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

The defense allowed:
Acting head of the department
Oleksandr Okhrimenko
____

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

Topic: «Manufacturing Process Planning for the Part "Bearing Housing "»

Developed by:
Student of the IV year of study, group MT-03
Mohamed Gamal Mohamed Mohamed Aly ______________

Supervisor:
Ph.D, associate professor Volodymyr Korenkov ______________

Reviewer:
Ph.D, associate professor Kholavik Olga ______________

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

Kyiv-2024

National Technical University of Ukraine
“Igor Sikorsky Kyiv Polytechnic Institute”
Educational and Research
Institute of Mechanical Engineering
Department of Manufacturing Engineering

Level of higher education – first (bachelor)
Specialty – 131 “Applied Mechanics”
Educational and Professional Program “Manufacturing Engineering”

APPROVED
Head of the department
______ Oleksandr OKHRIMENKO
«___»_____________2024

ASSIGNMENT
for the diploma project to the student

________Mohamed Gamal Mohamed Mohamed Aly__________________________

1. Topic of the diploma project: Manufacturing process planning for part "Bearing Housing"
project supervisor: Volodymyr Korenkov, PhD, associate professor

approved by the University Order dated «___» _____2024 No_______

2. The deadline for the student to submit a diploma project «**10**» **June** 2024

3. Initial data for the project:
Drawings of the product “Bearing Housing”;
Material: ISO 185 JL 200 Gray Cast Iron;
Production Volume: 3000 units per year

4. The content of the explanatory note, a list of tasks to be developed:
Chapter 1. General issues – Casting and Molding
Chapter 2. Manufacturing process planning
Chapter 3. Fixture design
Chapter 4. Economic calculations

5. A list of graphic and illustrative material
- Presentation of the Chapter 1 results: 1 sheet A1
- Drawing of a part and a blank – 1 sheet A1
- Manufacturing operation presentation – 2 sheets A1
- Results of NC-program development – 1 sheet A1
- Drawing of the workpiece clamping device – 1 sheet A1
- Presentation of the project – 5-10 PowerPoint slides

6. Consultants for chapters of the project

Chapter	Surname, initials, and position of consultant	Signature, date	
		Issued the task	Accepted the task
1	Volodymyr Korenkov, PhD, associate professor		
2	Volodymyr Korenkov, PhD, associate professor		
3	Volodymyr Korenkov, PhD, associate professor		
4	Volodymyr Korenkov, PhD, associate professor		

7. Issue date of the assignment: 20 May 2024

CALENDAR PLAN

No	Stages of the diploma project implementation	The deadline for the stages of the diploma project	Notes
1	Chapter 1. General issues – Casting	25 May 2024	
2	*Presentation of the Chapter 1 results: 1 sheet A1*	25 May 2024	
3	*Drawing of a part and a blank – 1 sheet A1*	25 May 2024	
4	Chapter 2. Manufacturing Process Planning	31 May 2024	
5	*Manufacturing Operations Presentation - 2 sheets of A1 Format*	31 May 2024	
6	*Results of NC-program development – 1 sheet A1*	31 May 2024	
7	Chapter 3. Fixture design	7 June 2024	
8	*Drawing of the workpiece clamping device – 1 sheet A1*	7 June 2024	
9	Chapter 4. Economic calculations	10 June 2024	
10	Presentation	10 June 2024	

Student Mohamed Aly

Supervisor Volodymyr Korenkov

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CHAPTER 1: Casting and Molding

1.1. Casting

Casting is one of the metals forming processes that involves pouring a metal or liquid alloy into a mold to reproduce, after cooling, a given piece (internal and external shape) while minimizing subsequent finishing work as much as possible. The techniques used depend on the alloy being cast, the dimensions, characteristics, and quantities of parts to be produced. It is most often a subcontracting industry heavily dependent on purchasing sectors such as automotive, steel, handling equipment, industrial equipment, electrical equipment, aerospace, armaments, etc. [01]

1.1.1. Types of Castings

- Ferrous metal casting: cast iron and steel.
- Non-ferrous metal casting: copper, zinc, and alloys.
- Light alloy casting: aluminum, zamac, and other light alloys.
- Art casting.
- Bell casting.
- Typographic casting.

1.1.2. Alloys

Casting does not produce its own alloys; it purchases the required grades in ingots. However, during melting, it is necessary to control the metal composition and make some adjustments considering the loss during melting.

For example, magnesium (Mg), which is part of many alloys, tends to evaporate at usual melting temperatures (although these are significantly below its vaporization temperature). It is necessary to compensate for this loss before pouring.

Therefore, when the metal is in a molten state, a spectrometry sample is taken and immediately analyzed. Based on the results of this analysis and the weight of metal in the furnace, the amount of magnesium to be added to reach the middle of the alloy specification range is determined. Generally, pure magnesium is not added, but a master alloy such as AG20, which contains 20% magnesium and 80% aluminum, is used.

Once the mixture is made, the alloy is refined and degassed; a second sample is taken to verify the effect of the correction.

If the analysis results of this second sample are compliant, the parts can be cast. These results will be recorded in the casting logbook and on the certificates of conformity that will be provided to the client along with the parts.

For technical parts, only "first melt" metal is generally used, meaning alloys made with new raw materials. However, highly complex parts such as engine heads for motor vehicles can be cast with "second melt" alloys, which are composed of carefully sorted recycled metals; this is mainly for mass-produced parts (pressure die casting).

Fig.1.1. Molten metal

1.1.3. Casting Quality

A prototype casting foundry must justify to its clients a quality management system compatible with their requirements. The main foundries are certified ISO 9001:2000 (formerly ISO 9002); however, aerospace clients increasingly request their suppliers to comply with the specific standard for this industry: EN 9100. While few clients today require the certificate corresponding to this standard, they nonetheless verify that their suppliers' organization is aligned with it.

1.1.4. Melting Furnaces

Different heating methods for melting furnaces can be used: gas, fuel, coke, and electricity, among others. In all cases, the furnace is made of refractory materials to insulate it from the surrounding environment and contains a graphite crucible. This crucible is filled with ingots and returns, then heated to a temperature above the melting point of the alloy it contains. Temperature regulation is performed using thermocouples placed in the heating chamber, between the resistances (in the case of an electric furnace) and the crucible. The temperature of this chamber is slightly higher than that of the metal contained in the crucible.

For sand casting of aluminum parts, the crucible is not removed from the furnace during pouring, but the metal is ladled out from it. Often, melting furnaces are partially buried so that the metal can be more easily ladled out. In all cases, a pit is provided under the furnace and a channel at the bottom of the furnace to collect the metal in case of crucible failure. This pit is often called "the cellar"; when foundry workers say "my metal has flowed to the cellar," it means a crucible has failed. Such an accident, though rare, can happen. If the furnace is well-designed, it can be repaired by replacing the crucible, and sometimes also by replacing a few resistances destroyed by the molten metal that may have flowed onto them. To prevent such incidents, a replacement schedule for crucibles is generally determined, as they are considered wear parts in a foundry.

1.1.5. Pouring

When the metal is ready, meaning:

- The pouring temperature is reached and controlled (this temperature depends on the alloy and the shapes of the part to be made).
- The composition, particularly the magnesium content, is compliant.
- Degassing has been performed and controlled.

The parts can be poured.

In the case of prototype or small series parts cast by gravity (as opposed to pressure casting), the pouring is done with a ladle. One or more operators, as some parts are cast with multiple simultaneous pours (for example, for a chemically bonded sand mold, two operators may pour at the same time), will draw the molten metal from the furnace with ladles preheated to the furnace's heat. When there are multiple simultaneous pours, the different operators must pour the metal simultaneously into the pouring openings to avoid a defect called "cold shut," which could weaken the part. The absence of such a defect will be checked later by visual inspection or by dye penetrant testing.

For some large parts, casting ladles that can be handled by an overhead crane or forklift are used. These ladles are preheated and then filled with the metal using ladles, and the part is poured from these ladles, which are mounted on a pivoting support and generally equipped with a control wheel.

On the surface of the molten metal in the ladles or casting ladles, an alumina skin forms upon contact with the air, which should not be carried into the part. Therefore, just before pouring the part, "skimming" is performed to move this alumina skin away from the lip of the ladle or casting ladle using a steel spatula. If a small amount of these alumina skins does pass, the filters, usually made of fiberglass mesh, inserted into the mold at the pouring channels will stop them.

The mold is completely filled in one go until the metal rises through the risers and reaches the top of the mold. Therefore, it is important to choose the size of the ladles or casting ladles based on the "weight of the cluster" (weight of the part and its various pouring appendices).

1.1.6. Molding Study

When the offer is accepted, the technical manager of the foundry usually visits the client's design office to participate in the molding study. In this phase, the machining allowances are defined, and the design of certain "non-functional" parts of the piece can be slightly modified to facilitate molding.

It is in this phase that the parting lines (the boundary between two parts of the foundry tooling), the various core boxes and their supports, and the molding direction are defined. These points are very important to achieve the specified quality, and that is why the foundry's input, bringing their expertise to complement the client's needs, is crucial in this phase of the study.

1.2. Molding

Molding is the action of creating an imprint that will then serve as a mold into which a material is placed, allowing the reproduction or production of multiple copies of a model. Molding involves placing a material (liquid, paste, powder, sheet, plate, parison, preform, pellet, etc.) into a mold, where it takes the shape of the mold.

There are several types of molding:

- Sand molding
- Metal molding or permanent molding
- Special molding processes

1.2.1 Sand Molding

Sand molding involves creating an imprint in a plastic material - sand - based on a model of the piece's shape. Two metal frames, perfectly aligned with each other, are used to hold the sand used to make the imprint of the model.

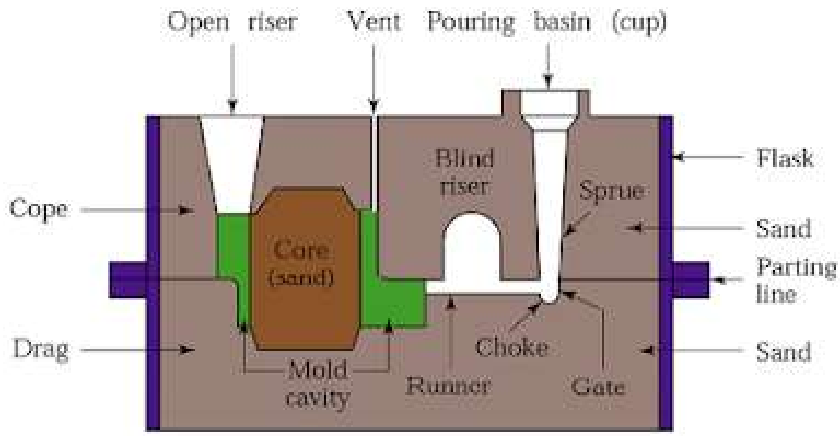


Fig.1.2. Sand molding

1.2.2 The Mold:

The sand mold is created from the described tooling. It consists of a mold bottom, a mold top, and, depending on the case, one or more cores. If the foundry tooling (the model) is permanent, the same does not apply to the mold, which will be broken to extract the finished piece. Therefore, as many molds are made as pieces to be produced.

Two types of sand can be used:

1.2.2.1 Silico-argillaceous sand molding, also known as “black or green sand”

This method is mainly used for models mounted on plates and can also be used for natural models, wood, or resin models. The sand is primarily composed of crystallized silica in the form of quartz and clay in the form of bentonite. It can be directly reused after being properly moistened, aerated, and sieved. Moistened clay serves as a binder between the grains of silica with precise grain size, by coating these grains. It is initially brown-yellow in color when new, but it quickly turns black upon contact with hot metal, hence the name "black sand." The two main parts of the mold, the bottom and the top, are held together by frames, usually made of aluminum, which have centering sockets into which pins are inserted to ensure the positioning of the two mold halves.

1.2.2.2 Chemical Bonded Sand Molding

The chemical bonded sand molding technique allows for more precision than black sand and provides a better surface finish. With this method, much finer textures can be achieved. It is mainly applied to models mounted in boxes and can also be used for certain natural wood or resin models as well as for stereolithography and polystyrene models, which cannot be molded using black sand. This time, it involves silica sand that has been sifted, washed, and dried. Resins and a catalyst are added to it shortly before making the mold to form a polyurethane (commonly referred to as "PEP-SET," for example) or other types of binders such as "Furanic." The lifespan of this sand (the duration during which it can be worked to make the mold) varies depending on the ambient temperature and the concentration of the catalyst.

1.2.3 Coring:

Internal hollow parts or certain external parts with undercuts "do not release" (meaning the model could not be removed from the sand mold without tearing part of it). Therefore, one or more cores are placed inside the mold, once the model is removed, to create the shapes of the piece. For the creation of these cores. [05]

1.2.4 Sand Molding Principle

- The founder prepares the lower part of the mold: the half model is covered with sand.

Fig.1.3. The lower part of the mold.

- For the upper part of the mold, the founder positions the second part of the model on the first. They add the model of the pouring channel and then fill the frame with sand.

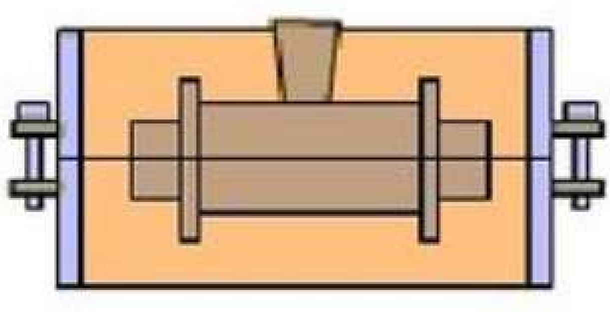


Fig.1.4. The mold.

- The founder then removes the half-model, drills the vents, and touches up the imprints if necessary.

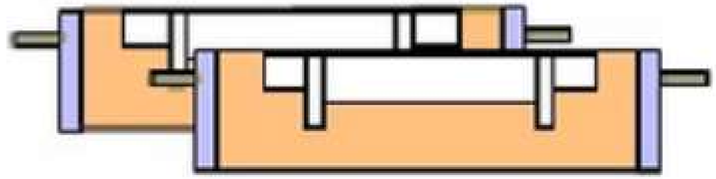


Fig.1.5. The imprint.

- The core is placed on its supports, and then the mold is closed.

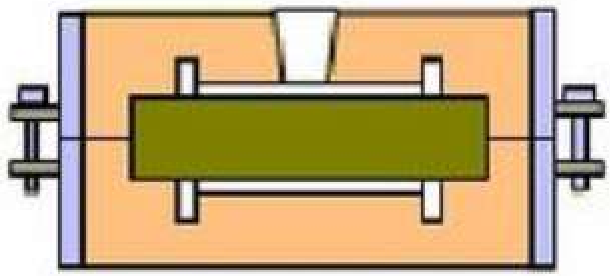


Fig.1.6. The core's location.

- The founder then pours the molten alloy into the mold.

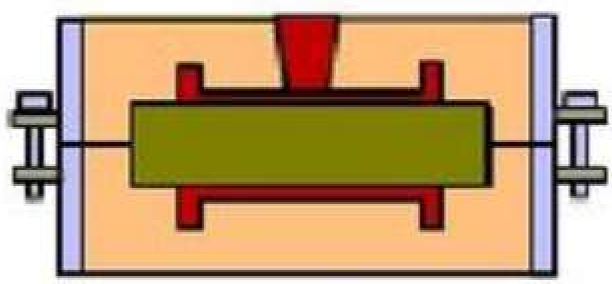


Fig.1.7. The alloy in the mold.

- Once the piece has cooled (allowing it to cool for 5 to 15 minutes), the mold is destroyed. The piece is separated by sawing from its pouring device and vents, and grinding removes any burrs. The raw casting piece is then ready for machining its functional surfaces.

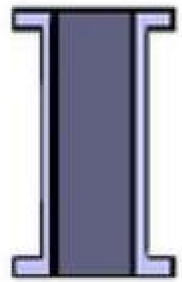


Fig.1.8. Finished piece

1.2.5 Materials Used in Sand Molding:

1.2.5.1 The Model: can be made of wood, resin, plaster, cement for reusable models, and polystyrene or wax for lost models. The model must be in 2 parts to allow demolding.

Fig.1.9. A molding model

1.2.5.2 Core Box: A core box is made for manual coring or on a core-making machine. The core box can be made of wood or resin. The core box must be in 2 parts to allow the core to be extracted.

Fig.1.10. the two sides of the core mold

1.2.5.3 Melting Preparation: Ingots with the correct composition (prepared by the steel mill) are used. They are placed in an induction furnace to ensure better efficiency. Then the mixture is transferred to a holding furnace.

Fig.1.11. the ingots.

Fig.1.12. holding furnace.

1.2.5.4 Mold Preparation: Two frames (upper and lower).

Fig.1.13. Two frames

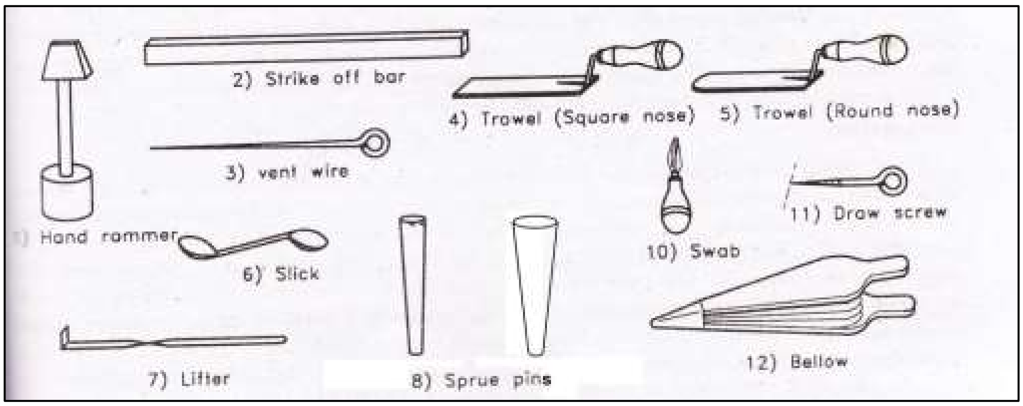


Fig.1.14. Casting and molding tools

1.2.5.5 Pouring: The molten alloy can then be poured into the mold cavity by quickly tilting the ladle.

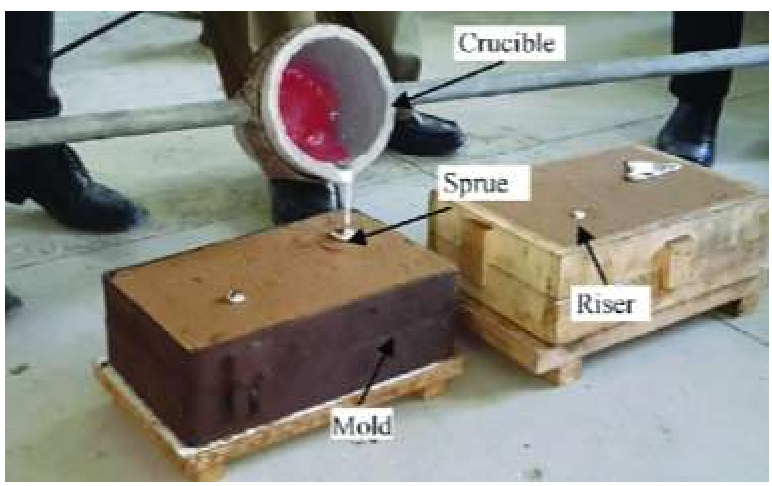


Fig.1.15. The molten alloy.

1.2.6 Heat Treatments

Heat treatments are intended to improve the mechanical properties of pieces obtained through aluminum casting. Although heat treatment is often associated with steel, aluminum alloys can also be quenched, which is typically the case for technical parts.

Depending on the type of alloy, the most common treatments are:

- Solution heat treatment, water quenching, tempering.
- Solution heat treatment, water quenching, aging.

However, other more specific treatments can be performed depending on the desired characteristics.

Given the deformations that quenching can cause, it is often necessary to perform straightening within a few hours after quenching (and before tempering).

This operation must be done quickly, otherwise, it may become impossible due to the aging process.

For more details, see the articles on aluminum casting alloys, heat treatment, and particularly quenching in the context of aluminum alloys.

CHAPTER 2: Manufacturing Process Plan

2.1. General analysis of the part

2.1.1. Analysis of the drawing

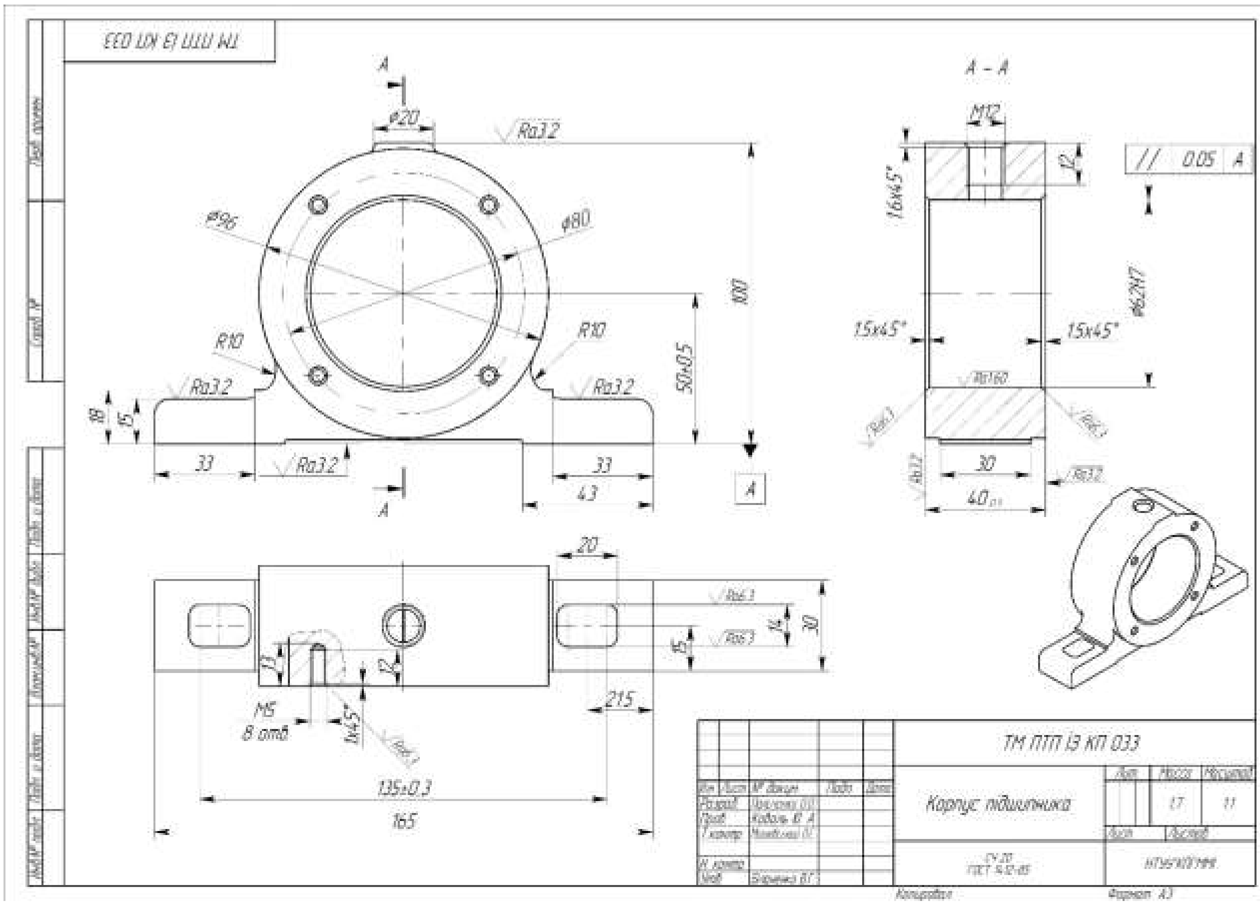


Fig.1. Initial variant drawing

As a result of checking the drawing "Bearing Housing", the following conclusions can be drawn:

- The part belongs to the classification of "Body"
- There are all the necessary dimensions to create the part;
- There are all the necessary roughness marks on responsible surfaces;
- The presence of permits in accordance with GOST

2.1.2. Part's working condition in the assembly

The part "Bearing Housing" encloses the bearings, which shields them from contaminants and ensure proper lubrication. The bearings are housed within the ⌀62H7 tolerance holes, while the ⌀M5 threaded holes serve to secure the bearing caps. During operation, the component experiences significant and continuous variations in load and vibrations.

2.1.3. Material analysis

Based the GOST 14.12-85 standard, the material of the part is "СЧ20" is a type of Cast Iron (Class 20), which has the following composition:

Table.1. Chemical Composition and Properties of the Material

Chemical Composition				
Carbon	Copper	Manganese	Silicon	Chromium
3.25-3.50%	0.15-0.40%	0.50-0.90%	1.80-2.30%	0.05-0.45%
Mechanical Properties				
Hardness (HB)	Tensile Strength (MPa)	Elasticity Modulus (GPa)	Compressive Stregth (MPa)	Shear Modulus (GPa)
156	152	66-97	572	27-39

The bearing housing operates under cyclic loading due to the presence of bearings requiring vibration isolation and lubrication. The lack of specified environmental protection implies a non-aggressive environment. Therefore, the selected material should be appropriate for these operating conditions. The provided drawing adequately details the design features, ensuring a comprehensive understanding of the bearing housing's functionality.

2.1.4. Type of production determination

In the designation of production type, we will be using the analog method, which is generally based on the part’s mass as well as the annual output volume.

- Part weight m=1497g (1.49 kg)
- Annual Output volume Np = 3000.

We have now the required information based on the mass properties data from Solidworks as well as the tasked given annual output of 3000, we can now use the table below to select the production type.

Table.2. Production type catalog

Weight of a part, kg	Type of production				
	Single	Small batch	Medium batch	High volume batch	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

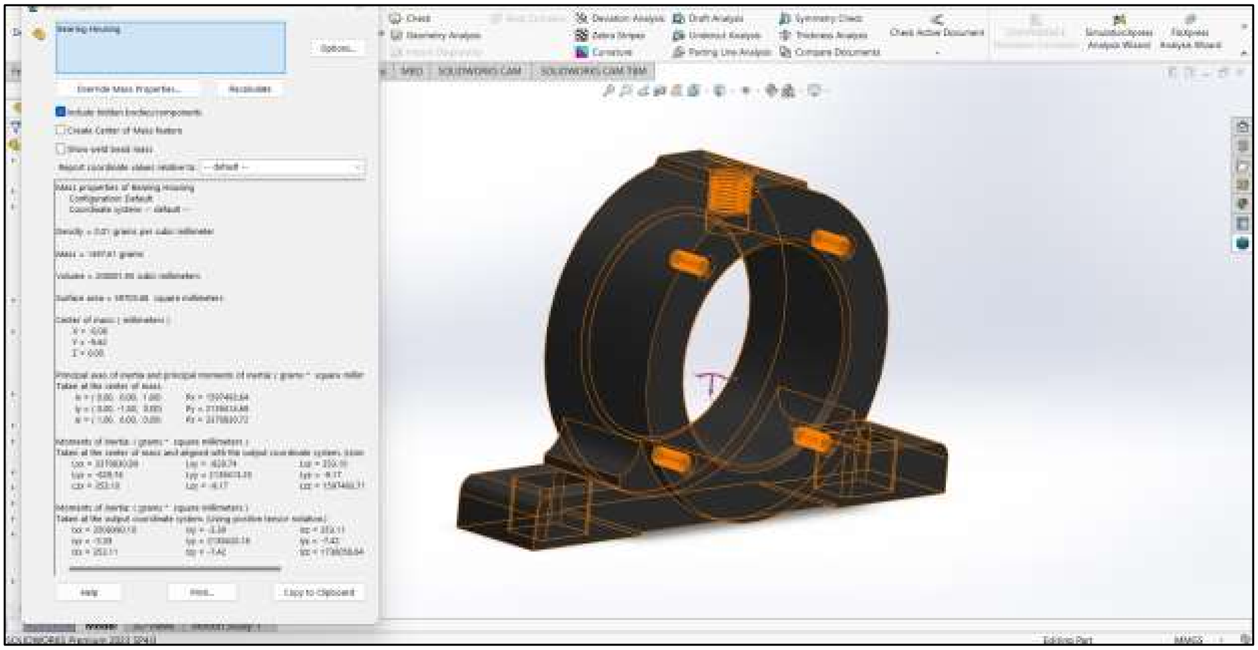


Fig.2. Mass properties of the part

<u>Conclusion</u>: the production type – medium batch. Therefore, we will perform all further calculations and make technological decisions for the medium-volume type of production.

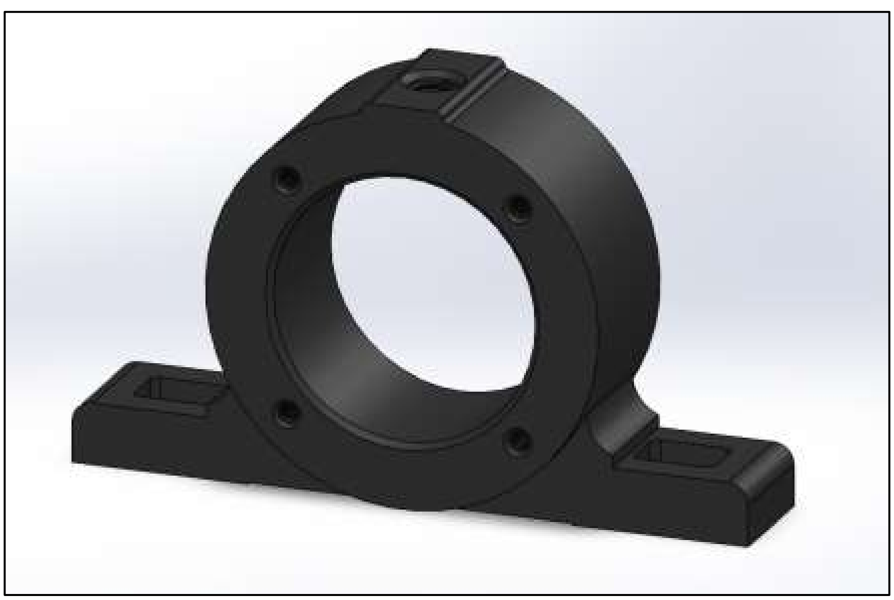


Fig.3. The 3D Model

2.2. Selection of the base process and Blank design

2.2.1. Selection of the base process

Initial data for the process selection:

- drawing of a part + 3D Model;
- material of a part – Cast Iron 20;
- Annual output – 3000 pcs

The Solidification processes' chart in Fig.4 allows us to effectively choose the most appropriate method for casting.

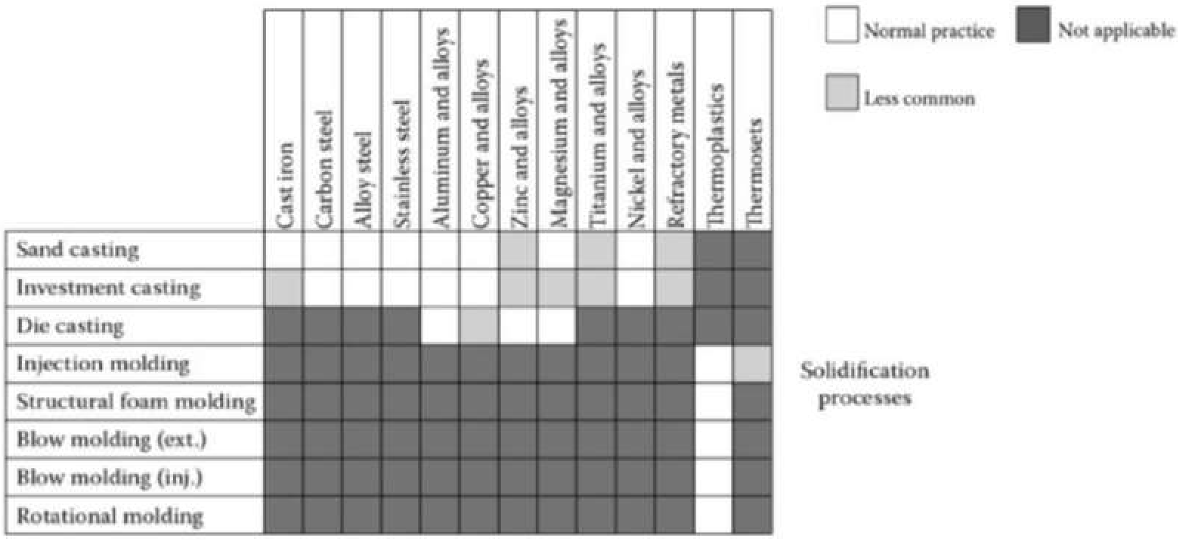


Fig.4. Solidification processes

An analysis of the part geometry, in conjunction with the provided chart, indicates sand casting as the optimal manufacturing process.

2.2.2. Casting Tolerance and Required Machining Allowance calculations

Considering both the material and relatively uncomplicated geometry of the part, sand casting appears to be a viable initial choice for the manufacturing process.

To determine the necessary machining allowance (RMA), we can refer to Table B.1 in reference [2]. As per the table, sand casting with Cast Iron recommends an RMA grade of F. Based on this grade and the part's largest dimension of 165mm (as shown in the drawing), Table 2 in reference [2] suggests a required machining allowance of 2mm.

Moving on to casting tolerance (CT) estimation, we can utilize Table A.1 in reference [2], considering this is a long production run. For sand casting with Grey Iron, the CT10 tolerance grade might be suitable. The estimated casting tolerances based on this selection are presented in Table 3.

The sketches of RMA and CT location are presented in Fig.5.

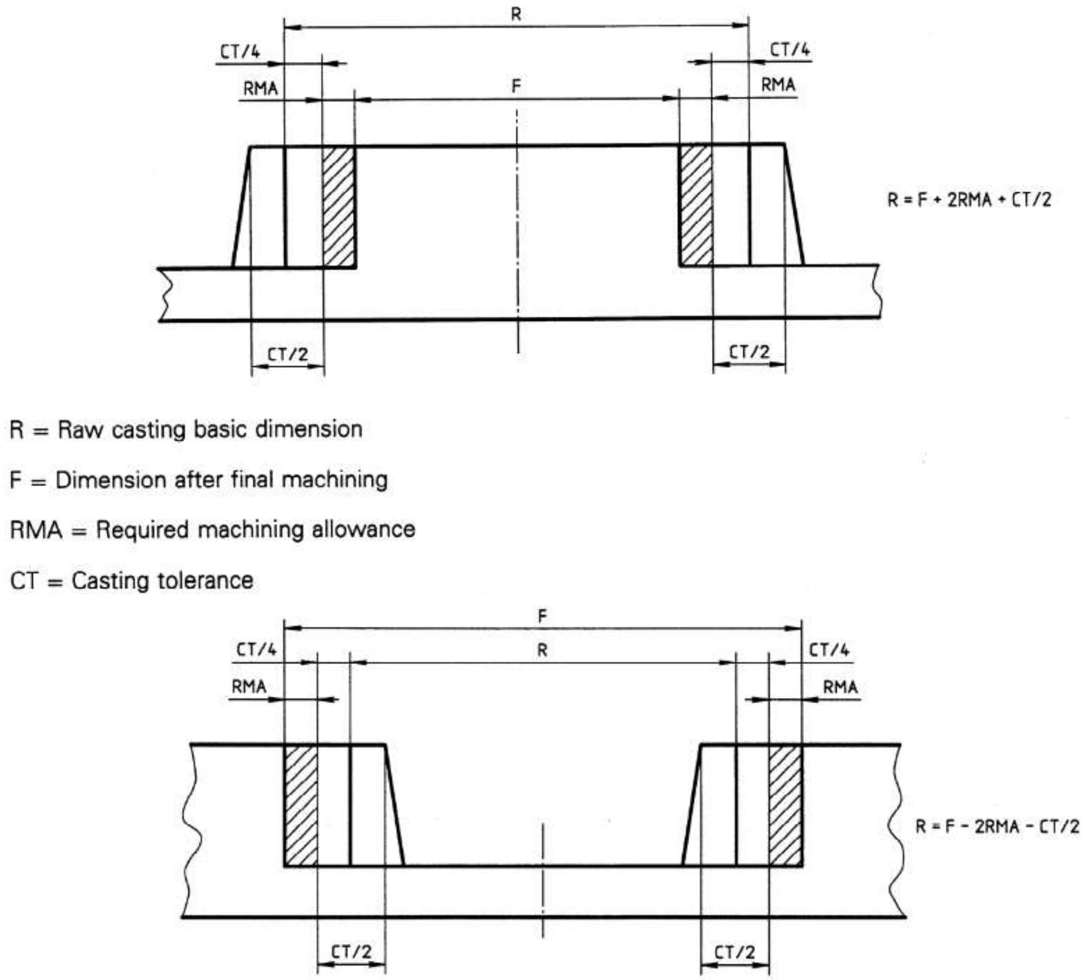


Fig.5. CT an RMA illustration

Table.3. CT and RMA Tolerances

Dimension of a part	RMA	Min limit of size for external features (or max for internal features)	Casting tolerance, mm	Raw casting basic dimension
165	2	169	4	171±2
100	2	104	3.6	105.8±1.8
30	2	34	2.6	35.3±1.3
40	2	44	2.2	45.1±1.1
15	2	19	2.2	20.1±1.1
20	2	24	2.4	25.2±1.2
18	2	22	2.4	23.2±1.2
43	2	47	2.6	48.3±1.3
⌀62	2	⌀60	3.2	58.4±1.6
14	2	18	2.2	19.1±1.1
⌀96	2	⌀100	3.2	101.6±1.6

To optimize the sand-casting process, the following design principles were incorporated:

- Minimized Mold Height: The part positioning prioritizes the lowest possible mold height to reduce material usage and potential casting defects.
- Symmetrical Parting Line: The parting line coincides with the plane of symmetry, simplifying mold assembly and core placement.
- Elimination of Sharp Corners: Sharp corners have been replaced with radii of 2-5mm, promoting better metal flow, reduced stress concentrations, and easier casting removal.
- Draft Angle for Demolding: All walls perpendicular to the parting line have a 2° draft angle, facilitating the removal of the casting from the mold.
- Machining Allowance Placement: The machining allowance (RMA) is strategically applied only to surfaces requiring secondary machining, minimizing material waste.

- Core Usage for Complex Features: Cores are utilized to create the central holes and main pocket, ensuring dimensional accuracy and reducing machining needs.
- Secondary Processing for Small Features: Small features like minor holes will be machined in a secondary process to maintain casting integrity and address limitations in core creation.

Fig.6. 3D Model of the Casting Blank

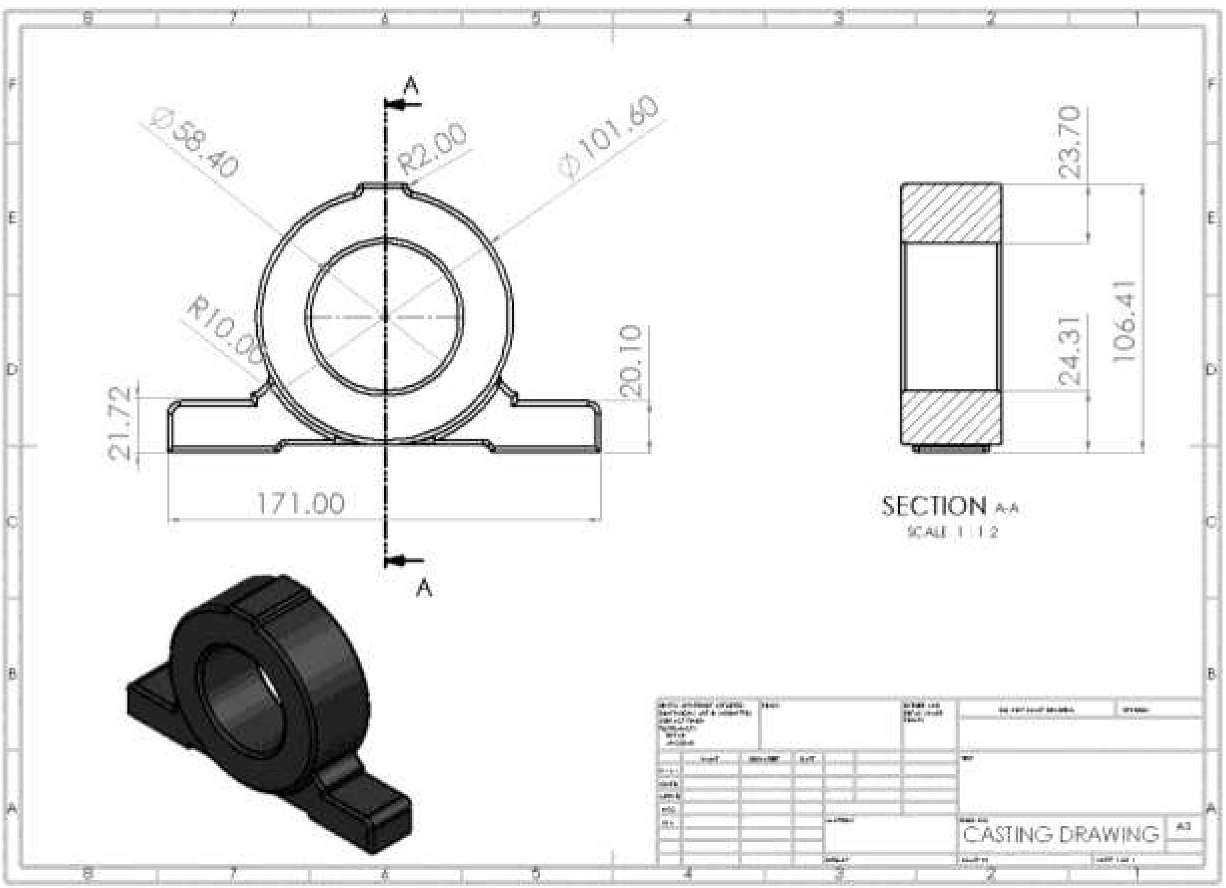


Fig.7. Technical 2D drawing of the Blank

2.3. Locating Scheme selection

The General Manufacturing Data (MD) correction algorithm consists of two stages:

- Rationale for choosing general manufacturing datum (GMD)
- Rationale for choosing a manufacturing datum for the first manufacturing operation.

2.3.1. Choosing General Manufacturing Datum (GMD)

A General Manufacturing Datum (GMD) refers to a collection of reference surfaces used throughout most, if not all, of a part's manufacturing process. The selection of appropriate GMDs is guided by the part's working drawing. To establish these GMDs, the part's surfaces are first categorized based on their intended function:

1. Primary Functional Datum (Design Datum): These surfaces define the critical functional features of the part according to its design specifications.
2. Secondary Functional Datum (Design Datum): These surfaces contribute to the part's functionality but to a lesser degree compared to primary datums.
3. Fastening Surfaces: These surfaces are specifically designed to accommodate fasteners like screws or rivets used to secure the part to other components.
4. Free Surfaces: These surfaces are not critical for the part's function or assembly and do not influence GMD selection.

For further analysis let's classify surfaces of a given part according to their purpose:

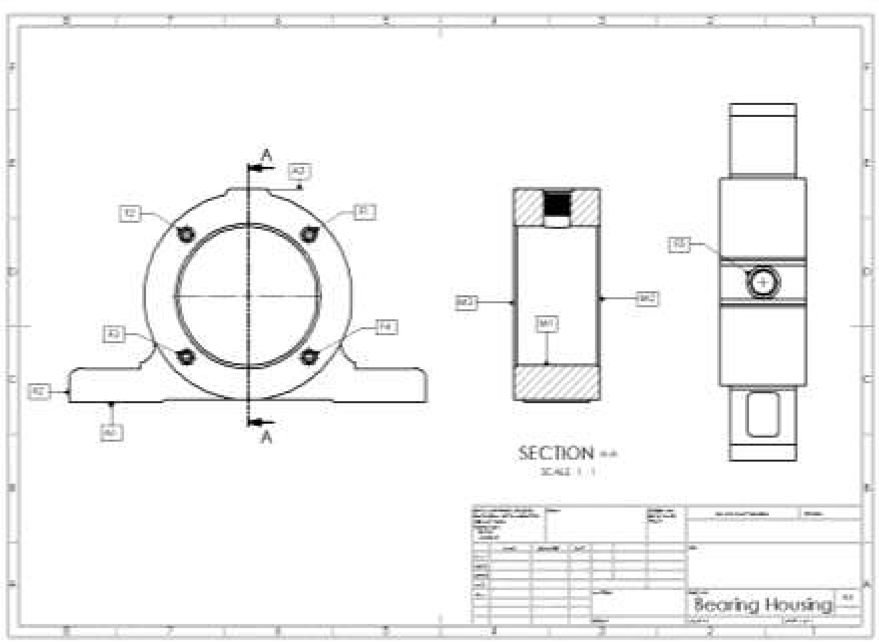


Fig.8. Surfaces Classification

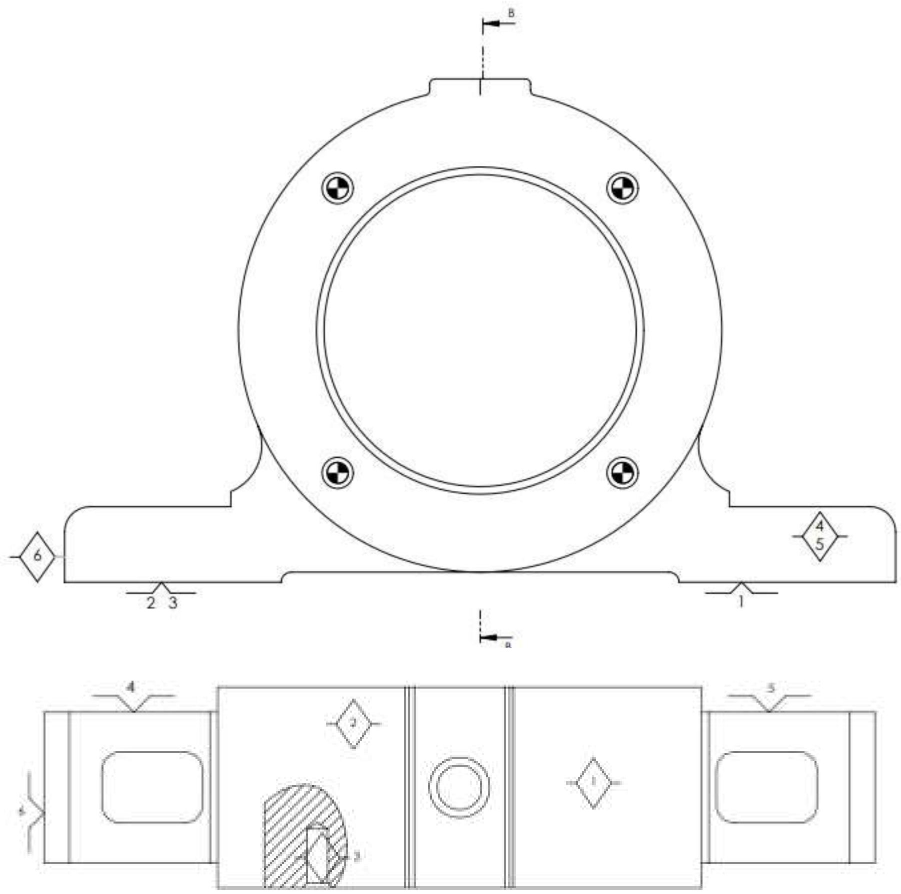


Fig.9. GMD Locating scheme

The formula for the locating scheme presented in Fig.8 is as follows:

$$LS_{GMD} = S(3) + DS(2) + O(1)$$

where S(3) – setting datum, deprives the workpiece 3 degrees of freedom,
DS (2) – double support datum, deprives the workpiece 2 degrees of freedom,
and O(1) – support datum, deprives the workpiece 1 degree of freedom.

This scheme is implemented using: a plane, round head and diamond head locating pins. In this case, the "Bearing Housing" is sufficiently oriented, which allows processing its surfaces with the specified requirements for the spatial position. In our case GMD remains unchanged.

$$GMD = Const$$

2.3.2. Choosing MD for the first manufacturing operation

When choosing datum surfaces for the first manufacturing operations it is necessary to ensure openness for processing of all surfaces of GMD and to choose machines that can carry out consecutive processing of GMD surfaces for achievement of the set quality characteristics. Otherwise, it is necessary to take into account that the full set of the GMD has to be processed during next first technological operations.

Let’s consider possible locating schemes for the first manufacturing operations as well as their advantages and disadvantages. For this purpose, we will use the following recommendations:

- for MD select surfaces that aren’t supposed to be processed according to the drawing
- if all surfaces of the workpiece have to be processed, then as MD we take the surfaces that have the lowest allowance, if the allowances are uniform, it is necessary to choose surfaces on which defects are not allowed;
- choose as MD surfaces for which it is necessary to provide a uniform allowance for the next stages of processing;
- if there are several possible schemes of basing, then as MD we accept the option with the shortest dimensional chain.

The first variant is presented in Fig.10.

Advantages:

- Easy to implement.
- Ensures the correct placement of untreated surfaces related to the treated ones.

Disadvantages:

- Blocks processing the workpiece from 2 sides (as it is cylindrical).
- Does not ensure the alignment of the perpendicularity of the main hole.

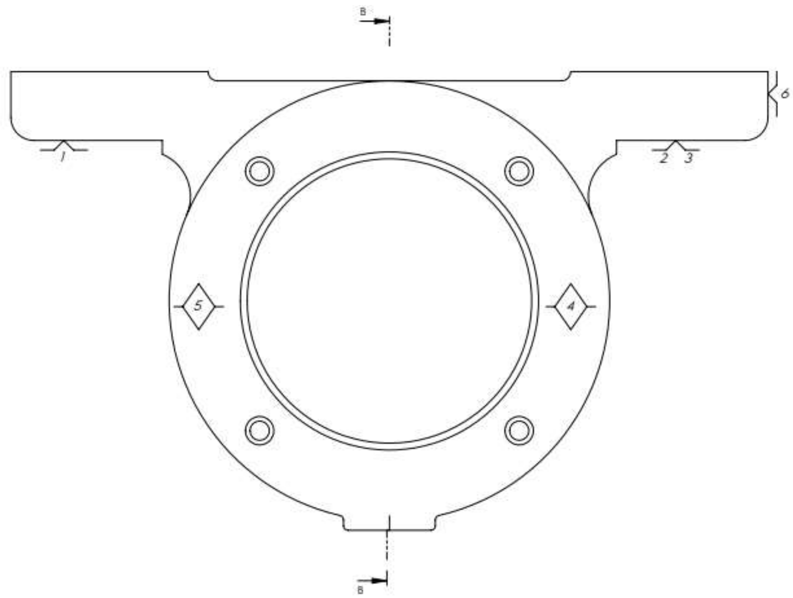


Fig.10. Locating scheme for first manufacturing operation MD

The second variant is presented in Fig.11.

Advantages:

- Provides perpendicularity of the untreated side plane to a datum surface
- Uniform allowance for further processing of the hole used for locating

Disadvantages:

- Quite difficult in the design implementation (double support datum is implemented by a special expansion plunger mandrel)
- The correct placement of untreated surfaces relative to the treated ones is ensured not for all surfaces.

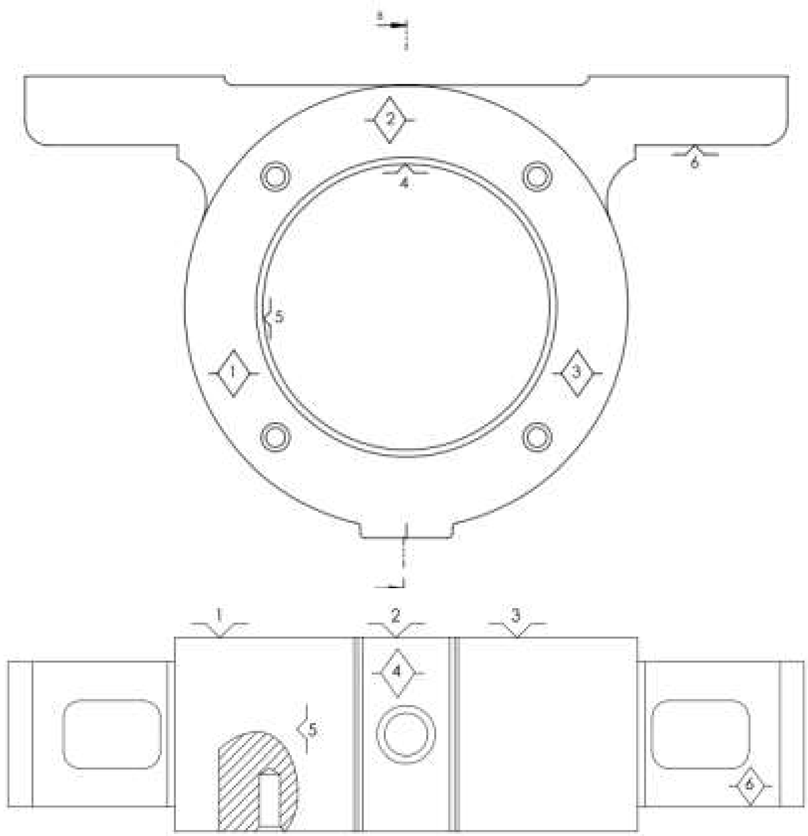


Fig.11. Locating scheme for first manufacturing operation MD 2

The third variant is presented in Fig.12.

Advantages:

- Easy to implement.
- Ensures the perpendicularity of untreated surface relative to the datum surface
- Ensures parallelism of untreated surface relative to the datum surface, but only in the specified cross section, where the mounting elements are located

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.

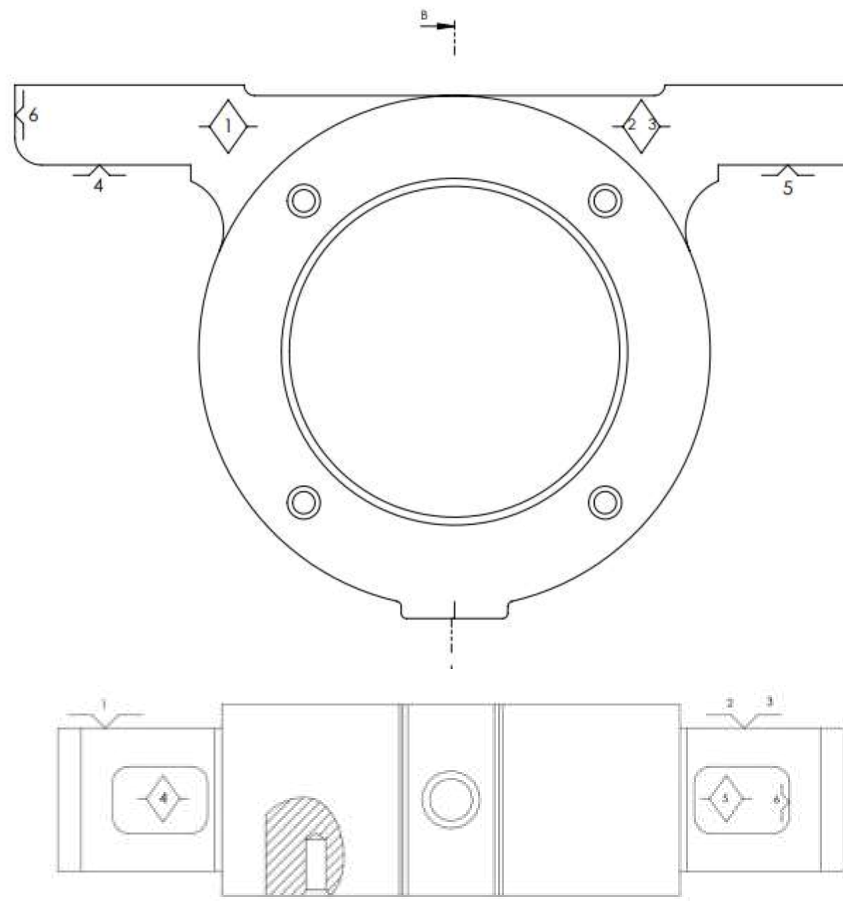


Fig.12. *Locating scheme for first manufacturing operation MD 3*

Conclusion: Among the various locating schemes considered (refer to Fig.12), the third variant offers several advantages for establishing the GMD. This scheme is not only straightforward to implement but also effectively ensures the precise spatial positioning of untreated surfaces relative to those undergoing processing in the first manufacturing operation. An additional benefit is the ability to process multiple surfaces besides the GMD during this initial stage, enhancing overall efficiency. Therefore, this third locating scheme has been chosen as the preferred method for defining the GMD.

2.4. Design of the typical surfaces processing routes

Parts can be broken down into fundamental geometric shapes, like cylinders, cones, planes, and even special shapes like threads, that all contribute to their overall purpose. The type of cutting tool used depends on the specific surface to achieve the desired accuracy. As a result, different sequences of machining operations are needed for different surfaces.

Developing machining sequences for individual elements is the first step in a seven-stage process for creating a process plan. This initial plan addresses dimensional accuracy, shape, and surface quality for each feature, but it doesn't consider their relative position yet. That aspect is tackled later by choosing locating schemes and dividing the machining into stages like roughing, finishing, and finalizing. To optimize time and cost-effectiveness, selecting standardized and proven processes for part manufacturing and key surface machining is recommended.

Table 4 serves as a reference for commonly used machining sequences, along with achievable accuracy and surface roughness values for these operations.

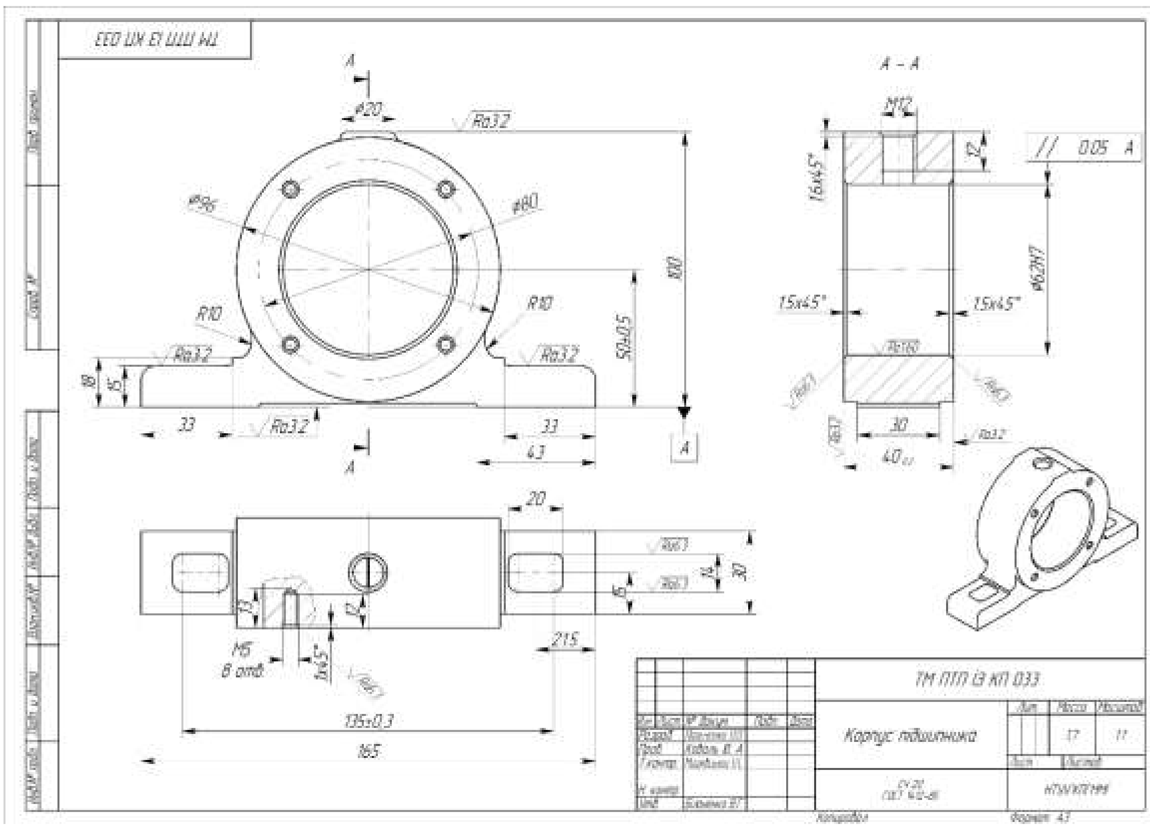


Fig.13. The part "Bearing Housing"

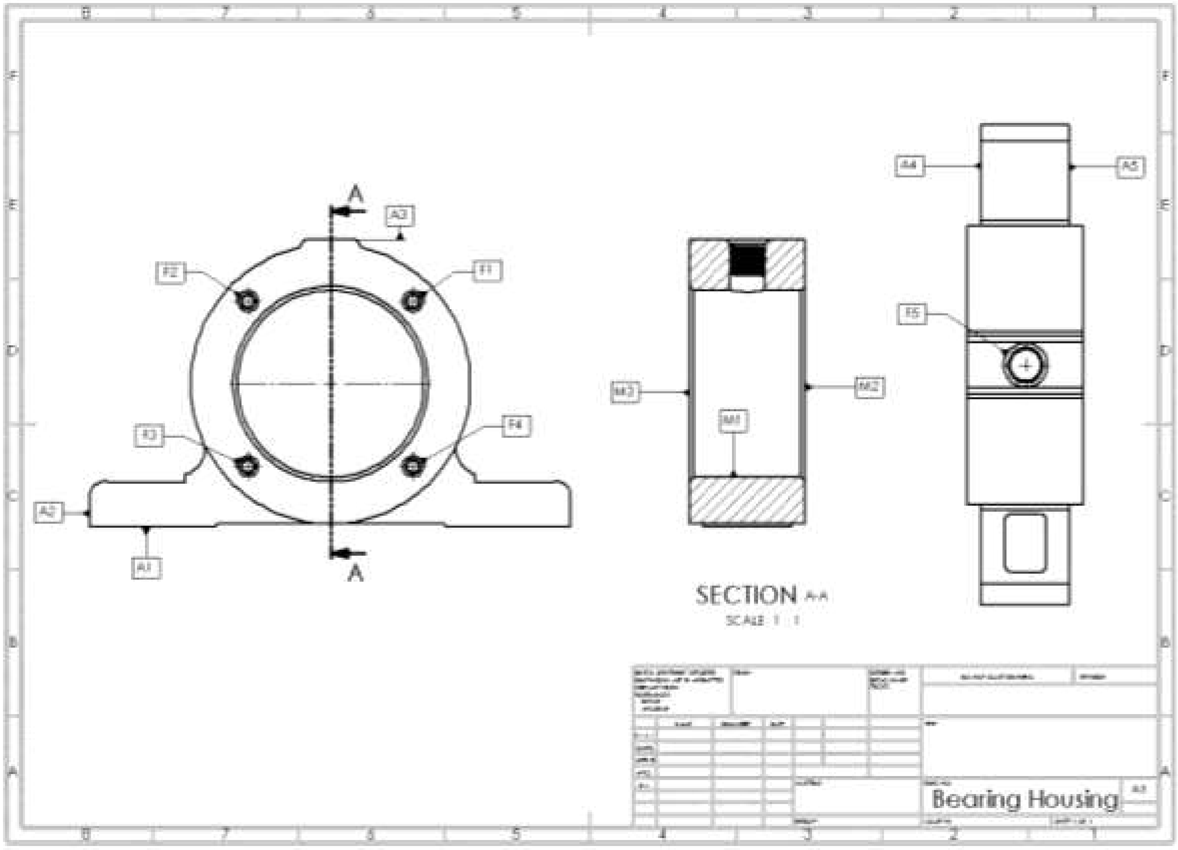


Fig.14. Surfaces Classification

Table.4. Machining Sequences

Surfaces	IT	Ra	Machining Sequence	IT	Ra
	According to the drawing			After Machining	
1	2	3	4	5	6
M1	H7	1.6	Centering Reaming Chamfering	H7	1.6
M2	14	6.3	Rough Milling Finish Milling	14	6.3
M3	14	6.3	Rough Milling Finish Milling	14	6.3
F1, F2, F3, F4	7H	6.3	Centering Drilling Countersinking Threading	7H	6.3
F5	7H	-	Centering	7H	-

			Drilling Countersinking Threading		
A1	14	-	Rough Milling Finish Milling	14	-
A2	14	-	Rough Milling Finish Milling	14	-

2.5. Design of the operational manufacturing process plan

This part of the project outlines the development of a manufacturing process plan that prioritizes accuracy, complexity management, and cost-effectiveness. Here are the key principles that will guide this plan:

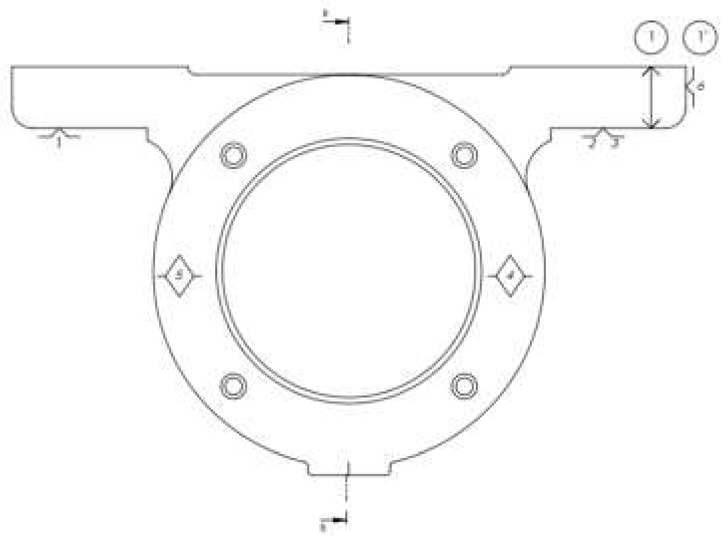
1. Datum First: Surfaces used as references for subsequent machining will be processed initially.
2. Progressive Improvement: Each successive operation should enhance the quality of the treated surfaces. If a step (like heat treatment) necessitates backtracking, the datum surfaces will be re-evaluated.
3. Roughing with Caution: Roughing operations for critical, large, or high-value parts may require separation by aging processes to minimize residual stresses.
4. Early Defect Detection: Surfaces with critical dimensional or quality requirements should be machined early to allow for timely defect identification and correction.
5. Roughing Sequence: During the roughing stage, prioritize surfaces with the largest machining allowances and those deemed most critical for functionality.
6. Finishing Priority: Final finishing should be reserved as the last step for the most critical surfaces.
7. Stiffness Considerations: To minimize workpiece distortion, prioritize machining of surfaces that have the least impact on overall rigidity.
8. Precise Location: Surfaces requiring precise relative positioning should be machined in a single setup.
9. Tool Consistency: Maintain the same tool for finishing critical and precise surfaces to ensure consistency.
10. Fastening Surface Timing: Machining of fastening surfaces should occur after finishing related surfaces, typically as a third-stage operation.

005 Multipurpose

Machine: TAJMAC-ZPS H500

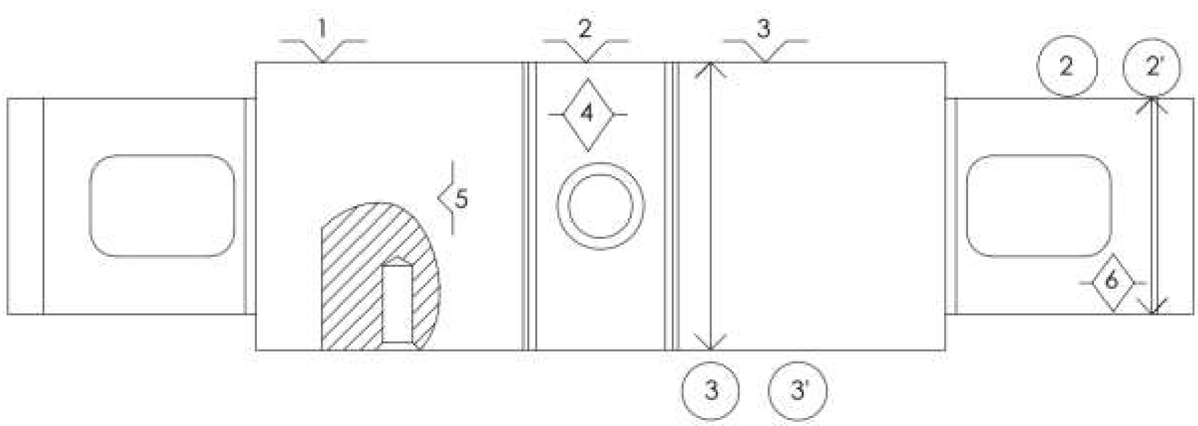
A. Install, secure, remove

Position 1



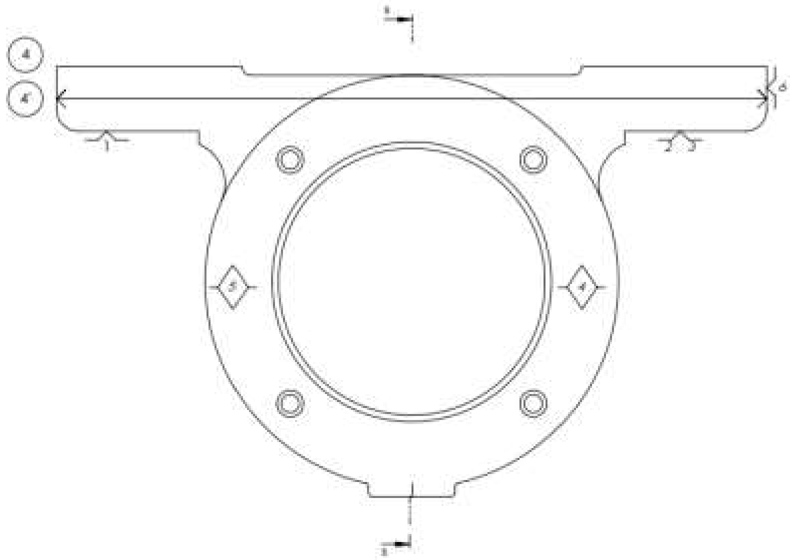
005.01 Rough Milling surface A1 to dimension l
005.02 Finish Milling surface M to dimension l’
005.03 Rough Milling surface A3

Position 2 - Turn the table 90 º clockwise



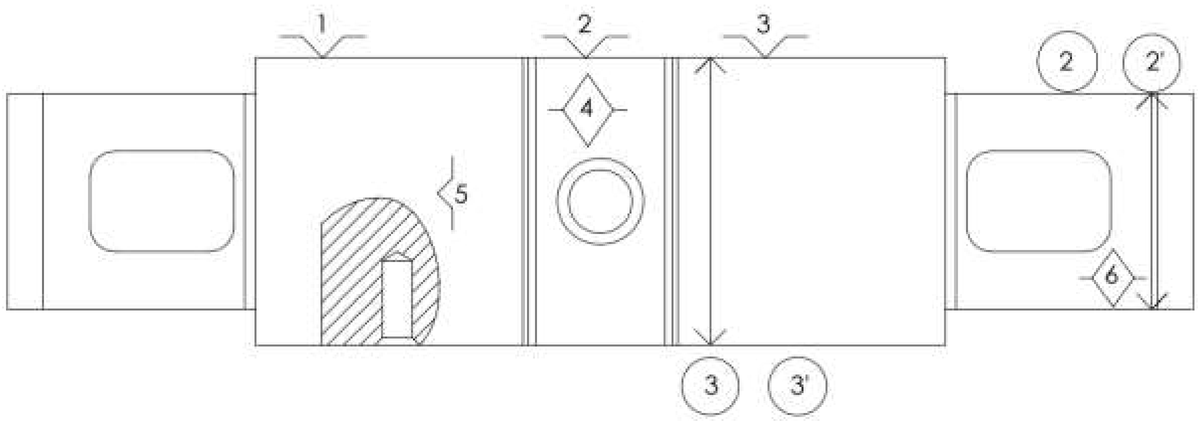
005.04 Rough mill the surface A4 to dimension 2
005.05 Finish mill the surface A4 to dimension 2’
005.06 Rough mill the surface M3 to dimension 3
005.07 Finish mill the surface M3 to dimension 3’

Position 3 - Turn the table 90 º clockwise



005.08 Rough mill the surface A2 to dimension 4
005.09 Finish mill the surface A2 to dimension 4'

Position 4 – Turn the table 90 º counterclockwise



005.10 Center the position of 4 holes F1, F2, F3 and F4
005.11 Drill the 4 through holes
005.12 Tap the 4 holes
005.13 Countersink the 4 holes

005.14 Center the hole M1
005.15 Ream the Hole M1
005.16 Chamfer the hole M1 edges

2.6 Machine and Tooling Selection

2.6.1. Machine Selection

The chosen production procedures dictate the type of machinery required. For example, turning necessitates a lathe or turning center.

Machine Size Considerations

The initial selection of a machine should consider the physical size of the workpiece in relation to the machine itself. For instance, a part cannot be machined on a lathe with a bed shorter than the part's length.

Power and Force Analysis

The power requirements for all operations should be assessed. Machines unable to meet the peak power demand can be excluded, unless there are no alternative options available. In such cases, reducing feed rates, speeds, or cutting depth can potentially lessen the power needed. Conversely, machines with excessive power capabilities can also be excluded, except when specific operations require a higher spindle speed. Again, if no other machines are available, adjustments to feed rates, speeds, or cutting depth can potentially reduce the power requirement.

Capability Analysis

This analysis considers the required dimensional and geometric accuracy, as well as the desired surface finish. Machines incapable of achieving these parameters should be excluded.

Operational Analysis

The batch size is a crucial factor to consider during machine selection. Machines that are not suitable for the specific production quantity should be discounted.

Justification for Horizontal Machining Center (TAJMAC-ZPS H500 A):

Taking all the aforementioned conditions and limitations into account, along with the process plan developed earlier, the TAJMAC-ZPS H500 A horizontal machining center emerges as the preliminary choice.

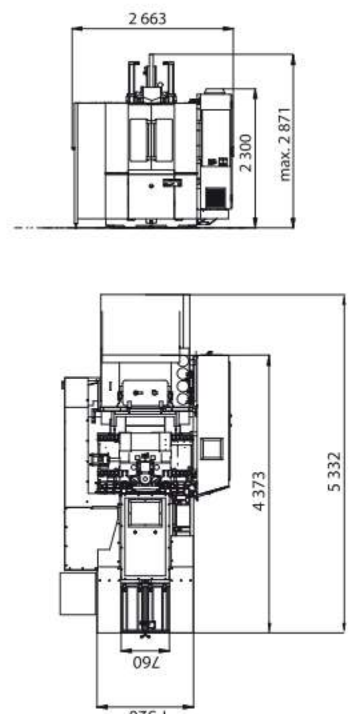
As detailed in Fig.15, the H500 is a highly productive machine suitable for complex machining of parts made from steel, grey cast iron, and soft metal alloys. This machine offers functionalities beyond simple milling. Its capabilities include:

- Three mutually perpendicular axes for milling (X, Y, Z)

- Rotary B-axis for additional flexibility
- Drilling, boring, reaming, and thread cutting operations
- Utilization of screw die heads without alignment bushings in the Z-axis

The TAJMAC-ZPS H500 A's versatility and power make it a strong candidate for effectively processing the parts as outlined in the process plan, considering factors like required machining operations, workpiece size, and production volume.

The horizontal machining centre in the **H 500** version is a highly productive machine for the complex chip machining of parts from the steel, grey cast iron and soft metal alloys clamped on the rotary table. It enables to perform the milling operations in three mutually perpendicular X, Y, Z coordinate axes and in the rotary B axis. It also enables to perform the drilling, boring, reaming and thread cutting operations as well as the usage of the 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/sec²		
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		
Power supplies			
Nominal voltage of mains	3 × 400 V/50 Hz, 3 × 480 V/60 Hz		
Operational power input (depending on spindle and equipment)	38 / 51 / 64 kVA		
Compressed air	0,6 – 0,8 MPa		
Complementary data			
Machine floor layout	5 332 × 2 663 mm		
Machine maximum height	2 871 mm		
Machine weight	10 000 kg		
Control system	SIEMENS, HEIDENHAIN*, FANUC*		

Fig.15. Technical data of the selected machine

2.6.2. Tooling Selection and Cutting Conditions

With the process (milling) and machine (horizontal machining center) defined, we can now narrow down the selection of suitable tools for milling surface A3 to dimension 9. Only tools compatible with both milling operations and the chosen machine should be considered.

Workpiece Characteristics

Analyzing the workpiece characteristics like material (type of steel, grey cast iron, or soft metal alloy), geometry (size and complexity of surface A3), and required dimensional and surface finish tolerances will further refine the tool selection process. These factors influence the choice of appropriate tool material and geometry for optimal performance.

Tool Analysis and Availability

Based on the tooling data available and the general tooling specifications generated earlier, we can identify the actual tools readily available for this specific operation. This eliminates theoretical options that might not be part of the existing inventory.

Tool Selection Process

The selection process depends on whether single-piece tooling or insert-type tooling is used:

Single-Piece Tooling

If a single-piece tool is chosen, the toolholder needs to be selected first. Once the toolholder is determined, the tool geometry and material can be finalized.

Insert-Type Tooling

For insert-type tooling, the selection process follows these steps

1. Clamping System Selection: Choose the appropriate insert clamping system based on the toolholder and insert type compatibility.

2. Toolholder Selection: Select the type and size of toolholder that fits the machine and accommodates the chosen insert size and clamping system.

3. Insert Shape Selection: Determine the insert shape most suitable for the milling operation (e.g., end mill, face mill) based on the geometry of surface A3.

4. Insert Size Selection: Choose the insert size (diameter or cutting edge length) that offers a good balance between material removal rate and tool life.

5. Tool Edge Radius Selection: Specify the desired tool edge radius on the insert, considering the required surface finish and potential corner radii on surface A3.

6. Insert Type Selection: Select the specific insert type (coating, material grade) based on the workpiece material, cutting speed, and desired tool life.

7. Tool Material Selection: If using a single-piece tool, determine the appropriate tool material considering factors like workpiece material, wear resistance, and overall tool life.

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.

Tool selection for the manufacturing step
005.06 Rough mill the surface M3 to dimension 3

Radial cutting width = 10mm
Required allowance = 2mm

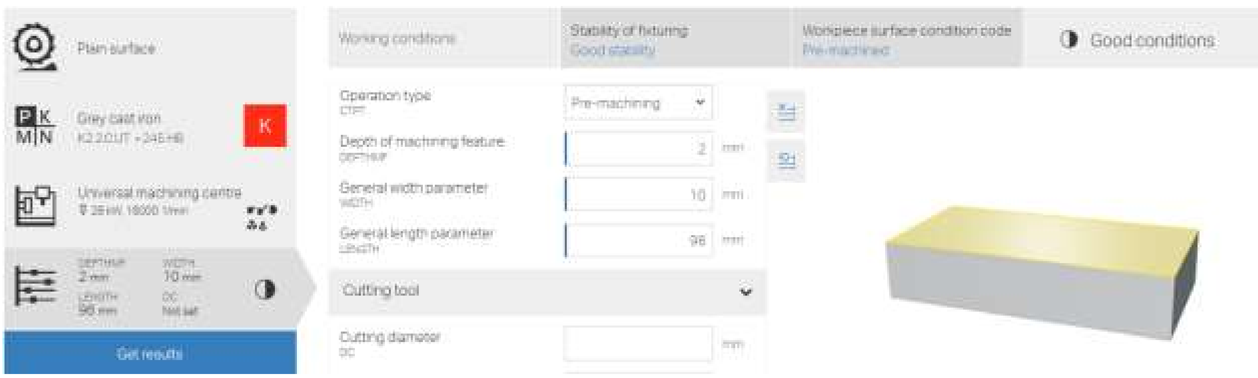


Fig.16. Initial Data

After applying the initial data, consider the results of analysis: recommended cutting tool and cutting conditions

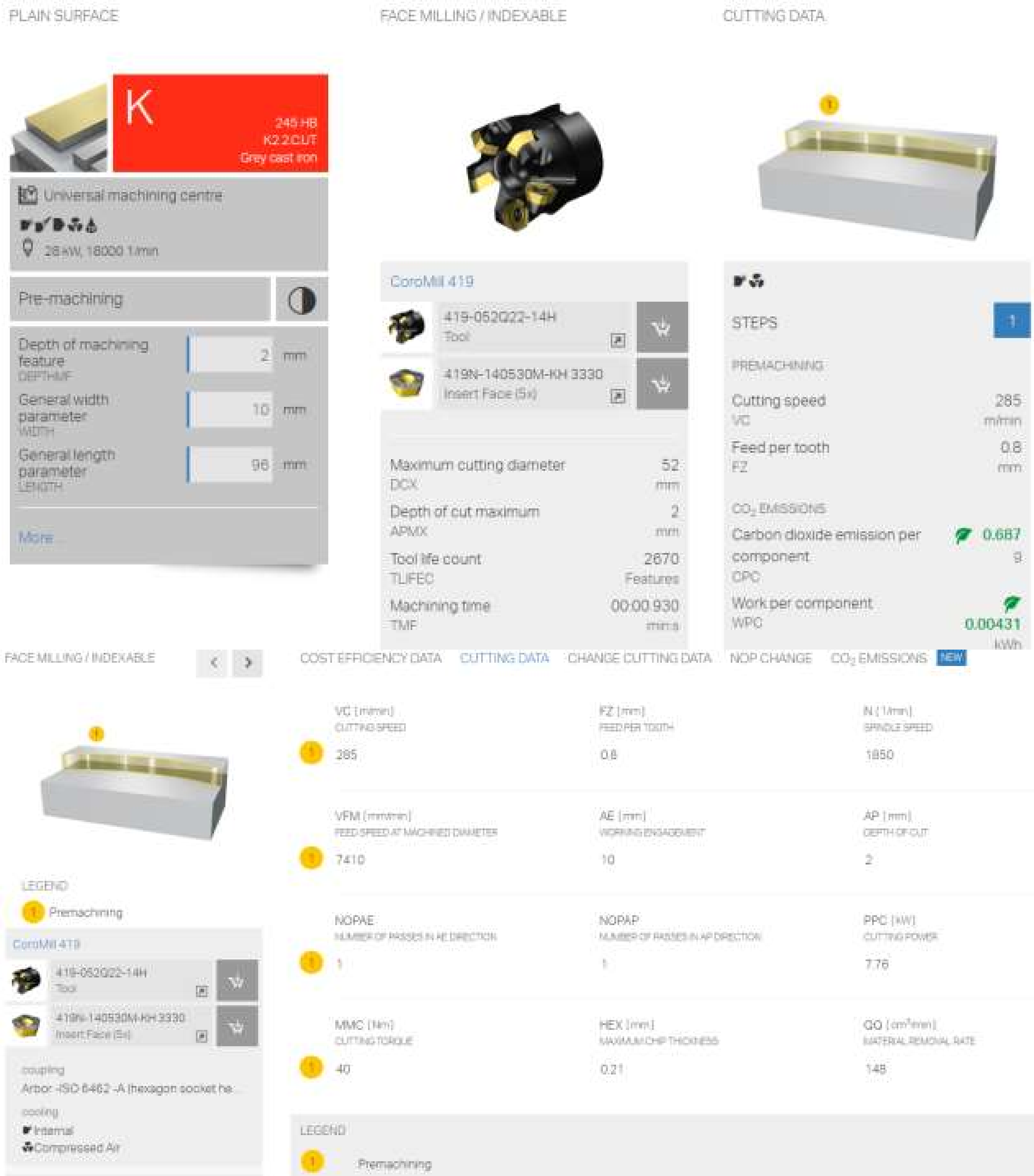
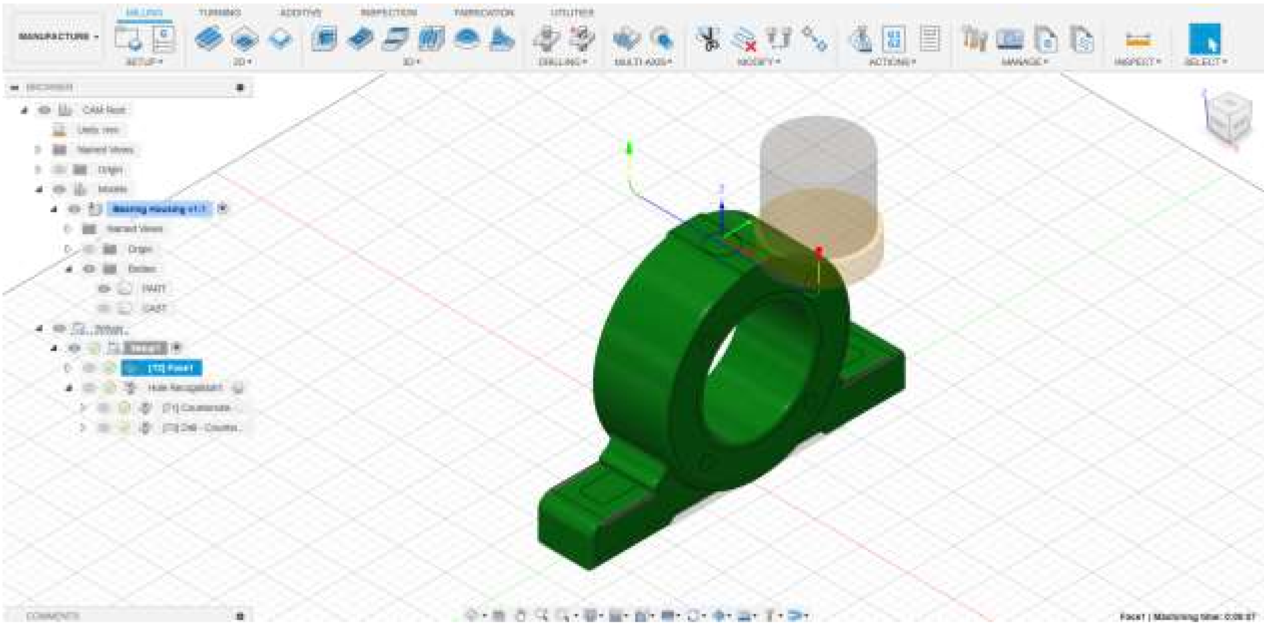


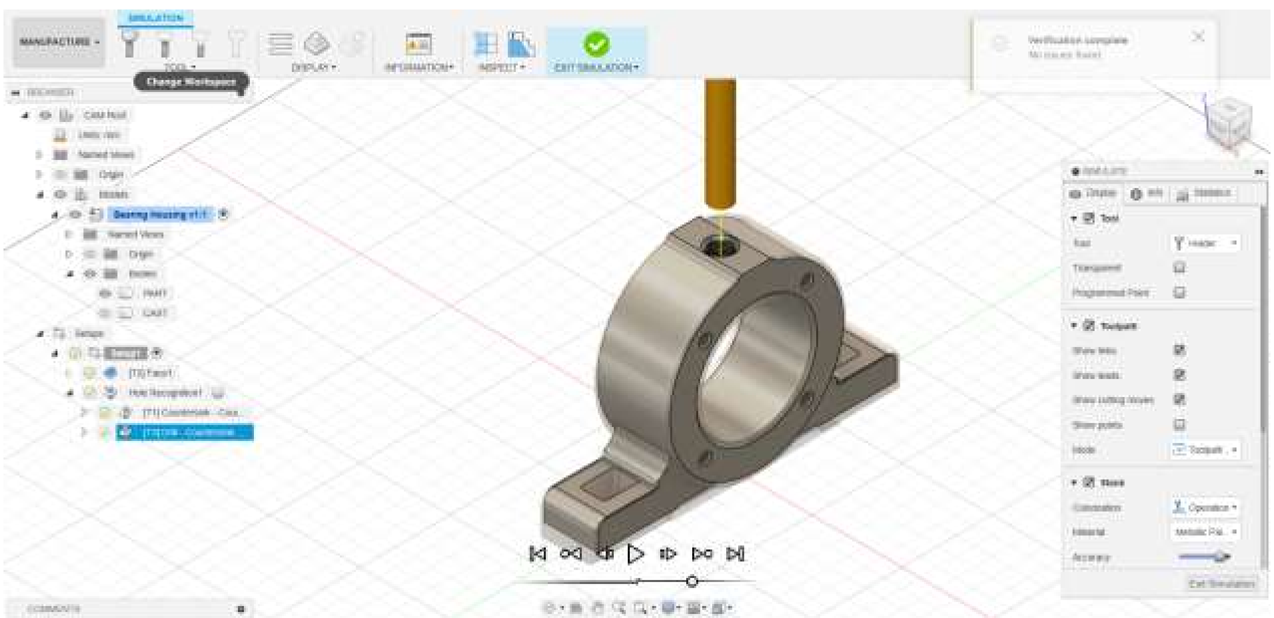
Fig.17. Recommended Cutting Tool and Cutting Data

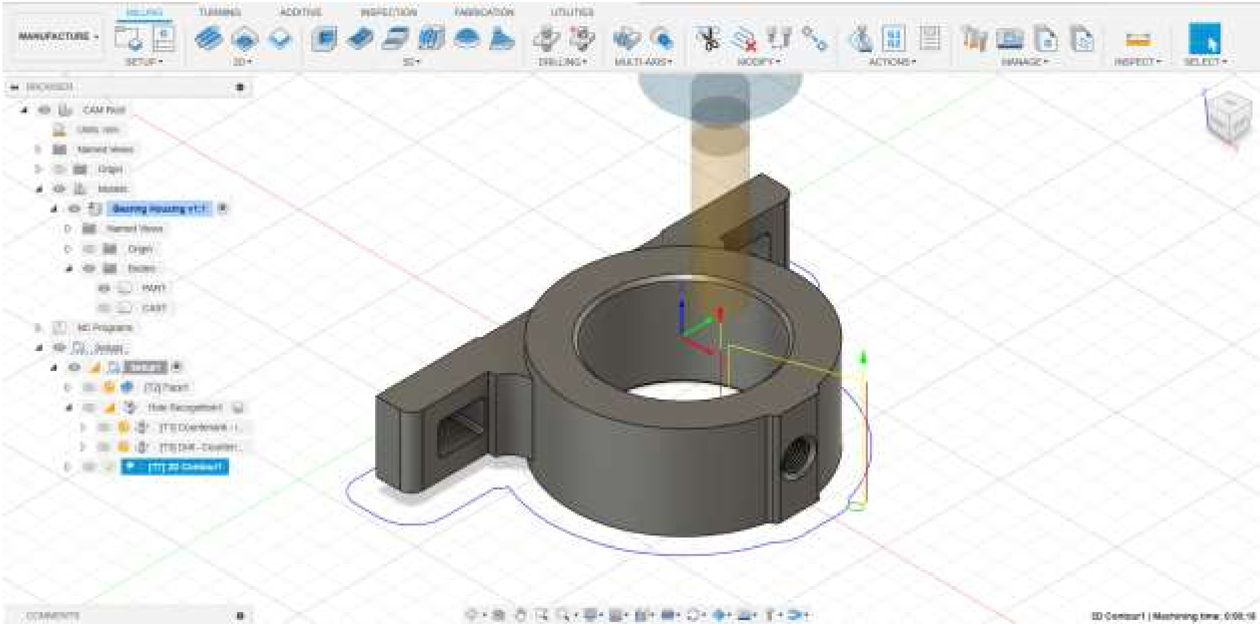
2.7. Simulation and G-Code

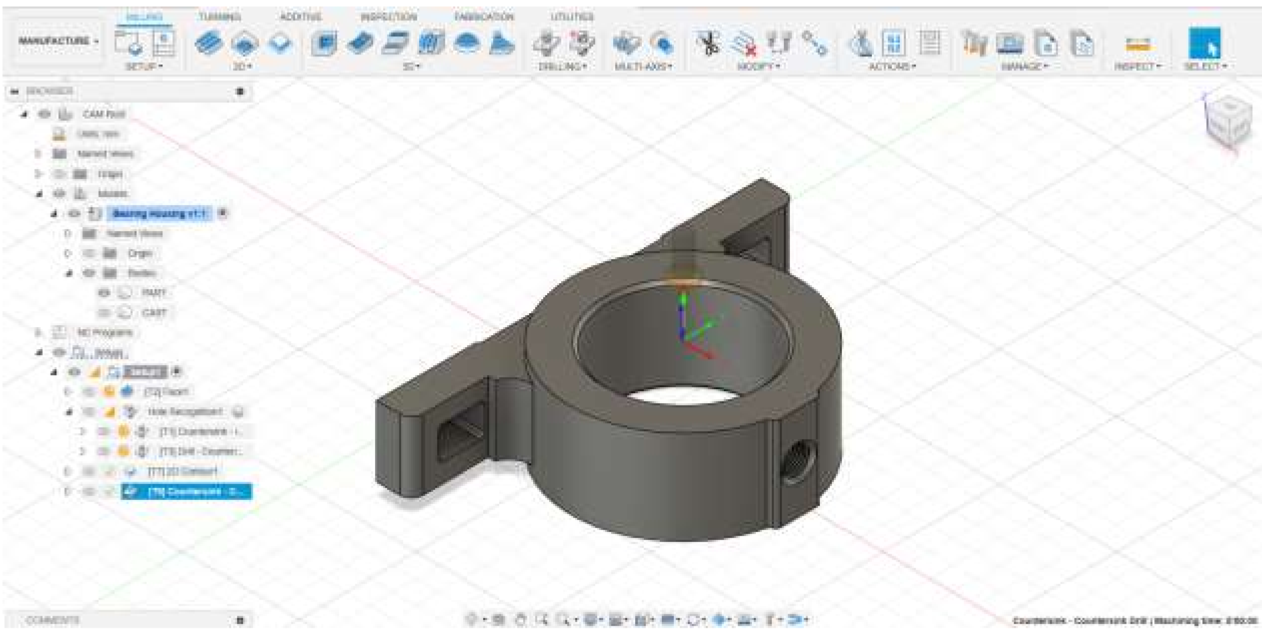
This part is reserved for simulation on Fusion 360 and the G-code generated using the same software, following are screenshots of the operations mentioned in the manufacturing process plan, following the screenshots will be the G code attached.

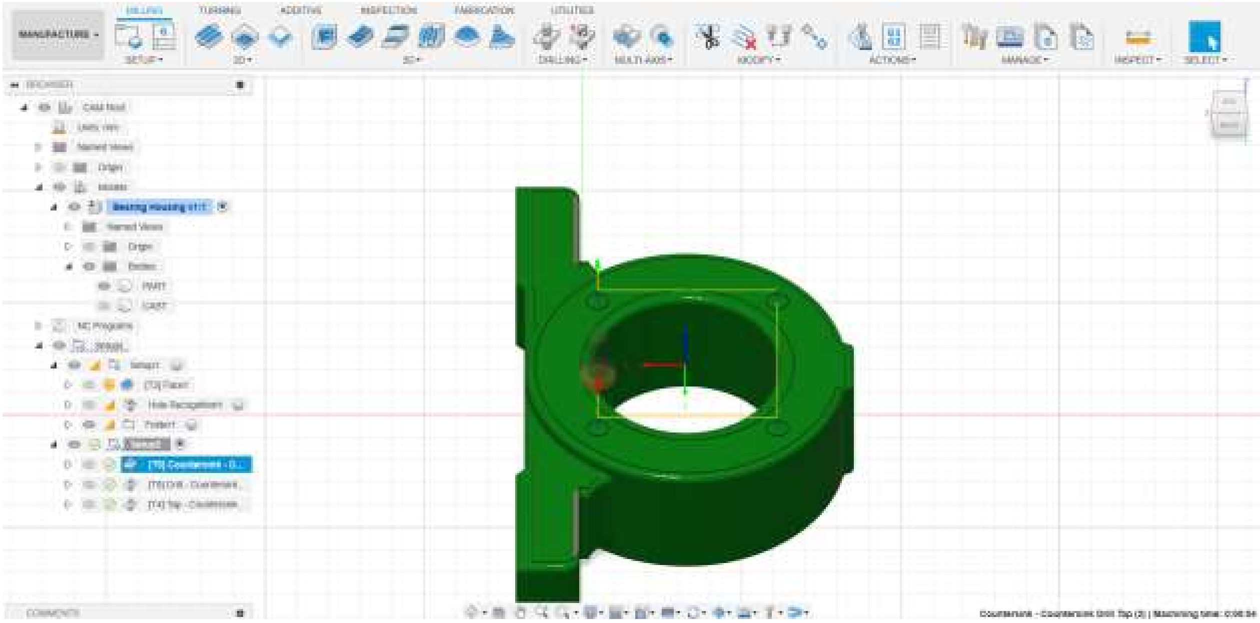
2.7.1. Simulation screenshots

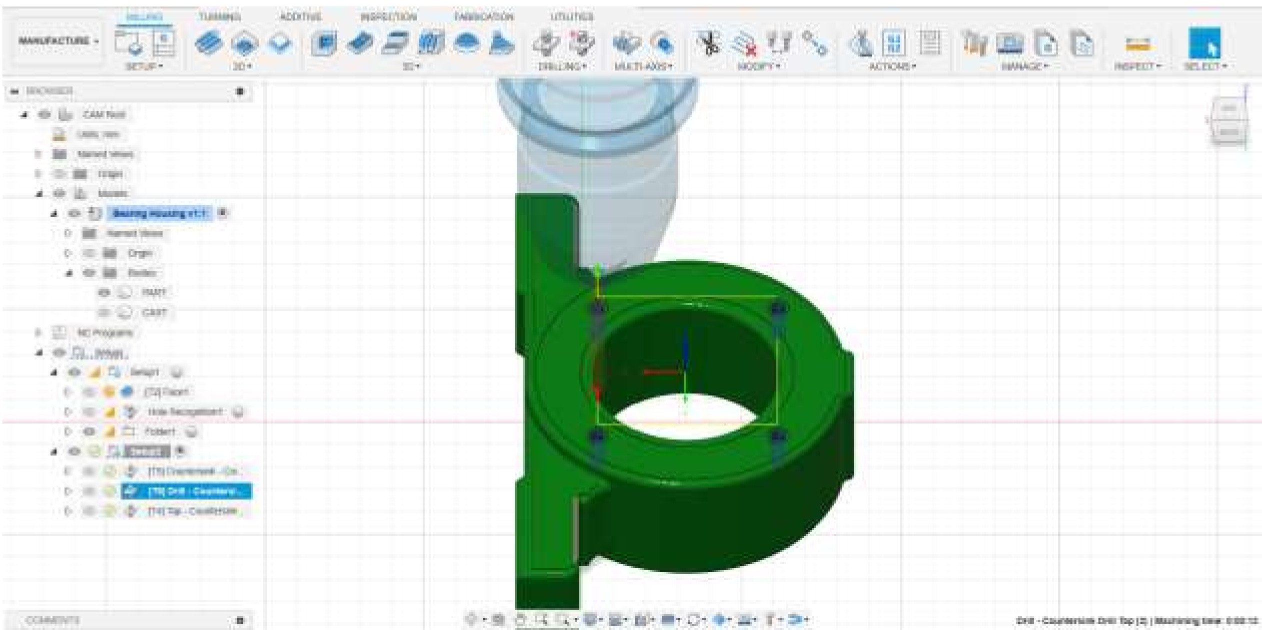


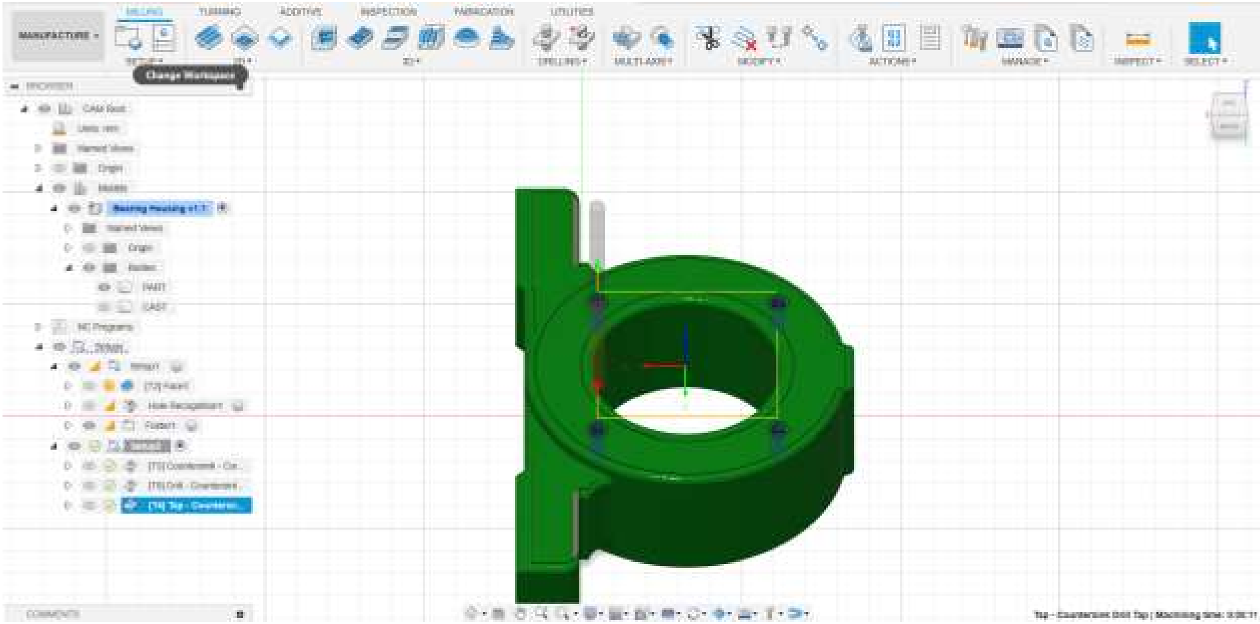












2.7.2. G-Code generated

```
%

O00210

(Using high feed G1 F650. instead of G0.)

(T1 D=15.875 CR=0. TAPER=90deg - ZMIN=-10.512 - spot drill)

(T2 D=50. CR=0. - ZMIN=-2.912 - face mill)

(T3 D=12. CR=0. TAPER=118deg - ZMIN=-26.985 - drill)

N10 G90 G94 G17

N15 G21

N20 G53 G0 Z0.


(Face1)

N25 T2 M6

N30 S5000 M3

N35 G17 G90 G94

N40 G54
```

```
N45 M8
N50 G1 X52.5 Y0.012 F650.
N55 G0 G43 Z15. H2
N60 T1
N65 G0 Z5.
N70 G1 Z2.088 F333.33
N75 G18 G3 X47.5 Z-2.912 I-5. K0. F1000.
N80 G1 X45.01
N85 X-45.01
N90 G3 X-50.01 Z2.088 I0. K5.
N95 G0 Z15.
N100 M9
N105 M5
N110 G53 G0 Z0.

(Countersink - Countersink Drill Tap)
N115 M1
N120 T1 M6
N125 S5000 M3
N130 G17 G90 G94
N135 G54
N140 M8
N145 G1 X0. Y0.012 F650.
N150 G0 G43 Z15. H1
N155 T3
```

```
N160 G0 Z5.
N165 G98 G81 X0. Y0.012 Z-10.512 R2.088 F333.33
N170 G80
N175 G0 Z15.
N180 M9
N185 M5
N190 G53 G0 Z0.

(Drill - Countersink Drill Tap)
N195 M1
N200 T3 M6
N205 S5000 M3
N210 G17 G90 G94
N215 G54
N220 M8
N225 G1 X0. Y0.012 F650.
N230 G0 G43 Z15. H3
N235 T2
N240 G0 Z5.
N245 G98 G73 X0. Y0.012 Z-26.985 R2.088 Q3. F1000.
N250 G80
N255 G0 Z15.

N260 M5
N265 M9
```

```
N270 G53 G0 Z0.
N275 G53 G0 X0. Y0.
N280 M30

%
%
O00215
(Using high feed G1 F650. instead of G0.)
(T5 D=12. CR=0. TAPER=90deg - ZMIN=0. - countersink)
(T7 D=18. CR=0. - ZMIN=-40.5 - flat end mill)
N10 G90 G94 G17
N15 G21
N20 G53 G0 Z0.

(2D Contour1)
N25 T7 M6
N30 S5390 M3
N35 G17 G90 G94
N40 G54
N45 M8
N50 G1 X18.394 Y-1.788 F650.
N55 G0 G43 Z15. H7
N60 T5
N65 G0 Z5.
N70 G1 Z1. F1065.76
```

```
N75 Z-38.7
N80 G18 G2 X20.194 Z-40.5 I1.8 K0. F3197.27
N85 G1 X21.994
N90 G17 G3 X23.794 Y0.012 I0. J1.8
N95 X-22.206 I-23. J0.
N100 X23.794 I23. J0.
N105 X21.994 Y1.812 I-1.8 J0.
N110 G1 X20.194
N115 G18 G3 X18.394 Z-38.7 I0. K1.8
N120 G0 Z5.
N125 G1 X61.746 Y17.564 F650.
N130 Z1. F1065.76
N135 Z-38.7
N140 X61.74 Y17.56 Z-38.866 F3197.27
N145 X61.72 Y17.549 Z-39.031
N150 X61.686 Y17.53 Z-39.193
N155 X61.64 Y17.505 Z-39.35
N160 X61.581 Y17.472 Z-39.502
N165 X61.511 Y17.432 Z-39.648
N170 X61.429 Y17.387 Z-39.785
N175 X61.336 Y17.335 Z-39.913
N180 X61.233 Y17.278 Z-40.03
N185 X61.121 Y17.216 Z-40.136
N190 X61.002 Y17.149 Z-40.23
N195 X60.875 Y17.078 Z-40.311
```

N200 X60.742 Y17.004 Z-40.378

N205 X60.604 Y16.928 Z-40.431

N210 X60.463 Y16.849 Z-40.469

N215 X60.319 Y16.769 Z-40.492

N220 X60.174 Y16.688 Z-40.5

N225 X58.601 Y15.812

N230 G17 G3 X57.904 Y13.364 I0.876 J-1.573

N235 G2 X59.294 Y8.012 I-9.61 J-5.352

N240 G1 Y-7.988

N245 G2 X55.38 Y-16.402 I-11. J0.

N250 X-21.632 Y-52.391 I-54.586 J16.414

N255 G3 X-21.783 Y-52.658 I0.785 J-0.619

N260 G2 X-24.206 Y-56.196 I-8.423 J3.17

N265 G1 Y-77.488

N270 G2 X-38.206 Y-91.488 I-14. J0.

N275 G1 X-48.206

N280 G2 X-57.206 Y-82.488 I0. J9.

N285 G1 Y-39.488

N290 G2 X-56.206 Y-35.365 I9. J0.

N295 G1 Y0.012

N300 Y35.389

N305 G2 X-57.206 Y39.512 I8. J4.123

N310 G1 Y82.512

N315 G2 X-48.206 Y91.512 I9. J0.

N320 G1 X-38.206

N325 G2 X-24.206 Y77.512 I0. J-14.

N330 G1 Y56.22

N335 G2 X-21.783 Y52.682 I-6. J-6.708

N340 G3 X-21.632 Y52.415 I0.936 J0.352

N345 G2 X55.38 Y16.426 I22.426 J-52.403

N350 X57.904 Y13.364 I-7.086 J-8.414

N355 G3 X60.353 Y12.667 I1.573 J0.876

N360 G1 X61.925 Y13.543

N365 X62.07 Y13.624 Z-40.492

N370 X62.214 Y13.704 Z-40.469

N375 X62.356 Y13.782 Z-40.431

N380 X62.493 Y13.859 Z-40.378

N385 X62.626 Y13.933 Z-40.311

N390 X62.753 Y14.004 Z-40.23

N395 X62.873 Y14.07 Z-40.136

N400 X62.985 Y14.133 Z-40.03

N405 X63.087 Y14.19 Z-39.913

N410 X63.18 Y14.242 Z-39.785

N415 X63.262 Y14.287 Z-39.648

N420 X63.333 Y14.327 Z-39.502

N425 X63.392 Y14.359 Z-39.35

N430 X63.438 Y14.385 Z-39.193

N435 X63.471 Y14.404 Z-39.031

N440 X63.491 Y14.415 Z-38.866

N445 X63.498 Y14.418 Z-38.7

```
N450 G0 Z15.
N455 M9
N460 M5
N465 G53 G0 Z0.

(Countersink - Countersink Drill)
N470 M1
N475 T5 M6
N480 S5000 M3
N485 G17 G90 G94
N490 G54
N495 M8
N500 G1 X0.794 Y0.012 F650.
N505 G0 G43 Z15. H5
N510 T7
N515 G0 Z5.
N520 G98 G81 X0.794 Y0.012 Z0. R5. F333.33
N525 G80
N530 G0 Z15.

N535 M5
N540 M9
N545 G53 G0 Z0.
N550 G53 G0 X0. Y0.
N555 M30
```

```
%
%
O00220
(Using high feed G1 F650. instead of G0.)
(T4 D=5. CR=0. - ZMIN=-12. - right hand tap)
(T5 D=12. CR=0. TAPER=90deg - ZMIN=0. - countersink)
(T8 D=5. CR=0. TAPER=118deg - ZMIN=-13.502 - drill)
N10 G90 G94 G17
N15 G21
N20 G53 G0 Z0.

(Countersink - Countersink Drill Tap 2)
N25 T5 M6
N30 S5000 M3
N35 G17 G90 G94
N40 G54
N45 M8
N50 G1 X27.49 Y28.296 F650.
N55 G0 G43 Z15. H5
N60 T8
N65 G0 Z5.
N70 G98 G81 X27.49 Y28.296 Z0. R5. F333.33
N75 X-29.078
N80 Y-28.272
```

N85 X27.49

N90 G80

N95 G0 Z15.

N100 M9

N105 M5

N110 G53 G0 Z0.

(Drill - Countersink Drill Tap 2)

N115 M1

N120 T8 M6

N125 S5821 M3

N130 G17 G90 G94

N135 G54

N140 M8

N145 G1 X27.49 Y28.296 F650.

N150 G0 G43 Z15. H8

N155 T4

N160 G0 Z5.

N165 Z2.

N170 G1 Z-1.25 F436.59

N175 G0 Z-1.15

N180 G1 Z-2.5 F436.59

N185 G0 Z-2.4

N190 G1 Z-3.75 F436.59

N195 G0 Z-3.65

N200 G1 Z-5. F436.59

N205 G0 Z-4.9

N210 G1 Z-6.25 F436.59

N215 G0 Z-6.15

N220 G1 Z-7.5 F436.59

N225 G0 Z-7.4

N230 G1 Z-8.75 F436.59

N235 G0 Z-8.65

N240 G1 Z-10. F436.59

N245 G0 Z-9.9

N250 G1 Z-11.25 F436.59

N255 G0 Z-11.15

N260 G1 Z-12.5 F436.59

N265 G0 Z-12.4

N270 G1 Z-13.502 F436.59

N275 G0 Z5.

N280 X-29.078

N285 Z2.

N290 G1 Z-1.25 F436.59

N295 G0 Z-1.15

N300 G1 Z-2.5 F436.59

N305 G0 Z-2.4

N310 G1 Z-3.75 F436.59

N315 G0 Z-3.65

N320 G1 Z-5. F436.59

N325 G0 Z-4.9

N330 G1 Z-6.25 F436.59

N335 G0 Z-6.15

N340 G1 Z-7.5 F436.59

N345 G0 Z-7.4

N350 G1 Z-8.75 F436.59

N355 G0 Z-8.65

N360 G1 Z-10. F436.59

N365 G0 Z-9.9

N370 G1 Z-11.25 F436.59

N375 G0 Z-11.15

N380 G1 Z-12.5 F436.59

N385 G0 Z-12.4

N390 G1 Z-13.502 F436.59

N395 G0 Z5.

N400 Y-28.272

N405 Z2.

N410 G1 Z-1.25 F436.59

N415 G0 Z-1.15

N420 G1 Z-2.5 F436.59

N425 G0 Z-2.4

N430 G1 Z-3.75 F436.59

N435 G0 Z-3.65

N440 G1 Z-5. F436.59

N445 G0 Z-4.9

N450 G1 Z-6.25 F436.59

N455 G0 Z-6.15

N460 G1 Z-7.5 F436.59

N465 G0 Z-7.4

N470 G1 Z-8.75 F436.59

N475 G0 Z-8.65

N480 G1 Z-10. F436.59

N485 G0 Z-9.9

N490 G1 Z-11.25 F436.59

N495 G0 Z-11.15

N500 G1 Z-12.5 F436.59

N505 G0 Z-12.4

N510 G1 Z-13.502 F436.59

N515 G0 Z5.

N520 X27.49

N525 Z2.

N530 G1 Z-1.25 F436.59

N535 G0 Z-1.15

N540 G1 Z-2.5 F436.59

N545 G0 Z-2.4

N550 G1 Z-3.75 F436.59

N555 G0 Z-3.65

N560 G1 Z-5. F436.59

N565 G0 Z-4.9

N570 G1 Z-6.25 F436.59

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N575 G0 Z-6.15
N580 G1 Z-7.5 F436.59
N585 G0 Z-7.4
N590 G1 Z-8.75 F436.59
N595 G0 Z-8.65
N600 G1 Z-10. F436.59
N605 G0 Z-9.9
N610 G1 Z-11.25 F436.59
N615 G0 Z-11.15
N620 G1 Z-12.5 F436.59
N625 G0 Z-12.4
N630 G1 Z-13.502 F436.59
N635 G0 Z5.
N640 Z15.
N645 M9
N650 M5
N655 G53 G0 Z0.

(Tap - Countersink Drill Tap)
N660 M1
N665 T4 M6
N670 S500 M3
N675 G17 G90 G94
N680 G54
N685 M8
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N690 G1 X27.49 Y28.296 F650.

N695 G0 G43 Z15. H4

N700 T5

N705 G0 Z5.

N710 G98 G84 X27.49 Y28.296 Z-12. R5. F750.

N715 X-29.078

N720 Y-28.272

N725 X27.49

N730 G80

N735 G0 Z15.


N740 M5

N745 M9

N750 G53 G0 Z0.

N755 G53 G0 X0. Y0.

N760 M30


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CHAPTER 3: Fixture Design

3.1. Purpose of the Fixture

This chapter focuses on the design and analysis of a critical component for achieving successful machining of the bearing housing: the fixture. As repeatability and security are paramount during the machining process, the fixture plays a vital role in ensuring the bearing housing is precisely positioned and held securely throughout all machining operations.

3.2. Clamping Force Calculation

Calculating the clamping force is essential for machining operations because theoretical projections often fall short in accounting for real-world variables, such as material inconsistencies and machining dynamics. These calculations ensure that the fixture applies sufficient force to hold the workpiece securely without causing deformation. To achieve accurate and practical results, we employ the method detailed below, which considers the actual cutting forces, the coefficient of friction between the workpiece and the fixture, and other operational parameters.

3.2.1 Determining forces

To determine the machining forces acting on the workpiece during the milling operation, we'll focus on the tangential force (Fc) as the main component due to the use of a large diameter (66mm) end mill for plane milling. However, the radial force (Fr) and axial force (Fa) will also be considered for a more comprehensive analysis.

The specific values of these forces will be calculated by taking into account the workpiece material properties, cutting parameters (speed, feed rate, depth of cut), and the specific geometry of the chosen 66mm end mill (number of flutes, helix angle). This force analysis is crucial for selecting an appropriate machine tool with sufficient rigidity and power to handle the expected loads during machining.

To calculate the main component of the cutting force, we can use the following formula:

$$Pz = \frac{10 \times C_p \times h^{xp} \times Sz \times Bf \times z}{Dfr \times n \times k}$$

Here, Pz represents the main component of the cutting force, Cp, xp, yp, up, qp, wp are coefficients of proportionality and exponents, h is the cutting depth in mm, Sz is the feed per tooth in mm/tooth, Bf is the milling width in mm, z is the number of cutter teeth, Dfr is the diameter of the mill in mm, n is the speed in rpm, and k is a coefficient that accounts for the difference between the actual material of the cutter and the one used for calculations.

Substituting the given values, we get:

$$Pz = \frac{10 \times 545 \times 0.95 \times 0.15^{0.75} \times Sz \times 6}{66^{1.3} \times 1920^{0.2}}$$

$$Pz = 1246\ N$$

3.2.2. Calculating required Clamping force

To calculate the necessary clamping force for a fixture, use the equation below:

$$Clamping\ Force = {Cutting\ Force}/{Coefficient\ of\ Friction}$$

To determine the cutting force, we use the following formula:

$$Cutting\ Force = {4.5 \times k \times f \times d \times b}/{Cutting\ Speed}$$

Where:

- k: for the material constant
- f: for the feed rate
- d: for the depth of the cut
- b: for the width of the cut

$$Cutting\ speed = {3.14 \times 15 \times 1200}/{60{,}000} = 0.942$$

$$Cutting\ Force = {4.5 \times 5 \times 0.3 \times 15 \times 40}/{0.942} \approx 4{,}300$$

We will assume a Coefficient of Friction close to 0.4, so now we can calculate the required Clamping Force

$$Clamping\ Force = {Cutting\ Force}/{Coefficient\ of\ Friction}$$

$$Clamping\ Force = {4300}/{0.4} = 10{,}750\ N$$

So the required Clamping Force will tally up to the mentioned 10,750 N

3.3. Designating of the Fixture

Having calculated the required clamping force and reviewed the planned manufacturing operations, we've determined that a table vise is a well-suited option for securely holding the workpiece during machining.

For reference, the table vise design we'll be employing is depicted in Figure 20 below. This selection ensures the part is adequately secured throughout the manufacturing process.

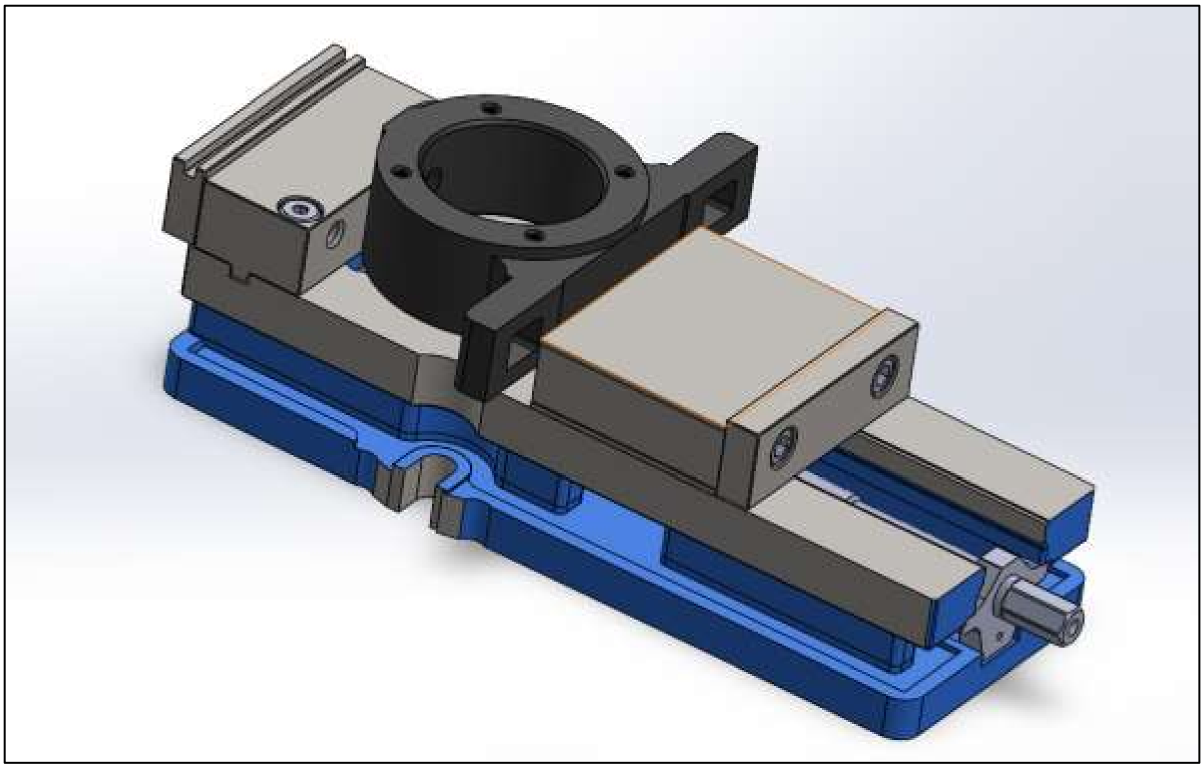

Fig.20. Vise 3D Model + Part

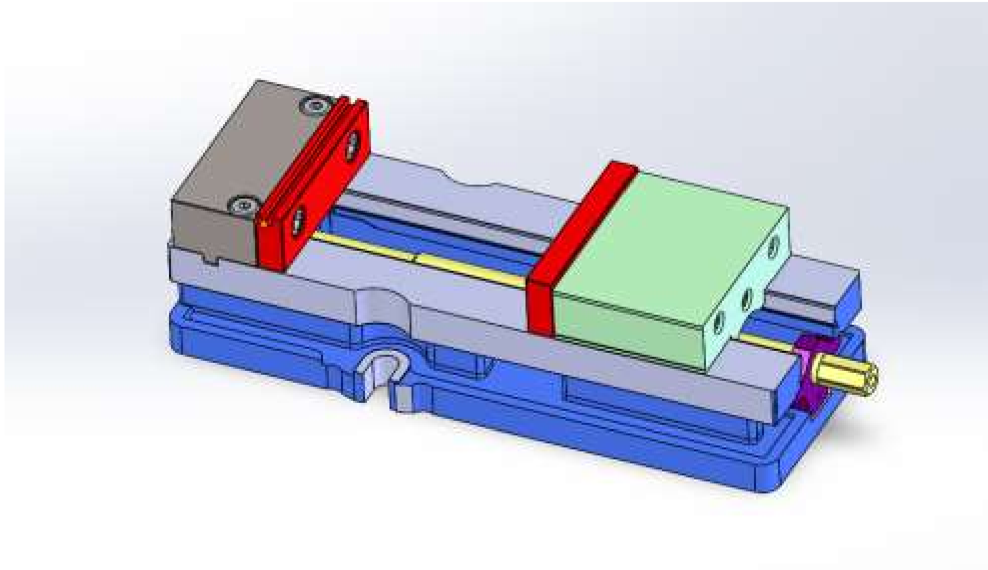

Fig.21. Vise 3D Model (Color designation of components)

CHAPTER 4: Economical Calculations

4.1. Cost Estimation

To estimate the cost of casting we will use the on-line application Cost Estimator at the custompartnet.com.

Due to an error in the website, there was no option to change material to Grey Iron, in order to go further with our estimation processes we had to choose the closest material to it, in terms of price per kg, as well as density, which plays a crucial role in determining the cost of Casting.

The Estimation process will be split in two different processes:

- Casting Cost Estimation
- Machining Cost Estimation

The latter will be our guide to Time estimation in further steps of this project.

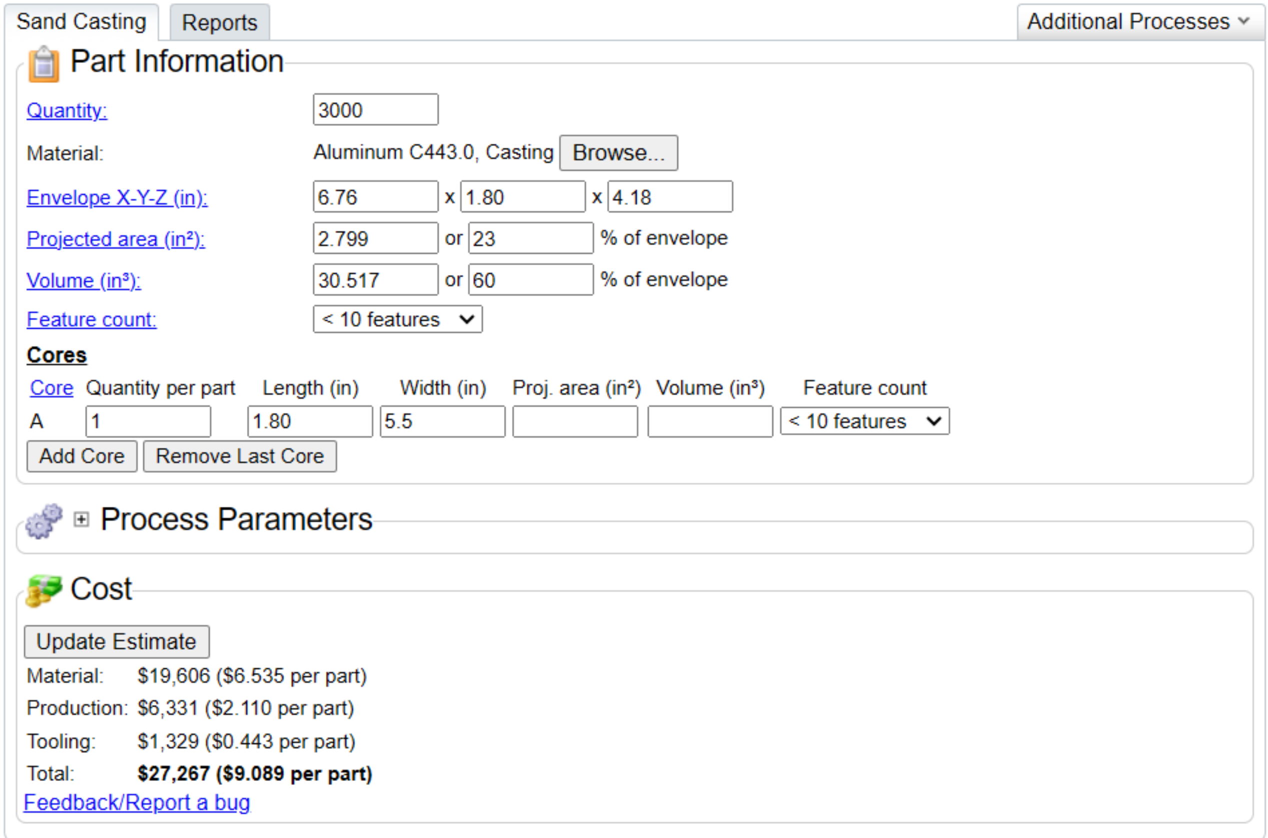

Fig.18. Sand Casting Cost Estimation

Cost Summary

Material cost	$0 ($0.000 per part)
Production cost	$64,425 ($6.442 per part)
Tooling cost	$0 ($0.000 per part)
Total cost	**$64,425**

Fig.19. Cost Estimation for Machining Sequences

Overall, the tally cost of producing 200 parts will be the sum of sand-casting costs and machining costs, as following:

$$C_T = C_c + C_m = 27{,}267 + 64{,}425 = \$91{,}692$$

C_T: Total Cost; C_C: Cost of Casting ; C_m: Cost of Machining

Which accords to roughly: ~$30.56 per part.

4.2. Time Estimation

After simulating and estimating the cost of the Machining, we come up with a rough Time estimation per part, as illustrated below.

Due to Difficulties estimating Casting time we will leave that for a foundry to give us a quote, which can be done at a later date.

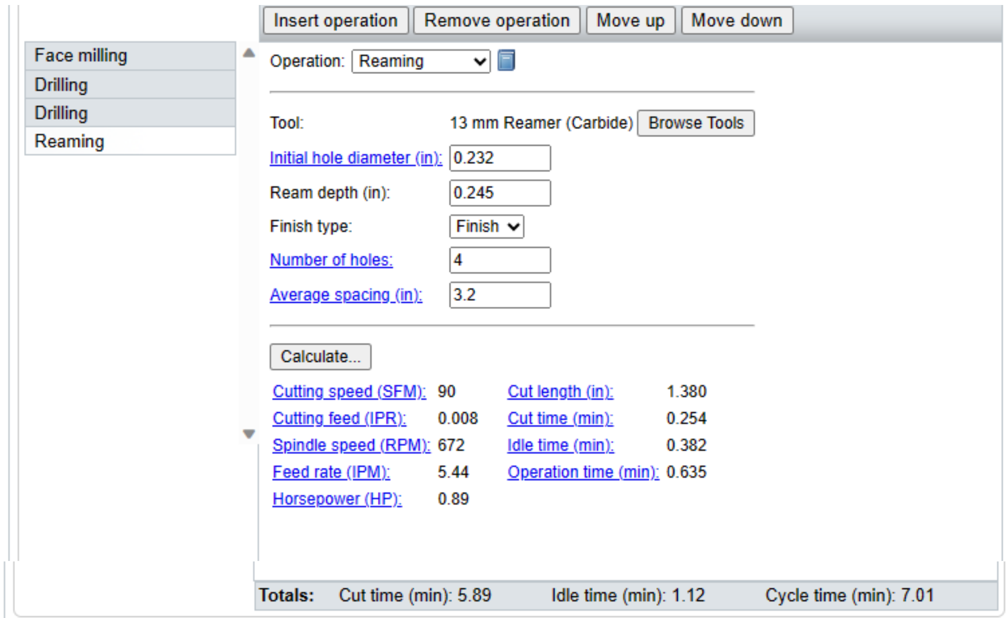

Fig.19. Time Estimation

The Time estimation for Machining per part will amount to the following:

The Cut Time for a total of 5.89 min
The Idle Tie for a total of 1.12 min

Therefore, the Cycle Time will be 7.01 min.

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