '', #296, #283) ;
#396 = MANIFOLD_SOLID_BREP ('Boss-Extrude6', #227) ;
#397 = LOCAL_TIME (0, 28, 42.00000000000000000, #88) ;
#398 = EDGE_CURVE ('NONE', #79, #16, #267, .T.) ;
#399 = ORIENTED_EDGE ('NONE', *, *, #255, .T.) ;
#400 = APPLICATION_CONTEXT ('configuration controlled 3d designs of mechanical parts and assemblies') ;
#401 = DIRECTION ('NONE', (-1.000000000000000000, 0.000000000000000000, 0.000000000000000000)) ;
#402 = CARTESIAN_POINT ('NONE', (30.00000000000000000, 3.673940397442059178E-15, 99.99999999999997158)) ;
#403 = CYLINDRICAL_SURFACE ('NONE', #177, 30.00000000000000000) ;
#404 = LINE ('NONE', #139, #72) ;
#405 = APPROVAL (#354, 'UNSPECIFIED') ;
#406 = DIRECTION ('NONE', (1.000000000000000000, 0.000000000000000000, 0.000000000000000000)) ;
#407 = CARTESIAN_POINT ('NONE', (-40.67384683690001879, 0.000000000000000000, 119.9999999999999716)) ;
#408 = CARTESIAN_POINT ('NONE', (0.000000000000000000, 0.000000000000000000, 0.000000000000000000)) ;
#409 = DIRECTION ('NONE', (-1.000000000000000000, 0.000000000000000000, 0.000000000000000000)) ;
#410 = DIRECTION ('NONE', (0.000000000000000000, 0.000000000000000000, 1.000000000000000000)) ;
#411 = ORIENTED_EDGE ('NONE', *, *, #255, .F.) ;
#412 = AXIS2_PLACEMENT_3D ('NONE', #12, #78, #416) ;
#413 = EDGE_CURVE ('NONE', #324, #148, #147, .T.) ;
#414 = PLANE ('NONE', #180) ;
#415 = VECTOR ('NONE', #339, 1000.000000000000000) ;
#416 = DIRECTION ('NONE', (1.000000000000000000, 0.000000000000000000, 0.000000000000000000)) ;
#417 = CARTESIAN_POINT ('NONE', (0.000000000000000000, 0.000000000000000000, 79.99999999999998579)) ;
#418 = ORIENTED_EDGE ('NONE', *, *, #50, .F.) ;
#419 = PERSON_AND_ORGANIZATION (#96, #358) ;
#420 = ORIENTED_EDGE ('NONE', *, *, #2, .T.) ;
#421 = LOCAL_TIME (0, 28, 42.00000000000000000, #220) ;
#422 = DIRECTION ('NONE', (0.000000000000000000, 0.000000000000000000, 1.000000000000000000)) ;
#423 = APPROVAL_DATE_TIME (#427, #405) ;
#424 = AXIS2_PLACEMENT_3D ('NONE', #417, #245, #248) ;
#425 = PERSON_AND_ORGANIZATION_ROLE ('design_supplier') ;
#426 = CC_DESIGN_PERSON_AND_ORGANIZATION_ASSIGNMENT (#216, #425, (#296)) ;
#427 = DATE_AND_TIME (#218, #49) ;
#428 = ORIENTED_EDGE ('NONE', *, *, #373, .T.) ;
#429 = ADVANCED_FACE ('NONE', (#208), #243, .T.) ;
#430 = EDGE_LOOP ('NONE', (#261, #98, #252, #323)) ;
#431 = CIRCLE ('NONE', #52, 40.67384683690001879) ;
#432 = ADVANCED_FACE ('NONE', (#102), #195, .F.) ;
#433 = CIRCLE ('NONE', #29, 30.00000000000000000) ;
#434 = DIRECTION ('NONE', (-0.000000000000000000, -0.000000000000000000, -1.000000000000000000)) ;
#435 = AXIS2_PLACEMENT_3D ('NONE', #239, #369, #409) ;

```
ENDSEC;
END-ISO-10303-21;
```

Appendix C: Part of the C# code

Part of the C# code

This is a part of the code that has been wrote by the C sharp (C#) language to develop this program.

```
  private FinalFeatures RightAndLeftSideOfTheFeature(FinalFeatures feature,
List<FinalFeatures> originalFinalFeatures, out List<IntersectingFeatures>
sumIntersectingFeatures)
        {
            string right = "Right";
            string left = "Left";
            bool secondFeatureRight;
            bool secondFeatureLeft;
            double maxXofFeature = FindMaxXofFeature(feature);
            sumIntersectingFeatures = new List<IntersectingFeatures>();
            IntersectingFeatures intersectingFeature = new IntersectingFeatures();
            int positionOfFeature = FindFeaturePosition(feature, originalFinalFeatures);
            List<FinalFeatures> rightSideFeatures = GetTheFeaturesOnASide(maxXofFeature,
positionOfFeature, feature, originalFinalFeatures, right, out secondFeatureRight, out
secondFeatureLeft);
            List<FinalFeatures> leftSideFeatures = GetTheFeaturesOnASide(maxXofFeature,
positionOfFeature, feature, originalFinalFeatures, left, out secondFeatureRight, out
secondFeatureLeft);

            FinalFeatures iamAFinalFeature = new FinalFeatures();
            if (rightSideFeatures.Count <= 2 && leftSideFeatures.Count <= 2)
            {
                iamAFinalFeature = feature;

            }

            if (rightSideFeatures.Count == 2 && rightSideFeatures[1].FeatureKey ==
originalFinalFeatures.First().FeatureKey)
            {
                rightSideFeatures.RemoveAt(0);
                GoToFindIntermidateFeatures(rightSideFeatures);
            }

            if (leftSideFeatures.Count == 2 && leftSideFeatures[1].FeatureKey ==
originalFinalFeatures.Last().FeatureKey)
            {
                leftSideFeatures.RemoveAt(0);
                GoToFindIntermidateFeatures(leftSideFeatures);
            }

            if ((rightSideFeatures.Count > 2))
            {
```

```
                rightSideFeatures = rightSideFeatures.AsEnumerable().Reverse().ToList();
                double secondMaxXofFeature = FindSecondXValue(rightSideFeatures);
                rightSideFeatures = UpdatFeatures(rightSideFeatures, maxXofFeature,
secondMaxXofFeature, out intersectingFeature);
                sumIntersectingFeatures.Add(intersectingFeature);
                if (rightSideFeatures.Count == 1)
                {
                    iamAFinalFeature = rightSideFeatures.First();
                }

                else if (rightSideFeatures.Count >= 2)
                {
                    GoToFindIntermidateFeatures(rightSideFeatures);
                }
            }

            if ((leftSideFeatures.Count > 2))
            {
                double secondMaxXofFeature = FindSecondXValue(leftSideFeatures);
                leftSideFeatures = UpdatFeatures(leftSideFeatures, maxXofFeature,
secondMaxXofFeature, out intersectingFeature);
                sumIntersectingFeatures.Add(intersectingFeature);
                if (leftSideFeatures.Count == 1)
                {
                    iamAFinalFeature = leftSideFeatures.First();
                }

                else if (leftSideFeatures.Count >= 2)
                {
                    GoToFindIntermidateFeatures(leftSideFeatures);
                }
            }


            return iamAFinalFeature;

        }
```

RESUME

EDUCATION

High School : 2013 graduated from AL-bayan High School in Baghdad.

Bachelor : 2017 graduated from the University Of Technology in Baghdad, Production And Metrology Department, branch of CAD/CAM engineering.