Mateus do Lago Chagas

Mechanical Engineering BSc

Hungarian University of Agriculture and Life Sciences

Szent István Campus

Mechanical Engineering BSc

Computer aided manufacturing with 3D part model

Primary Supervisor: Dr. Keresztes Róbert
Associate Professor

Author: **Mateus do Lago Chagas**
ACK6SR

Institute / Department: Institute of Technology /
Department of machine construction

Gödöllö Year 2024

Programme leader's signature

INSTITUTE OF TECHNOLOGY MECHANICAL ENGINEERING (BSC) Machine Production Technologies specialization

THESIS

worksheet for

Mateus do Lago Chagas (ACK6SR)

(BSc) student

Entitled:

Computer aided manufacturing with 3D part model

Task description:

This study will describe the process of designing a 3D model of a piece and how can we take this model and make it become a real piece through milling and its technologies.

Department: Department of Material Science and Industrial Processes

Supervisor: Dr. Keresztes Róbert

Submission deadline: 04.29.2024

Gödöllő, 04.25.2024

Contents

List of images

1 Introduction

In the realm of modern manufacturing, precision and efficiency are not merely desirable traits; are imperative. As industries continue to evolve and demand ever higher standards of quality and efficiency, the role of milling technologies emerges as pivotal.

It is a computer-controlled process that involves using a cutting tool to remove part of a workpiece. The basic setup involves placing the workpiece on the machine table while the cutting tool attached to the spindle rotate and move to shape the workpiece into a finished product.

The rotation and movement of the cutting tool depends on the type and level of sophistication of the CNC router. The process is highly versatile and compatible with various materials, such as aluminum, plastic, wood, and glass.

In this project the aim is to not only explain milling but most importantly to set different approaches and parameters, analyze the differences between the different setups and get to the most optimal result granting us the best result possible.

2 Objective

This study has the goal show the process involved into making a 3d model of a workpiece and from that 3d model use milling technologies, which will be explained, to turn that raw material into the designed model

3 Literature review

CNC, or Computer Numerical Control, revolutionized manufacturing processes worldwide. Essentially, CNC is a method of controlling machines through programmed sequences of commands, allowing for precise and automated machining of various materials such as metal, plastic, wood, and composites.

At the heart of CNC lies the integration of computers and machinery. Instead of manually operating machines, CNC systems rely on computer programs to dictate the movements and actions of the tools. These programs are created using specialized software, which translates designs or blueprints into instructions that the CNC machine can understand.

The primary components of a CNC system include the machine itself, which could be a lathe, mill, router, or any other type of machining equipment; the controller, which interprets the program and sends commands to the machine; and the software, which generates the CNC program based on the desired part geometry and machining operations.

Since the emergence of Numerical Command (CN) in the middle of the 20th century, several industries, especially aeronautics and automotive, have been making significant gains with the use of this technology. Its application in the control of machine tools allows the performance of repetitive tasks of great kinematic complexity. This enables the reproducibility of products with different geometric shapes. Furthermore, companies that produce with high diversification and in small batches greatly benefit from the flexibility inherent in this equipment.

Despite not having represented a revolution in already known manufacturing processes, as it did not change their behavior, NC technology, combined with other information systems, revolutionized the modus operandi in the production systems in which it was adopted. This revolution can be, in a simplified way, evaluated by its impact on the flow of information within these systems.

CN technology, associated with digital modeling found in CAD (Computer-Aided Design) and CAM (Computer-Aided Manufacturing) systems, largely supports the transfer of a product model to the machine with little human intervention, in addition to providing substitution of the means of transmission, paper or verbal, for the electronic one.

This small human intervention is still present in machining planning, an activity that has not yet been automated, despite the enormous efforts of the scientific community in the development of CAPP systems (Computer-Aided Process Planning) (YUEN et al., 2003).

This revolution, brought about by this type of information technology, can also be evaluated by human replacement in manufacturing activities. In the past, in complex manufacturing systems, several people were employed in design, drawing, conference, archiving, interpretation, transfer, planning, and execution tasks. Currently, these same systems employ people only for design and planning tasks.

Although CAD-CAM-CN technologies facilitate this revolution, carrying out a spatio-temporal analysis makes it clear that this did not occur in all companies in the same industrial segment. Whether due to an inability to invest or due to restrictions imposed by the production chain, some companies still rely heavily on the transmission of information in written and spoken media.

In work carried out among companies providing machining services (COSTA, 2001), it was observed that companies considered third- and fourth-tier suppliers within the automotive industry, and metal mechanics in general, still receive product designs printed on paper and carry out the programming and (or) operation of their processes manually.

This contributes to reducing the competitiveness of these companies, as it prevents them from moving up the production scale, becoming, for example, direct suppliers in the first or second tier (FERRO, 2000).

A frequently recommended alternative for such companies is investment in missing technologies, for example, in CAM systems. Currently, you can find an extensive range of this type of software, most of which is aimed at machining processes. Some are modular, allowing the user to purchase modules according to the processes of interest, for example, turning, milling, or EDM. Others are more comprehensive and include more than one process. In some cases, a complete CAD-CAM platform can be purchased. This last option avoids some hassles when transferring data between systems from different manufacturers.

Except for some formatting limitations, once the product has been modeled, you can choose the manufacturing process among those made available by CAM, select the machine, inform the manufacturing sequence, and choose tools and cutting conditions. From this, the system automatically calculates the trajectory of the tools, transferring them, in the form of a NC program, to the machine tool determined a priori.

This set of software (CAD-CAM-CNC) is a necessary, but not sufficient, condition for a given company to have an integrated manufacturing system. However, this "technological package" provides a competitive advantage.

However, investment in CAM software is very high. In this investment, two components stand out: the acquisition price and the amount spent on staff training. This cost may vary according to the number of modules that make up the system. (PEREIRA, 2003)

One of the most significant advantages of CNC machining is its precision. Since the movements of the machine are controlled by computer programs, it can execute tasks with incredible accuracy and consistency, often achieving tolerances measured in thousandths of an inch. This level of precision is crucial in industries such as aerospace, automotive, and medical, where even minor deviations can have significant consequences.

Another key benefit of CNC is its versatility. With the appropriate tooling and programming, a single CNC machine can perform a wide range of machining operations, from simple drilling and cutting to complex contouring and engraving. This flexibility allows manufacturers to produce a variety of parts and products without the need for multiple specialized machines, streamlining production processes and reducing costs.

Furthermore, CNC machining offers increased efficiency and productivity compared to traditional manual methods. Once a program is developed and tested, it can be used repeatedly to produce identical parts with minimal setup time. Additionally, CNC machines can operate continuously, running unmanned overnight or over weekends to maximize throughput and minimize lead times.

Despite its numerous advantages, CNC machining also presents some challenges. The initial investment in CNC equipment and software can be substantial, particularly for small businesses or startups. Moreover, the complexity of CNC programming requires skilled operators and programmers, highlighting the importance of training and education in this field.

CAM seeks to interconnect CAD and Computer Numerical Control (CNC). In this way, the designer can plan the real manufacturing process, using input data from CAD with the interpretation of data in CAM, through simulations and machining strategies, whether autonomous or not. In this context, its main objective is to integrate design and manufacturing quickly and practically, usually called CAD/CAM (CARDOZO, 2012).

It is very important that, to obtain an adequate result, the cutting tool must have a correct trajectory, that is, good planning of the tool path is necessary, considering various elements such as: surface finish, time and type of machining, tool life, cutting speed, feed and rotation adjustments. For this, the CAM module becomes essential for visualizing decision-making in the fabrication process, according to the needs of the project (CARDOZO, 2012).

The numerical control (NC) of the CNC machine is carried out through programmable automation functions, which will act on the machine tool. The program that is made up of numbers and letters is iterative, that is, it must be changed according to the needs of changing the project. The preparation of the program will depend on several factors, such as the manufacturing strategy adopted, the material and geometry of the part to be produced, the CAM Software used for manufacturing simulation and mainly the type of machine to be used (COSTA, 2011).

CAM Software allows the creation of NC programs in an easy and agile way, enabling the development of programs that are extremely difficult or even impossible to do annually, in cases of complex geometries. But, even in simple cases, the use of CAM allows for practicality, avoids errors, and reduces the time spent on this type of service (CARDOZO, 2012)

Chronologically important events

Until 1950

At that time, there were two main types of production systems:

- Manually operated equipment with a small or medium production volume and great flexibility.
- Automatic production systems: large production volumes with dedicated, hardware-based technology.

After 1950

- There has been a decrease in the lifespan of products due to increased competition and consumer demands for all medium-volume production.
- Increasing the complexity of the shape of parts in order to meet the aesthetic preferences and technical requirements of parts for technologically advanced products, such as aeronautics and automobiles, requires the production of parts with complex shapes.

1949: First technological feasibility study of equipment for manufacturing parts using chip starting (milling machine), controlled by a programmable system (MIT, USA);

1952: First vertical milling machine with three axes controlled by a new type of controller, consisting of a hybrid analog/digital system that used a punch tape as a means to store the program. It was designated as a numerically controlled machine (CN);

1952-1955: New developments with the application of this technology to other types of equipment (Air Force);

1956: Construction of 100 milling machines begins, numerically controlled to manufacture parts for companies linked to aircraft construction.

1955–1958: Development of the first computer application to assist in the generation of numerical command programs (predecessors of the CAD/CAM system). It was called Automatically Programmed Tool (APT) and ran on MIT's IBM machines.

1962: The development of this technology continued with its application to drills and developments in mechanical systems to eliminate causes of inefficiency in controlling the tool's trajectory, such as gaps.

1970: Application of microprocessors and ROM memory to numerical controllers.

- Appearance of CAD Systems
- Incorporation of a dedicated computer into the numerical controller, Computerized Numerical Control (CNC);

Present:

- Spread of the use of CAD/CAM systems and CNC equipment in other types of industries such as plastic injection, the wood and furniture industry, and finally the electronic systems production industry.
- Developments to increase equipment performance, particularly in terms of forward speed and cutting speed.
- Developments aimed at automating production processes, namely raw material feeding systems, parts handling systems, and automatic tool change systems.
- Developments in machining processes with a view to taking advantage of the capabilities of CNC equipment, particularly in cutting tools.
- Development of computerized control systems.

But regarding the machines used by humanity, those date from way back long before any of these technologies existed, the origins of machine tools can be traced back to the Upper Paleolithic period, around 6,000 BC, where our ancestors developed primitive planers, using pieces of wood to provide a structure and chipped stone as a tool.

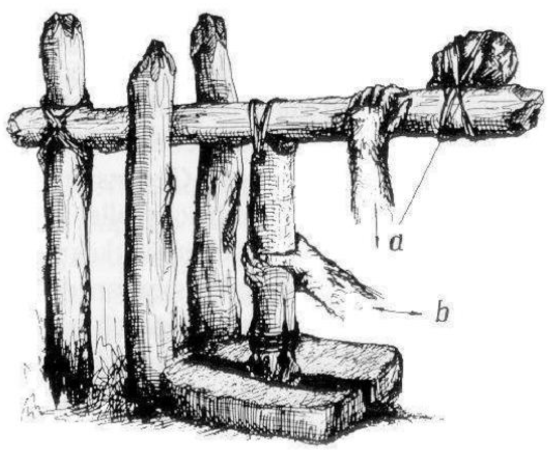

Figure 3-1Paleolitchic Planer

Egyptian frescoes dating back to 1500 BC show work with drills using rotating tools driven by an arc, an element that remained the main drive for machine tools into the 16th century.

Figure 3-2 Egyptian arch drilling 1500 b.c

The Renaissance (16th century) brought trade to Europe again, and along with it the need to produce more, with better quality, at a lower cost and in the shortest time possible, needs that led to the replacement of arches by water wheels as a driving source in machinery. During this period, machines still used wooden structures and their precision and productivity still rivaled the production of skilled craftsmen.

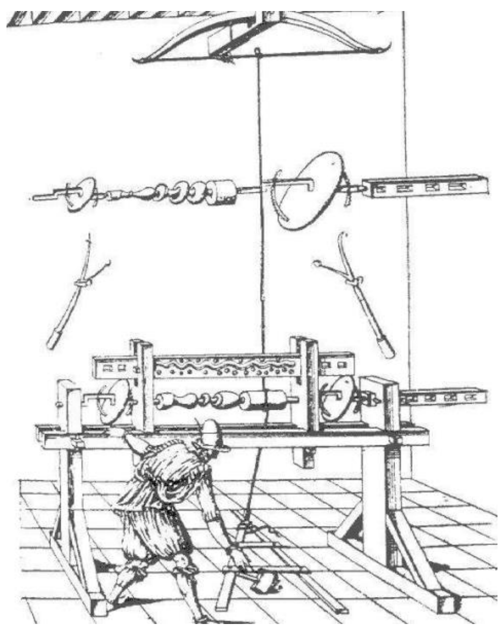

Figure 3-3 Bow driven lathe 1565

This period is basically marked by ornamental turning, with the Frenchman Jacques Benson in 1569, who is considered one of its greatest exponents. The Renaissance period (end of the 14th century and beginning of the 15th century) still presents the unique figure of Leonardo Da Vinci, in whose sketches there are machines with revolutionary characteristics, ideas which influenced many designers in the Industrial Revolution.

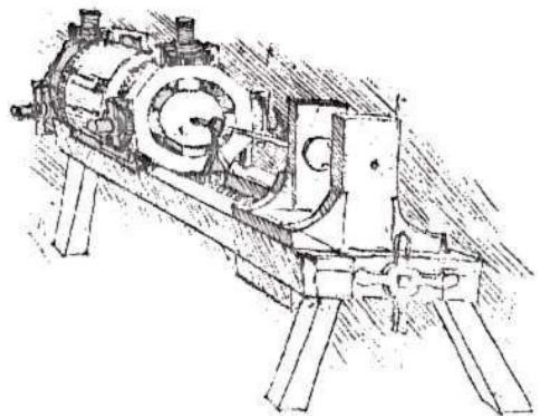

Figure 3-4 Da Vinci sketch of drill with centering plate

At the end of the 16th century, with the introduction and dissemination of gunpowder on the European continent, there was a development in drilling techniques, associated with advances in casting techniques, mainly with regard to the manufacture of weapons.

One of the first known works on turning is published by the Frenchman Charles Plumier in the 18th century, in the same period the first machines designed according to modern principles appeared (Moore, 1975).

The Dutch Verbruggen, in 1755, improved the cannon drilling technique, which remained unchanged for around four centuries. Originally, the cannon drilling technique was based on guiding the tool through the hole from the casting, which resulted in misaligned and imprecise holes. The technique developed by Verbruggen consisted of guiding the drill at both ends.

Drills in this period already had helical channels, which were introduced by Verbruggen in 1755. Small variations in the method would allow Wilkinson, in the industrial revolution, to obtain tolerances no larger than a finger on cylinders with a diameter of 1829mm (Moore, 1975). The improvement in the process introduced by Wilkinson allowed James Watt to develop the steam engine.

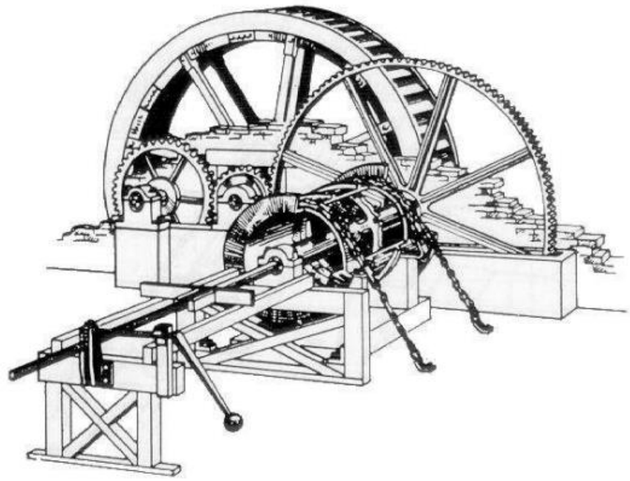

Figure 3-5 Water wheel driven Willkinson's drill

The first lathes designed according to modern principles were made by the Frenchman Vaucanson, around 1765. They were lathes with parallel V-shaped prismatic busbars, which only found acceptance in the following century, through Maudslay. This brought together under a single project the use of iron, steel and bronze as opposed to wood as the structural element of a machine. Maudslay combined his common sense as an instrument maker with machine design and generated disciples such as Bramah, Clement, Whitworth, Nasmyth and others (Morre, 1989; Thyer, 1991).

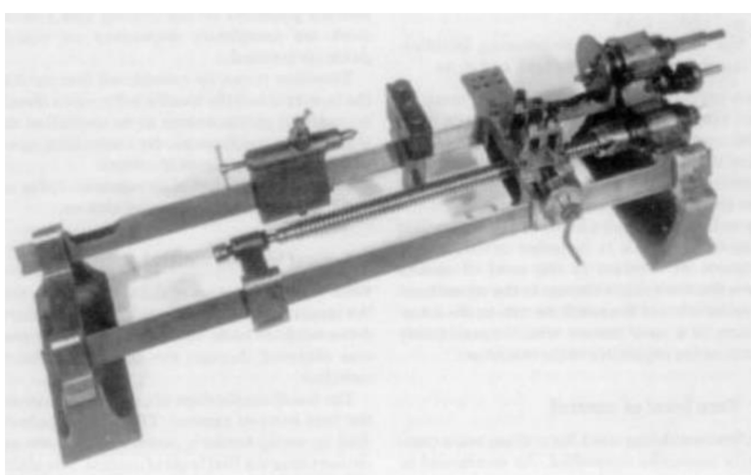

Figure 3-6 Maudslay's lathe

Nasmyth, the inventor of the steam forge, was the person who expressed Mausdlay's ideas in three basic rules:

- Have a clear idea of what you want to achieve and then you will have all the conditions to do it.

- Maintain strict quality control over your materials; have a clear vision of each gram of material and its importance, ask yourself the question (is there really a need for such a component to be there?). Avoid complexity and make everything as simple as possible.
- Remember to have an idea of the function performed by each of the pieces.

These rules have become the essence for designing a quality machine. However, despite the countless existing design theories, the tendency throughout a designer's training is for them to develop their own methodology, systematizing procedures and synthesizing the best of different design techniques (Davidson, 1972; Slocun, 1992; Weck, 1992 ;Paul-Beitz, 1996).

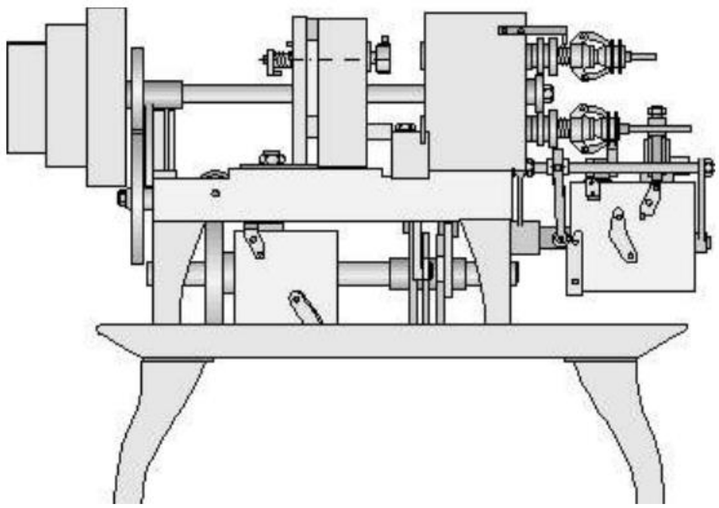

Figure 3-7 Multi-spindle lathe from the end of the 19th century

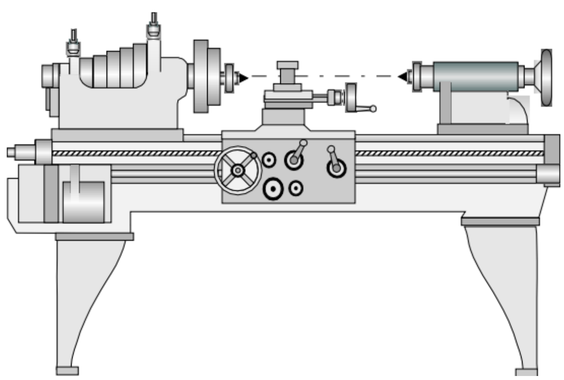

Figure 3-8 Belt driven universal lathe from the beginning of the 20th century

The evolution of electronics in the first half of the 20th century, combined with the development of computers, led to the creation of the first numerically controlled machine tool. In 1946, the first digital electronic computer, the ENIAC, was developed, in 1947 the first transistor was invented in Bell laboratories, and in 1950, using an electronic computer EDSAC, the first numerically controlled (NC) machine tool was developed, in laboratories of the Massachusetts Institute of Technology - MIT.

Currently, the design of machines for manufacturing with defined geometry points to three distinct areas of development. The first aimed at obtaining maximum production flexibility, being characterized by hexapot type machines, the second characterized by the maximum removal rate, which forms the basis of high-speed machining – HSM, and the third aimed at meeting the needs to obtain high dimensional and geometric accuracy and high surface quality, that is, for ultra-precision.

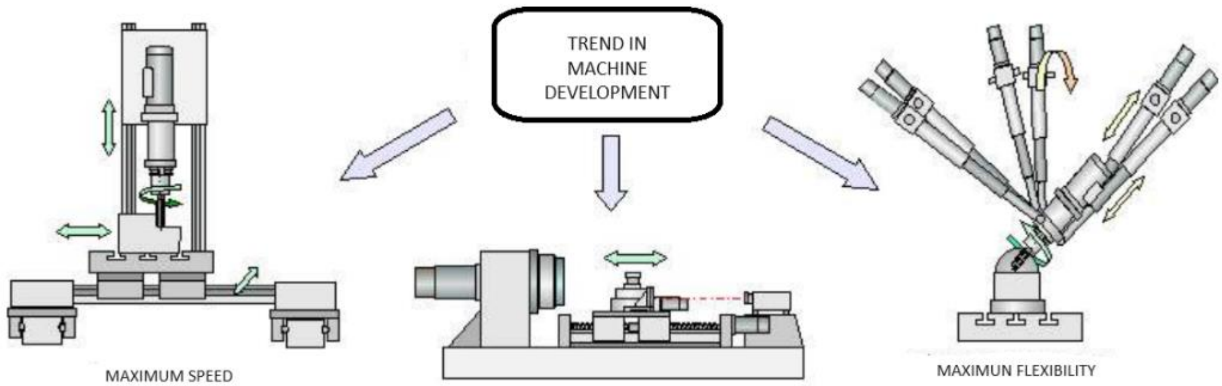

Figure 3-9 Machine trends

Considered by many to be the state-of-the-art in terms of machining, very high-speed machining technology (HSC - High Speed Cutting) is completing 70 years. The method developed by C. Salomon was patented on April 27, 1931, in Germany, with the patent granted to the company Krupp A.G. Although the first research into high-speed cutting machining (HSC) dates back to the 1930s, This was basically based on the concept of high relative cutting speed between part and tool, which could only be obtained with high rotation of the machine spindle. The possibility of obtaining high feed speeds transformed the concept of cutting speed machining – HSC – into high-speed machining – HSM, where the possibilities in terms of increasing removal rates are greatly expanded.

High-speed machining technology only began to arouse interest in the world of metal-mechanical manufacturing, specifically machining, over the last decade of the last century. This technology has received a major boost due to advances in drives, rolling element guides and control electronics, particularly in the ability to process digitally and at high speed the high volume of data transferred between the measuring system and the controls.

Figure 3-10 Modern day CNC machine

4 The model

The designed model is as shown below:

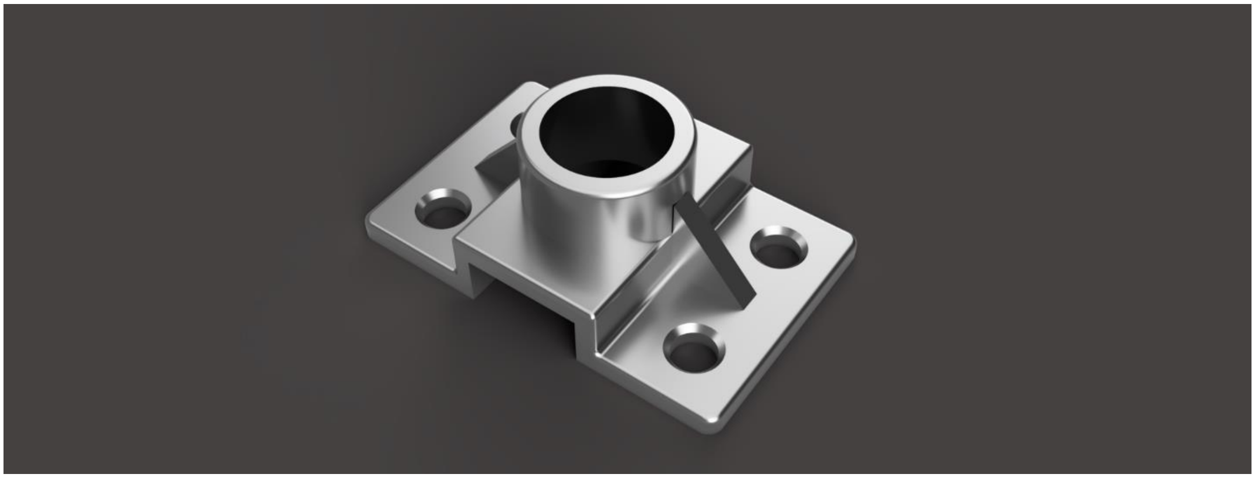

Figure 4-1 Rendered model

The workpiece is a support with a through hole in the middle and 4 chamfered holes to be used for fixation.

This piece can be used to provide support to a rod going through it for example making a long rod have fixed supports to sustain itself without needing to have cuts in it.

Another possible use for this piece could be as well to fit a bearing in the middle of it with a shaft or another moving piece going through the bearing and through the workpiece

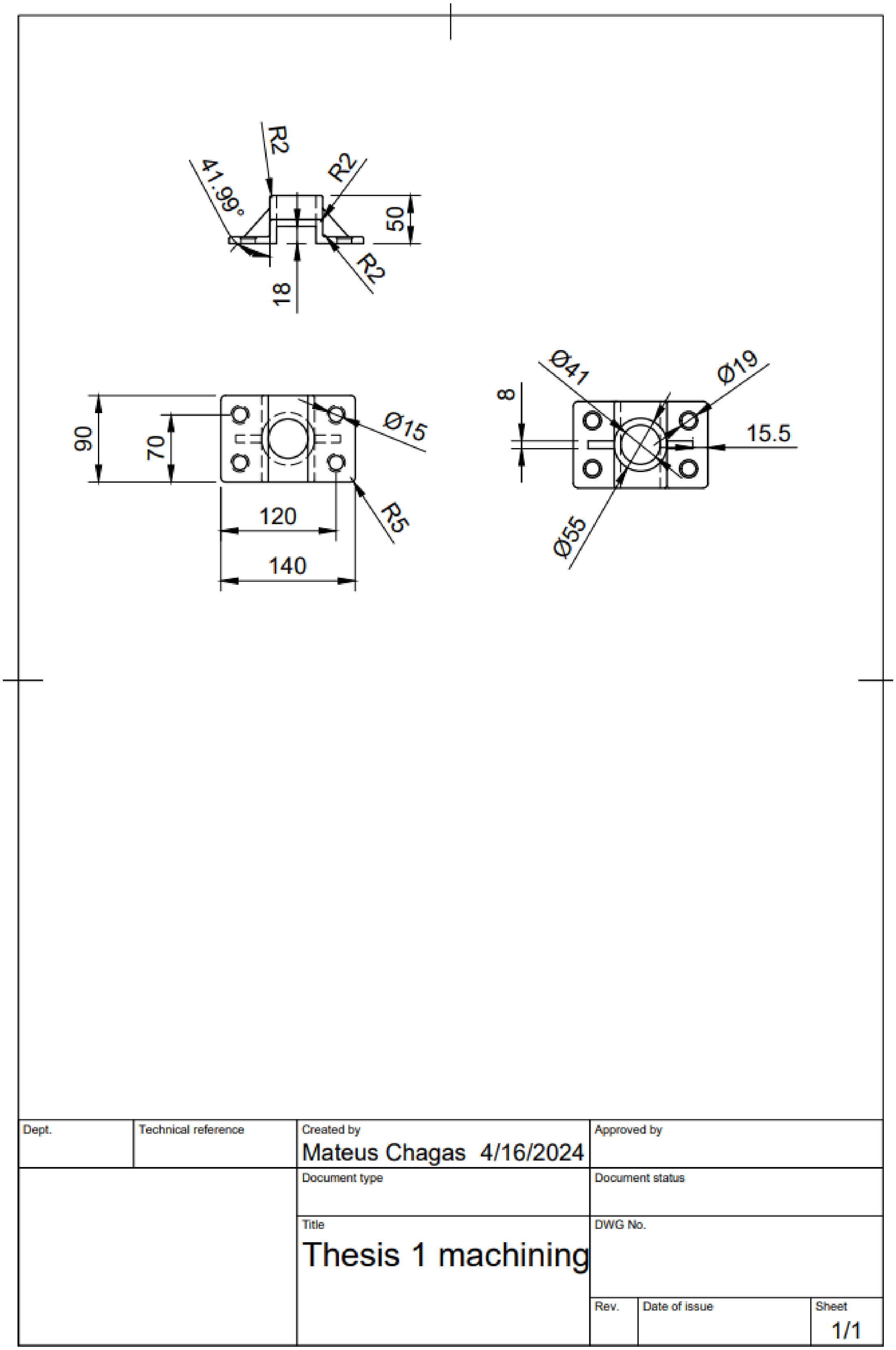

Figure 4-2 Workpiece technical drawing

5 Material

The chosen material for the workpiece is a EN8 Steel

EN8 Carbon Steel, 080M40 BS 970 Specification - Otai Special Steel (astmsteel.com)

EN8 is an unalloyed medium carbon steel which is used in applications where better properties than mild steel is required but where the costs do not justify the purchase of a steel alloy. EN8 can be heat treated to provide a good surface hardness and moderate wear resistance by flame or induction hardening processes. From the automotive trade to wider general engineering applications, EN8 is a popular steel in industry.

5.1 Applications

• Automotive parts

• Connecting rods

• Studs, bolts

• Axles, spindles

• General engineering components

5.2 Key features

• Unalloyed medium carbon steel

• Reasonable tensile strength

• Can be flame or induction hardened

• Readily machinable

• Moderate wear resistance if heat treated

5.3 Related material specifications

BS970: 1955	EN8
BS970/PD970: 1970 onwards	080M40
European	C40, C45, Ck40,Ck45, Cm40, Cm45
Werkstoff No.	1.0511, 1.1186, 1.1189
US SAE (AISI)	1039, 1040, 1042, 1043, 1045

Figure 5-1 Material specifications

5.4 Chemical Composition (weight %)

	C	Si	Mn	P	S
min.	0.36	0.10	0.60		
max.	0.44	0.40	1.00	0.05	0.05

Figure 5-2 Material Chemical composition

5.5 Mechanical Properties

Max Stress	700-850 n/mm2	
Yield Stress	465 n/mm2 Min	(up to 19mm LRS)
0.2% Proof Stress	450 n/mm2 Min	(up to 19mm LRS)
Elongation	16% Min	(12% if cold drawn)
Impact KCV	28 Joules Min	(up to 19mm LRS
Hardness	201-255 Brinell	

Figure 5-3 Material mechanical properties

6 Tools

Here is a list of all the tools used in this project, their number in this list is also their respective number in the machine slot.

1. Face mill 50mm
2. End mill 14mm
3. Spot drill 12mm
4. Jobber drill 15mm
5. Ball end mill 4mm

This is also the order that they will be used in the machining of the piece, more details on these tools will be given next.

6.1 CoroMill® 210 face milling cutter - R210-063Q22-09H

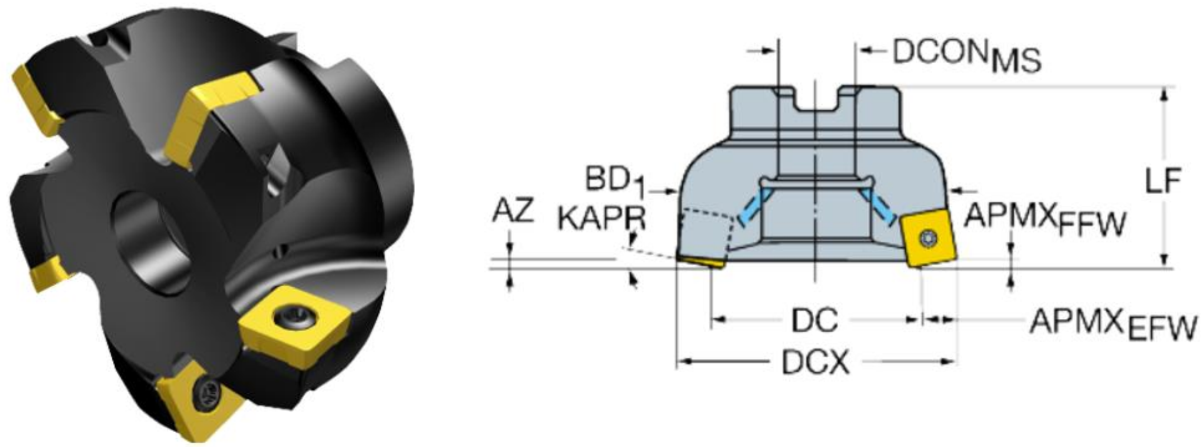

Figure 6-1 Face milling tool model and technical dimensions

<u>R210-050Q22-09M (coromant.com)</u>

Tool cutting edge angle (KAPR)	10 deg	Body diameter(BD)	46.96 mm
Cutting diameter (DC)	35.9 mm	Connection diameter(DCONMS)	22 mm
Maximum cutting diameter(DCX)	50 mm	Functional length(LF)	50 mm
Cutting item count(CICT)	4	Depth of cut maximum(APMXEFW)	8 mm
Maximum plunge depth(AZ)	1.8 mm	Depth of cut maximum(APMXFFW)	1.2 mm

6.2 14mm Dia. Carbide End Mill

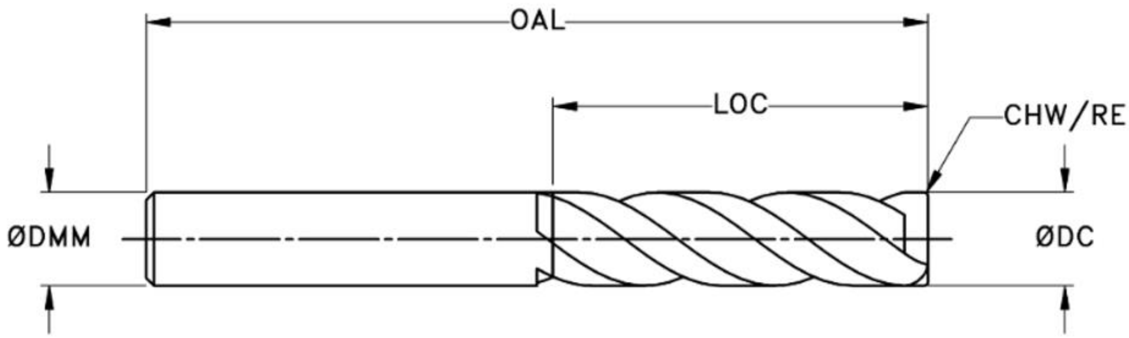

Figure 6-2 Endmill tool model and technical dimensions

<u>14mm Dia. Carbide End Mill, 4 Flute, Hyb. AlCrN Coated, 14mm Weldon Shank x 30mm LOC, 0.5mm Radius, HTPM (haascnc.com)</u>

[ØDC] Cutting Diameter	14mm
[OAL] Overall Length	88mm
[LOC] Length Of Cut	30mm
[CHW\RE] Chamfer \ Radius Size	0,5mm
[NOF] Number of Flutes	4
[FHA°] Helix Angle	35/37 º

6.3 KenDrill™ Spot • 120° Spot Angle • 12mm

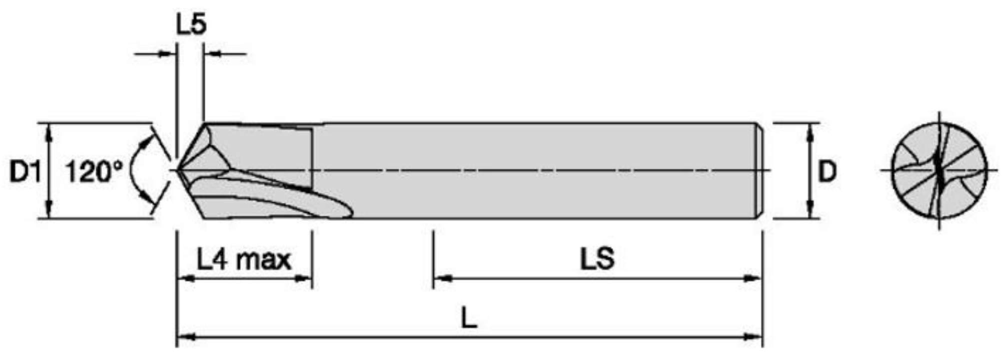

Figure 6-3 Spot drill tool model and technical dimensions

KenDrill™ Spot • 120° Spot Angle • Straight Shank • Metric (kennametal.com)

[D1] Drill Diameter	12mm
[L] Overall Length	73mm
[L4 Max] Maximum Drilling Depth	14mm
[LS] Shank Length	52mm
[D] Shank diameter	12mm

6.4 Drill, 15mm Jobber, Type N, HSS, Steam Oxide

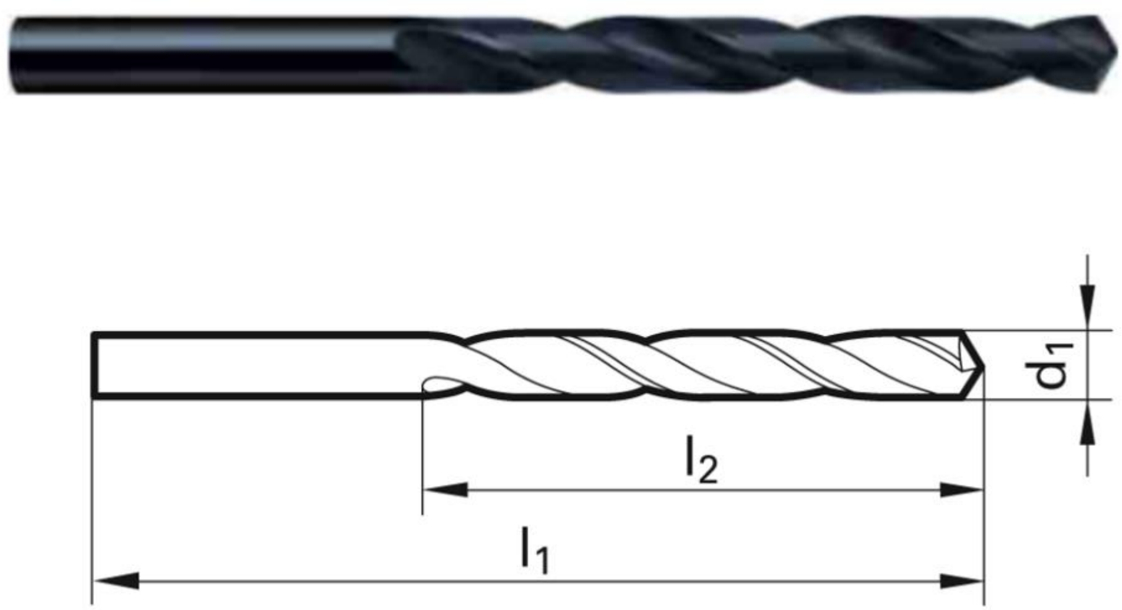

Figure 6-4 Jobber drill tool model and technical dimensions

Guhring Drills - Part Number 9002050150000 (205-15.000) - Drill, 15mm Jobber, Type N, HSS, Steam Oxide

[D1] Drill diameter	15mm
[L] Overall Length	169mm
[L2] Flute Length	114mm
[tMAx] Maximum Drilling Depth	91,5mm
[D] Shank diameter	15mm
Flutes	2

6.5 4mm Dia. Carbide Ball End Mill

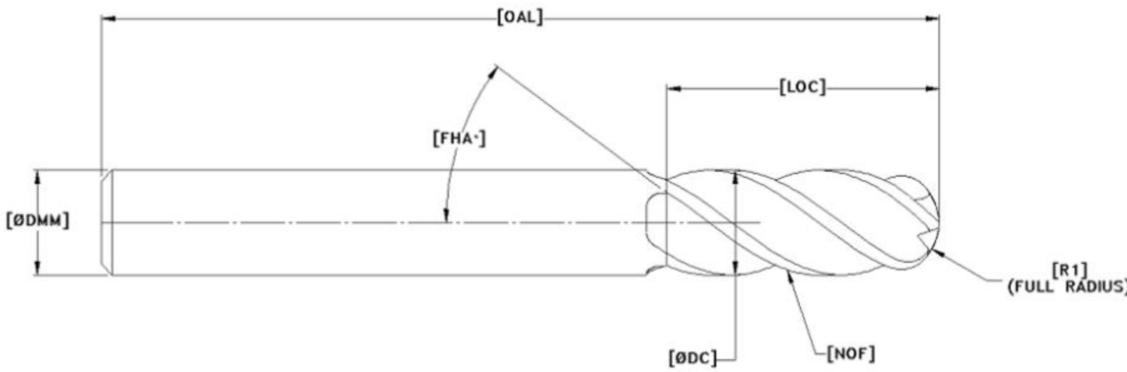

Figure 6-5 Ball endmill tool model and technical dimensions

<u>4mm Dia. Carbide Ball End Mill, 4 Flute, Hyb. AlCrN Coated, 4mm Smooth Shank x 12mm LOC, HTPM (haascnc.com)</u>

[ØDC] Cutting Diameter	4mm
[OAL] Overall Length	50mm
[LOC] Length Of Cut	12mm
[ØDMM] Shank Diameter	4mm
[R1] Radius	2mm
[NOF] Number of Flutes	4
[FHA°] Helix Angle	35/37 º

7 Milling

Milling is one of the most important activities in today's modern industry, combining aspects of art and science. In general, milling involves the process of transforming materials from raw materials into final products; It gives engineers and craftsmen a powerful tool to transform the world around us.

At the heart of the milling process is the cooperation between the cutting tool and the workpiece. A cutting tool, usually in the form of a rotary cutter, acts like a craftsman's chisel, cutting the workpiece with each calculated movement. Whether it is a simple or complex point, the precise details of grinding guided by the hands of skilled workers or machines transform the raw material into perfect shape.

Milling art is important not only in the final product but also in production quality. All cutting operations, where speed and feed change each time, are evidence of workmanship that is sensitive to the behavior of the tools and the tools in motion. It is a dance of control and pleasure, where experience and intuition show the way to perfection.

However, underlying this artistic vision lies the basis of scientific principles. Milling is one of those fields where mathematics, physics and engineering come together to achieve success. Everything from the geometry of the cutting tool to its working force is carefully calculated to ensure efficiency, effectiveness and safety. Engineers are pushing the boundaries of what can be achieved by using advanced software and finite element analysis to predict and optimize machine parameters.

Moreover, milling is not a fixed process but a dynamic discipline. Innovations in scientific instruments, technological tools, and processing techniques are constantly updating the landscape, creating new possibilities and applications. High-speed machining, multi-grinding, and tool integration using algorithms are just a few examples of how the boundaries of milling are being pushed even further, pushing the industry forward.

In manufacturing, milling is the cornerstone of innovation. From wind turbines to advanced medicine, it is the invisible hand that shapes the complexities of our daily lives. But beyond its value, milling also involves combining human skills with technological skills, reminding us that even in most industrial processes there is an art waiting to be discovered.

7.1 Roughing

Wound milling refers to the first stage of the material removal process in which a large amount of material (excess material) is quickly removed from the process to obtain the desired shape or size. This method is generally characterized by high cutting speed, high feed rate and reduced intensity such as deep cutting to effectively remove large amounts of material.

The main purpose of grinding is to speed up the machining process, reduce tool wear and increase productivity. Solidification quickly eliminates excess material, reducing the machining time required to create a finished part. It also helps extend tool life by shortening the usage time of the cutting tool and reduces heat and wear on the side of the tool.

Wounding is usually followed by a finishing and finishing process in which the working surface is gradually improved, and the final line and surface quality is achieved. While roughing removes a large portion of the material, these subsequent operations aim to achieve high tolerances and a good finish.

A variety of grinding techniques can be used for machining, including conventional grinding, surface grinding, and high-speed machining; each offers unique advantages depending on the specific requirements of the workpiece and the characteristics of the workpiece.

In general, grinding hardness plays an important role in the machining process; It effectively eliminates excess material to speed up production and extend tool life while laying the foundation for subsequent operations.

7.2 Face Milling

Surface grinding is a machining process used to obtain a smooth surface on the work surface. In this method, a grinding wheel with multiple cutting edges rotates perpendicular to the surface of the work surface, efficiently removing material in a non-abrasive manner. The cutting edge of the grinding wheel extends outwards and often overlaps, allowing efficient material removal from all work surfaces.

Surface grinding is generally used to achieve smoothness, fineness and smoothness on large surfaces such as the surface of a casting or the face of a casting. Ideal for machining large, curved surfaces where other methods such as surface grinding or surface grinding may not be efficient or practical.

Many different types of surface grinders are available, including grinders, flywheels, and face mills, each designed for specific applications and job requirements. These cutters can vary in size, shape, number of cutting edges and insert geometry to accommodate different work materials, sizes and finishing requirements.

Face milling can be performed on manual milling machines, CNC machining centers and special milling machines designed for milling operations. With the development of CNC technology, complex face milling operations such as machining and engraving can be planned and executed efficiently and effectively.

In general, surface grinding is a versatile machining process widely used in the manufacturing industry to create a flat surface with high tolerances and excellent surface quality; hence it is essential for a variety of applications in aerospace, automotive, machining, and other industries.

7.3 Profiling

Profiling in milling refers to the process of machining a contoured shape or profile on the edge or surface of a workpiece using a milling cutter. Unlike face milling, which focuses on flat surfaces, profiling involves cutting along a defined path to create complex shapes, curves, chamfers, or other geometries.

There are several methods for profiling in milling:

Contour milling: This method involves milling along the outline of a part or feature, following a predefined contour or shape. It is commonly used for creating external profiles, such as the perimeters of parts or the edges of components.

Pocket milling: Pocket milling involves machining enclosed or partially enclosed areas within the workpiece. It is often used to create recesses, slots, or pockets with defined depths and contours.

3D profiling: In this method, the milling cutter follows a three-dimensional path to machine complex shapes and contours on the surface of the workpiece. It is commonly used for sculpted surfaces, intricate molds, and freeform geometries.

Edge profiling: Edge profiling refers to machining specific features or contours along the edges of the workpiece, such as chamfers, fillets, or grooves. It is often used to improve the aesthetics, functionality, or assembly of parts.

Profiling in milling can be performed using various milling techniques, including conventional milling, climb milling, and high-speed machining, depending on the material properties, part geometry, and machining requirements. Additionally, advanced CAD/CAM software enables engineers to design complex profiles and generate toolpaths for precise machining.

Overall, profiling in milling is a versatile machining technique that allows for the creation of intricate shapes, contours, and features on workpieces, making it essential for manufacturing a wide range of components and parts in industries such as aerospace, automotive, medical, and mold making.

7.4 Drilling

Drilling in milling refers to the process of creating holes in a workpiece using a milling machine equipped with a drilling tool or drill bit. While milling machines are primarily used for milling operations such as face milling, profiling, and contouring, they can also perform drilling operations with the appropriate tooling and setup.

Drilling in milling offers several advantages over dedicated drilling machines:

Versatility: By using a milling machine for drilling operations, manufacturers can leverage the machine's versatility to perform multiple machining processes in a single setup. This reduces the need for additional equipment and streamlines production workflows.

Accuracy: Modern milling machines are equipped with precise spindle controls and positioning systems, allowing for accurate hole placement and dimensional consistency. This is essential for applications where tight tolerances are required.

Flexibility: Milling machines can accommodate a wide range of drill sizes and types, including twist drills, center drills, and specialty drills. This flexibility enables manufacturers to adapt to various hole sizes, materials, and machining requirements.

Cost-effectiveness: Utilizing a milling machine for drilling operations can be cost-effective, particularly for small to medium-sized production runs. It eliminates the need for investing in dedicated drilling equipment and reduces setup and changeover times.

Drilling in milling can be performed using different milling techniques, such as plunge milling, peck drilling, or helical interpolation, depending on the hole size, depth, material, and surface finish requirements. Additionally, advanced CNC programming capabilities allow for the automation and optimization of drilling operations, further enhancing productivity and efficiency.

Overall, drilling in milling expands the capabilities of milling machines, enabling manufacturers to efficiently produce precise holes in workpieces while benefiting from the machine's versatility, accuracy, flexibility, and cost-effectiveness.

8 Machining

Operation: Face milling

Tool used: Tool 1 – Face mill 50mm

This operation is done to remove material from flat surfaces, in this case the top surface so we can reach the height needed for the piece we are manufacturing.

The tool in this case, unlike the previous operation, only works at one height since we don't need to remove much material, but unlike the previous operation where we had to do multiple passes in the vertical or Y axys, due to the height of the piece, in this case we have to do multiple passes in the horizontal, or the X axys due to the size of the piece and the size of the tool

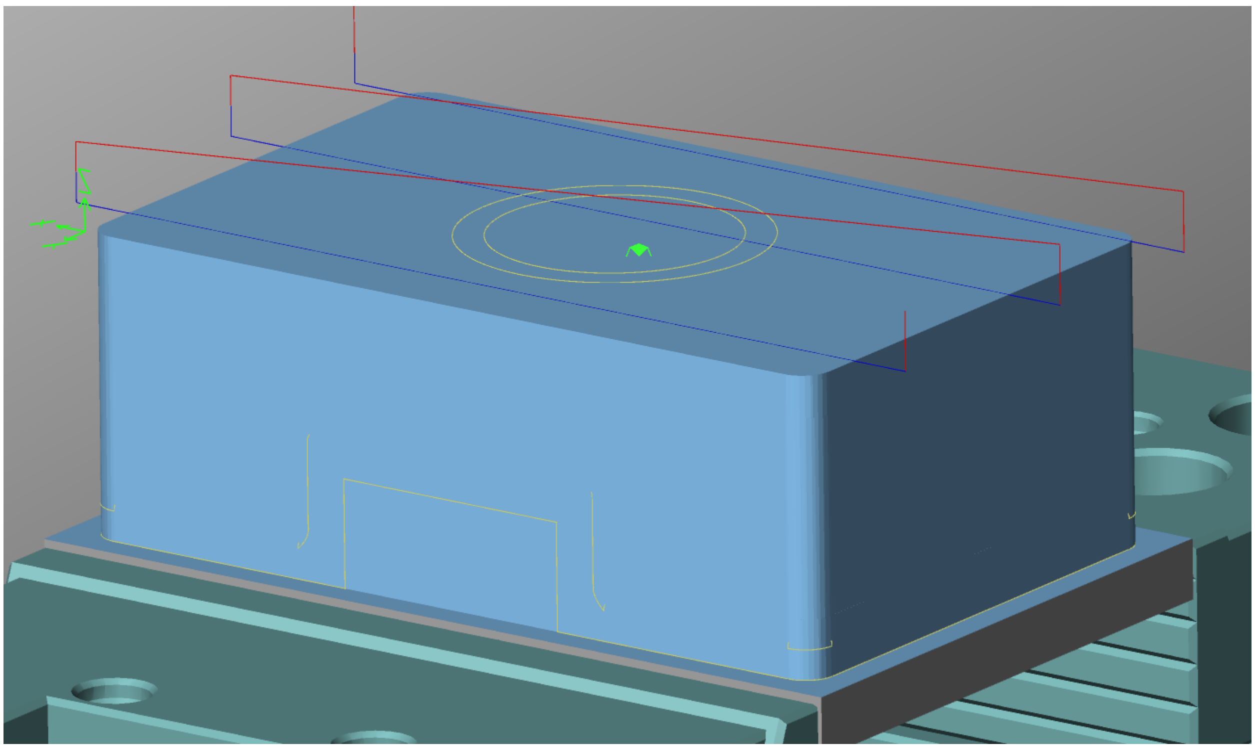

Figure 8-1 Face milling

Operation: Roughing

Tool used: Tool 1 – End mill 14mm

The next operation is a roughing, in this operation most of the raw material will be removed and we will obtain the rough shape of our workpiece.

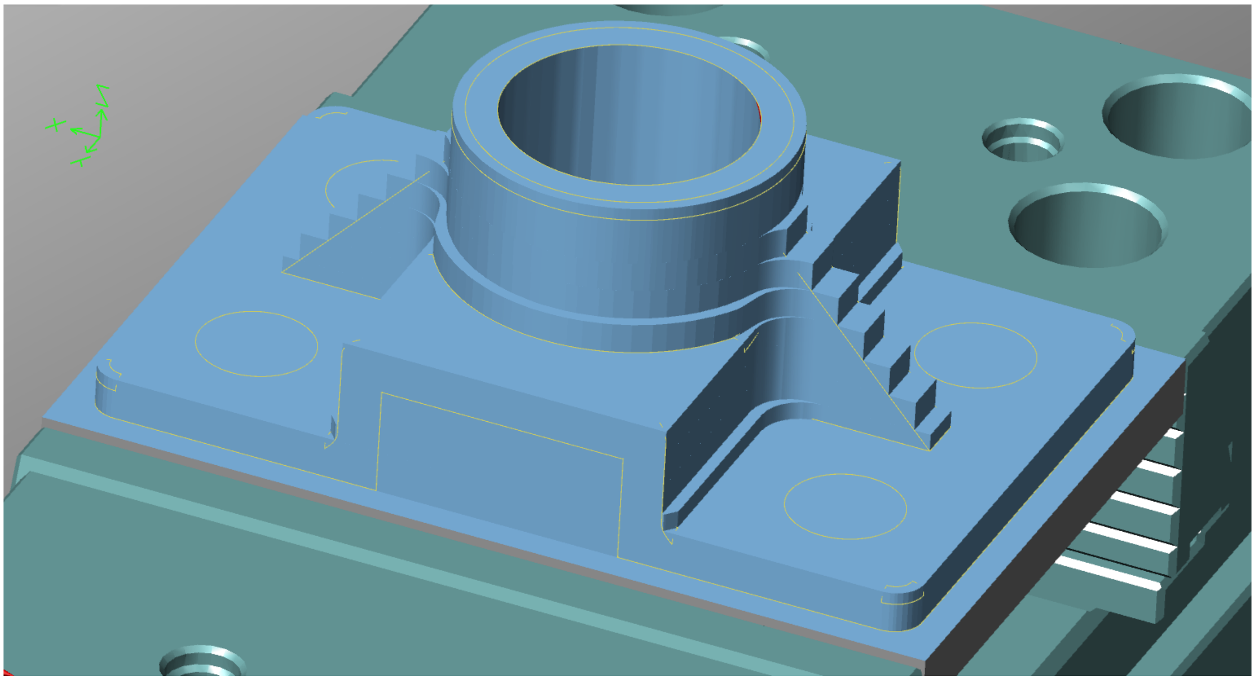

Figure 8-2 Roughing

Operation: Drilling and chamfer

Tool used: Tool 1 – Spot drill 12mm and Jobber drill 15mm

Next step is to drill the hole in our piece, which we have 4 of them.

In this case since we are using steel as our material, is necessary to firstly drill a center hole with a specialized tool called spot drill.

This is necessary so when we have our drill to make the hole, it has this center point to center itself and follow so, in this way the hole will be straight and in line with where it should be, because without this center hole when the drill contact the metal due to it's spinning motion it could move the tip of the drill ever so slightly to the side before making the hole but a slip that could cause in the hole not being parallel or being off center

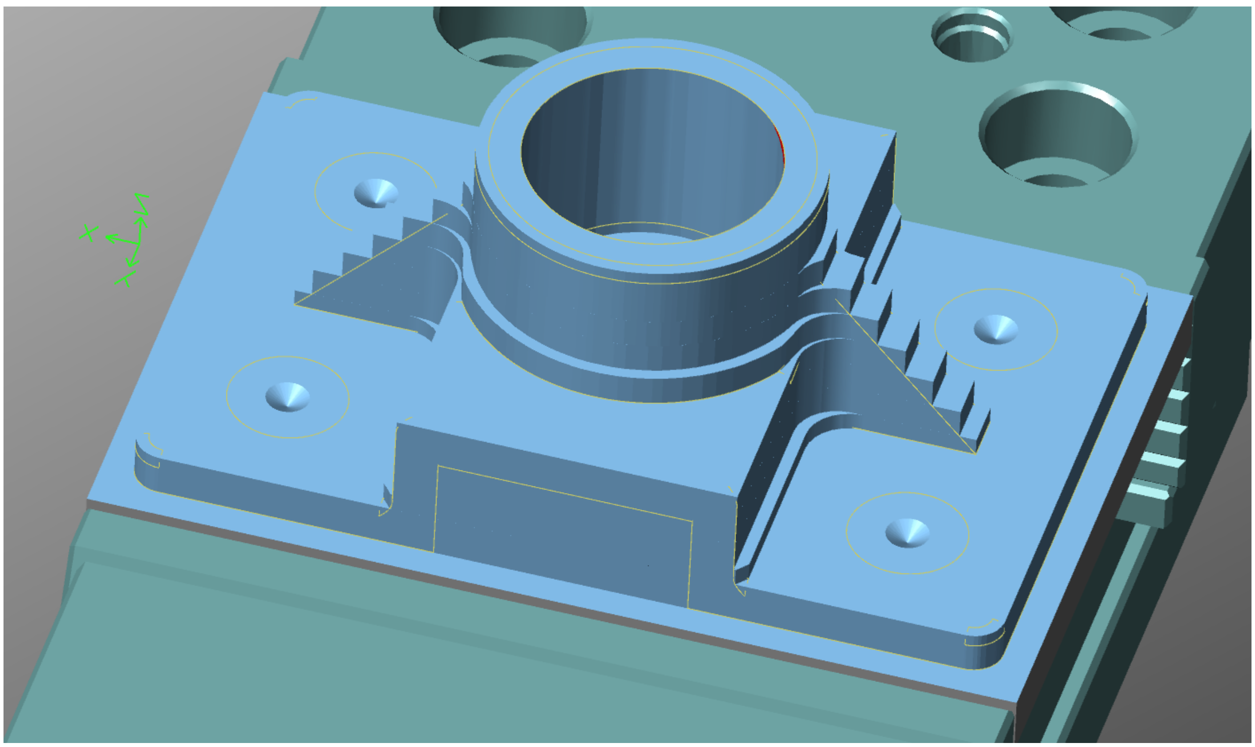

Figure 8-3 Center hole pre drill

So as explained before, after we have the center hole made with the spot drill we can then change the tool to our Jobber drill, this drill but, unlike the spot drill used before, is proper for making holes in the workpiece without posing any risk of breaking the tool and also providing more control on the chipping

So after we have made the holes, according to the piece design, a chamfer is needed. This process is also done with the drill bit so no tool change is needed in this part

And after we made the holes and chamfer, this is what we are left with. Note that at this stage the holes aren't all the way through because we have some extra stock on the bottom which will be removed in later steps

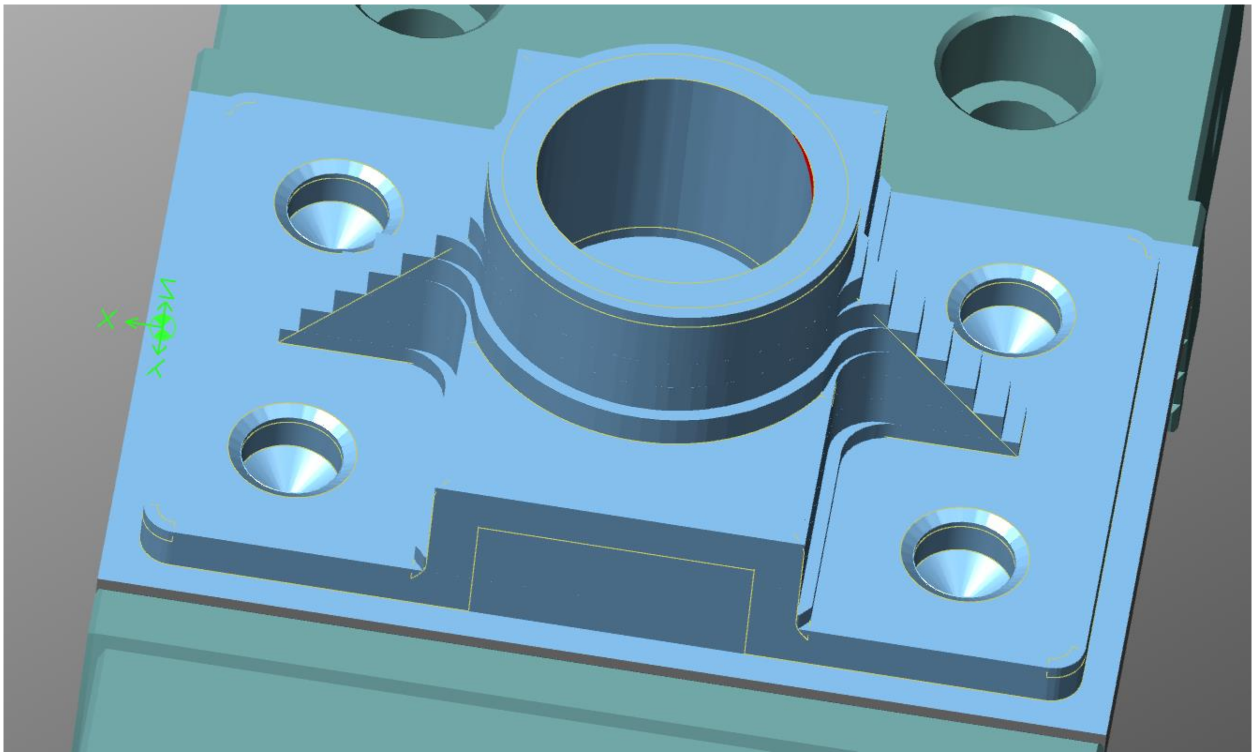

Figure 8-4 Drill and chamfer

Operation: Profilling

Tool used: Tool 1 – Ball end mill 4mm

This operation is to make the rough shape of the material to be smoother and have a finished surface.

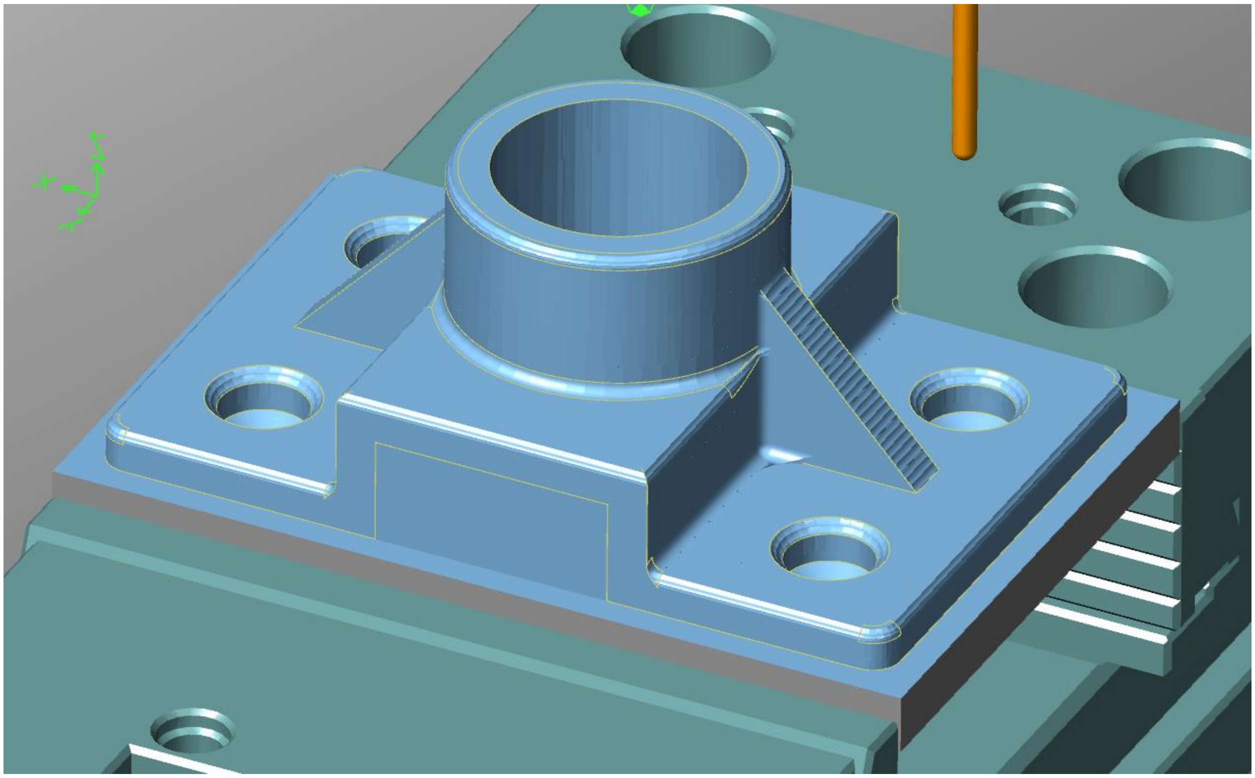

Figure 8-5 Profiling

8.1 First machining technical report from simulation

Section 1 : Nctapes loading

Machine : sample mill vertical mm

Channel : 1

Decoding nctape : traj_34.txt

Number of errors :
Total number of errors : 0

Sequence of tools use :

#	Reference	Total time	Rapid time	Cutting time	Various time	Sequence time	F min	F max	F average	S min	S max	Radius comp.	Working distance (tcp)

Rapid time of all sequences : 00"
Cutting time of all sequences : 00"
Various time of all sequences : 00"
Total time of all sequences : 00"
Program time : 00"

Decoding nctape : traj_35.txt

Number of errors :
Total number of errors : 0

Sequence of tools use :

#	Reference	Total time	Rapid time	Cutting time	Various time	Sequence time	F min	F max	F average	S min	S max	Radius comp.	Working distance (tcp)
2	50.0 mm Face Mill x 90 Degree 354	01'07"	09"	58"	00"	01'07"	509.296 mm/min	509.296 mm/min	509.296 mm/min	1000 rpm	1000 rpm	Without	0.495 m

Rapid time of all sequences : 09"
Cutting time of all sequences : 58"
Various time of all sequences : 00"
Total time of all sequences : 01'07"
Program time : 01'07"

Decoding nctape : traj_36.txt

Number of errors :
Total number of errors : 0

Sequence of tools use :

#	Reference	Total time	Rapid time	Cutting time	Various time	Sequence time	F min	F max	F average	S min	S max	Radius comp.	Working distance (tcp)
2	50.0 mm Face Mill x 90 Degree 354	05"	05"	00"	00"	05"	NA	NA	NA	NA	NA	Without	0 m

Rapid time of all sequences : 05"
Cutting time of all sequences : 00"
Various time of all sequences : 00"
Total time of all sequences : 05"
Program time : 05"

Decoding nctape : traj_37.txt

Number of errors :
Total number of errors : 0

Sequence of tools use :

#	Reference	Total time	Rapid time	Cutting time	Various time	Sequence time	F min	F max	F average	S min	S max	Radius comp.	Working distance (tcp)
3	14.0 mm Multi-Flute End Mill 357	18'16"	02'55"	15'21"	00"	18'16"	1273.24 mm/min	1273.24 mm/min	1273.24 mm/min	1000 rpm	1000 rpm	Without	19.535668 m

Rapid time of all sequences : 02'55"
Cutting time of all sequences : 15'21"
Various time of all sequences : 00"
Total time of all sequences : 18'16"
Program time : 18'16"

Decoding nctape : traj_38.txt

Number of errors :
Total number of errors : 0

Sequence of tools use :

#	Reference	Total time	Rapid time	Cutting time	Various time	Sequence time	F min	F max	F average	S min	S max	Radius comp.	Working distance (tcp)
3	14.0 mm Multi-Flute End Mill 357	04'16"	06"	04'10"	00"	04'16"	286.479 mm/min	286.479 mm/min	286.479 mm/min	1000 rpm	1000 rpm	Without	1.191585 m

Rapid time of all sequences : 06"
Cutting time of all sequences : 04'10"
Various time of all sequences : 00"
Total time of all sequences : 04'16"
Program time : 04'16"

Decoding nctape : traj_39.txt

Number of errors :
Total number of errors : 0

Sequence of tools use :

#	Reference	Total time	Rapid time	Cutting time	Various time	Sequence time	F min	F max	F average	S min	S max	Radius comp.	Working distance (tcp)
3	14.0 mm Multi-Flute End Mill 357	04"	04"	00"	00"	04"	NA	NA	NA	NA	NA	Without	0 m

Rapid time of all sequences : 04"
Cutting time of all sequences : 00"
Various time of all sequences : 00"
Total time of all sequences : 04"
Program time : 04"

Decoding nctape : traj_40.txt

Number of errors :
Total number of errors : 0

Sequence of tools use :

#	Reference	Total time	Rapid time	Cutting time	Various time	Sequence time	F min	F max	F average	S min	S max	Radius comp.	Working distance (tcp)
4	12.0 mm Spot Drill 330	32"	09"	24"	00"	32"	509.296 mm/min	509.296 mm/min	509.296 mm/min	1000 rpm	1000 rpm	Without	0.2 m

Rapid time of all sequences : 09"
Cutting time of all sequences : 24"
Various time of all sequences : 00"
Total time of all sequences : 32"
Program time : 32"

Decoding nctape : traj_41.txt

Number of errors :
Total number of errors : 0

Sequence of tools use :

#	Reference	Total time	Rapid time	Cutting time	Various time	Sequence time	F min	F max	F average	S min	S max	Radius comp.	Working distance (tcp)
4	12.0 mm Spot Drill 330	04"	04"	00"	00"	04"	NA	NA	NA	NA	NA	Without	0 m

Rapid time of all sequences : 04"
Cutting time of all sequences : 00"
Various time of all sequences : 00"
Total time of all sequences : 04"
Program time : 04"

Decoding nctape : traj_42.txt

Number of errors :
Total number of errors : 0

Sequence of tools use :

#	Reference	Total time	Rapid time	Cutting time	Various time	Sequence time	F min	F max	F average	S min	S max	Radius comp.	Working distance (tcp)
5	15.0 mm Jobber Drill 340	43"	08"	35"	00"	43"	407.437 mm/min	407.437 mm/min	407.437 mm/min	1000 rpm	1000 rpm	Without	0.238026 m

Rapid time of all sequences : 08"
Cutting time of all sequences : 35"
Various time of all sequences : 00"
Total time of all sequences : 43"
Program time : 43"

Decoding nctape : traj_43.txt

Number of errors :
Total number of errors : 0

Sequence of tools use :

#	Reference	Total time	Rapid time	Cutting time	Various time	Sequence time	F min	F max	F average	S min	S max	Radius comp.	Working distance (tcp)
5	15.0 mm Jobber Drill 340	02'54"	12"	02'42"	00"	02'54"	424.413 mm/min	424.413 mm/min	424.413 mm/min	1000 rpm	1000 rpm	Without	1.146517 m

Rapid time of all sequences : 12"
Cutting time of all sequences : 02'42"
Various time of all sequences : 00"
Total time of all sequences : 02'54"
Program time : 02'54"

Decoding nctape : traj_44.txt

Number of errors :
Total number of errors : 0

Sequence of tools use :

#	Reference	Total time	Rapid time	Cutting time	Various time	Sequence time	F min	F max	F average	S min	S max	Radius comp.	Working distance (tcp)
5	15.0 mm Jobber Drill 340	04"	04"	00"	00"	04"	NA	NA	NA	NA	NA	Without	0 m

Rapid time of all sequences : 04"
Cutting time of all sequences : 00"
Various time of all sequences : 00"
Total time of all sequences : 04"
Program time : 04"

Decoding nctape : traj_45.txt

Number of errors :
Total number of errors : 0

Sequence of tools use :

#	Reference	Total time	Rapid time	Cutting time	Various time	Sequence time	F min	F max	F average	S min	S max	Radius comp.	Working distance (tcp)
6	4.0 mm Ball Nose Mill 369	01h 03' 01"	12"	01h 02' 48"	00"	01h 03' 01"	400 mm/min	400 mm/min	400 mm/min	1000 rpm	1000 rpm	Without	25.122503 m

Rapid time of all sequences : 12"
Cutting time of all sequences : 01h 02' 48"
Various time of all sequences : 00"
Total time of all sequences : 01h 03' 01"
Program time : 01h 03' 01"

Section 2 : Nctapes decoding

Machine : sample mill vertical mm

Channel : 1

Number of files read : 12
Total number of errors : 0
Number of tools used : 5
Number of tool change : 11
Rapid cumulated time : 04'09"
Cutting cumulated time : 01h 26' 58"
Addition times of the sequences : 00"
Cycle total time : 01h 31' 07"
Addition times of the programs : 01h 31' 07"

Amplitude of moves :

Axis	min range	max range
Z	-461.575 mm	0 mm
Y	-128.858 mm	0 mm
X	-82.977 mm	83.003 mm

Section 3 : Simulation

Simulation options :

Alarms to detect :
Rapid machining in material   Machining with stopped Spindle/Chuck   Machining with tool noncutting portion
Material removal with holders (milling cuts)

Collisions to detect :
Machine / Machine   Machine / Rough stock   Machine / Part
Machine / Clamps   Machine / Tools   Holder / Rough stock
Tool / Clamps
Machine clearance : 10 mm

9 Second side machining

After we are done machining the first side of the workpiece, we need to flip it 180º so we can machine the bottom part of it as well to give it it's final geometry.

For this process we need to manually grab the workpiece and place it with the new position in the vice and then place it inside of the machine so it can be worked on and finished

Operation: Roughing

Tool used: Tool 1 – Face mill 50mm.

We do a face milling at the bottom surface which has not been cut yet removing the excess raw material.

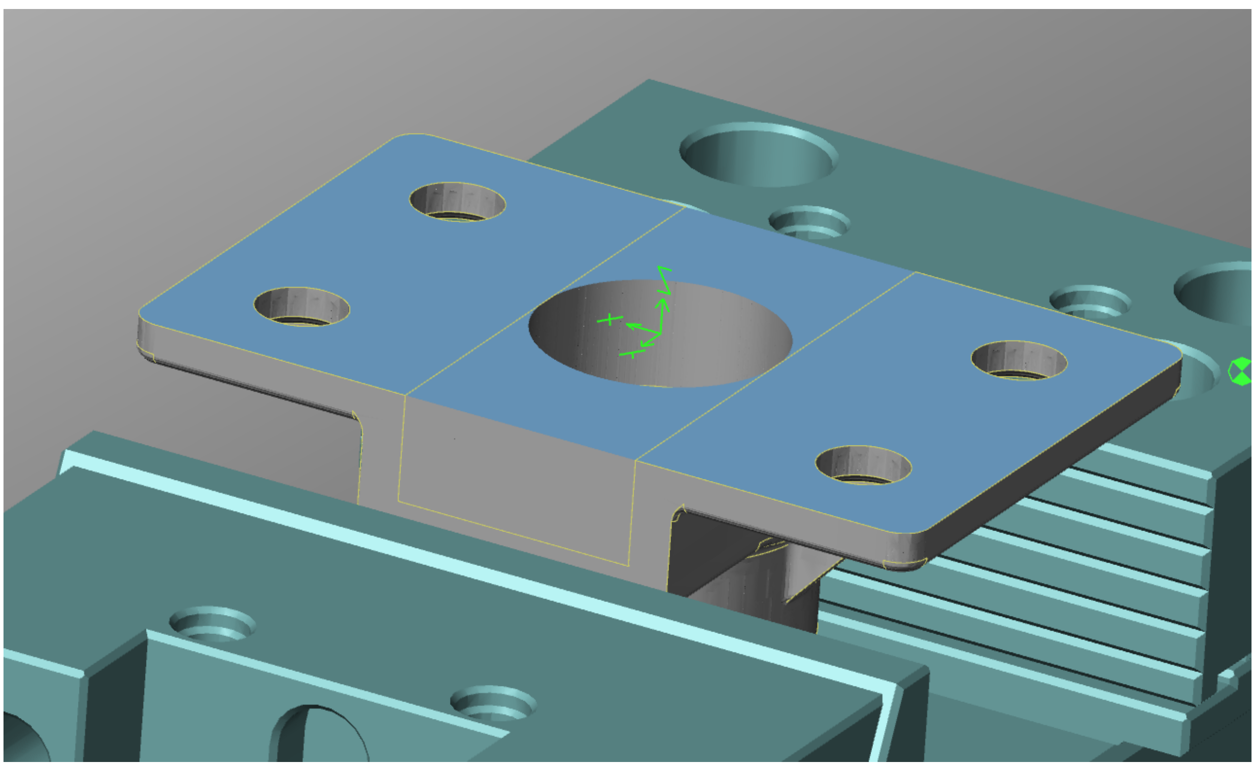

Figure 9-1 Bottom surface face mill

Operation: Roughing

Tool used: Tool 1 – End mill 14mm.

Now the last step is to do the roughing of the pocket, so we finish the manufacturing of our workpiece.

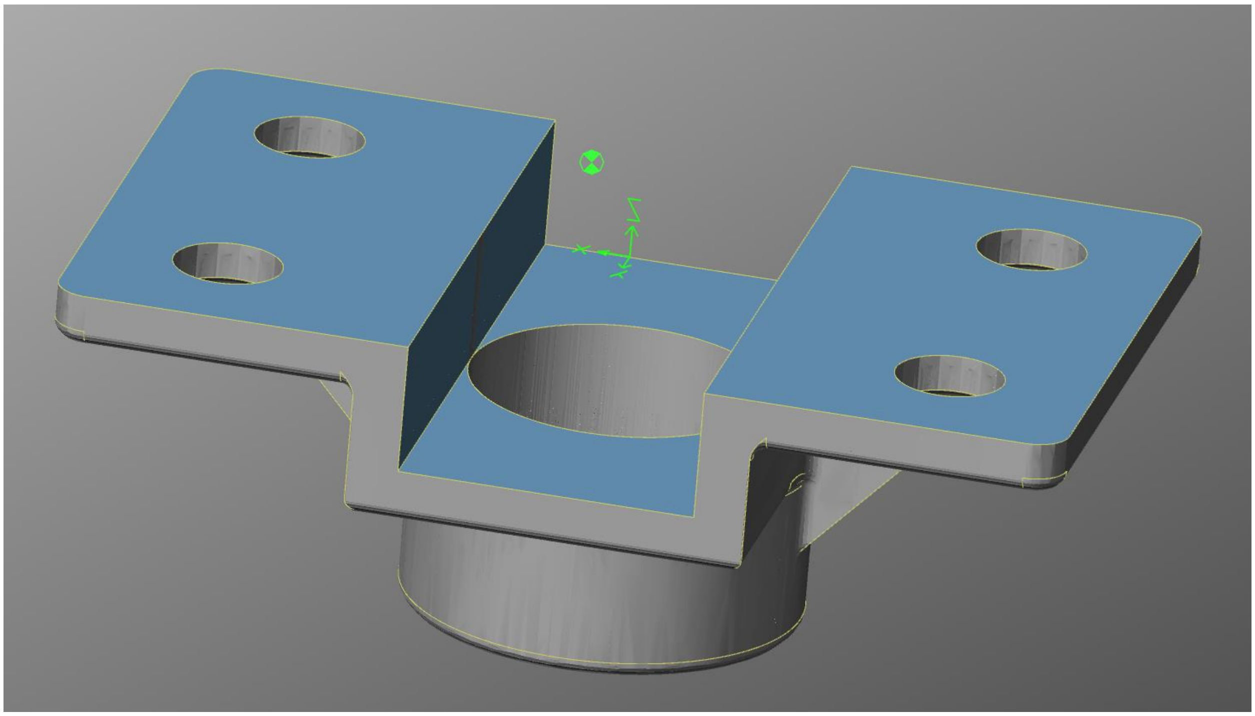

Figure 9-2 Bottom surface roughing

9.1 Second machining technical report from simulation

Section 1 : Nctapes loading

Machine : sample mill vertical mm

Channel : 1

Decoding nctape : traj_34.txt

Number of errors :
Total number of errors : 0

Sequence of tools use :

#	Reference	Total time	Rapid time	Cutting time	Various time	Sequence time	F min	F max	F average	S min	S max	Radius comp.	Working distance (tcp)

Rapid time of all sequences : 00"
Cutting time of all sequences : 00"
Various time of all sequences : 00"
Total time of all sequences : 00"
Program time : 00"

Decoding nctape : traj_35.txt

Number of errors :
Total number of errors : 0

Sequence of tools use :

#	Reference	Total time	Rapid time	Cutting time	Various time	Sequence time	F min	F max	F average	S min	S max	Radius comp.	Working distance (tcp)
11	50.0 mm Face Mill x 90 Degree 198	01'11"	09"	01'02"	00"	01'11"	509.296 mm/min	509.296 mm/min	509.296 mm/min	1000 rpm	1000 rpm	Without	0.524998 m

Rapid time of all sequences : 09"
Cutting time of all sequences : 01'02"
Various time of all sequences : 00"
Total time of all sequences : 01'11"
Program time : 01'11"

Decoding nctape : traj_36.txt

Number of errors :
Total number of errors : 0

Sequence of tools use :

#	Reference	Total time	Rapid time	Cutting time	Various time	Sequence time	F min	F max	F average	S min	S max	Radius comp.	Working distance (tcp)
11	50.0 mm Face Mill x 90 Degree 198	05"	05"	00"	00"	05"	NA	NA	NA	NA	NA	Without	0 m

Rapid time of all sequences : 05"
Cutting time of all sequences : 00"
Various time of all sequences : 00"
Total time of all sequences : 05"
Program time : 05"

Decoding nctape : traj_37.txt

Number of errors :
Total number of errors : 0

Sequence of tools use :

#	Reference	Total time	Rapid time	Cutting time	Various time	Sequence time	F min	F max	F average	S min	S max	Radius comp.	Working distance (tcp)
8	14.0 mm Multi-Flute End Mill 309	09'19"	07"	09'12"	00"	09'19"	286.479 mm/min	286.479 mm/min	286.479 mm/min	1000 rpm	1000 rpm	Without	2.633803 m

Rapid time of all sequences : 07"
Cutting time of all sequences : 09'12"
Various time of all sequences : 00"
Total time of all sequences : 09'19"
Program time : 09'19"

Section 2 : Nctapes decoding

Machine : sample mill vertical mm

Channel : 1

Number of files read : 4
Total number of errors : 0
Number of tools used : 2
Number of tool change : 3
Rapid cumulated time : 22"
Cutting cumulated time : 10'13"
Addition times of the sequences : 00"
Cycle total time : 10'35"
Addition times of the programs : 10'35"

Amplitude of moves :

Axis	min range	max range
Z	-457.575 mm	0 mm
Y	-117.518 mm	0 mm
X	-80 mm	80 mm

Section 3 : Simulation

Simulation options :

Alarms to detect :
Rapid machining in material Machining with stopped Spindle/Chuck Machining with tool noncutting portion
Material removal with holders (milling cuts)

Collisions to detect :
Machine / Machine Machine / Rough stock Machine / Part
Machine / Clamps Machine / Tools Holder / Rough stock
Tool / Clamps
Machine clearance : 10 mm

Number of errors :
Total number of errors : 0

10 Prices

For this work let's check the prices involved

Price for a machine:

It was checked with the company Tormach the prices for the following machine:

770M CNC Mill

770M CNC Mill (tormach.com)

Ranging from **$9,210** to **$27,146** depending on what type of complements you would like to have with the machine, with the complete version containing all the following options and the cheapest one none of them.

Figure 10-1 Tormach mill features and machine design.

And according to calculations written by Written by True Tamplin (2023)

Calculating the Machine Hour Rate | Finance Strategists

Machine cost	28000
Estimated scrap value	4000
effective working life (h)	13500
Hours worked in a month (avg)	120
Repair and maintenance cost	5600

Depreciation:

Which is equal to $\frac{\text{Machine cost} - \text{Estimated scrap value}}{\text{effective working life}} = \frac{28000 - 4000}{13500} = 1{,}77\$/h$

Repairs and maintenance:

Which is equal to $\frac{\text{Repair and maintenance cost}}{\text{effective working life}} = \frac{5600}{13500} = 0{,}41\$/h$

Total: 2,20$/h

According to www.glassdoor.com, the average salary for a CNC operator in the United States for 2024 is an average of **21$/h**.

This adds up to a total of **23,2$/h** for the machine without considering costs such as electricity, rent of property if applicable, coolant, raw material, etc.

According to the simulations of the part machining, the total time of machining will take 01h 41m, making the cost of this piece to be at least **39,05** dollars per piece.

11 Summary

The manufacturing of pieces has greatly evolved ever since CNC and specific software for manufacturing, and this is due to the ease it provides in the process of the manufacturing as it could be observed in this thesis.

Another great improvement that the technology provides for manufacturing is the fact that much software's nowadays automatically does all the calculations for feed and speed for you, which is the case of EdgeCAM which was used in this thesis

Although the piece itself was not machined, since we selected the material for the raw material and the tools were also selected from real tools store and not just some fictional numbers, this means that if we setup a machine with the same parameters we set in this simulation, according to the simulations results, there were no errors so this simulation should run smoothly and we should end up with the desired workpiece

This simulation process is necessary not only to accelerate the programing process of the CNC but also to run the simulation and check if there will be any problems with the machining of the workpiece, making the process safer and not only that but also saving money for the company in the meantime as it means less time working in programing and also possible less incidents when it comes to the machining part of the process

Although this process can be quite frustrating as you're trying to program a certain cut and the software won't accept it in the exact same way you wanted it to be that maybe could easily be achievable if you were programing the CNC directly in the GCODE, however this usually happens in my experience when something that I'm trying to do isn't quite right or up to standards that are used commonly so even the downside is only due to my own lack of expertise in the subject matter for the time being.

Overall the aid of computer in the manufacturing is a great addition making many processes that would take long hours to be done to be automated and be done either instantly or with a greatly reduced time taken, and in the future I believe we will see the AI market getting involved in this area and we will have Ais being completely autonomous to making the manufacturing of simpler pieces by itself.

12 References

CARDOZO, C. A. G. Manufatura Digital Aplicada no Contexto de Engenharia Reversa . Estudo de Caso : Protótipo Virtual do Avião Blériot. [s.l.] Universidade Estadual de Campinas, 2012.

COSTA, D. D., da.. Análise da Competitividade do Setor de Usinagem no Estado do Paraná. Máquinas e Metais n. 426, p. 132-139, 2001.

COSTA, G. G. D. S. Contribuição para os usuários de sistemas CAD/CAM/CNC em opeção de fresasmento de topo em aço para moldes e matrizes. [s.l.] Universidade Federal de Uberlandia, 2011.

DAVIDSON, A. Handbook of Precision Engineering - vol. 5. McGraw Hill, 1972.

FERRO, J. R. (Coord.). Relatório anual do Programa Paraná Automotivo Publicado pelo SEBRAE e SINDIMETAL do Paraná, 2000

IKAWA, N.; et ali. Ultraprecision Metal Cutting - The Past, the Present and the Future. In: CIRP. Anais. V. 40, feb. 1991.

ISO 230 - 1. Test Code for Machine Tools, Part – 1, Geometric Accuracy of Machines Operating Under no Load or Finishing Condition. 1996-07-01(E).

ISO 230 - 2. Acceptance Code for Machine Tools, Part – 2, Determination of Accuracy and Repeatability of Positioning of Numerically Controlled Machine Tools. 1988-11-01(E).

ISO 230 - 4. Test Code for Machine Tools, Part – 4, Circular Tests for Numerically Controlled Machine Tools. 1988-11-01(E).

MOORE, W. R. Fundations of Accuracy. TMSTC. 1989.

PEREIRA, Athos G. Desenvolvimento e avaliação de um editor para programação CN em centros de usinagem Programa de Pós-Graduação em Engenharia Mecânica, Universidade Federal do Paraná, 104 p., dissertação (mestrado), 2003.

S. KALPAKJIAN. Manufacturing Engineering & Technology, 4th Edition, Addison Wesley, 2000. ISBN: 201361310

SPUR, G.; STÖFERLE, Th. Handbuch de Fertigungstechnik - vol. 3. Viena: Carl Hanser Verlag, 1979.

THYER, G. E. Computer Numerical Control of Machine Tools. Nova Iorque: Industrial Press, 2ª edição, 1991.

W.D. CALLISTER JR. Materials Science and Engineering - An Introduction, 5th Edition, John Wiley & Sons, 2000.

WECK, M. Werkzeugmaschinen Fertigungssysteme, vol. 3. VDI-Verlag, 1992.

WECK, M. Werkzeugmaschinen Fertigungssysteme, vol. 4. VDI-Verlag, 1992.

YUEN, C. F. et al. Development of a generic computer-aided process planning support system. Journal of Materials Processing Technology v. 139, p. 394-404, 2003.

DECLARATION

on authenticity and public assess of final essay/thesis/mater's thesis/portfolio[1]

Student's name: Mateus do Lago Chagas

Student's Neptun ID: ACK6SR

Title of the document: Computer aided manufacturing for 3D models

Year of publication: 2024

Department: ____________________

I declare that the submitted final essay/thesis/master's thesis/portfolio[2] is my own, original individual creation. Any parts taken from an another author's work are clearly marked, and listed in the table of contents.

If the statements above are not true, I acknowledge that the Final examination board excludes me from participation in the final exam, and I am only allowed to take final exam if I submit another final essay/thesis/master's thesis/portfolio.

Viewing and printing my submitted work in a PDF format is permitted. However, the modification of my submitted work shall not be permitted.

I acknowledge that the rules on Intellectual Property Management of Hungarian University of Agriculture and Life Sciences shall apply to my work as an intellectulal property.

I acknowledge that the electric version of my work is uploaded to the repository sytem of the Hungarian University of Agriculture and Life Sciences.

Place and date: Godollo year 2024 month 04 day 25

[illegible signature]

Student's signature

STATEMENT ON CONSULTATION PRACTICES

As a supervisor of Mateus Chagas (Student's name) ACK6SR(Student's NEPTUN ID), I here declare that the final essay/thesis/master's thesis/portfolio[1] has been reviewed by me, the student was informed about the requirements of literary sources management and its legal and ethical rules.

I recommend/don't recommend[2] the final essay/thesis/master's thesis/portfolio to be defended in a final exam.

The document contains state secrets or professional secrets: yes no*[3]

Place and date: Godello year 2024 month 04 day 25

Internal supervisor