MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
NATIONAL TECHNICAL UNIVERSITY OF UKRAINE
“IGOR SIKORSKY KYIV POLYTECHNIC INSTITUTE”
EDUCATIONAL AND RESEARCH
INSTITUTE OF MECHANICAL ENGINEERING
Department of Manufacturing Engineering

Readiness for qualification
Acting head of the department
Olexander OKHRIMENKO

«___»_____________2023

Diploma project
Level of higher education – first (bachelor)
Program subject area – 131 “Applied Mechanics”
Educational Program “Manufacturing Engineering”

topic: Technological preparation of a manufacturing process to produce a part “Bushing”

Signature:

Student:

Greg Anthony Soriano

Supervisor:

Assoc. Prof. Danylova Liudmyla.

Reviewer:

Assoc. Prof. Krasnovyd Dmytro.

I confirmed that in this diploma project there are no borrowings from the works of other authors without proper references.

Student

Kyiv 2023

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APPROVED

Acting head of the department
Olexander OKHRIMENKO ______________

«___»_____________2023

ASSIGNMENT
for the student's diploma project
GREG ANTHONY SORIANO

1.Topic of the project: Technological preparation of a manufacturing process to produce a part “bushing”
Project supervisor: Phd, associate professor Danylova Liudmyla
approved by the University Order «23_»__05_ 2023 № 49/23-ci

2.Deadline for submission of the project « 20» June 2023
3. Initial data for the project Part drawing and material, Production quantity per annum, working conditions of the part in the assembly unit. Determining the relationship between burr height and cutting force for a given material, tool and cutting parameters for manufacturing process control

4. Content of the text part (explanatory note): Design of the operational manufacturing process plan, calculation of the allowance, fixture design, economic calculation, and safety and Study of the issue of plunge milling.

5.List of the graphic material (indicating mandatory drawings, posters, presentations,etc.) 3-D drawing of the part and drawing of the workpiece. Schematic representation of a technological operation. Assembly drawing of the machine tool. Study of the issue of plunge milling

6.Date of the task issue«20 » MAY 2023

No	The stage of the diploma project execution	Deadline	Notes
1	Analysis of design features of the part	20.04.23	completed
2	Determining the type of production	20.04.23	completed
3	Calculation of the allowance	30.04.23	completed
4	Design of the typical surfaces processing routes	10.04.23	completed
5	Design of the operational manufacturing process plan	15.05.23	completed
6	Setting cutting conditions	20.05.23	completed
7	Development of the fixture design	30.05.23	completed
8.	Calculation of the cost processing	30.05.23	completed
9	General questions : Plunge Milling	10.06.23	completed

Signature:

Student Greg Anthony Soriano

Supervisor Danylova Liudmyla

Acknowledgement

I dedicate this work to my family, who have consistently encouraged and supported us.
I would also want to thank my lecturers at "KPI" who helped me develop the abilities I needed to do this job effectively.
My profound gratitude goes out to my supervisor, professor Danylova Liudmyla, for her unwavering support and direction during the entire procedure. Their advice and support have been crucial in determining how successfully my work has turned out.
I genuinely appreciate my coworkers and friends who offered insightful criticism and supportive words all along the way. Their continuous support had a crucial role in determining how my work turned out.

ABSTRACT

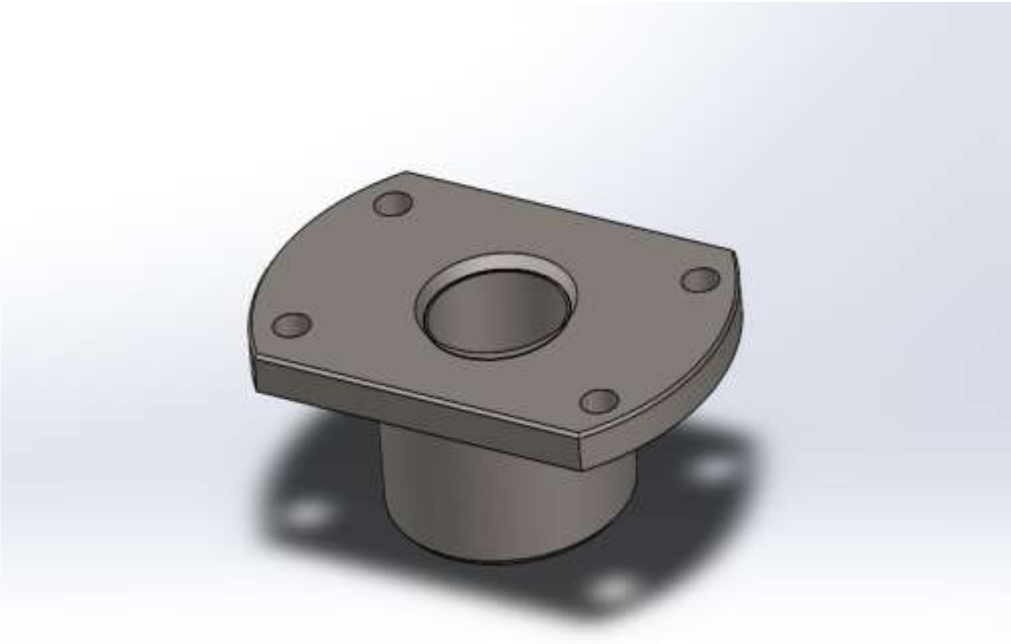
This work primarily focuses on the technological preparation required for the manufacturing process involved in producing a part bearing housing. The thesis consists of 63 A4-sized sheets and drawings and upon a total of 17 literature sources, including reference books and scientific papers.

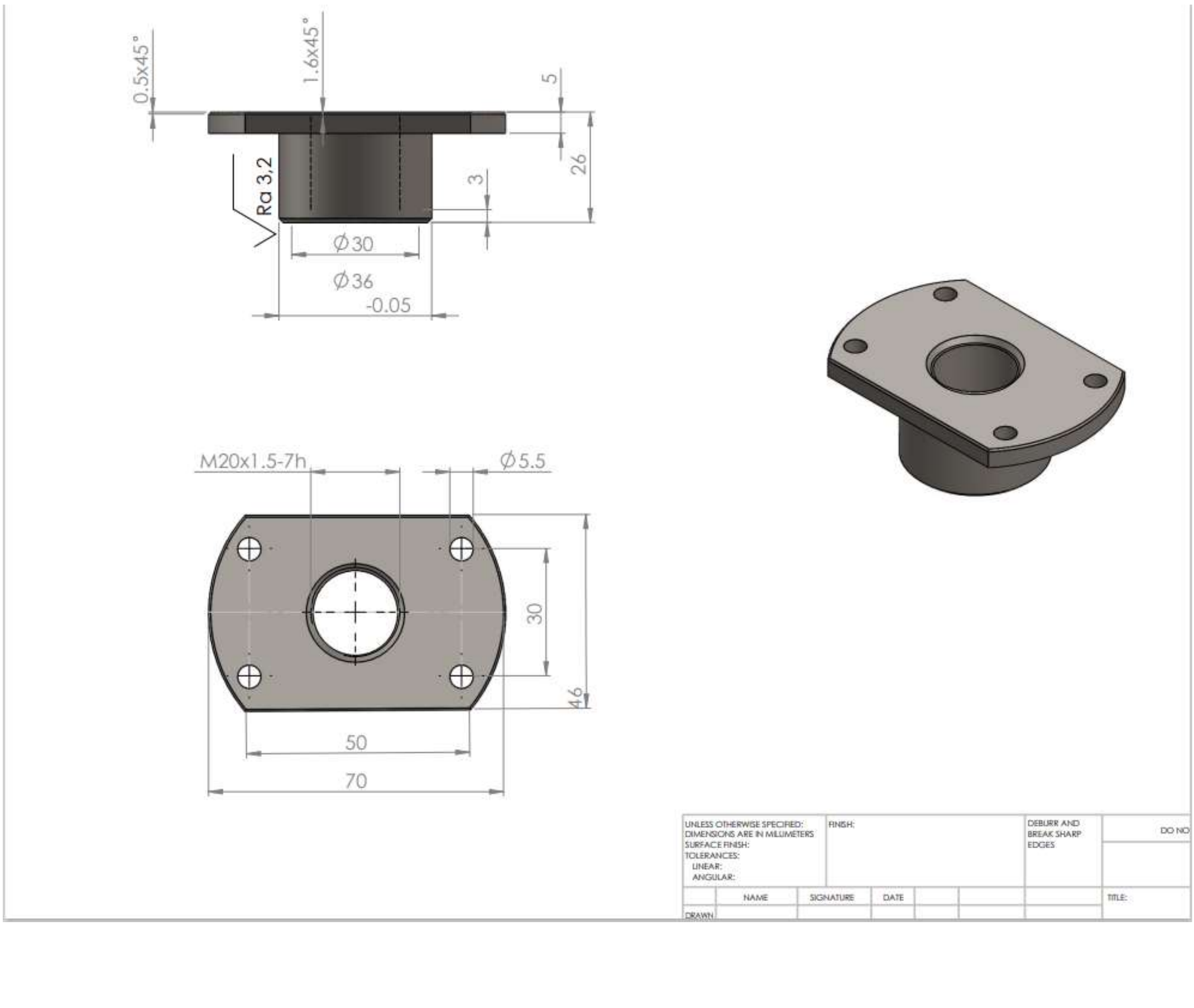
Chapter 4 of this thesis extensively discusses the topic of plunge milling. The mechanism behind plunge milling is thoroughly examined.

The overall objective of this work is to provide a comprehensive understanding of the technological aspects involved in preparing the manufacturing process for producing a part “Bushing” It encompasses critical elements such as process planning, fixture design, economic analysis, safety measures, and addressing the challenge of burr formation.

Annotations

Contents





0.5x45°
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26
Ra 3,2
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M20x1.5-7h
Ø5.5
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UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
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1.1 Analysis of the purpose and operating conditions of the part in the assembly unit

Analysis of design features of the part and its classification

Considering the configuration of the part 'Bushing' we defined that it belongs to the class "Body"

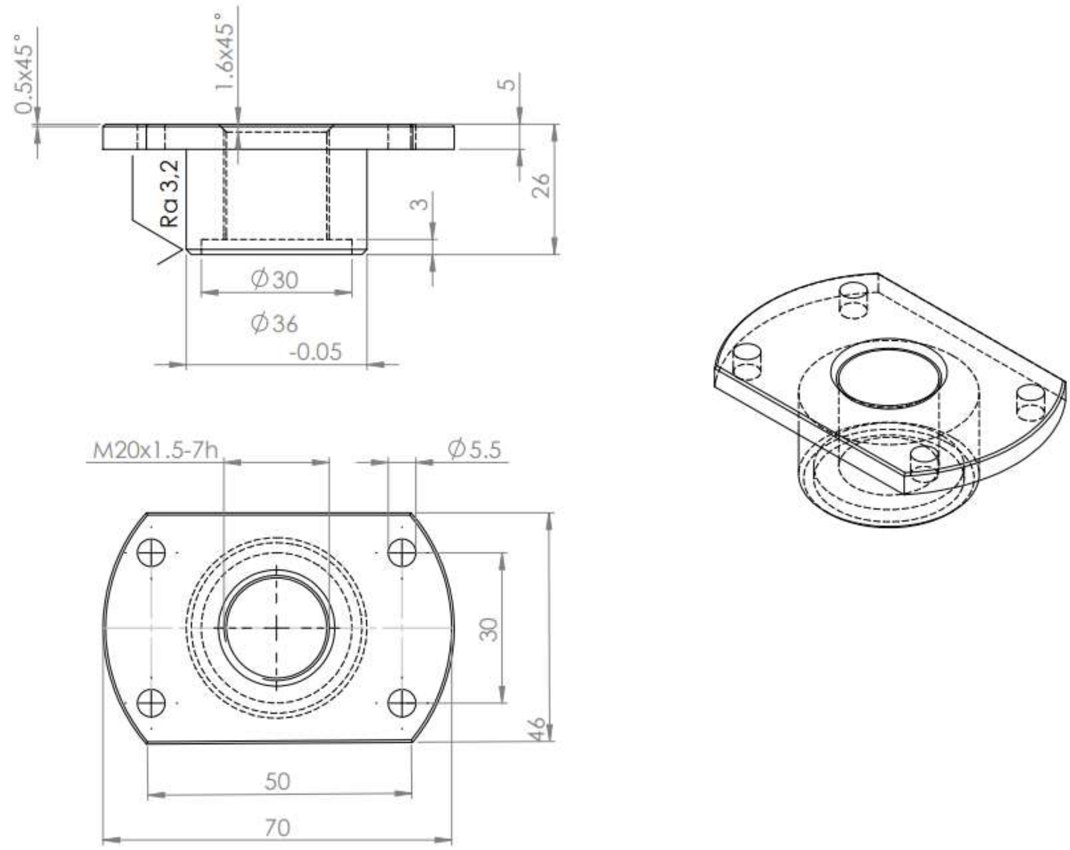


Fig.1.1 – Drawing of a part 'Bushing'

In general, the requirements for the accuracy and quality of the surfaces of the part are not very high, but there are a few surfaces that are subject to increased requirements.

During manufacturing a special attention must be paid to the machining of hole M20x1.5-H7, ensuring their perpendicularity to the ends, and alignment.

Analysis of the part’s working conditions in the assembly unit
The part of the "pump housing" belongs to the class of body parts. Overall dimensions of the part 70*46*26mm, part Mass = 206.03 grams
The "bushing" is designed to protects the pump shaft against mechanical damage caused by shaft seals and bearing and against chemical damage caused by aggressive fluids. A mechanical bushing can be important in various applications where two parts need to be joined or connected. Here are some of the common reasons why a mechanical bushing is important:

Strength and durability: A mechanical bushing can add strength and durability to a joint or connection, especially when the parts being joined have different sizes, shapes, or materials.
Alignment: A mechanical bushing can help align the two parts being joined or connected, which can improve the performance and efficiency of the final product.
Protection: A mechanical bushing can protect the joint or connection from environmental factors such as dust, dirt, moisture, or corrosion.
Ease of assembly: A mechanical bushing can make the assembly process easier and faster, especially in applications where the joint or connection is difficult to reach or assemble.

Overall, a mechanical bushing can play a crucial role in ensuring that a joint or connection is strong, durable, aligned, protected, aesthetically pleasing, and easy to assemble. The fundamental components of a machine are the body parts, which must guarantee a secure placement of the connecting parts under operating conditions subject to four environmental factors and variations in temperature.

After analyzing the materials suitable for producing this part, it can be inferred that gray cast iron would be the most suitable option. Gray cast iron is highly machinable, resistant to wear and vibrations, making it ideal for the purpose.

Analysis of the selected material

Material of the part is СЧ.45 ГОСТ 1050-88 Carbon Steel (AISI 1045) and it has the following: chemical composition and mechanical characteristics.
Chemical composition (in %)

Chemical Composition

The chemical composition of AISI 1045 carbon steel is outlined in the following table.

Element	Content (%)
Carbon, C	0.43-0.50
Manganese, Mn	0.60-0.90
Sulfur, S	0.05 (max)
Phosphorous, P	0.04 (max)
Iron, Fe	Balance

Linear shrinkage: 1.1%
Tensile strength $\sigma_в$= 585 MPa; hardness **HB 10** $^{-1}$ **=** 163 **MPa**; density ρ= 7.87 g/cm^3

Carbon steel is a popular material choice for mechanical bushings due to several reasons. Carbon steel is known for its strength and durability, making it ideal for mechanical bushings that need to withstand high stresses and loads. It is relatively inexpensive compared to other metals, making it a cost-effective option for mechanical bushings. Carbon steel is also easy to machine and fabricate, which makes it easy to produce complex mechanical bushing designs and can be easily welded, which simplifies the manufacturing process and allows for the creation of strong, continuous joints. Carbon steel can also be treated to enhance its corrosion resistance, making it suitable for use in harsh environments where corrosion is a concern and is widely available and can be sourced from many different suppliers, making it easy to obtain for manufacturing mechanical bushings.

Overall, carbon steel is a versatile and practical material choice for mechanical bushings, offering a balance of strength, durability, cost-effectiveness, and ease of manufacturing.

Taking into account the information given above, it can be concluded that the part works with periodic loading and is not under the influence of an aggressiveenvironment and the material proposed by the designer ensures the operability of the part in such conditions. The drawing of the part has a sufficient number of types, sections, which provide a complete understanding of the design features of the part.

Determining the type of production and analysis of its impact on themanufacturing process plan
The production type is a classification category of production that determines the characteristics of the latitude of the nomenclature, regularity, stability and volume of the part.
There are the following types of production:
1. Single.
2. Serial. Serial.
2.1. Low-series.
2.2. Medium series.
2.3. Large-scale.
3. Massive.

The choice of the type of production is carried out by:
- Annual program of release.
- A lot of the product.

The type of production depends on the coefficient of consolidation of operations K_{CO}, which is calculated as the ratio of the number of all different manufacturing operations performed or to be performed by the production unit during the month, to the number of workstations that perform different operations.

$$K_{c.o.} = \frac{\sum_{i=1}^{n} OP_i}{\sum_{j=1}^{k} WS_j}$$

For educational purposes we will use analog methods of designation ofproduction type based on weight of a part and production volume.
Part weight m= 206g = 0.206kg (Fig. 1.2)
Production volume N_p =10000.

Let's determine the type of production according to the following table (table. 1.1)Table 1.1 – Estimation of the production type

Weight of a part, kg	Type of production				
	Single	Small batch	**Medium batch**	High volumebatch	Mass
<1	**< 10**	**10 .. 2000**	**2000 .. 75000**	**75000 .. 200000**	**> 200000**
>1 .. 2.5	< 10	10 .. 1000	1000 .. 50000	50000 .. 100000	>100000
> 2.5 .. 5.0	< 10	10 .. 500	500 .. 35000	35000 .. 75000	>75000
> 5.0 .. 10.0	< 10	10 .. 300	300 .. 25000	25000 .. 50000	>50000
> 10.0	< 10	10 .. 200	200 .. 10000	10000 .. 25000	>25000

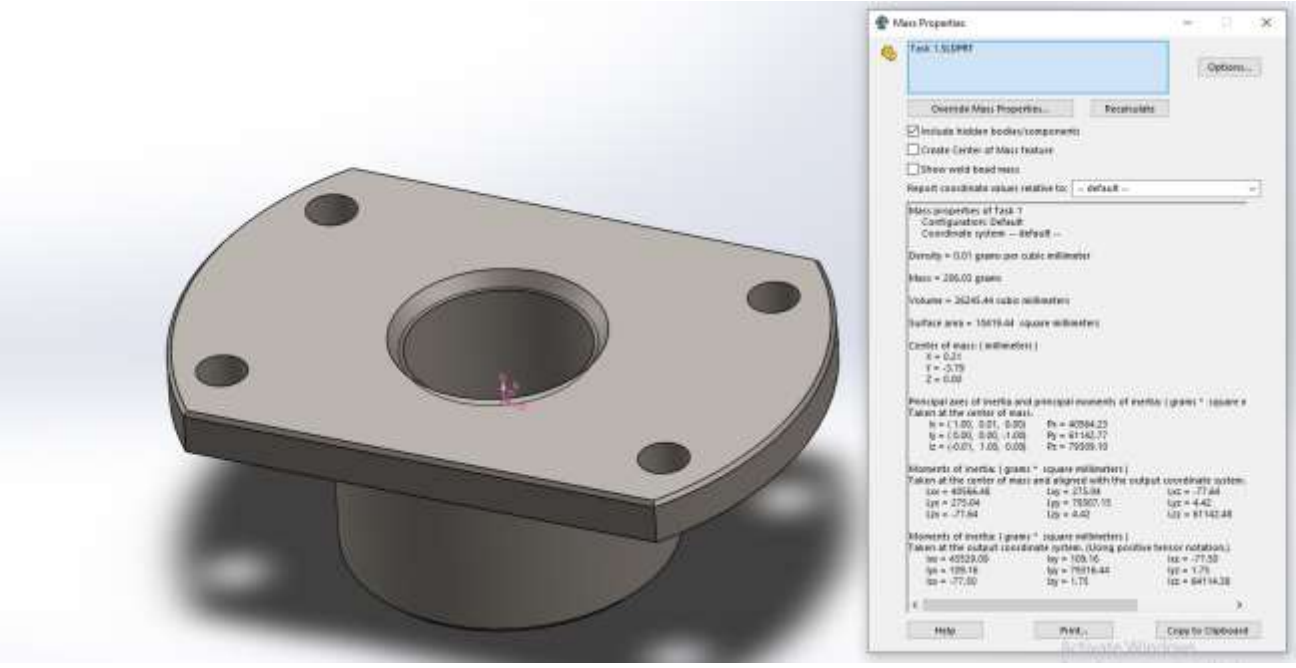
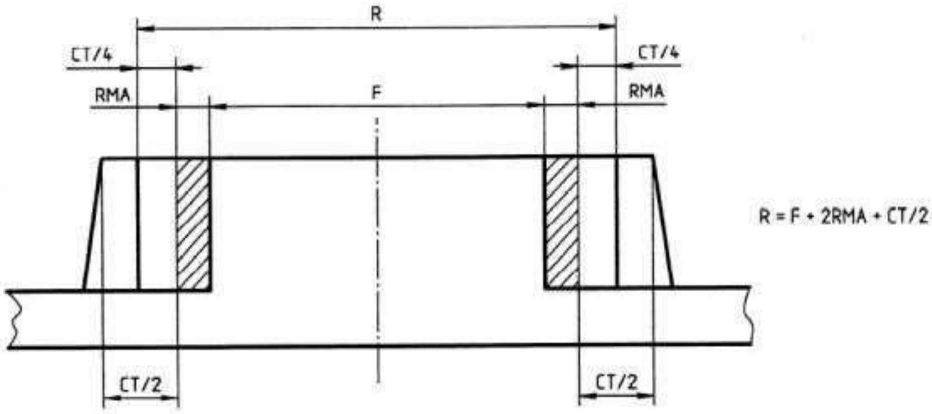


Fig. 1.2 – Characteristics of the part ‘Bushing’ and its 3-D model

Conclusion: the production type –medium batch, therefore, we will performall further calculations and make technological decisions for the medium- type of production.

1.3 Selection of the base process and design of the blank

Considering the material and geometry of a part, the sand casting process could be applied as the base process. To estimate the required machining allowance (RMA) grade we will use Table B.1. [2]. For the sand casting process and Carbon Steel the recommended RMA grade is F. Required machining allowance according to the F grade and the largest dimension of a part 70mm (see drawing) is 1 mm according to the table 2 [2].

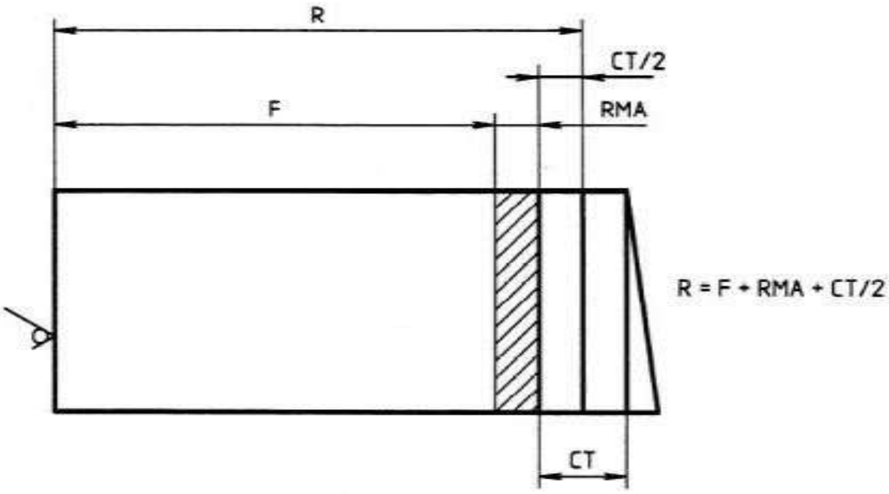


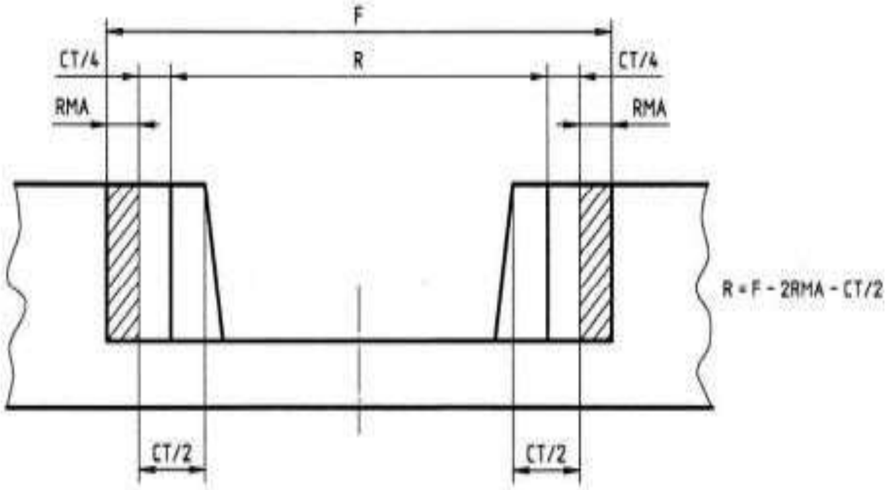
R = Raw casting basic dimension

F = Dimension after final machining

RMA = Required machining allowance

CT = Casting tolerance





Designing a casting involves considering a variety of factors to ensure that the final product is of high quality and meets the required specifications. Selecting the right material is critical to ensuring that the casting has the required properties such as strength, ductility, and corrosion resistance. The material selection can be influenced by the intended use of the part, its environment, and the manufacturing process. The choice of casting process can depend on factors such as the complexity of the part, the required accuracy, and the production volume. The geometry of the part can influence the casting process and the quality of the final product. Machining allowances are added to the part design to allow for post-casting machining operations. These allowances should be carefully designed to minimize material waste and machining time.

To estimate casting tolerance (CT) grade we will use table A1 (for long series) [2]. For the sand casting process and the Carbon Steel the CT 11 could be applied. The results of estimation of casting tolerances are presented in Table 1.3

Table.1.3 Calculations of allowances

Dimension ofa part	RMA	Min limit of size for external features (or max for internal features)	Casting tolerance, mm	Raw castingbasic dimension
70	1	70+1=71	4.4	74.2±2.2
46	1	46+1=47	4	49.2±2.0

26	1	26+1=26	3.6	29.8±1.8
30	1	30-1=29	3.6	26.2±1.8
5,5	1	5.5-1=4.5	2.8	2.1±1.4
20	1	20-1=19	3.2	16.4±1.8
5	1	5+1=6	2.8	8.4±1.4

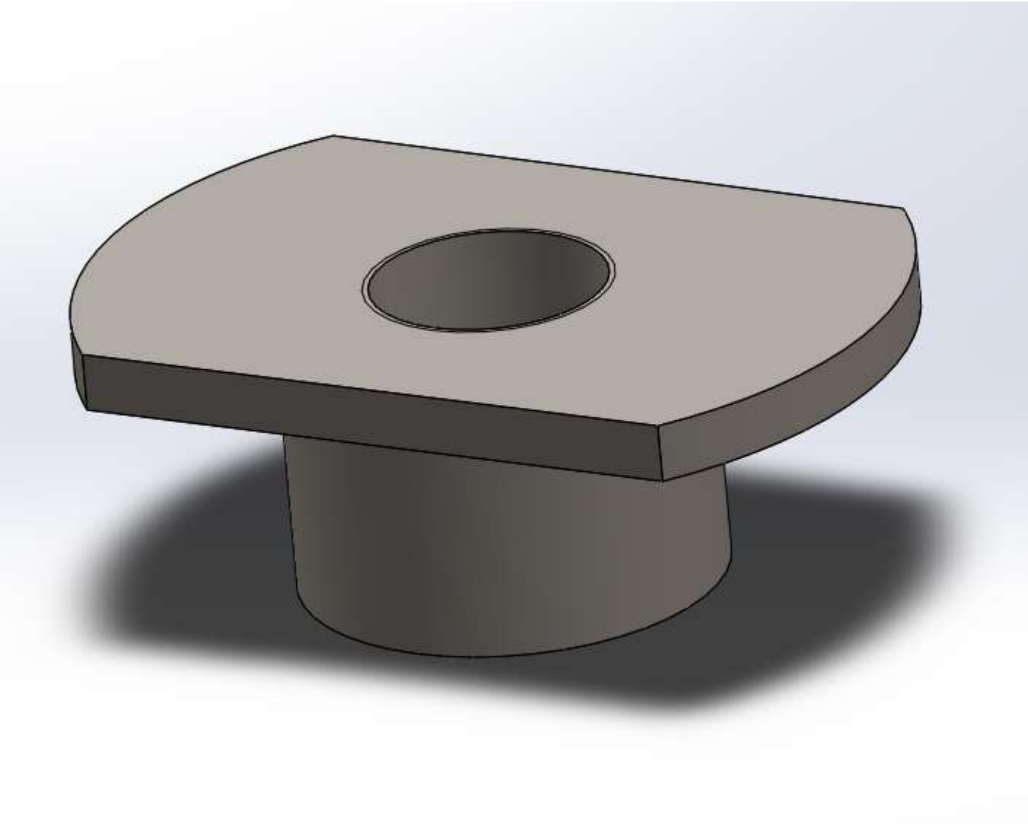


Fig Drawing of the casting

Design for manufacturing considerations

2.1.1 Design rules for sand castings:

1. Geoffrey Boothroyd. Product design for manufacture and assembly. Computer- Aided Design., 1994; 26(7): 311-313, 537-539

During the development of the casting design, we took into account the following suggestions and guidelines. [11]:

When developing the casting design, we took into consideration the impact of the metal structure on the shape of the casting section. To ensure optimal casting quality, we avoided incorporating sharp angles and multiple-section joints.

Another aspect we considered was designing sections with uniform thickness. We aimed for consistent section thickness throughout the casting to promote uniform cooling and solidification.

Additionally, we paid attention to proportioning the inner wall thickness. Recognizing that inner sections cool more slowly than sections exposed to the mold face, we ensured that the inner wall thicknesses were appropriately adjusted.

Furthermore, the design accounted for metal shrinkage. We acknowledged that nearly all alloys shrink as they solidify, and we factored in this shrinkage phenomenon during the design process.=

These recommendations were taken into account to optimize the casting design for structural integrity and quality.

2.1.2 Design guidelines for machined components:

The following rules were considered for the design of the "Bushing" part **:**

The design of the component aims to eliminate the need for machining on the unexposed surfaces of the workpiece when it is securely held in the fixture. This helps streamline the manufacturing process and reduces machining requirements.

Interference checks were conducted to ensure that when features are machined, there is no interference between the cutting tool, tool bushing, workpiece, and fixture. This prevents any collisions or obstructions during the machining process.

The part design avoids extreme lengths or thin sections, which can pose challenges in terms of manufacturing and structural integrity. By maintaining reasonable proportions, the design promotes easier manufacturing and assembly processes.

One of the considerations in the design process is to ensure that assembly of the component is feasible. This involves evaluating the design for proper fits, clearances, and accessibility for assembly operations.

The operating surfaces of the component have been specified with tolerances and surface roughness requirements that are wide enough to accommodate the required performance. This allows for efficient manufacturing while still achieving the desired functionality.

1.4 Locating the workpiece during the manufacturing process

The choice of the method of obtaining the workpiece is influenced by: the material of the part, its purpose and technical requirements for manufacture, volume and serial production, the shape of the surfaces and the size of the part.
The optimal method of manufacturing the workpiece will be a method that ensures the manufacturability of the part made of it, at a minimum cost. The optimal method is determined on the basis of detailed comprehensive analysis of the above factors.

The "Bushing " part is made of Carbon steel. Carbon steel is not inherently fragile, but its toughness and hardness depend on its specific composition and manufacturing process. Carbon steel is an alloy of iron and carbon, and the amount of carbon present in the steel determines its hardness and strength.
Carbon steel with higher carbon content is harder and more brittle, making it more susceptible to fractures and cracks under stress. However, carbon steel can be heat-treated to increase its strength and toughness.

The most efficient method of obtaining a workpiece made up of carbon steel depends on several factors such as the required dimensions, shape, accuracy, and the quantity of workpieces needed. The method of obtaining the workpiece in this case will be casting. In mechanical engineering there are several types of castings:

Mechanical casting: is the process of pouring molten metal into a mold to create a specific shape. There are several types of mechanical casting techniques, including:

Sand Casting: This is the most common type of mechanical casting. In this process, a pattern is made of the desired shape, and it is placed in a sand mold. The mold is then filled with molten metal, which solidifies and forms the desired shape.
Investment Casting: Also known as lost-wax casting, this technique involves creating a wax

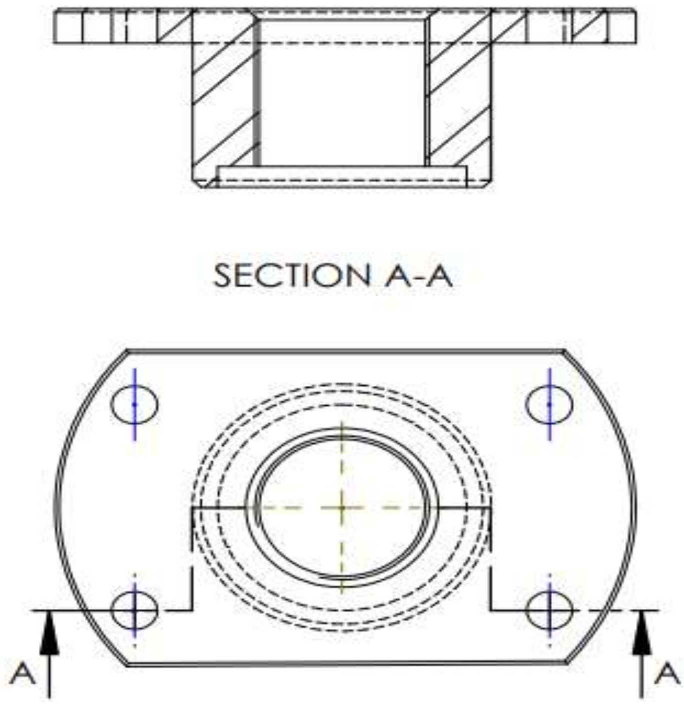
pattern of the desired shape and coating it with a ceramic shell. The wax is then melted out of the shell, leaving a cavity, which is filled with molten metal.

Die Casting: In this process, molten metal is forced into a metal mold, also known as a die, under high pressure. This technique is used to create complex shapes with a high degree of accuracy.

Continuous Casting: This process involves pouring molten metal into a continuous mold, which produces a continuous sheet or bar of metal. This technique is often used to produce large quantities of metal products.

Centrifugal Casting: In this technique, molten metal is poured into a spinning mold, which creates a centrifugal force that distributes the metal evenly around the mold. This process is used to create hollow shapes with a high degree of accuracy.

The configuration of the outer contour and inner surfaces of the housing does not cause significant difficulties. However, the casting must take place using a rod that will form the inner cylindrical hole of the housing. Since the requirements for quality and accuracy of surfaces are relatively low, the annual output is 10,000 parts per year, it is advisable to use casting in sand-clay molds with machine molding on a metal model. The method of casting in sand-clay forms is widely used in mechanical engineering and is quite well developed. Size, weight and accuracy tolerances achieved by this type of casting are determined by the standard.



1.4.1 Locating scheme for the first manufacturing operation

The general algorithm of substantiation of manufacturing datum (MD) includes two stages:

- Rationale for the choice of general manufacturing datum (GMD)
- Rationale for the choice of manufacturing datum for the first manufacturing operations

General manufacturing datum (GMD) is a set of datum surfaces that can be used to perform all operations of the manufacturing process or most of it.
The initial data to justify the choice of GMD are the working drawing of the part. To solve the problems of the first stage, it is necessary to classify the surfaces of the part for their intended purpose.

The design of any part can be represented as a set of four types of surfaces:
Main functional (design) datum (M): The main functional datum is a surface datum that is used to establish the location of features such as holes, slots, and other mating surfaces that are critical for the product's operation

Auxiliary functional (design) datum (A): Auxiliary functional datums are often used to establish the location of features that are critical for the proper assembly or operation of the product, but are not as critical as features defined by the main functional datum. They can also be used to establish tolerances for features that are not as critical as those defined by the main functional datum.

Fastening surfaces (F): Fastening surfaces are surfaces on a component or product that are used to secure or attach it to another component or surface. Fastening surfaces can take many different forms depending on the application, but they generally provide a means for holding components in place and transmitting loads between them.

Free surfaces (B): Free surfaces (B) are surfaces on a component or product that are not used for fastening or attachment purposes. These surfaces are typically not in contact with any other components and are not critical for the proper function of the product.

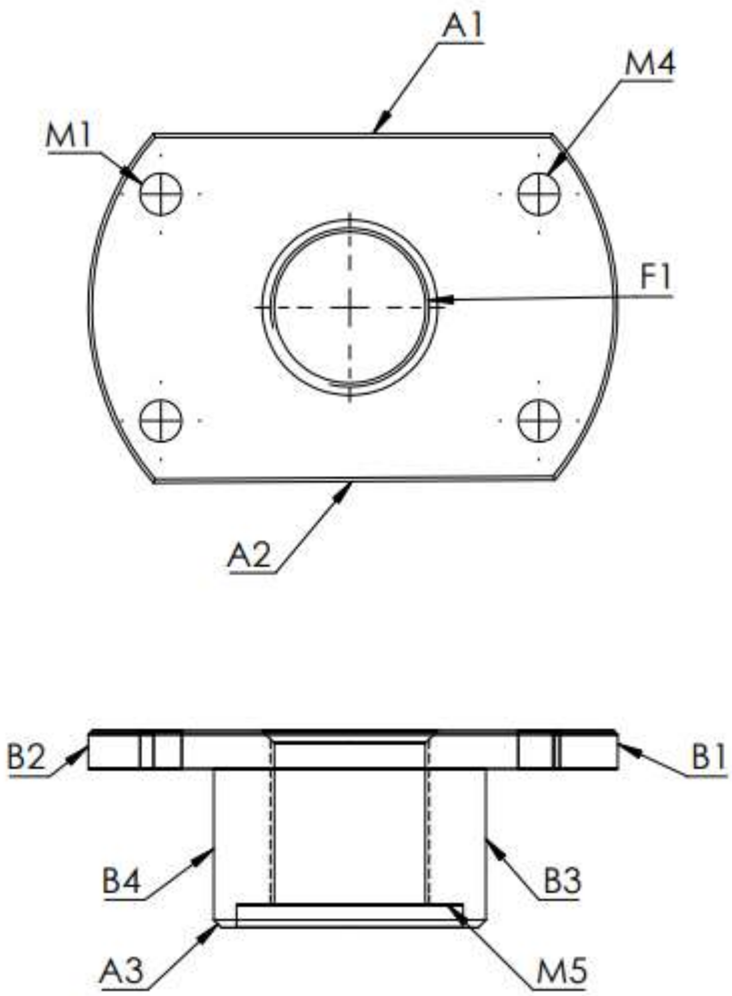


Fig 1.14 – Locating scheme for the first manufacturing operation

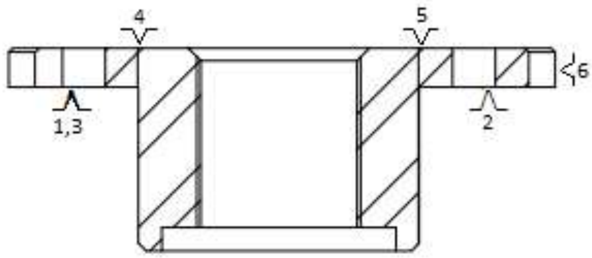
The formula for the locating scheme presented in Fig 1.13 is as follows:

LSMD=>S(3) + G(2) + O(1) (2.6)

Conclusion: The forth locating scheme (Fig. 1.14) is easy to implement, and provides the correct spatial position of the untreated surfaces relative to the processed surfaces. The given scheme allows processing several additional surfaces besides the general manufacturing datum during the first manufacturing operation. Therefore, we will use the forth variant of locating scheme for processing general manufacturing datum.

Advantages:
Easy to implement.
Ensures the perpendicularity of untreated surface relative to the datum surface.

Disadvantages:
Blocks processing the workpiece from three sides,
Forms an uneven allowance for the main holes of the housing for the next stages of processing;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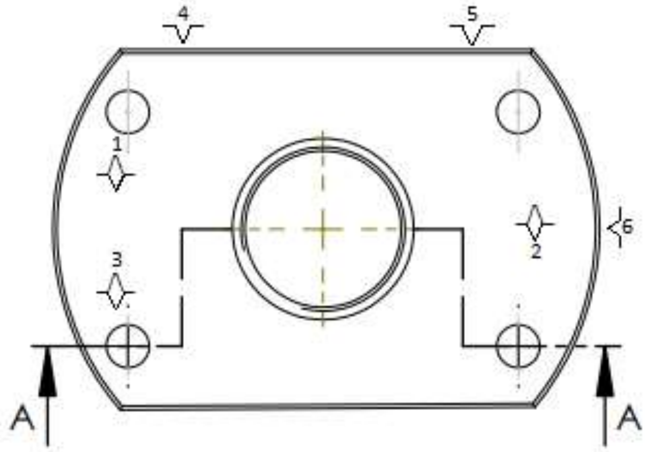
4
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3
A
A

1.5 Design of the typical surfaces processing routes

The design of a part can be divided into a set of typical geometric shapes, united by a common service purpose of the part. Typical structural elements are: cylindrical or conical external and internal surfaces, a set of planes, shaped surfaces - screw, involute and others. Depending on the type of surface, different cutting tools can be used to achieve a given surface accuracy and, as a result, there are different sequences of surface treatment.

The development of machining routes for individual surfaces is the first of seven tasks solved in the design of process plan. The manufacturing process thus created, rolled up in time and space, solves the problems of dimensional accuracy, shape and quality of individual surfaces, but does not take into account the accuracy of the relative position at all. This task will be solved later by assigning the locating schemes and dividing the processing stages into modules - rough, finish and final.
When developing a manufacturing process, it is necessary to select one of several possible machining options, which will provide the best economic solution.

Therefore, in order to save time, it is necessary to use standard, proven in practice, processes for manufacturing parts and machining their main surfaces.

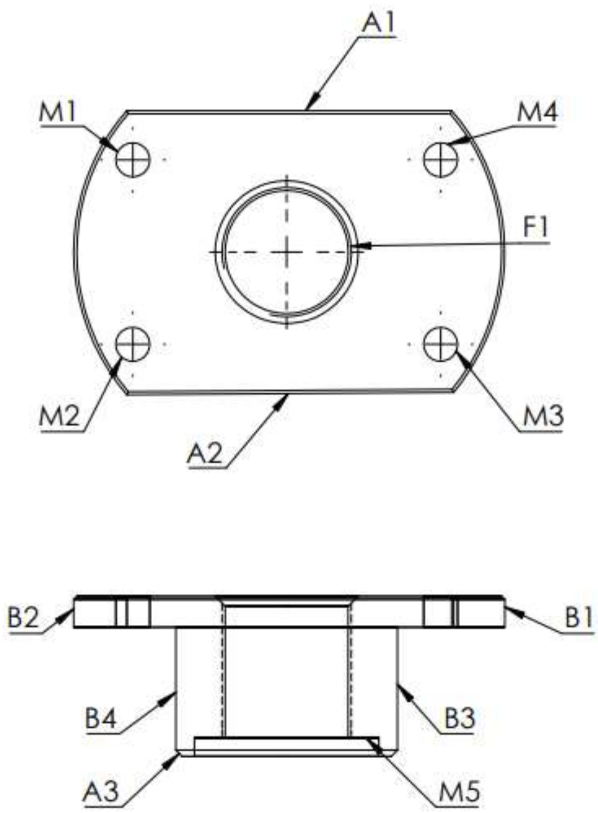


Table 1.3 Processing routes for surfaces of a part “Bushing”

Surfaces	IT	Ra	Machining sequence	IT	Ra
	According to the drawing			After machining	
1	2	3	4	5	6
M1,M2,M3,M4	14	-	Rough turning Semi- finishing finishing	14	-
A1	14	-	Rough milling Finish milling	14	-
B3,B4	14	-	Rough milling Finish milling	14	-
F1	7H	-	Centering Drilling Countersinking Threading	7H	-
B1, B2	14			14	-
A3	14	3,2	Rough milling	14	6,3 3,2
A2	14	-	Rough milling	14	-
M5	14	-	Centering Drilling Boring	14	-

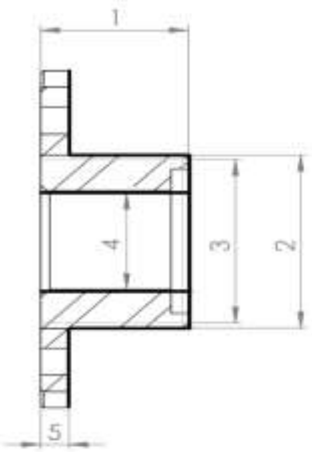
1.6 Design of the operational manufacturing process plan

The technological process of manufacturing parts can be divided into 4 stages: roughing, semi-finishing, finishing and finishing. Depending on the requirements for the accuracy and quality of individual surfaces of the part, the appropriate treatment is assigned. The purpose of designing the content of technological operations is to determine the sequence of processing a certain surface of the part.
The content of technological operations for the part "Pump housing" is given below.

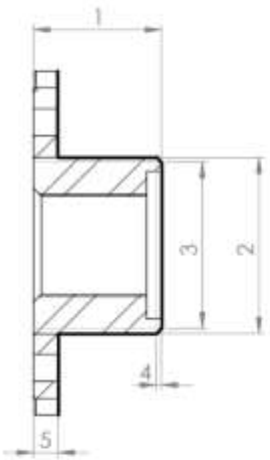
1.6.1 Design of the operational manufacturing process plan

The technological process of manufacturing parts can be divided into 4 stages: roughing, semi-finishing, finishing and finishing. Depending on the requirements for the accuracy and quality of individual surfaces of the part, the appropriate treatment is assigned. The purpose of designing the content of technological operations is to determine the sequence of processing a certain surface of the part.
The content of technological operations for the part "Bushing" is given below.

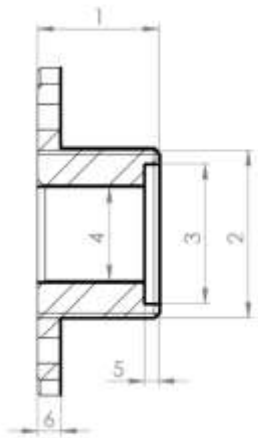
005. TAJMAC-ZPS H500**.**



A. Install, secure, remove.
005.01. Sharpen the end beforehand, keeping the size 1 and 5
005.02. Sharpen the cylindrical surface while simultaneously trimming the adjacent end, keeping the dimensions 2 and 3.
005.03. Turning Facing in succession, pre-maintaining the size 4.
005.04. Turning external – finishing finally, keeping the size 4

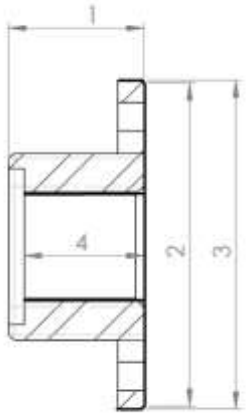


005.05. Sharpen the end beforehand, keeping the size 1.
005.06. grinding external – finishing, pre-maintaining size 2 and 3.
005.07. Honing hole – finishing, keeping size 5



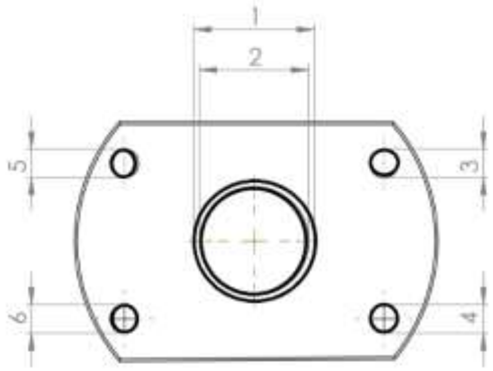
005.08 Turning in succession, pre-maintaining the sizes 3
005.09. Grind the surface completely, keeping the size 4,5 and 6

010. TAJMAC-ZPS H500**.**

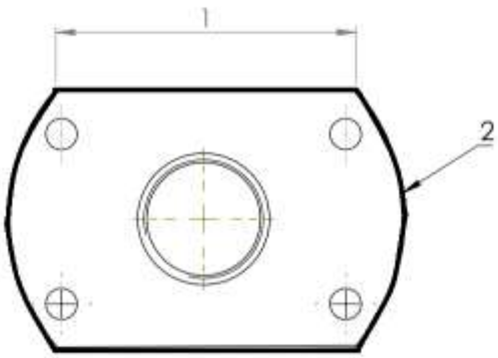


A. Install, secure, remove.
010.01. Sharpen the surface with a contour cutter sequentially, finally, keeping the sizes 1 - 4
010.02. Grind the inner cylindrical surface completely, keeping the sizes 4

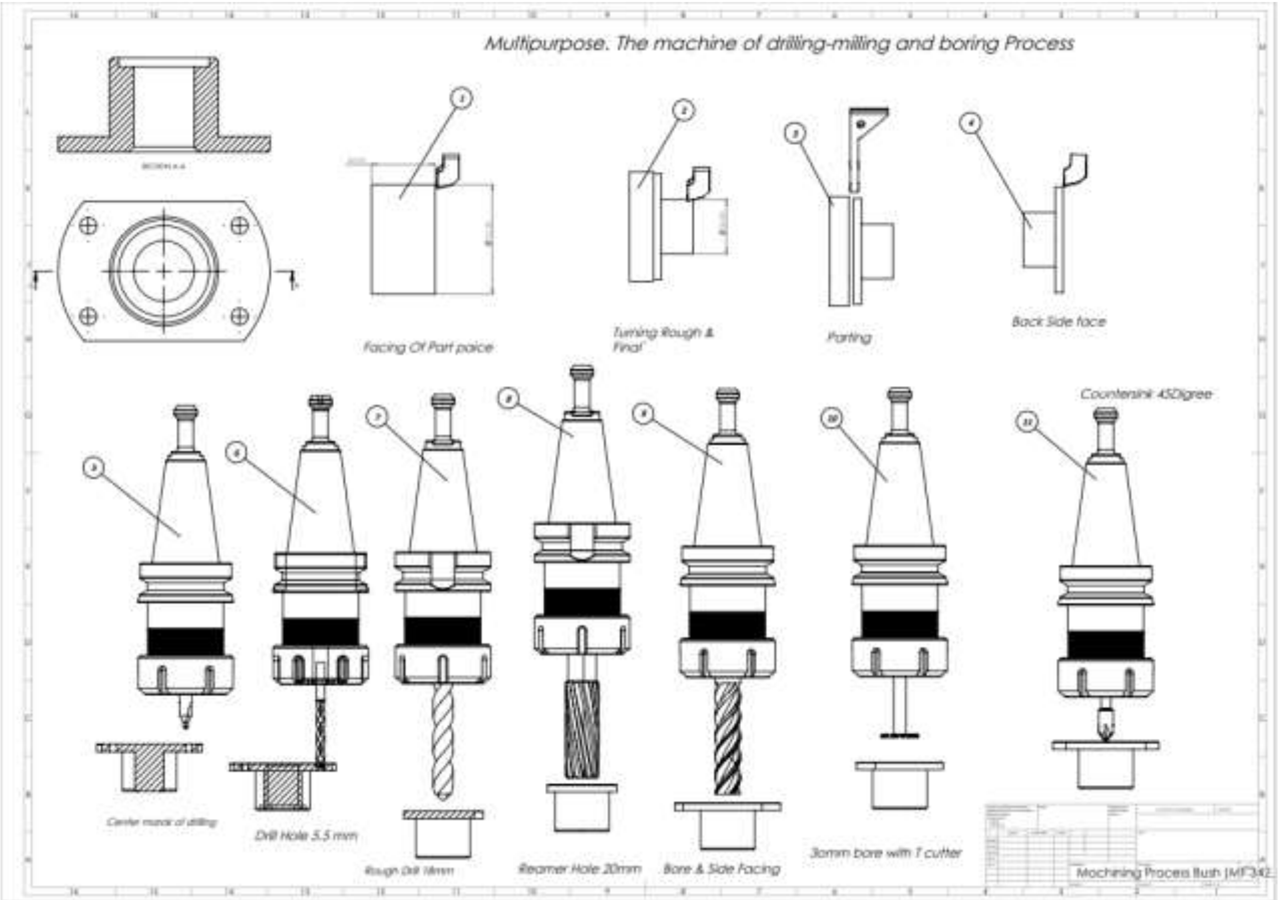
015. Multipurpose. The machine of drilling-milling and boring mod.



A. Install, secure, remove.
015.01. rough drill in succession, pre-maintaining the sizes 3,4,5 and 6
015.02. finish drill finally, keeping the sizes 3,4,5 and 6
015.03. Boring hole, keeping the sizes 2
015.04. Counter sinking, keeping the size 1



015.05. Sharpen tool for chamfering
015.06. chamfer the flat surfaces, keeping the size 1
015.07. chamfer the curved surfaces, keeping the size 2


Multipurpose. The machine of drilling-milling and boring Process
Facing Of Part paice
Turning Rough &
Final
Parting
Back Side face
Countersink 45Digree
Drill Hole 5.5 mm
Reamer Hole 20mm
Bore & Side Facing
3omm bore with T cutter
Machining Process Bush

1.7 Short description of a manufacturing equipment

.

Fig 1.7.1 TAJMAC-ZPS H500.

1.8 Machine and tool selection

Machine selection

Machine Type and Size:

The type of machine to be used is determined by the selected manufacturing process. For instance, if turning is the chosen process, a lathe or turning center would be the appropriate machine type. During the initial selection, the physical size of the machine in relation to the workpiece is the primary factor. If a lathe has a machine bed shorter than the length of the part, it cannot be used for turning that particular part.

Power/Force Analysis:

After calculating the power requirements for all operations, machines that cannot meet the maximum power requirement are eliminated, unless there are no other options available. In such cases, reducing feeds, speeds, or the depth of cut can help lower the power required. Machines with significantly higher power output than necessary are also disregarded, except when specific operations require higher spindle speeds.

Capability Analysis:

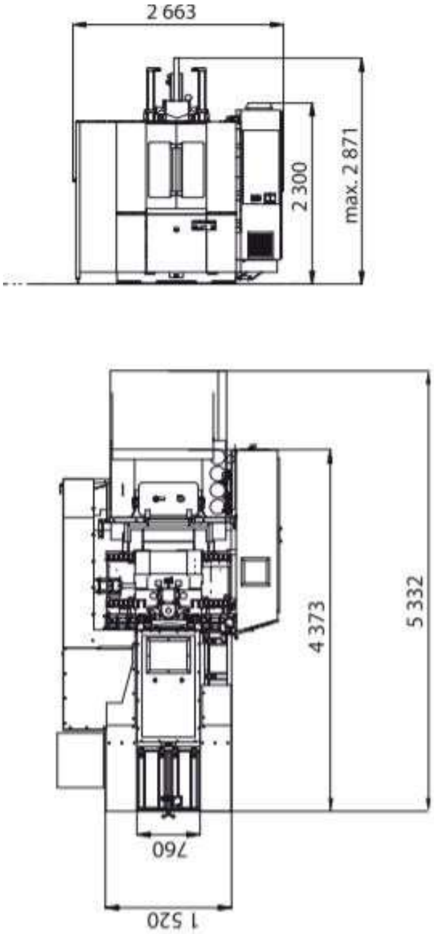
The capability analysis focuses on the dimensional and geometric accuracy as well as the required surface finish.

Operational Analysis:

The batch size plays a significant role in the operational analysis. Machines that do not meet the economic batch quantity are excluded.

Considering the aforementioned requirements, limitations, and the process plan developed in the previous chapter, the preliminary selected machine is the TAJMAC-ZPS H500 horizontal machining center.

The TAJMAC-ZPS H500 in the horizontal machining center version is a highly productive machine suitable for complex chip machining of steel, grey cast iron, and soft metal alloy parts clamped on the rotary table. It enables milling operations in three mutually perpendicular X, Y, Z coordinate axes, as well as the rotary B axis. Additionally, it allows drilling, boring, reaming, thread cutting operations, and the use of screw die heads without aligning bush in the Z axis.



Travels			
X-axis (column)	560 mm		
Y-axis (spindle head)	560 mm		
Z-axis (table)	560 mm		
Max. working feed	50 m/min		
Rapid traverse	50 m/min		
Acceleration	5 m/sec^2		
Spindle			
Tool interface	ISO 40	ISO 40	HSK–A63
Maximum speed	10 000 rpm	15 000 rpm*	18 000 rpm*
Continuous output S1 / overload S6 – 40 %	20/30 kW	25/31 kW	25/31 kW
Torque S1 / overloading S6 – 40 %	76/115 Nm	159/197 Nm	159/197 Nm
Transmission type	belt drive	electrospindle	
Rotary table with pallet			
Pallet dimensions	500 × 500 mm		
Range of turning	360 °		
Pallet max. load	300 kg		
Workpiece max. size (dia × height)	ø 600 × 750 mm		
Pallet change time	10 sec		
Measuring accuracy (VDI/DGQ 3441)	**direct / indirect**		
Positioning accuracy (P)	0.008/0.010 mm		
Repeatability (Ps max.)	0.005/0.006 mm		
NC table positioning accuracy (P)	6/22 arc sec		
Distances			
Spindle nose to rotary table axis	130 – 690 mm		
Spindle axis to pallet clamping surface	50 – 610 mm		
Working pallet to floor	1 010 mm		
Tool magazine			
Number of tool pots in magazine	45		
Tool interchange time	3.5 sec		
Tool maximum diameter:			
– fully occupied magazine	70 / 90 mm		
– without adjacent tools	125 mm		
Tool maximum length	300 mm		
Tool maximum weight	7 kg		

Fig. 1.7.2 Technical data of the selected machine

Tooling selection

Evaluation of process and machine selections – Provided the selection of processes and machines is satisfactory, the range of tools that can be used shouldbe limited to those suitable for the processes and machines selected. Therefore this limits the initial list of possible suitable tooling.

Analysis of machining operations – A specific machine will carry out every operation required. Each machine tool to be used will have specific tool types to carry our certain operations. This analysis should enable the identification ofspecific tool types for specific operations.
Analysis of workpiece characteristics – At this step the following should be considered: workpiece material and geometry, dimensional and geometric accuracy, and surface finish. This enables to identify suitable tool materials and geometry.

Tooling analysis – Using the tooling data available, the general tooling specifications generated ant the 3rd stage can be translated into a statement of tooling requirements for the job, that is, a tooling list. This will obviously reflect whatever tooling is actually available for the operations required.

Selection of tooling – If single-piece tooling is being used, then a suitable toolbushing should be selected before fully defining the tool geometry and material. If insert-type tooling is being used then the following steps should be followed:
Select clamping system;
Select toolbushing type and size;
Select insert shape;
Select insert size;
Determine tool edge radius;
Select insert type;
Select tool material.

Tool selection for the manufacturing step“005.09 Mill surface *A3* to dimension *9*”Allowance = 2.8mm
Radial cutting width = 24mm

To select the appropriate cutting tool and cutting conditions we will use CoroPlus® ToolGuide [1] Firstly, enter the initial data, incl. type of surface, depth of cut, radial cutting width and workpiece material (fig. 8.2).

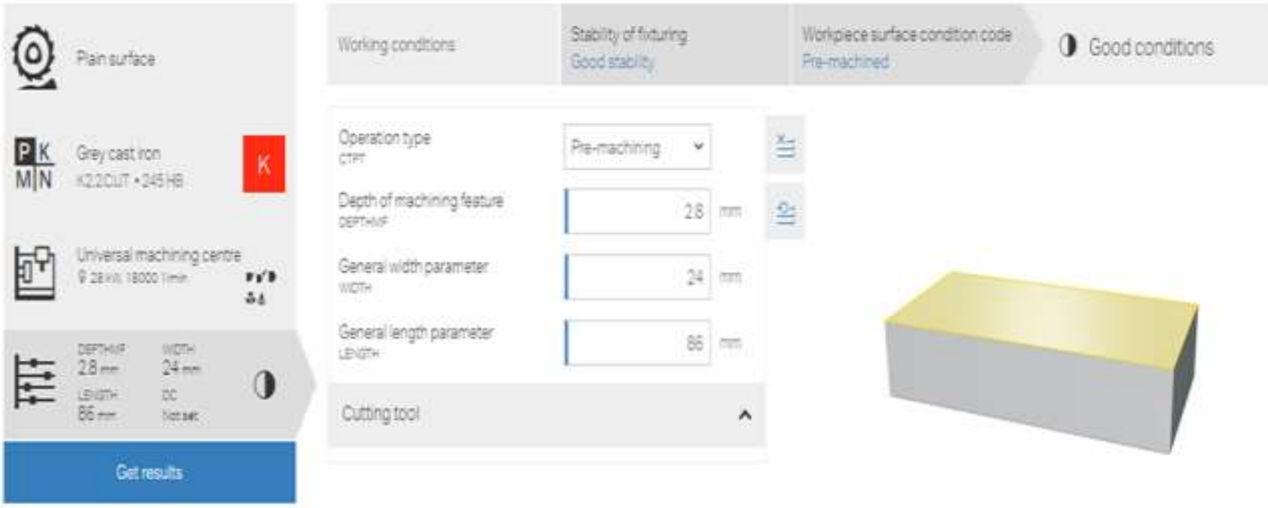
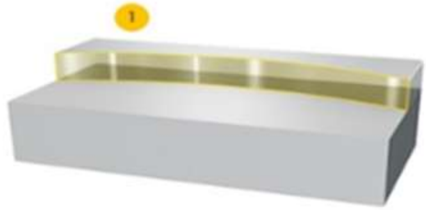


Fig. 1.7.3 Initial Data for tooling selection (screenshot)

After applying the initial data, consider the results of analysis: recommendedcutting tool and cutting conditions (fig. 8.3)



CoroMill 745

A725-076R25-21H
Tool

745R-2109E-M50 K20D
Insert Face

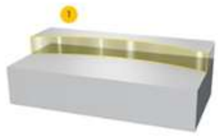
Arbor -ISO 6462 -A (hexagon socket head cap screw) -inch: 1

STEPS 1

PREMACHINING

Cutting speed VC 284 m/min

Feed per tooth FZ 0.453 mm



LEGEND

1 Premachining

CoroMill 745

A725-076R25-21H
Tool

745R-2109E-M50 K20D
Insert Face

coupling
Arbor -ISO 6462 -A (hexagon socket head cap screw) -inch: 1

cooling
External
Compressed Air

Plain surface

K K2.2.C.UT 245 HB

	VC [m/min] CUTTING SPEED	FZ [mm] FEED PER TOOTH	N [1/min] SPINDLE SPEED
1	284	0.453	1020
	VFM [mm/min] FEED SPEED AT MACHINED DIAMETER	AE [mm] WORKING ENGAGEMENT	AP [mm] DEPTH OF CUT
1	4150	24	2.8
	NOPAE NUMBER OF PASSES IN AE DIRECTION	NOPAP NUMBER OF PASSES IN AP DIRECTION	PPC [kW] CUTTING POWER
1	1	1	11.7
	MMC [Nm] CUTTING TORQUE	HEX [mm] MAXIMUM CHIP THICKNESS	QQ [cm^3/min] MATERIAL REMOVAL RATE
1	110	0.17	279

LEGEND

1 Premachining

Time and cost calculations

Calculating the time and cost of a bushing depends on various factors such as the material used, the complexity of the design, the type of manufacturing process, the machine used, and the labor costs.

Assuming that we have a basic design for a bushing, made of a common material like steel or aluminum, the time and cost can be estimated as follows:

1.9.1 Time Calculation:

Time needed for machine set-up includes activities such as machine and tooling arrangement, material preparation, and program loading. The duration of this stage can vary from a few hours to several hours, depending on the machine type and design complexity.

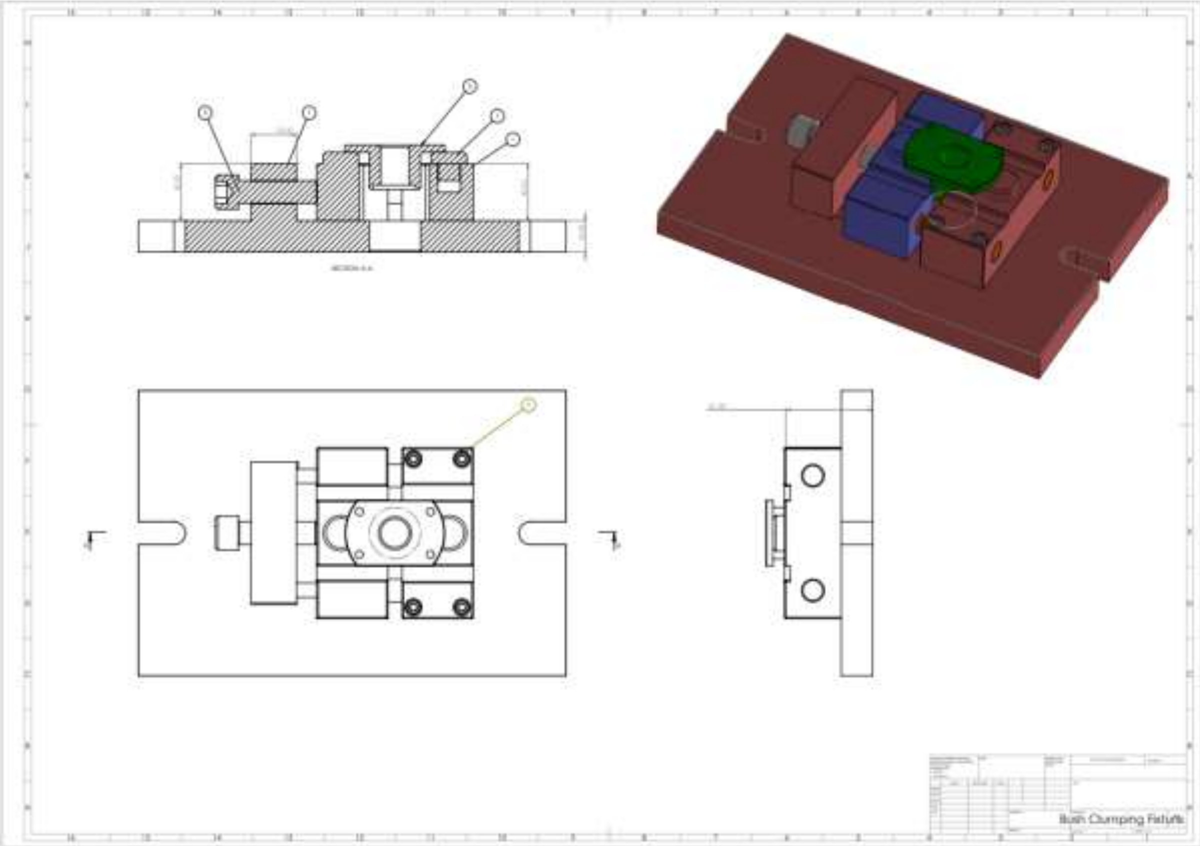
Machining time refers to the duration required for the machine to carry out the cutting operations. Factors influencing this time include the machine's speed, the type of cutting tool utilized, and the intricacy of the design. The machining process can range from a few minutes to several hours, depending on the specific machine and design being worked on.
1.9.2 Cost estimation
To estimate the cost of casting we will use the on-line application CostEstimator at the *custompartnet.com* [1].
References
https://www.custompartnet.com/estimate/sand-casting/

REFERENCE

ISO 8062 Castings – System of dimensional tolerances and machiningallowances

Chapter 2

2.1. Development of the fixture design



Attached to 005 operation

Lever wedge cartridges are more accurate, stiffer and more durable. The self-centering mechanism consists of a triple bevel wedge clutch and a main cam located in a groove in the housing to center the cartridge. The clutch and cam have ramps that form twin wedges at an angle of 15°. When the driving force W moves the clutch, the main cam moves radially and the replacement cam clamps the workpiece. The change cam is connected to the main cam by a T-slot mounted cracker and can be reset within specified adjustment limits. Reversing the clutch causes the lever to move the cam to the center of the chuck, securing the workpiece. He has two types of rotary pneumatic cylinders. Unilateral and bilateral. The end of the protruding rod has a threaded hole for connection. Compressed air is supplied to the right side of the cylinder through the nipple and the central hole in the rod, moving the piston to the left and creating a pulling force on the rod. Compressed air enters the left side of the cylinder through the nipple, radial hole and rod chamfer, moving the piston to the right and generating power.

2.2. Estimation of locating and clamping errors

For 005 operations we choose vices. This vise is designed to hold cylindrical workpieces during processing on milling and centering machines. The workpiece is secured by self-centering jaws that move within the guides of the device under the force of the drive rod (labeled as W). The jaws interact with the gear through a rack and pinion mechanism. To account for any shape errors in the workpiece, the prismatic jaw can rotate around its axis. For self-centering vises, the prismatic jaws must have enough range of motion to allow for easy installation and removal of the workpiece. The vise has a nominal pressure of 0.4 MPa and uses a pneumatic cylinder as the clamping source.

2.3. Estimation of necessary clamping force

To estimate the clamping force required for a fixture, the following formula can be used:

Clamping Force = Cutting Force / Frictional Coefficient

The cutting force is determined by the formula:

Cutting Force = 4.5kfdb / Cutting Speed

Where:

k is the material constant
f is the feed
d is the depth of cut
b is the width
The cutting speed is calculated as:

Cutting Speed = 3.14 * tool diameter * spindle speed / 60,000

For example, let's assume a cutting speed of 0.942 (units depend on input values) and substitute the given values into the cutting force formula:

Cutting Force = 4.5 * k * f * d * b / Cutting Speed

Once the cutting force is determined, it can be divided by the frictional coefficient to calculate the clamping force. In this case, the frictional coefficient is assumed to be 0.3. Therefore:

Clamping Force = Cutting Force / Frictional Coefficient

For the provided example, with a cutting force of 4299.36 N, the clamping force would be 14331.2 N.

It's important to note that these calculations are based on the given formulas and assumptions. Depending on the specific fixture design and machining process, there may be other factors or considerations to take into account. It is advisable to consult relevant literature, engineering handbooks, or seek the guidance of an experienced engineer for

precise calculations in your specific application.
It's important to note that this estimation provides a starting point, and further refinement may be necessary based on practical considerations and engineering judgment. Additionally, specific fixture design considerations, such as the number and location of clamps, type of clamping mechanism, and distribution of clamping forces, will also impact the final clamping force requirements

Chapter 3 CostEstimation

Part Design and Complexity

The cost of CNC machining pertains to the expenditures involved in utilizing computer numerical control (CNC) machines for producing parts or components. Various factors can affect the cost of CNC machining, such as the intricacy of the part, material choice, setup time for the machine, duration of the machining process, expenses related to tools, labor charges, and any supplementary services or finishes needed.

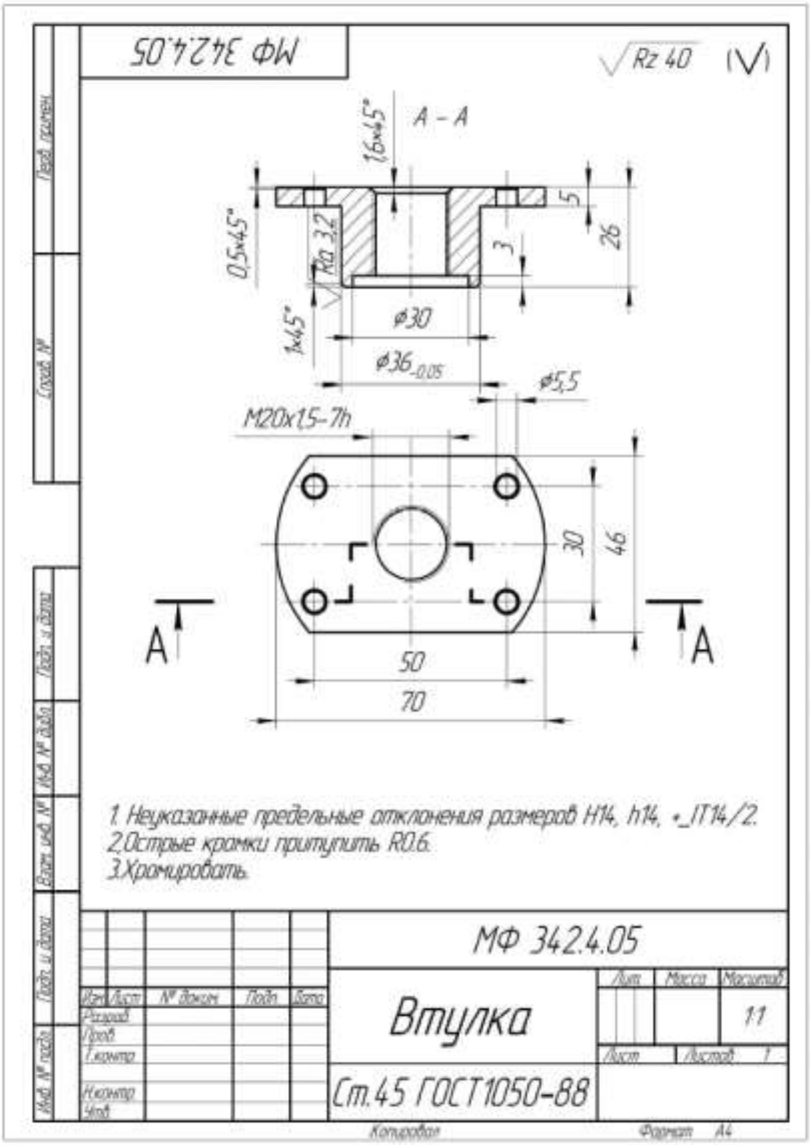


Fig 3.1 Drawing for design of machine part "Bushing"

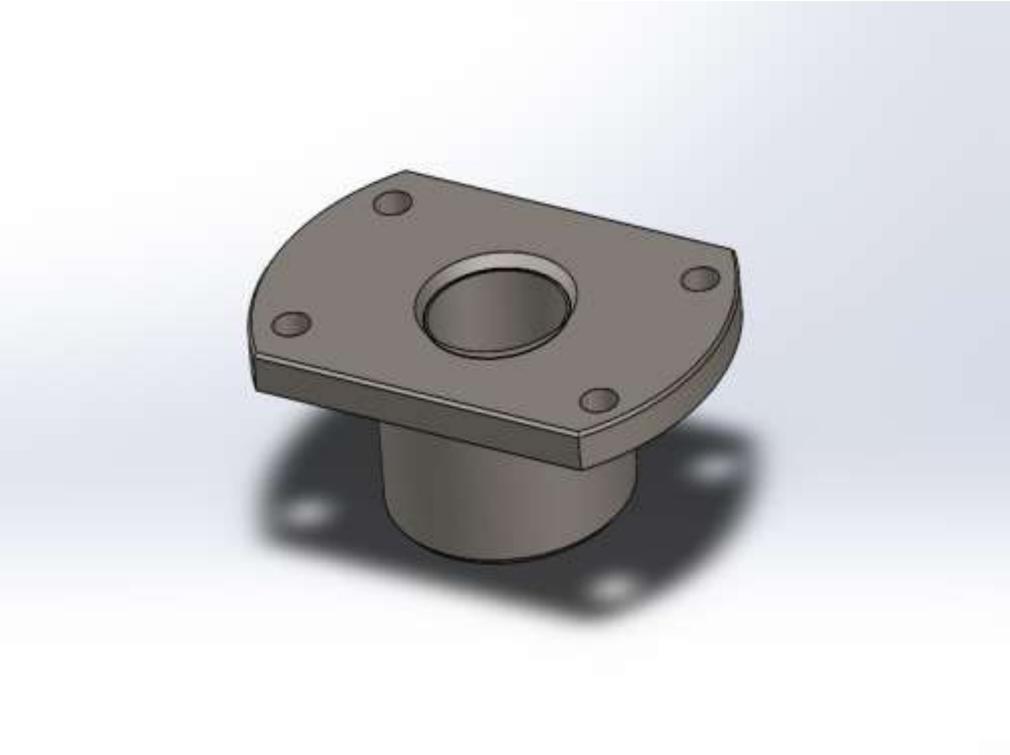


Fig 3.2 Machine part “BUSHING”

The design and complexity of manufacturing a bushing can have a significant impact on the cost of production. Here are some factors related to part design and complexity that can influence the manufacturing cost of a bushing:

The cost of production can be greatly influenced by the complexity of the part you intend to manufacture. Part design and geometry play a crucial role in determining the machining cost. As the complexity of a part increases, so does the expense associated with manufacturing it. Several factors contribute to this increased cost, including the requirement for more advanced machinery, longer fabrication times for each part, the potential need for multiple setups and processes, and the necessity for meticulous quality control to meet tight tolerances. Additionally, non-standard parts with features such as thin walls, deep cavities, irregular hole sizes, or high surface quality may result in higher costs per part.

The complexity of a bushing machine part refers to the intricacy and sophistication of its design and features. A more complex bushing machine part may have intricate geometries, multiple functional elements, or advanced mechanisms. The complexity of the part can affect the manufacturing process and the cost associated with producing it. It may require specialized machining techniques, longer production times, the use of advanced equipment, or additional quality control measures. The more complex the bushing machine part, the higher the manufacturing cost is likely to be due to these factors.

All calculations will be performed using online Cost Estimator custompartnet.com

First of all, according to our quantity of the number of our parts required for the manufacturing process to fill the customer's needs. In our case, our annual order is 10,000 parts. Material: Carbon Steel

We need to take into consideration possible defects when manufacturing

The defective rate in manufacturing refers to the proportion or percentage of defective or non-conforming products or parts within a manufacturing process. It is a measure of the quality performance and reliability of the manufacturing process. A lower defective rate indicates higher product quality and process efficiency, while a higher defective rate suggests issues or problems that need to be addressed.
Considering the defective rate for the manufacturing process is 1%, we calculate the defective rate as:

$$\text{defect rate} = \frac{\text{total number of defects}}{\text{observed projects}}$$

In our case that would mean the total run quantity will be 10100 parts, which is the total number of parts that are manufactured, including the possible defective/incomplete parts

For our part material we select carbon steel and the workpiece is "cast part" with the following dimensions (LxBxH): 74.2 mm (2.92) x 49.2mm (1.93)x 29.8 (1.17) and weight 0.206kg (0.45 lbs) (Fig 3.3

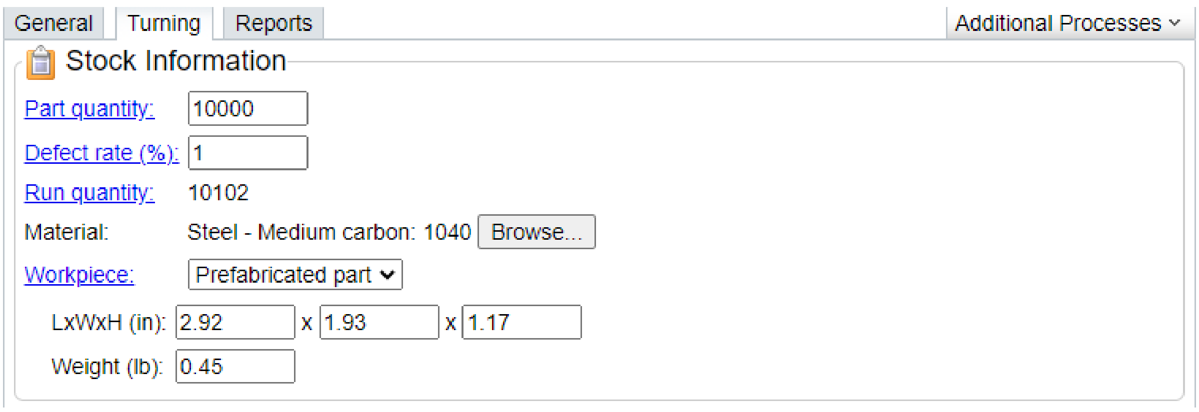


Fig 3.3 Stock Information

- Milling the plane surface: 70mm(2.29) x 46mm(1.93) x 5mm(0.19) with depth of cut 5mm(0.19 in). cutting tool -face mill Ø70 (Fig 3.4)

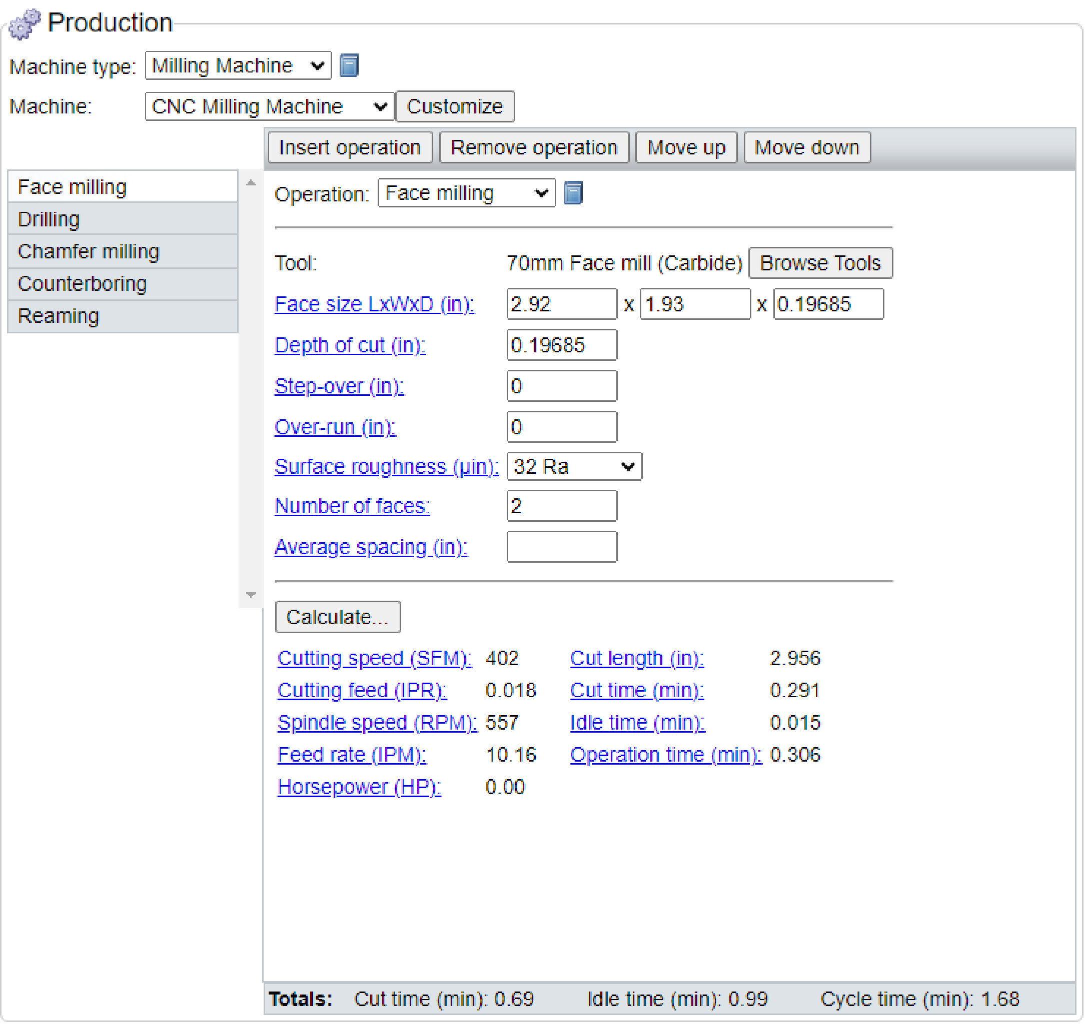


Fig 3.4 Face Milling

- Drilling 4 through holes Ø5.5 mm depth 5mm(0.19inch) as per Fig 3.5

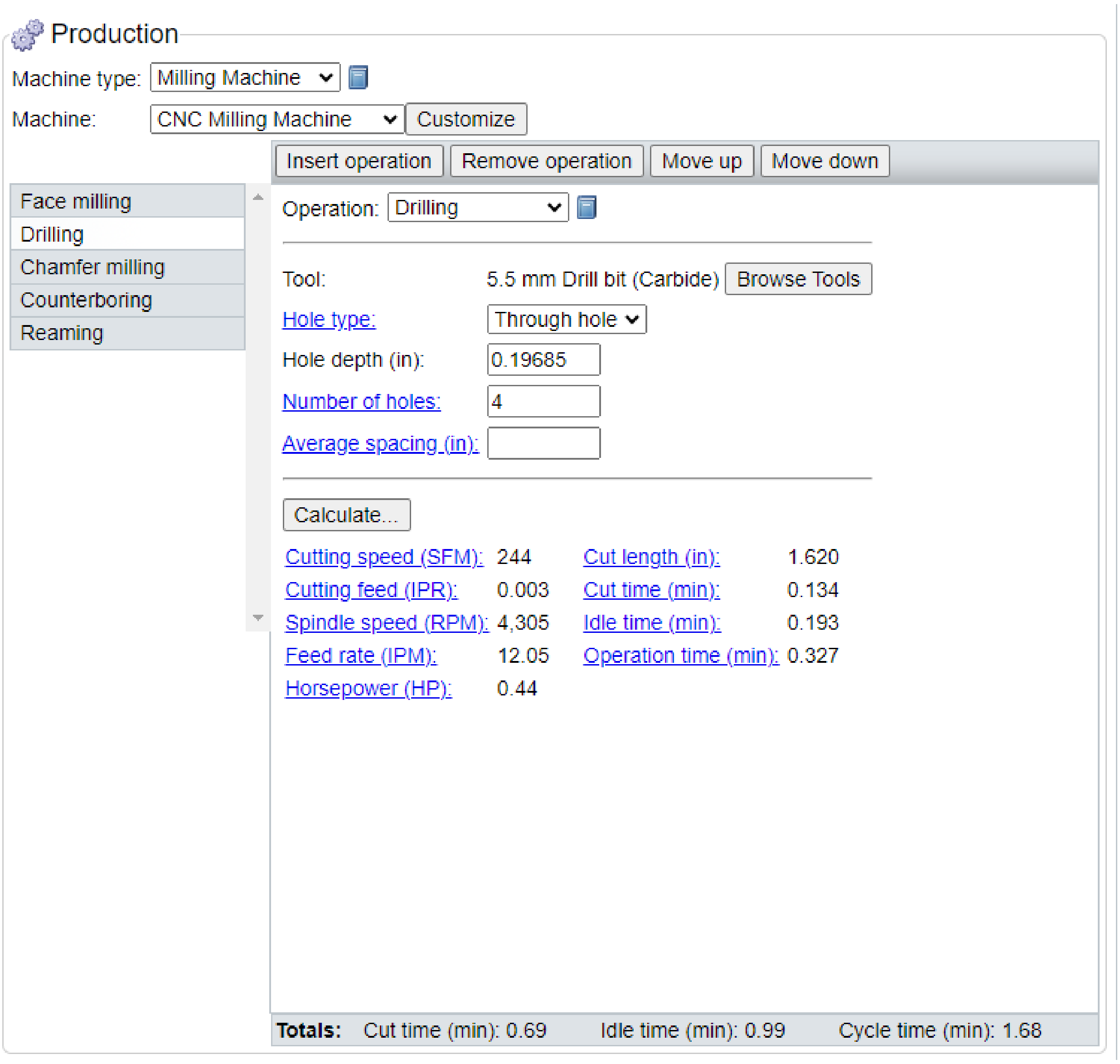


Fig 3.5 Drilling Operation

- Chamfer milling 2 curved surfaces and 2 straight surfaces with chamfer size 70mm (2.75inch)x 46mm(1.8inch)

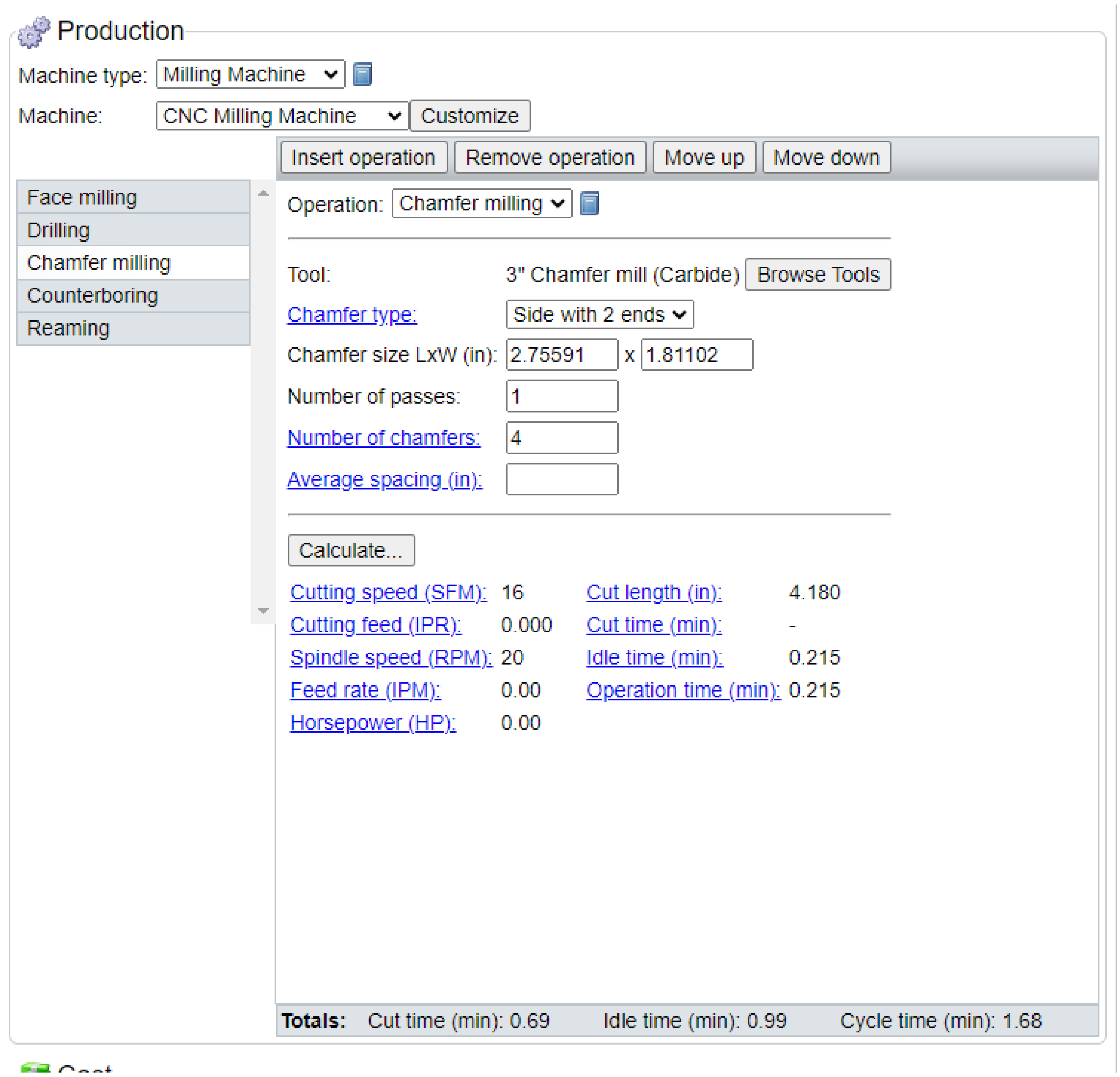


Fig 3.6 Chamfer Milling Operation

- Counter boring hole with initial hole size 30mm (1.81 inch) and counter hole depth 5mm(0.18 inch) using Ø 36mm counterbore carbide tool.

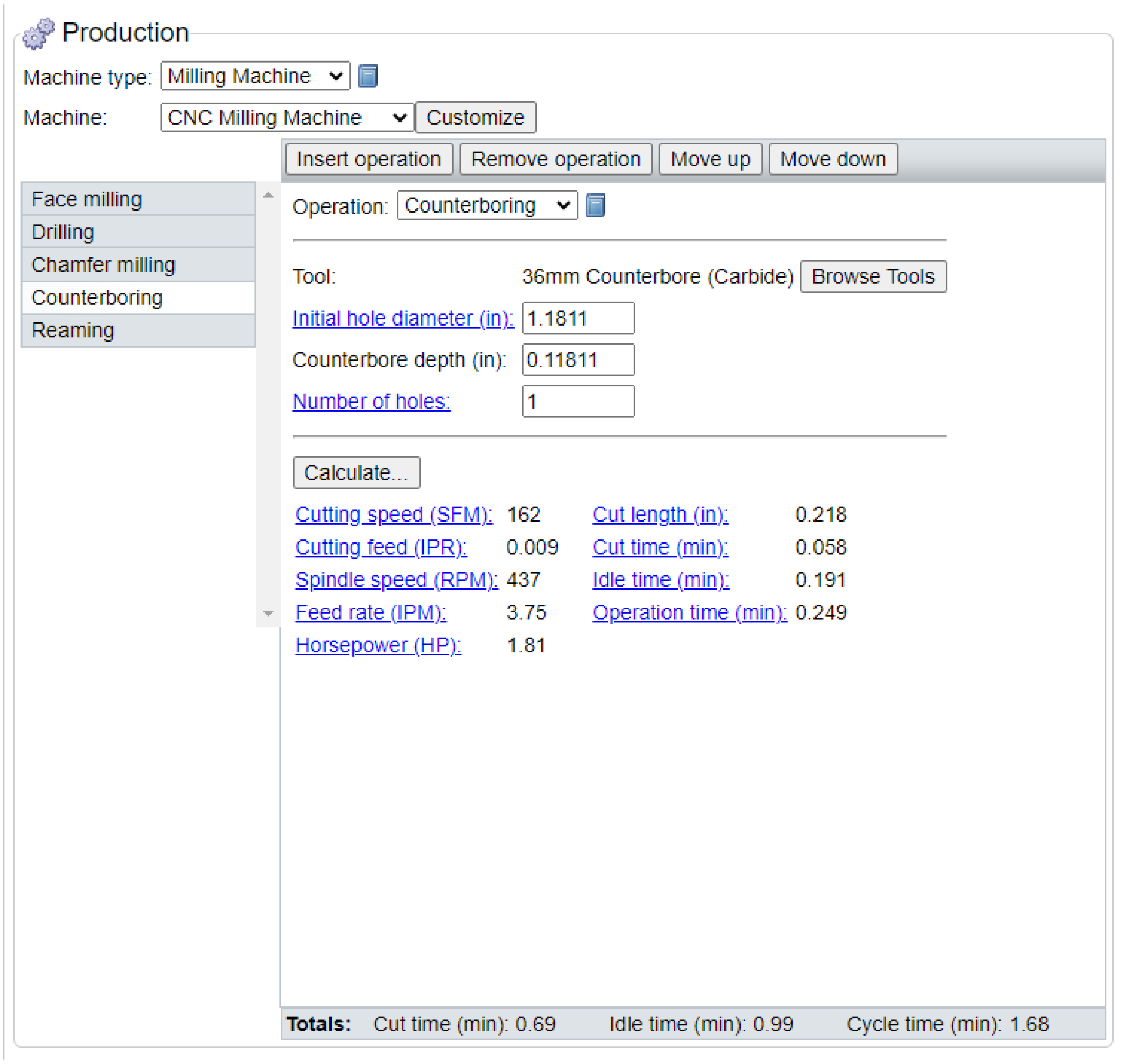


Fig 3.7 Counterboring Operation

- Reaming 4 holes Ø5.5mm , depth 5 mm (0.79 in) using 5.5mm reamer tool

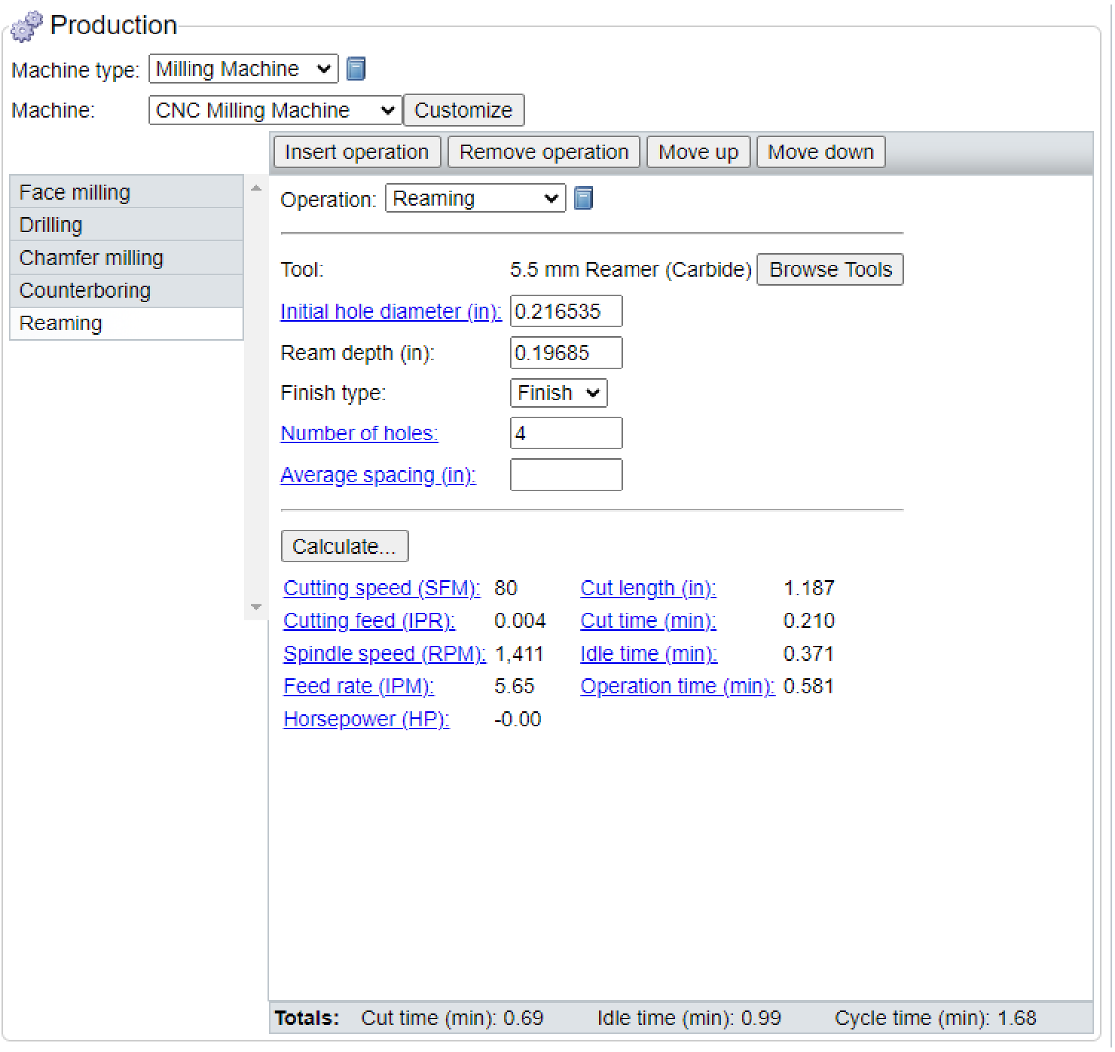


Fig 3.8 Reaming Operation

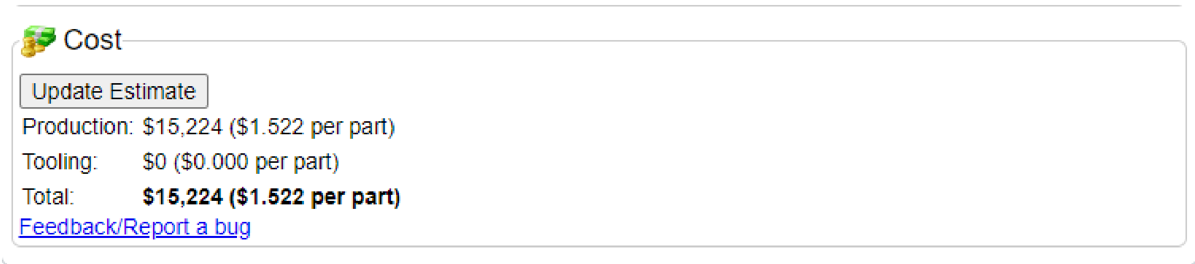


Fig 3.9 Final Cost Estimation

Chapter 4 General Questions

4.1 Plunge Milling

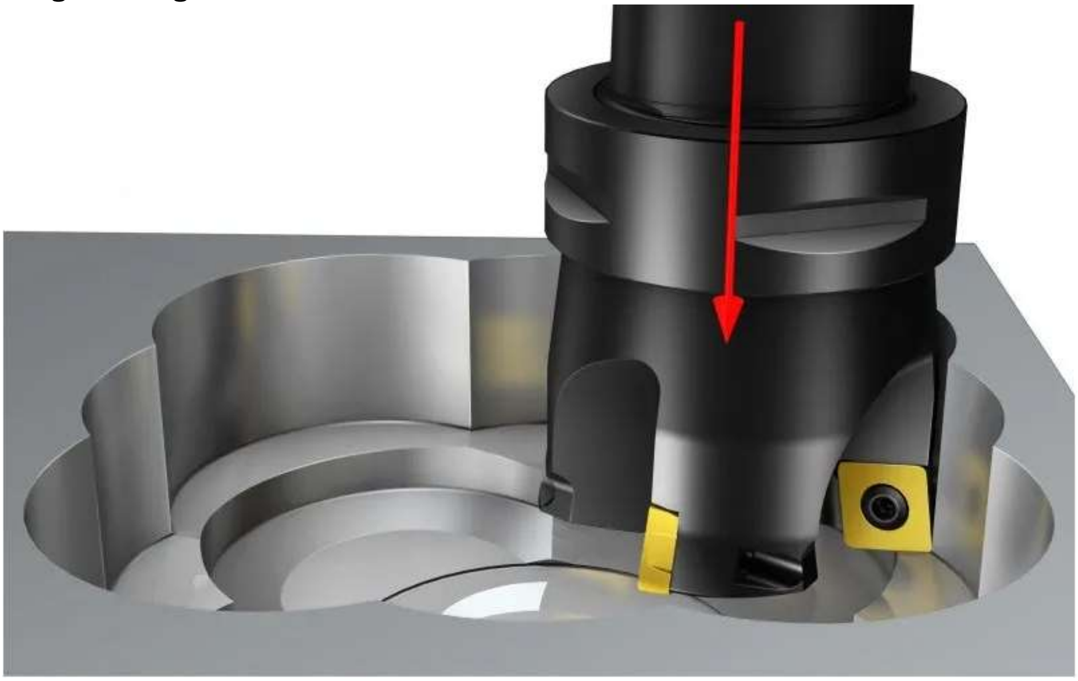


Fig 4.1 Illustration of plunge milling process

The term "CNC plunge milling" describes a milling method carried out with the aid of a CNC system.

During the CNC machining process, it entails feeding the material linearly along the tool axis. For rough machining operations involving complicated or irregular forms, such as impeller pieces, plunge milling is particularly beneficial. When using multi-axis plunge milling, it is essential to pick the plunge cutter section carefully and create a tool path that is appropriate for free-form surfaces. This adjustment significantly contributes to improving overall effectiveness and efficiency. [1]

Plunge milling is a milling technique where cutting is conducted at the end of the tool instead of the periphery. This approach offers advantages due to the shift in cutting forces from predominantly radial to axial direction. Plunge milling is typically employed as an alternative method when side milling is not feasible due to issues like vibrations.
Here are some scenarios where plunge milling is commonly used:
When the tool overhang exceeds 4 times the cutter diameter (4 x DC).
When there is poor stability in the machining setup.
For semi-finishing corners.
When dealing with difficult-to-cut materials, such as titanium.
It can also serve as an alternative when the available machine power or torque is limited.

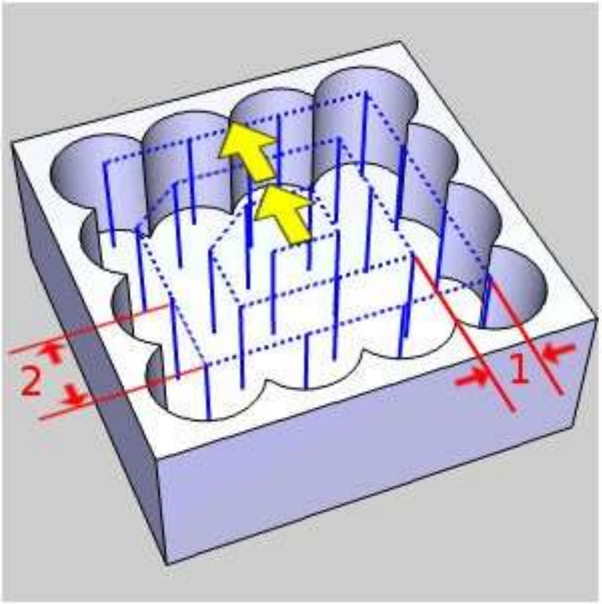


Fig 4.2 Plunge Milling a Pocket

The diagram illustrates a typical process of plunge milling for a square pocket. In this method, a series of holes are vertically plunged using a milling cutter to remove the bulk of the material within the pocket area. Subsequently, a finishing pass is employed to finalize the pocket shape, ensuring its completion.

Advantages of Plunge Milling

- Efficient material removal: Plunge milling allows for rapid and efficient removal of material, particularly in roughing operations. By plunging the cutter directly into the material, it enables aggressive chip formation and effective stock removal.
- Increased tool life: Plunge milling can lead to improved tool life compared to other milling methods, especially when dealing with difficult-to-cut materials. The axial cutting forces in plunge milling reduce tool wear and enhance tool longevity. [2]
- Reduced vibrations: Plunge milling can be advantageous in situations where side milling is not feasible due to vibrations. The axial cutting forces in plunge milling help to minimize vibrations, ensuring better stability during the machining process. [3]
- Versatility for complex shapes: Plunge milling is particularly suitable for machining complex shapes or free-form surfaces, such as impeller parts. It allows for efficient roughing of intricate geometries, enabling the production of complex components with higher accuracy.
- Alternative for limited machine power or torque: In cases where machine power or torque is limited, plunge milling can serve as an alternative. By controlling the cutting forces in the axial direction, it helps to manage the machining load and mitigate power-related limitations.

The disadvantages of plunge milling include:

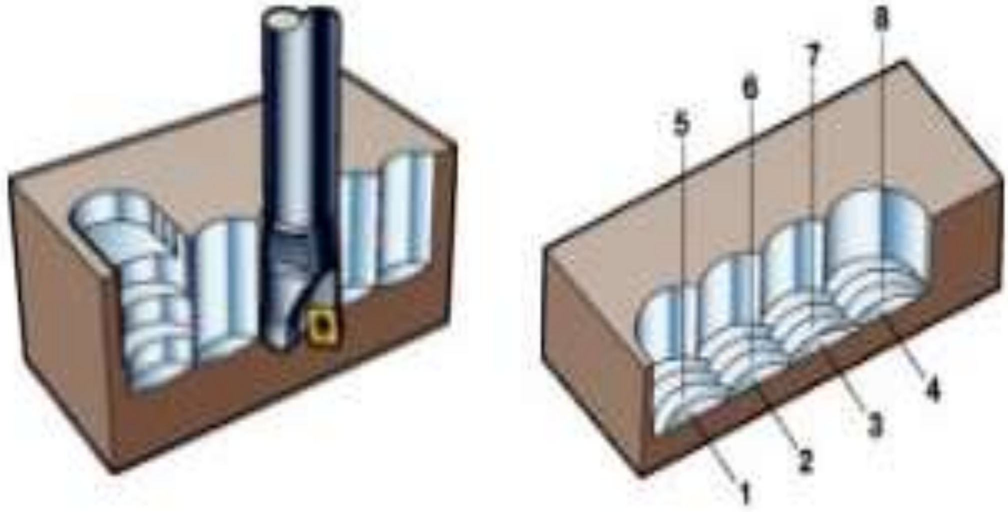


Fig 4.3 Disadvantages of Plunge Milling.

Plunge Milling leaves scalloped edges which may take a fair amount of cleanup or a semi-finishing pass before a true finish pass can be applied

- Scalloped Edges: Plunge cutting often results in scalloped edges that require removal through a subsequent finish pass. The extent of scalloping to be eliminated depends on the chosen X and Y stepover levels, which can sometimes be significant. If the scallops are excessive, an optional semi-roughing pass becomes necessary to address them before proceeding to the final finish pass.
- Lower productivity: Plunge milling typically has lower productivity compared to other milling methods. This is due to the nature of plunging the cutter into the material, which may result in slower material removal rates. [4]
- Additional finishing operations: Plunge milling often requires subsequent finishing operations. This is because the initial plunging operation leaves an uneven surface that requires additional machining or smoothing to achieve the desired surface finish.
- Challenges in chip evacuation: Plunge milling can pose challenges in chip evacuation, especially when dealing with deep cavities or closed slots. The chips generated during the plunging process may have difficulty escaping, leading to potential chip clogging or interference with the cutting process.

- Limited selection of cutting tools: Compared to other milling methods, plunge milling may have a more limited range of cutting tools available. The geometry and design of the tools suitable for plunge milling may be more specialized, potentially limiting the options for tool selection. [5]
- Wavy edges: Plunge milling can result in wavy or uneven edges on the machined surface. These irregularities may require additional effort and time for edge cleanup or subsequent finishing operations to achieve the desired surface quality.

When executing plunge milling procedures, it is advised to follow the following recommendations:

- It is desirable to use horizontal milling machines for plunge milling operations because the horizontal spindle direction makes chip evacuation easier.
- It is advised to begin the machining procedure at the bottom and work your way up gradually (Figure 4.4).
- Compressed air or cutting fluids should be used to help in chip evacuation.
- The feed per tooth in plunge milling is often lower than in conventional milling techniques.
- To cut effectively, several teeth must be used.
- Use only cutters with the lowest possible tooth pitch.
- Based on the dimensions of the workpiece, one should establish the maximum width of the cut B (Figures 4.5 ,4.6).
- To avoid re-cutting on the return stroke, the "retraction" feature is advised; at the conclusion of the machining pass, the cutter should be retracted 1 mm from the wall as per fig 4.7
- With L 4 Dc and s = 0.5 Dc (where Dc is the cutter diameter and L is the cutter overhang), the optimum feed step values in the lateral direction are shown in Figure 4.8
- The cutting depth must be gradually decreased to eliminate vibrations.
- It is recommended to always leave room for further finishing procedures.
- The consumed power in plunge milling is determined by formula 1 [6]

Formula 1: $$N = \frac{D_{ф} \cdot B \cdot s_{хв} \cdot F_{п}}{60 \cdot 10^{6}},$$

Where N is the amount of power consumed in kW, Dc is the cutter diameter in mm, B is the breadth of the cut in mm, sfeed is the feed rate in mm/min, and Fc is the specific cutting force in N/mm2 (i.e., the force needed to remove a 1 mm2 layer of material).

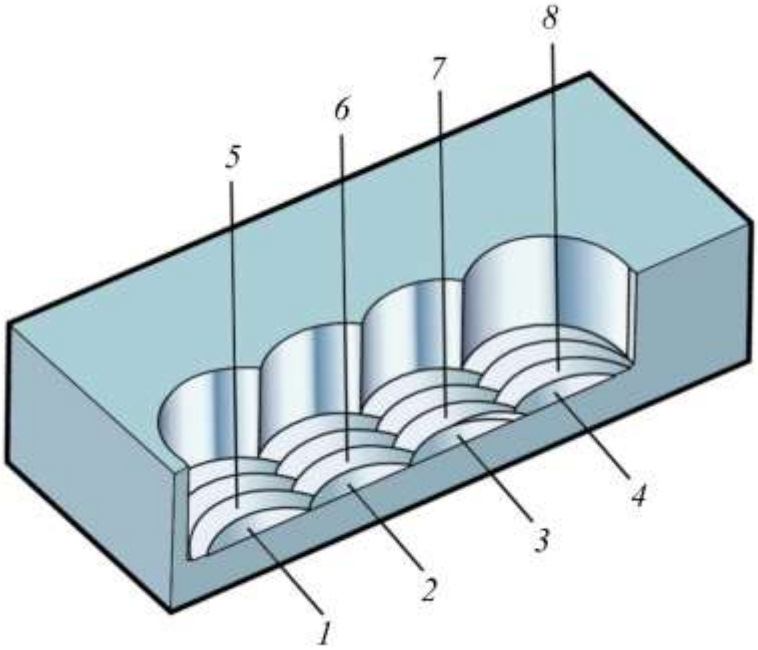


Fig 4.4 Plunge milling machining from the bottom and gradually raising

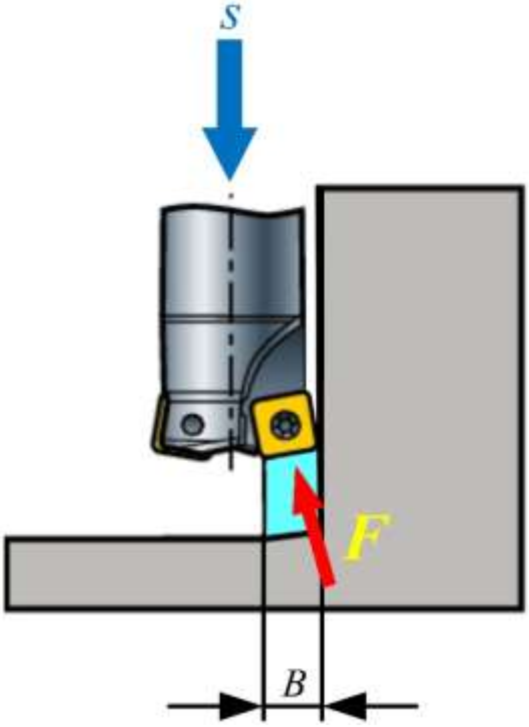


Fig 4.5 Redistribution of cutting forces in plunge milling

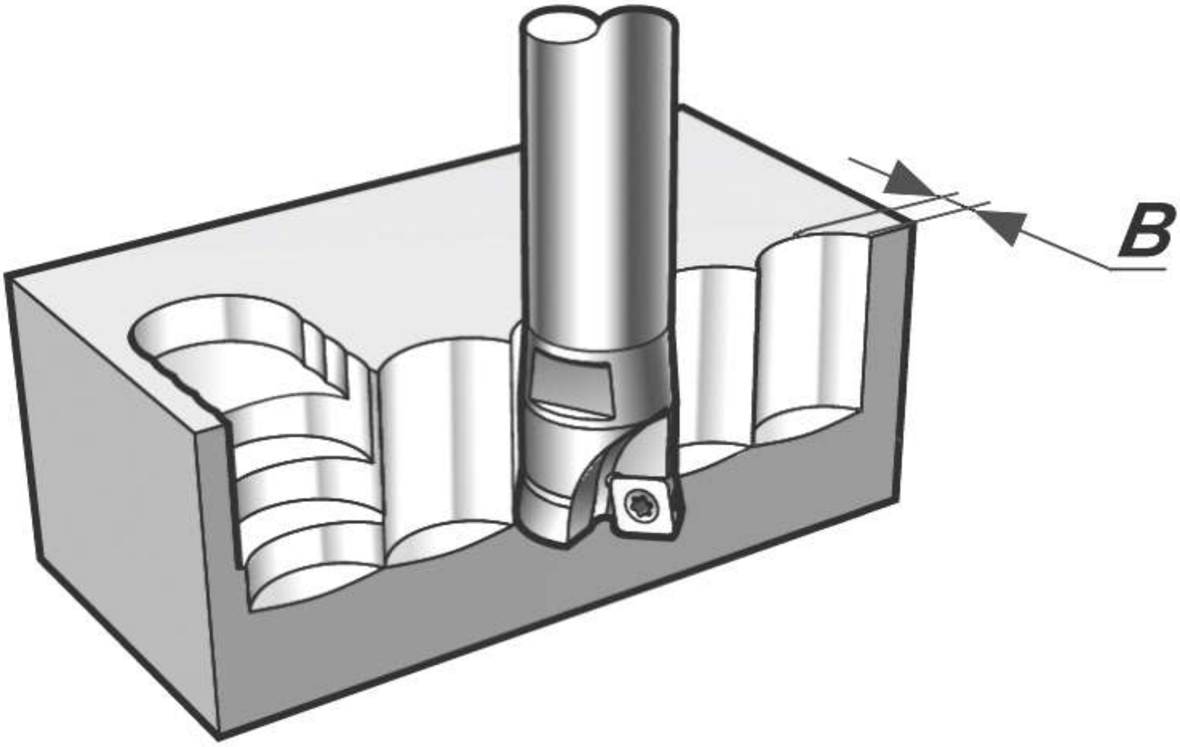


Fig 4.6 Width of milling in plunge milling

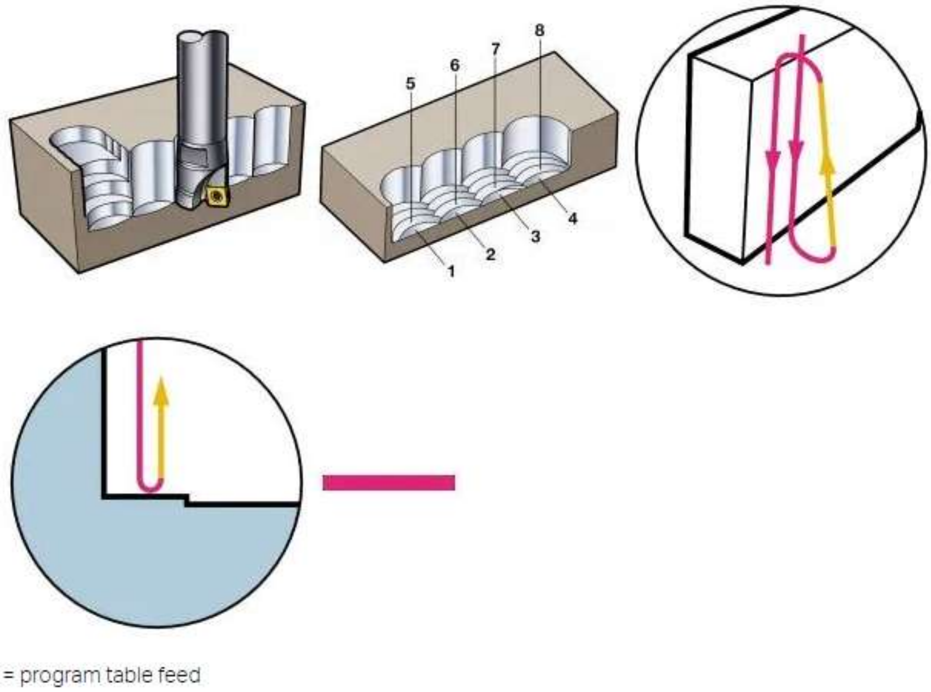
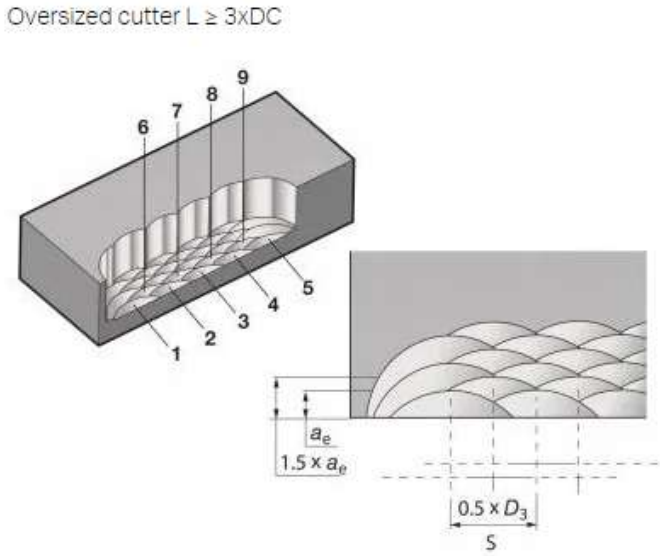


Fig 4.7 In plunge milling, retracting the cutter will stop it from cutting again during the return stroke.



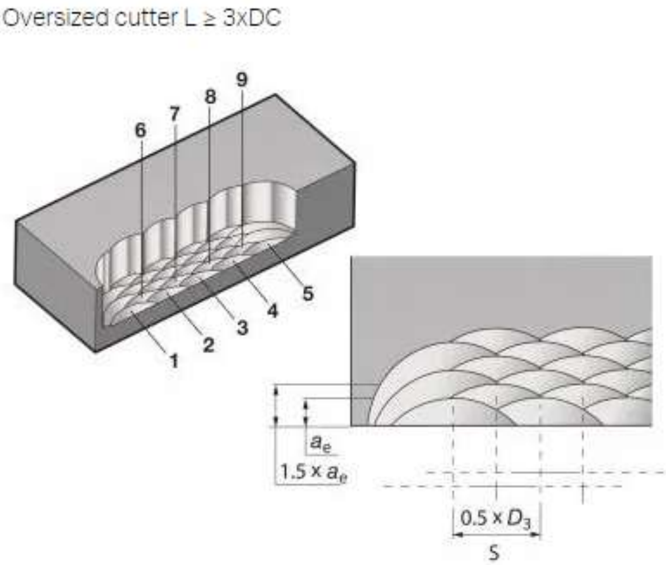
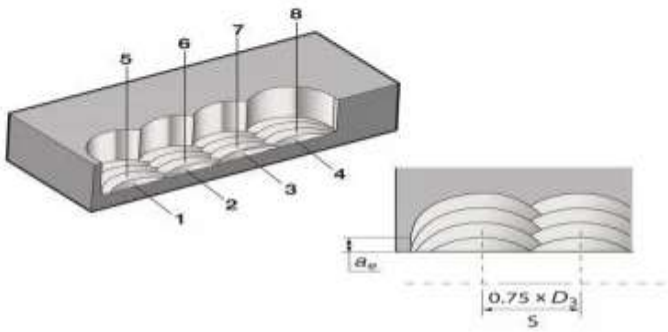


Fig 4.8 Recommended plunge milling stepover

The maximum cutting width B in plunge milling depends on the size of the insert iC and the tool overhang The feed per tooth sz in plunge milling also depends on the size of the insert iC. The tables and diagrams show how feed per tooth sz and maximum cutting breadth B depend on the size of the insert iC and tool overhang.

Feed in plunge milling		
Insert size	**Overhang < 3xDC**	**Overhang > 3xDC**
9	f_z = 0.15 (0.10 - 0.20)	f_z = 0.10 (0.08 – 0.15)
14	f_z = 0.20 (0.10 - 0.25)	f_z = 0.15 (0.10 - 0.20)

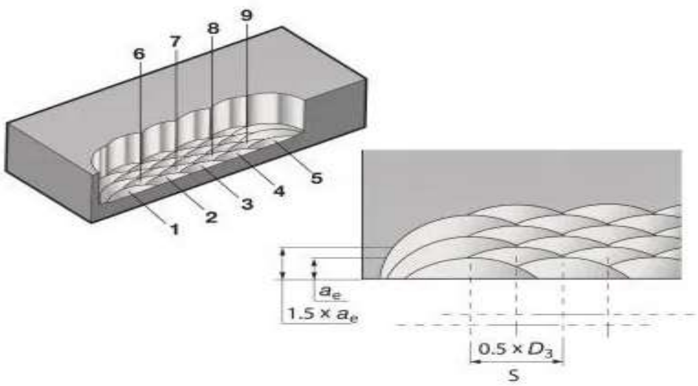
Oversized cutter L ≤ 3xDC



iC	max a_e
9	8
14	13

s = 75% DC

Oversized cutter L ≥ 3xDC



iC	max a_e
9	7
14	12

s = 50% DC

a_e = max for insert

Side step s = X % DC

** S is tool overhang specific*

The maximum cutting breadth B and feed per tooth sz rely on the insert's size iC and tool overhang in the following ways:

– When insert size iC and tool overhang are increased, the maximum cutting width B also rises.
– Larger insert size iC and tool overhang also result in an increase in the feed per tooth sz.

These relationships show that for plunge milling processes, bigger insert sizes and tool overhangs enable wider cutting widths and higher feeds per tooth.
As previously indicated and as per the figure below (Fig 4.9), plunge milling is a very efficient way to machine corners.

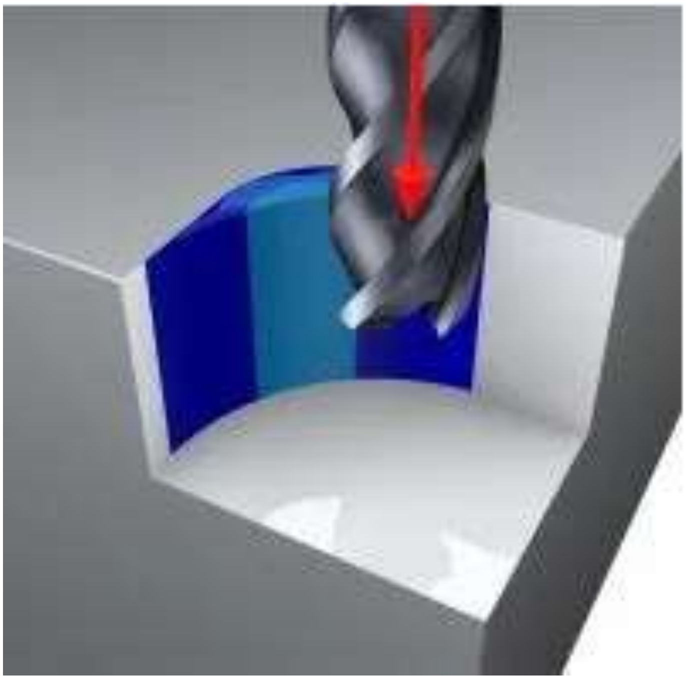


Fig 4.9 Deep 90-degree corners might benefit from plunge milling the residual material (rest milling) after a roughing operation.

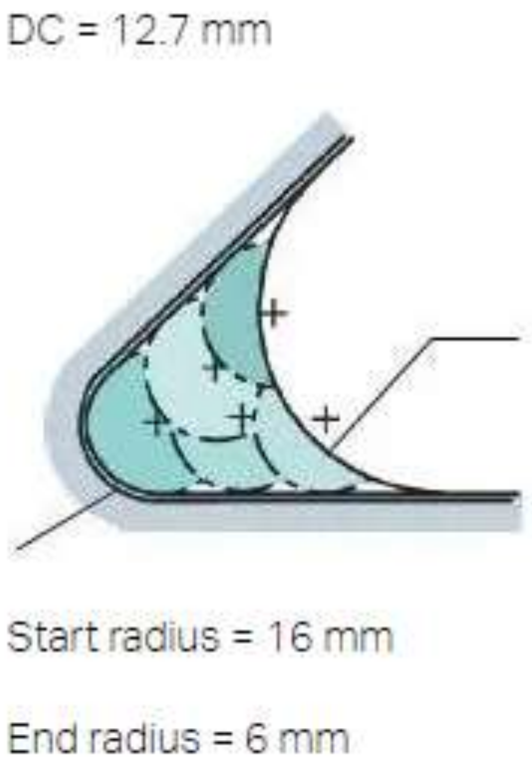


Fig 4.10 Scheme of machining a sharp corner using plunge milling

The diagram above (Fig 4.10) illustrates the process of machining an acute angle using plunge milling:

- Start of the process: The milling cutter begins by vertically plunging into the material near the acute angle.
- Initial pass: The milling cutter gradually advances into the material, moving along the contour of the acute angle. This allows for the removal of a significant portion of the material from the corner, creating the initial shape.
- Transition pass: Completing the initial pass may leave residual corners or edges. By performing an additional pass, the size of the residual corners and edges is reduced, facilitating further machining.
- Finishing the machining: After conducting the necessary transition passes, the desired form of the acute angle is achieved. If required, additional passes may be carried out to achieve a high-quality finish.
- This diagram outlines the key steps involved in plunge milling an acute angle, where the cutter is plunged and maneuvered to shape the desired angle.

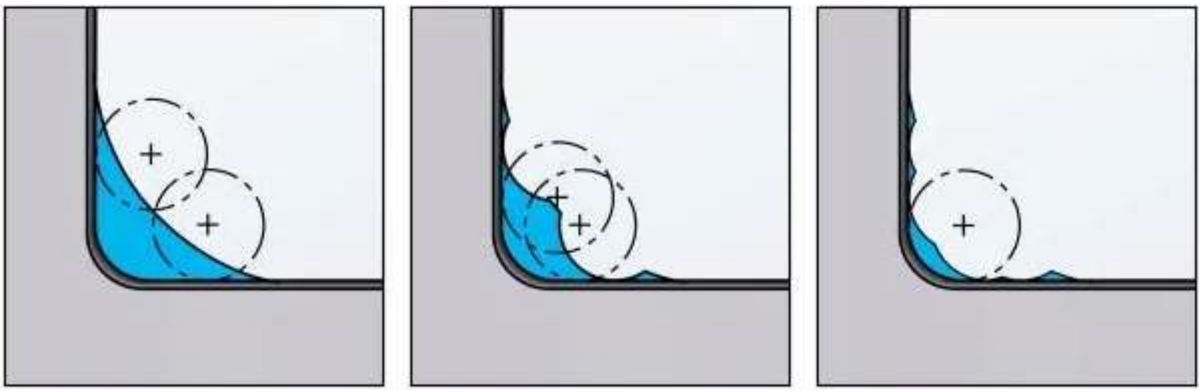


Figure 4.11 Machining a right-angle using plunge milling

Machining a right-angle using plunge milling can be done in the following simple steps (Fig 4.11)

- Position the workpiece and fix it securely.
- Select an appropriate milling cutter for plunge milling and place it at the workpiece's right-angle corner.
- To rough out the material, keep making plunge cuts around the right angle's perimeter. Lower the milling cutter vertically into the workpiece to the necessary depth.
- Perform a semi-finishing pass if necessary to smooth out any uneven surfaces or scalloped edges.
- Make a last pass throughout the machining process to ensure the right angle has the appropriate dimensions and surface quality.

Fig 4.12 Machining a pocket using plunge milling.

Using the plunge milling procedure to manufacture a pocket (Fig 4.12)

- Securely set up the workpiece in the milling machine or fixture.
- Choose an appropriate tool, such as an end mill, for plunge milling based on the material and pocket dimensions.
- Determine the tool path, considering factors like entry point, cutting direction, and tool retraction.
- Position the tool above the starting point of the pocket and gradually lower it into the material until the desired cutting depth is reached.
- Make multiple plunge milling passes, incrementally removing material and extending the pocket's dimensions.
- Perform a final pass to ensure the pocket's accuracy, surface finish, and dimensions meet the required specifications.

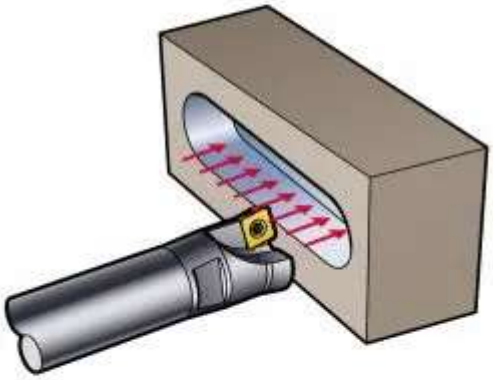


Fig 4.13 Machining a slot using the plunge milling

The process for machining a slot using the plunge milling method (Fig 4.13)

- Securely mount the workpiece to the fixture or milling machine.
- Select the proper end mill or slotting cutter for the material and required slot dimensions.
- Establish the tool path, which should include the entry and exit sites, the direction of the cut, and the depth of the cut.
- Place the tool in the desired slot location, above the slot's initial beginning point.
- Lower the tool into the material gradually while performing a plunge cut to the required slot depth.
- Move the tool along the route of the desired slot to remove material and lengthen the slot.

The following software options, based on our recent CAM Package Survey, are widely recognized, and their inclusion of plunge milling is indicated:

CAM Package	Plunge Milling
Alphacam	N
CamBam	N
FeatureCAM	N
Fusion360	N
HSMWorks	N
Vectric	N
BobCAD	Y
Camworks	Y
Edgecam	Y
Esprit *	Y
GibbsCam	Y
Hypermill	Y
mastercam	Y
OneCNC	Y
PowerMill	Y
Siemens NX	Y
SolidCAM	Y
SprutCam	Y
SurfCam	Y
TopSolid	Y
VisualMill	Y

* = Requires Add-In

When evaluating the quality of plunge milling toolpaths in your CAM software, there are two important aspects to consider.

Firstly, determine whether the software supports 2D plunge milling or true 3D milling. While 2D plunge milling is limited to features with flat bottoms, 3D milling offers greater versatility in handling various geometries.

Secondly, it is crucial to check if the plunge cycle retracts away from the wall during the overall retract process. This feature is particularly beneficial when machining difficult materials as it reduces chatter and extends tool life. An example of such a feature is the Plunge Rough retract style, which was developed collaboratively by WorkNC and Ingersoll.

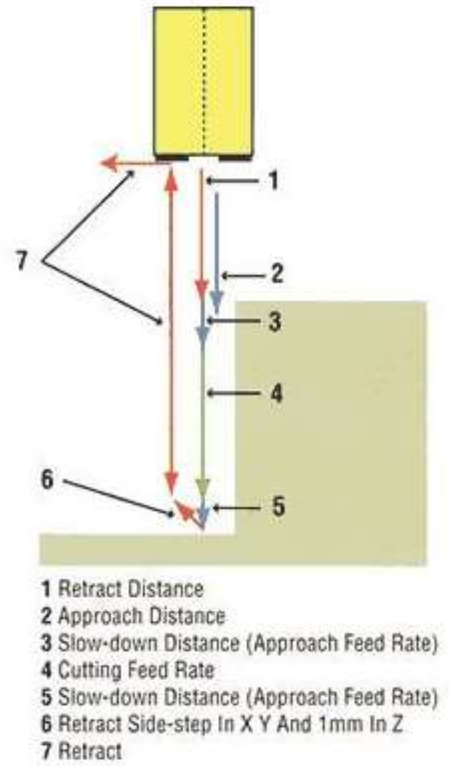


Fig 4.14 During Plunge Rough, slightly retracting from the Wall

According to the technique's developers, gradually retracting from the wall during each Plunge Rough stroke can increase tool life by 10% to 15%. (Fig 4.14)

To ensure the quality of plunge milling, it is necessary to verify whether the CAM system supports the following:

- Whether it supports plunge 3D milling or only 2D milling - 3D milling can be used for various tasks, while 2D milling is limited to features with flat bottoms.
- Whether the tool retracts from the wall during the overall retract - this feature reduces vibration and increases tool life by 10-15% when machining.

If the CAM system does not support plunge milling, the main implementation scheme for the toolpath trajectory is as follows:

- Create a grid of holes within the contour of the pocket or other machined surface.
- Define the finishing allowance (which may need to be increased depending on the complexity of hole placement within the contour).
- Develop the program code based on the hole grid to guide the tool into each hole according to the specified coordinates (similar to drilling cycle programming).
- Manually program the tool retraction from the walls.

Figures 4.15- 19 provide an example of the above implementation scheme for plunge milling. Figure 13 shows the contour of the pocket where the finishing allowance needs to be defined. Next, create a circle with a diameter corresponding to the plunge milling tool's diameter and position it to touch the boundary of the finishing allowance (Figure 14). Then, create an array of holes with a step size in both the X and Y directions (tool movement between passes) that will be used (Figure 15).

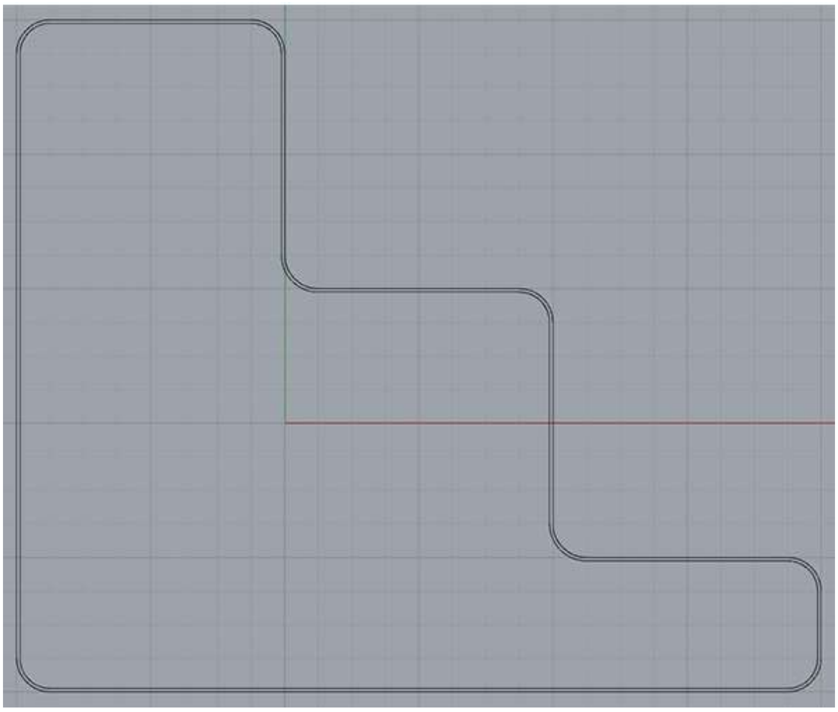


Fig 4.15 Allowance setting for machining

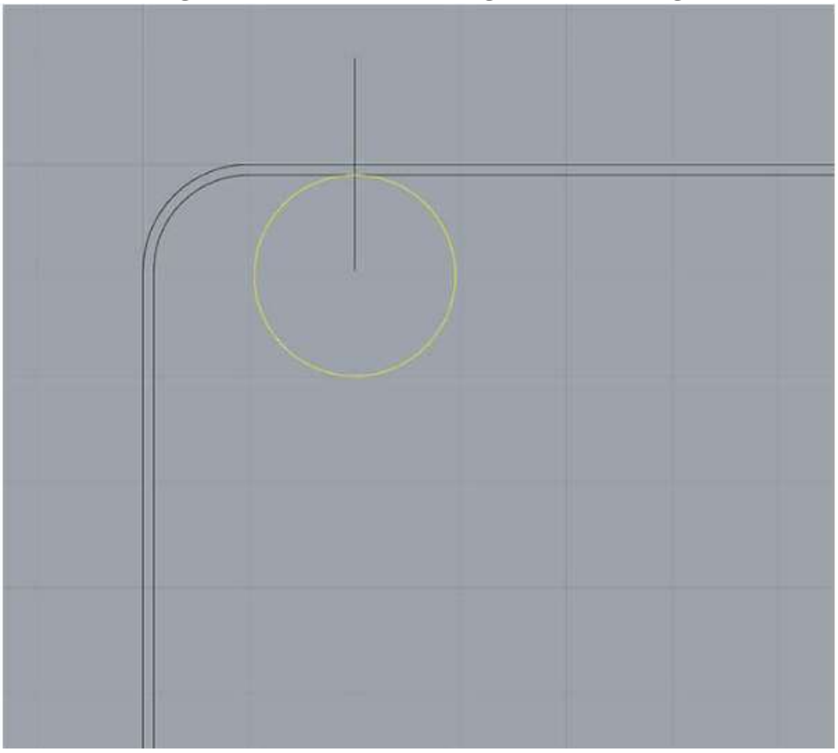


Fig 4.16 Creating a circle with a diameter matching the plunge milling tool diameter and positioning it in such a way that it touches the boundaries of the allowance.

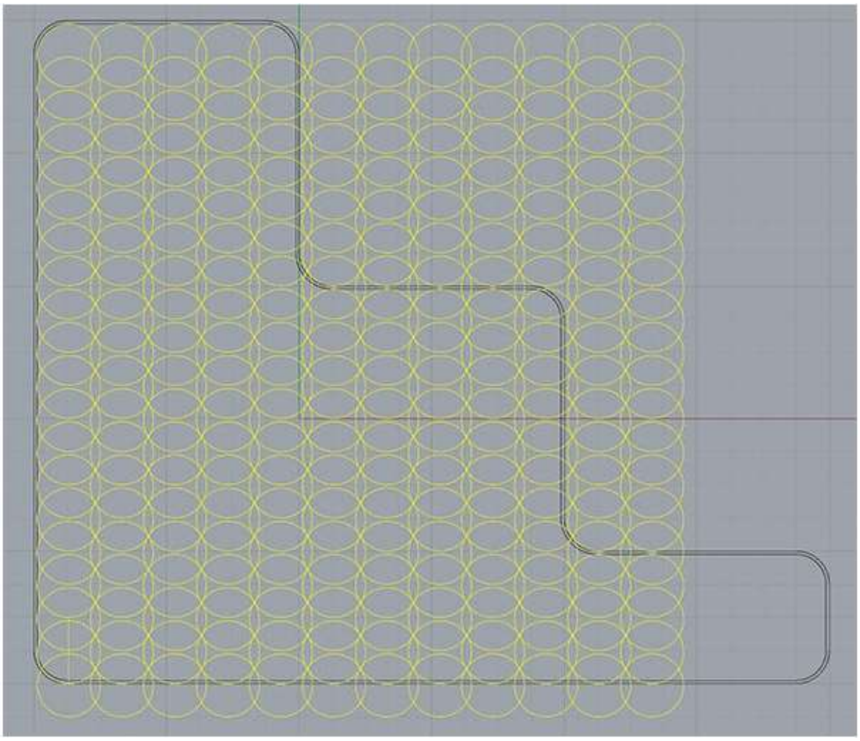


Fig 4.17 Creating an array of holes with a step size in the X and Y directions that will be used

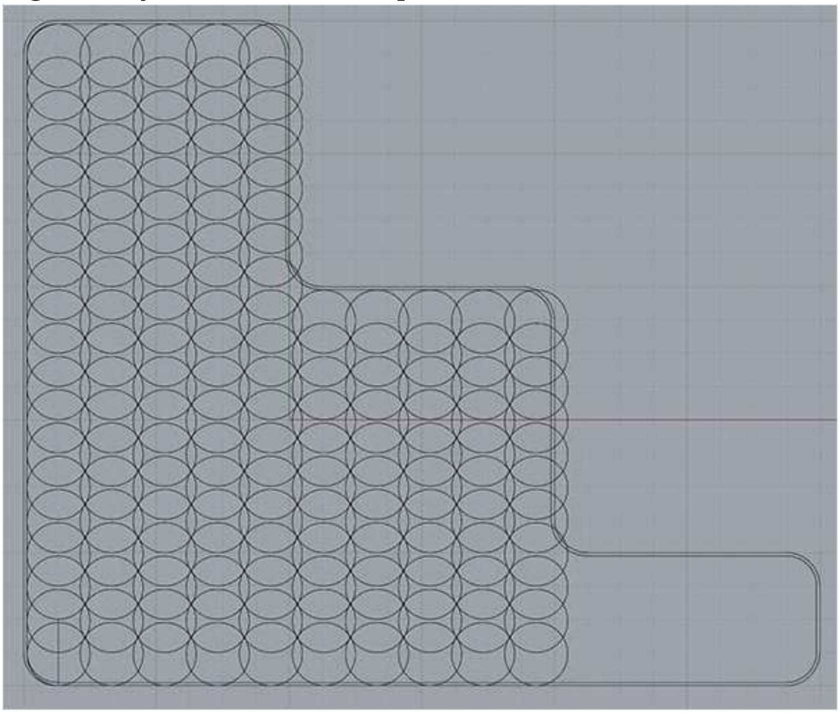


Fig 4.18 Removing all unnecessary holes that extend beyond the boundaries of the pocket contour

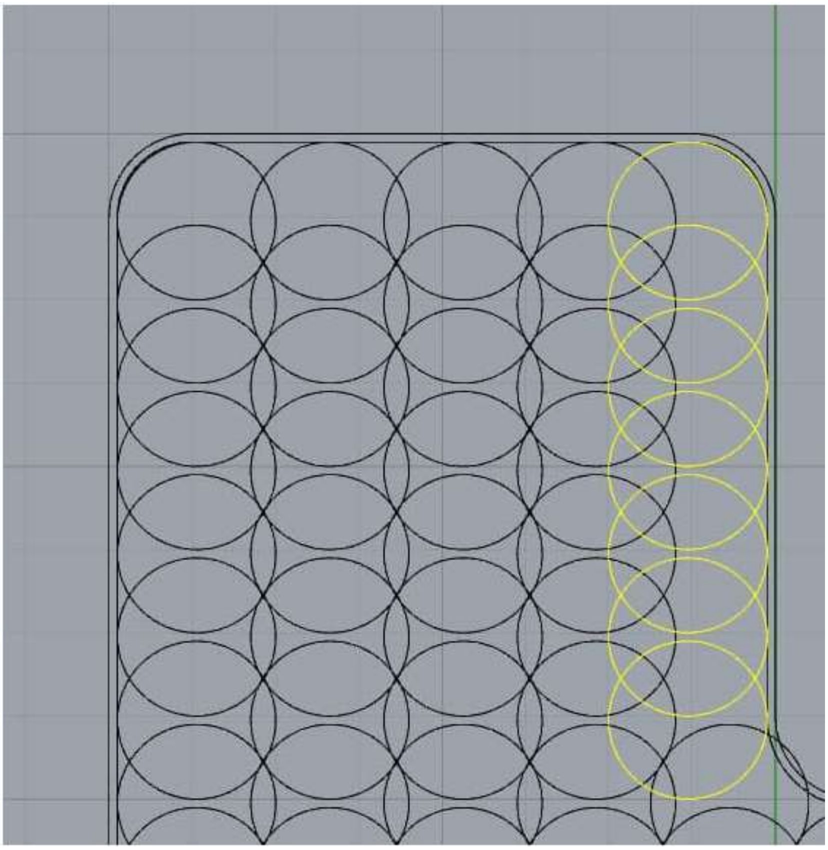


Fig 4.19 Adjusting the position of the remaining holes so that they touch all the contours with the specified allowance that they intersect

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