National Technical University of Ukraine
«Igor Sikorsky Kyiv Polytechnic Institute»

EDUCATIONAL AND RESEARCH
INSTITUTE OF MECHANICAL ENGINEERING
Department of Manufacturing Engineering

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Head of the department

____Oleksandr OKHRIMENKO

“___”____________2024

Diploma project

for a bachelor's degree

according to the educational and professional program

«Manufacturing Engineering»

in the speciality 131 «Applied mechanics»

on the topic: «Manufacturing Process Planning for Production of a Part «Corpsth at directs»

Developed by:
the student of 4th year of study, group MT-03

Abdalla Salah Mahmoud Mohamed Moustafa____________________ ____________
(full name) (signature)

Academic supervisor Vadym Medvedev, PhD, Associate Professor __________________ ____________
(position, academic degree, academic title, surname and initials) (signature)

Reviewer ____ ____________
(position, academic degree, academic title, surname and initials) (signature)

I certify that in this diploma project there are no borrowings from the works of other authors without appropriate references.
Student ____________
(signature)

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 р.

ASSIGNMENT
for the diploma project to the student

_____________ Abdalla Salah Mahmoud Mohamed Moustafa ____________
(full name)

1. Topic of the diploma project Manufacturing Process Planning for Production of a Part «Corps that directs» ______________________
____

project supervisor Vadym Medvedev, PhD, docent ____________________ ,
(full name, academic degree, academic title)

approved by the University Order dated «____» ______2024 р. №_______

2. The deadline for the student to submit a diploma project «10» _06_.2024
3. Initial data for the project _______ Drawing of a part that must be manufactured in conditions of medium series production _________________
____

4. The content of the explanatory note, a list of tasks to be developed
_____________ Purpose of the part, development of manufacturability, selection

of the workpiece, floor plan, selection of equipment and tools, technology, calculations of cutting modes and allowances, time rationing, adjustment calculation

Special part: Methods of finishing cylindrical holes

5. A list of graphic and illustrative material detail, workpiece to detail, special part, manufacturing technology, CPC adjustment, machine tool adaptation

6. Consultants for chapters of the project

Chapter	Surname, initials, and position of consultant	Signature, date	
		Issued the task	Accepted the task
Economic	Vadym Medvedev		
Occupational Health	Vadym Medvedev		

7. Issue date of the assignment 20.05.2024

CALENDAR PLAN

No	Stages of the diploma project implementation	The deadline for the stages of the diploma project	Notes
1	Detail, workpiece, general part	1 week	
2	Manufacturing technology	2 week	
3	Technological equipment	3 week	
4	Economy, labor protection	4 week	
5	Designing the work	4 week	

Student Abdalla MOUSTAFA

Supervisor Vadym MEDVEDEV

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CHAPTER 1: General issues – Heat Treatments

1. Introduction

Heat treatments are operations involving heating, maintaining the temperature, followed by cooling, with the aim of giving a metal piece the most suitable properties for its use. They allow for a significant improvement in the mechanical characteristics of steel with a determined composition. Generally, a heat treatment does not alter the chemical composition of the alloy but brings about the following modifications:

- Constitution (state of carbon and allotropic form of iron).
- Structure (grain size and distribution of constituents).
- Mechanical properties.

The purpose of these treatments is to enhance the characteristics of materials and make them more suitable for a given application, based on the following modifications:

- Increase in tensile strength and yield strength (Rem, Re), providing better performance of the element.
- Increase in hardness, allowing parts to better resist wear or impact.

2. Heat Treatment Cycle

In general, heat treatment includes three stages:

1. Heating to a temperature that depends on the type of treatment desired.
2. Isothermal holding at this treatment temperature.
3. Cooling in a predefined medium.

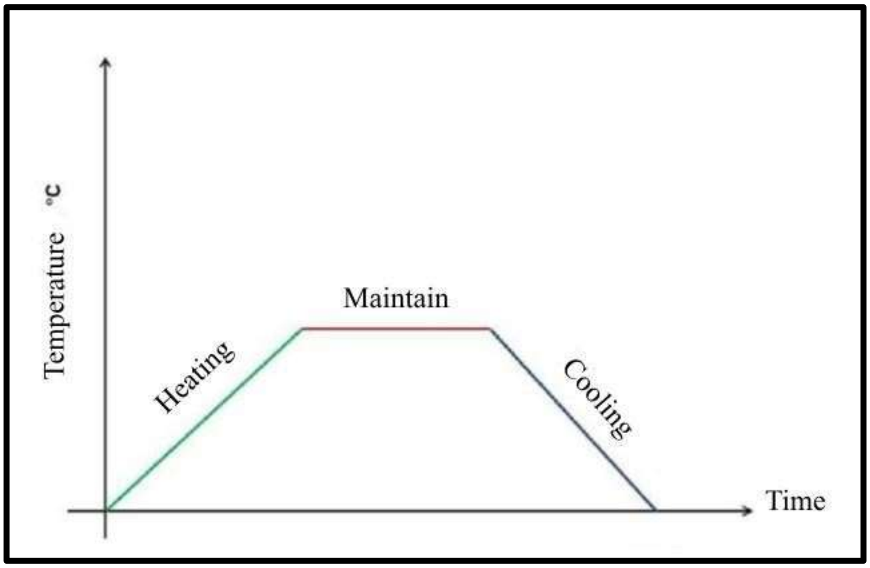


Fig.1.1. Heat treatment cycle

ElementsofHeatTreatment

A heat treatment involves manipulating three elements:

- Temperature
- Time
- The environment during the holding phase at the treatment temperature (neutral or reactive).

In general, the critical and determining phase is the cooling. The appropriate speed to achieve the desired characteristics leads to the selection of a cooling medium (for example, air, water, salt bath, oil, gas, or pressurized gas mixtures) depending on the size of the piece to be treated and its hardenability.

3. Main Types of Heat Treatment

Heat treatments applied to steels can be classified into three main types:

- Homogenization Treatments: Generally applied to cast products before their transformation or also to already wrought products.
- Softening Treatments by Annealing or Restoration: Generally applied during or at the end of the transformation process.
- Structural Quenching Treatments: These include:
    - Solutionizing
    - Quenching
    - Aging and/or tempering, which produce hardening.

4. Range of Heat Treatments for Steel

The main modes of heat treatment that modify the structure and properties of an alloy in various ways through operations of heating to a certain temperature, holding at that temperature, and followed by cooling at a more or less accelerated rate are:

- Quenching
- Tempering and aging
- Annealing

The primary factors that distinguish between different types of heat treatments are the holding temperature and the cooling rate.

5. Quenching

After heating and holding, the pieces are subjected to cooling according to the appropriate method, with the speed regulated by the quenching medium used. This cooling can be done in still air, blown air, oil, salt baths, etc., depending on the alloy of the pieces and the desired characteristics. To achieve effective quenching, the metal must be heated to a sufficiently high temperature until it reaches the austenitic range.

5.1. Different Types of Quenching

There are different types of quenching, including martensitic quenching, bainitic quenching, and austenitic quenching (also known as hyperquenching).

<u>MartensiticQuenching</u>

Martensitic quenching involves rapidly cooling the metal to a temperature below the critical value “Ms”, usually 20°C or lower. The rapid cooling of austenite causes the carbon atoms inserted in the gamma lattice to become trapped. This lattice instantly becomes body-centered tetragonal, forming a new structure known as martensite (a solid solution of insertion). To obtain a martensitic structure, the cooling rate must exceed the critical quenching rate for martensite. However, this condition is not met at all points within a piece. The cooling rate at any given point depends on the metal's thermal conductivity, the piece's shape and dimensions, and the quenching fluid's cooling power, which in turn depends on the agitation of the fluid.

<u>BainiticQuenching</u>

To obtain bainite through quenching, austenitized steel is cooled to a selected temperature at a sufficient rate to prevent the formation of ferrite or pearlite. It is maintained at this temperature (240°C to 450°C) to achieve complete transformation, then cooled to room temperature. The temperature chosen for bainitic quenching depends on the desired microstructure (and hardness) and the steel's transformation rate.

Bainite imparts certain qualities to steels, including better ductility (for high carbon content) than martensitic quenching and improved creep properties (at temperatures of 400°C to 500°C) compared to tempered martensite. Both structures (martensite and bainite) exhibit high hardness.

AusteniticQuenching(orHyperquenching)

Austenitic steels, whose structure does not change through heating or cooling, do not undergo traditional quenching. The hyperquenching process is used to soften these steels by heating the pieces to about 1,100°C. Rapid cooling is necessary to avoid carbide precipitation between 600°C and 800°C, typically performed with water. Oil is used as the quenching fluid for high-nickel steels.

This technique is particularly applied to stainless steels and ferromanganese steels, allowing for subsequent machining or maintaining, or even redissolving in austenite, the carbides whose precipitation at grain boundaries would promote intergranular corrosion.

5.2. Heating technologies

The three types of quenching can be carried out in almost any heating environment, such as a controlled atmosphere furnace, a vacuum furnace, a salt bath, etc. In summary, the choice of heating technology is determined by the nature of the pieces, their size, their conductivity, etc. Below is a general illustration of the quenching treatment cycle. It should be noted that a quenching treatment is always followed by one or more tempering treatments to remove the material's brittleness, eliminate stresses, and adjust the final hardness.

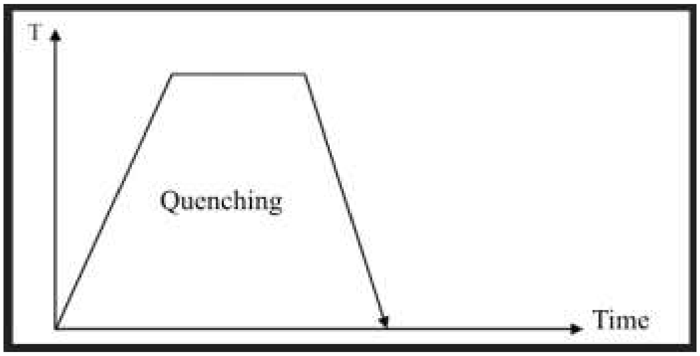


Fig.1.2. Quenching cycle

5.3. Choice of Holding Time

Maintaining the metal at the quenching temperature must ensure core heating and completion of phase transformations without being too slow to avoid grain growth and decarburization of the surface layers of the parts.

The total heating time, � depends on:

- The time for core heating, ��, to the required temperature. This time depends on the shape and dimensions of the parts, the metal grade, the type of furnaces, etc.

- The isothermal holding time, �, which depends on the composition and initial state of the metal.

So: �= �� + �.

In practice, to determine � we refer to experimental data. (Table.1.1) summarizes the average duration for a thickness of 1 mm in different types of furnaces.

Table.1.1. Approximate Austenitization Time in Different Types of Furnaces

Heating method	Duration in (s/mm) of thickness for different types of pieces		
	Square	Round	Rectangular
Electric furnace	40 – 50	50 – 60	60 – 75
Flame furnace	35 – 40	45 – 50	55 – 60
Salt bath	12 – 15	15 – 18	18 – 22
Lead bath	6 – 8	8 – 10	10 – 12

5.4. Quenching Media

Quenching is generally done in water, oil, or air. The quenching medium is chosen mainly based on the hardenability of the steel. The nature of the quenching bath (water, oil, etc.) determines the cooling rate of the immersed piece after heating.

Table.1.2. The cooling rate according to the quenching medium

Quenching Medium	Cooling Rate (°C/second)
Brine	220
Cold water	160
Warm water	150
Hot water	140
Quenching oil	70
Blown air	20
Still air	2
In sand mold	0.05
In furnace	0.01 (or according to the cycle programming)

JominyTest

The purpose of the Jominy test is to obtain, in a single operation on a standardized specimen, overall indications about the hardenability of a steel, in the form of a curve called the Jominy curve. This test is conducted in three stages:

- Austenitization of a standardized specimen taken from the steel to be tested.
- End-quenching by a water jet under specified conditions.
- Hardness measurement on a flat along a generatrix, where machining must not cause excessive heating. Hardness measurement points are located at: 1.5 - 3 - 5 - 7 - 9 - 11 - 13 - 15 - 20 - 30 - 40 - 50 - 60 - 70 - 80 mm from the watered end and are designated by J1.5 - J3 - J5 - Jx.

WaterQuenching

This treatment is reserved for low-alloy steels that require this medium to achieve the desired characteristics (e.g., 1045, W1). The high cooling rate in water poses significant risks of distortion or even cracking.

OilQuenching

This treatment is used for low-alloy steels such as 1045, 4140, 4340, 8620, 9310, 52100, or tool steels like O1.

ForcedAirQuenching

This treatment is mainly used for steels whose dimensions exceed the capacity of vacuum furnaces (e.g., stainless steels 410, 420, 431, and tool steel H13).

VacuumQuenching

This type of treatment is primarily for tool steels (A2, D2, S7, H13, H21, T1, M2) and martensitic stainless steels.

Subzero(orCryogenic)Quenching

This process involves cooling the quenched martensitic specimens in dry ice or liquid air when the austenite-martensite transformation is insufficient to achieve the desired hardness. This quenching method is particularly useful for carburized steels, where the quenching temperature is a compromise between core quenching and surface quenching temperatures. Cryogenic treatment involves cooling mechanical parts below room temperature after a quenching heat treatment. The holding temperature ranges from 0°C to 150°C (typically between 80°C and 100°C for steels).

6. Tempering

Tempering is a final operation of the heat treatment process aimed at correcting defects caused by quenching. It involves heating the quenched metal to a temperature below Ac1, holding it at this temperature, and finally cooling it to room temperature. Tempering causes a structural evolution of the material towards a state closer to the physicochemical equilibrium state, although it does not reach it entirely. It allows for a satisfactory compromise between strength properties (Rm, Re, H) and ductility properties (A, Z, and K).

The cooling rate after tempering has a very small influence on the state of residual stresses. However, the slower the cooling, the lower the residual stresses.

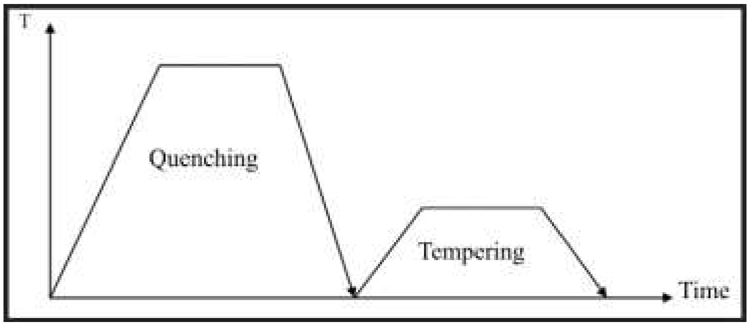


Fig.1.3. Complete Quenching and Tempering cycle

6.1. Relaxation or Stress Relief Tempering

This process is carried out between 180°C and 220°C. It does not cause any structural modification but rather a relaxation of the multiple stresses resulting from the rapid cooling during quenching and the transformation from austenite to martensite structure. It leads to a slight decrease in hardness and a slight increase in resilience. It is performed on parts subjected to high stresses without impact or requiring a high surface hardness to be maintained.

6.2. Structural Tempering or Conventional Tempering

In this case, tempering is carried out between 500°C and Ac1. An increase in characteristics K, A, and Z is observed, along with a more significant decrease in H, Rm, and Re. This type of tempering allows for a compromise to be established between the mechanical characteristics according to the steel's application.

6.3. Hardening Tempering

Tempering conducted between 450°C and 600°C on alloy steels can induce hardening phenomena known as secondary hardening (as in the case of chromium tool steels or high-speed steels). Initially, there is precipitation of complex carbides maintained in solution within residual austenite, followed by destabilization of the latter, which transforms into martensite during cooling. These two successive transformations require a second tempering to prevent excessive brittleness caused by the secondary martensite. (In some high-speed steels, three successive temperings may be necessary).

6.4. Low-Temperature Tempering

This is carried out with heating to around 250°C and helps reduce internal stresses. It transforms quenched martensite into tempered martensite. This tempering increases strength and improves ductility without significantly altering hardness (58 to 63 HRC), resulting in good wear resistance. It is applied to cutting tools and measuring instruments made of carbon steel and low-alloy steel. The duration of this tempering varies from 1 to 3 hours.

6.5. Intermediate-Temperature Tempering

This is performed between 350°C and 500°C and is used for various springs and gears. It provides high yield strength and fatigue resistance. The structure is of tempered troostite or troostite-martensite type, with hardness ranging from 40 to 50 HRC. Cooling after tempering at 400°C or 450°C is done with water, contributing to the formation of residual compressive stresses on the surface, which increases the fatigue limit of the springs.

6.6. High-Temperature Tempering

This is done between 500°C and 680°C. It gives the steel the structure of tempered sorbite. This type of tempering creates a better balance between the strength and ductility of the steel. Quenching followed by high-temperature tempering (this double treatment is called improvement) improves rupture and yield limits, as well as ductility and resilience compared to normalized or annealed states. This improvement is primarily applied to medium-carbon construction steels (0.3% to 0.5%).

7. Annealing

Steels have the ability to acquire a wide range of very different properties through various heat treatments. Annealing, in general, brings alloys to a physicochemical and mechanical equilibrium. It tends to achieve structural equilibrium by eliminating out-of-equilibrium states resulting from previous heat and mechanical treatments.

Annealing corresponds to maximum values of ductility characteristics (resilience and elongation) and minimum values of strength characteristics (hardness, yield strength, tensile strength). The purpose of annealing is to:

- Reduce the hardness of a quenched steel.
- Achieve maximum softening to facilitate machining or mechanical treatments.
- Regenerate work-hardened or overheated metal.
- Homogenize heterogeneous textures.
- Reduce internal stresses.

7.1. Thermal Cycle of Annealing Includes

a) Heating up to a temperature known as annealing temperature, which depends on the type of annealing to be performed.
b) Isothermal holding at the annealing temperature or oscillations around this temperature.
c) Very slow cooling, typically in still air. The cooling rate must be slower than the critical annealing rate.

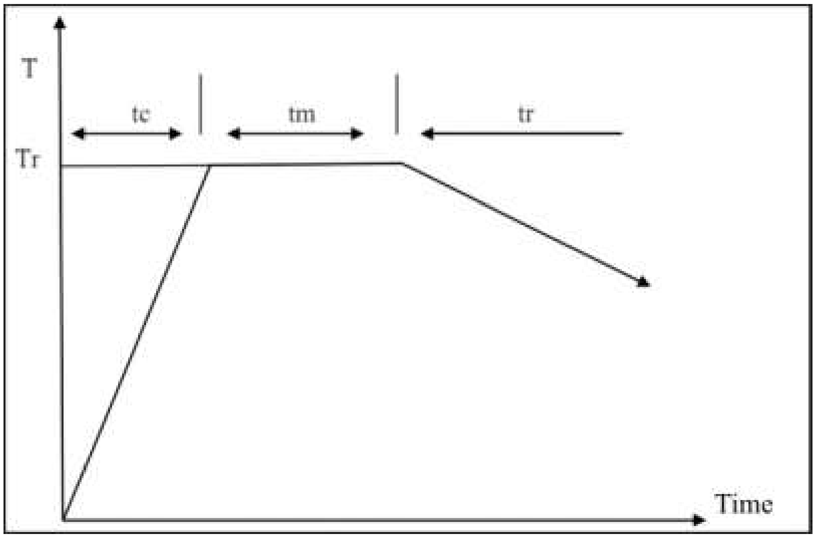


Fig.1.4. Cycle of annealing

- Tr : Annealing temperature
- tc : Heating time
- tm : Holding time
- tr : Cooling time

7.2. Homogenization Annealing

This treatment is mainly applied to raw cast products in alloys with a wide solidification range (e.g., eutectic-tin, eutectic-beryllium) to facilitate transformation or improve the technological properties of semi-finished products.

Its effect is to reduce or eliminate dendritic segregation, dissolve out-of-equilibrium phases, precipitate elements in supersaturated solution, and evenly distribute constituents.

Homogenization can sometimes be accelerated by the practice of oscillating annealing, during which the holding temperature undergoes a certain number of cycles between two values generally bracketing a transformation point.

7.3. Softening Annealing

This type of annealing involves prolonged heating of steel at temperatures close to AC_1 (650 - 680°C), followed by slow cooling at a rate of approximately 10°C'/h. For carbon steels, the heating temperature ranges from 650 to 750°C.

In the $\gamma + Fe_3C$ phase field, if slowly cooled from slightly above AC_1 to the point AR_1, the precipitated carbide crystallizes directly into globular grains, diverting the formation of lamellar pearlite.

The purpose of softening annealing is to give the steel a structure suitable for quenching and to transfer it to a machinable and ductile state. After forging and normalization, the structure of carbon steels is pearlitic.

7.4. Full Annealing

It involves heating and holding at (Ac3 + 50°C), followed by cooling in the furnace at a slight degree of supercooling to ensure the decomposition of austenite and prevent the formation of high-hardness structures (martensite, bainite). This annealing is carried out on parts that have undergone various heat and mechanical treatments to facilitate their machining or cold deformation. This is generally referred to as "annealing".

7.5. Regenerative Annealing

This annealing is used to restore the normal structure after a defective heat treatment, but it can only be applied to metals and alloys that undergo a phase change. It involves heating the parts, for a relatively short time, slightly above the transformation point.

The most common case is the destruction of the overheated structure that promotes intergranular brittleness. This treatment is practically not applicable to industrial copper alloys, whose grain regeneration after overheating can only be achieved by work hardening followed by recrystallization annealing.

7.6. Stress Relief Annealing

This annealing is mainly used to eliminate or reduce internal stresses in cold-formed products. It is carried out at a temperature lower than that of recrystallization, so as not to significantly alter the mechanical characteristics obtained through work hardening. Stress relief annealing is also used to stabilize certain parts during machining when asymmetric fiber cutting disrupts the internal stress equilibrium, causing deformations.

7.7. Recrystallization Annealing

The cold working of a metal by plastic deformation (rolling, drawing, etc.) leads to work hardening. A work-hardened structure is characterized by a strong orientation of the grains and a high density of crystalline defects. The structure becomes brittle and is accompanied by increased strength properties and reduced plastic properties. This annealing is carried out in the recrystallization zone, which is above a temperature depending on the grade of steel and its degree of work hardening. New grains germinate and grow until they come into mutual contact.

7.8. Coalescence Annealing

This annealing consists of heating the steel to a temperature slightly below Ac1, holding it at this temperature for a more or less extended period, and then slowly cooling it, so that it is in as soft a state as possible and free of stresses. It is also an annealing process used to evolve the geometric shape of carbides, such as cementite lamellae, into a stable spherical shape. It also serves to improve the cold deformation capacity of the treated material.

8. Conclusion

In conclusion, we can say that the thermal treatment of steel encompasses various types and involves several stages to provide us with steel possessing suitable properties.

CHAPTER 2: Manufacturing Process Plan

2.1. General analysis of the part

2.1.1. Geometry analysis

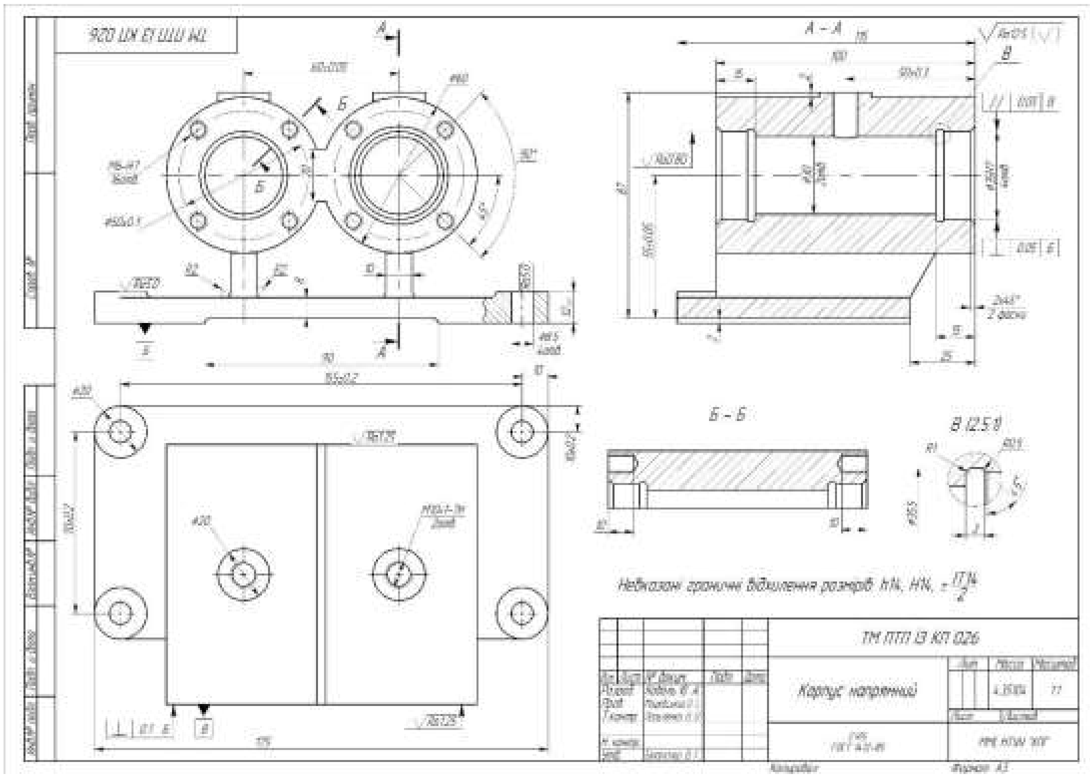


Fig.1. Initial variant drawing

Overall, the quality and demands of this piece are somewhat relaxing. However, our focus should shift on the holes ø35 as they require the most attention. The perpendicularity and Coaxiality of these holes with the main inner core ø30 hole are of most importance as the most allowable deviation is limited to 0.05mm, as well as a tolerance of H7, while the average roughness has been set extremely tight, of value Ra0.8. Meanwhile, the outer shell of these holes should be manufactured to an extremely demanding perpendicularity with the datum surface with a tolerance of 0.1.

During the manufacturing process, we should adhere to these guides and tolerances to achieve the most accurate of parts.

2.1.2. Part’s working condition in the assembly

Due to the absence of the assembly drawing of the part “Corps that direct”, it is difficult to determine the functional purpose of the part.

However, based on the initial drawing we can assume that the part “Corps that direct” is designed to provide means of installing and securing shafts that are supported by bearings. It features a variety of holes, both tapped and untapped, which serve a variety of purposes. They ensure the mounting shaft bearing sits exactly where it needs to for proper function. They also act as anchor points for securely fastening the part. Additionally, their precise design allows them to work with jigs and fixtures, which are tools used for consistent and accurate manufacturing.

2.1.3. Material analysis

Material of the part is "СЧ15" corresponds to a specific grade of cast iron according to the GOST 14.12-85 standard, which criteria are stated on Table.1.

Table.1. Chemical composition and mechanical properties of C15

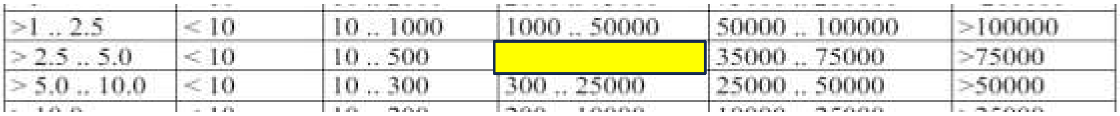
Chemical Composition				
C	Si	Mn	P	S
3.5-3.7%	2.0-2.4%	0.5-0.8%	0.2%	0.15%
Mechanical Properties				
Tensile Strength (MPa)	Density (g/cm^3)	Linear Shrinkage (%)	Impact Energy (J)	Hardness (HB)
≥150Mpa	7.0	1.1%	≥60J	130-241 HB

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 aggressive environment and the material proposed by the designer ensures the operability of the part in such conditions.

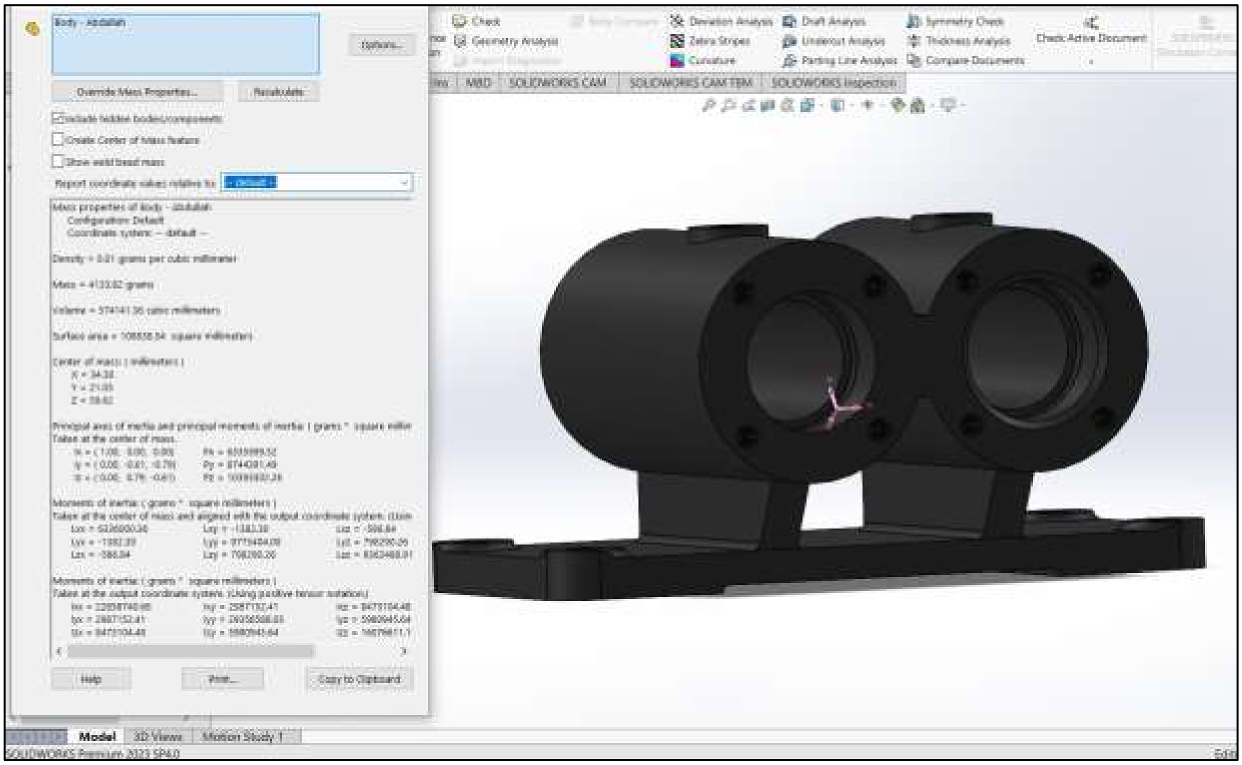
2.1.4. Type of production determination

As per instructions, we will determine the type of production based on the part weight (Fig.2), as well as Production Volume required. In accordance with the table below (Table.2).

Table.2. Production type catalog



>1 .. 2.5	< 10	10 .. 1000	1000 .. 50000	50000 .. 100000	>100000
> 2.5 .. 5.0	< 10	10 .. 500	🟨	35000 .. 75000	>75000
> 5.0 .. 10.0	< 10	10 .. 300	300 .. 25000	25000 .. 50000	>50000



Mass properties of Body - Abdullah
Configuration: Default
Coordinate system: -- default --

Density = 0.01 grams per cubic millimeter

Mass = 4133.82 grams

Volume = 374141.36 cubic millimeters

Surface area = 108838.84 square millimeters

Center of mass: (millimeters)
X = 34.28
Y = 21.05
Z = 59.82

Fig.2. Mass properties of the part

So, the data we now have is: �= 4.133��and production quantity per annum: 1500

Conclusion: According to the data as well as the table, we conclude that all further calculations and technological decisions will be based on the Medium-batch production type.

2.1.5. The 3D model of the part

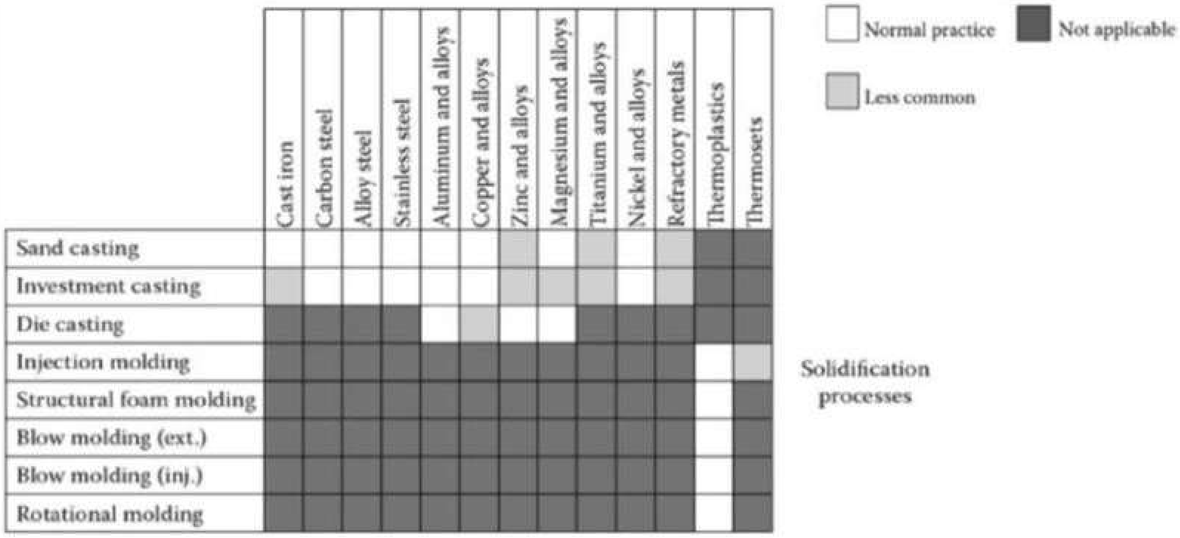
2.2. Selection of the base process and Blank design

2.2.1. Selection of the base process

Having provided the necessary information regarding the part:

- Drawing of the part
- Component Material _Grey Cast Iron 15_
- Production volume per annum (5000)

We can now choose the Process with the help of The Solidification processes' chart in Fig.3



	Cast iron	Carbon steel	Alloy steel	Stainless steel	Aluminum and alloys	Copper and alloys	Zinc and alloys	Magnesium and alloys	Titanium and alloys	Nickel and alloys	Refractory metals	Thermoplastics	Thermosets
Sand casting	□	□	□	□	□	□	▨	□	▨	□	▨	■	■
Investment casting	▨	□	□	□	□	□	▨	▨	▨	□	▨	■	■
Die casting	■	■	■	■	□	▨	□	□	■	■	■	■	■
Injection molding	■	■	■	■	■	■	■	■	■	■	■	□	▨
Structural foam molding	■	■	■	■	■	■	■	■	■	■	■	□	■
Blow molding (ext.)	■	■	■	■	■	■	■	■	■	■	■	□	■
Blow molding (inj.)	■	■	■	■	■	■	■	■	■	■	■	□	■
Rotational molding	■	■	■	■	■	■	■	■	■	■	■	□	■

□ Normal practice ■ Not applicable

▨ Less common

Solidification processes

Fig.3. Solidification processes

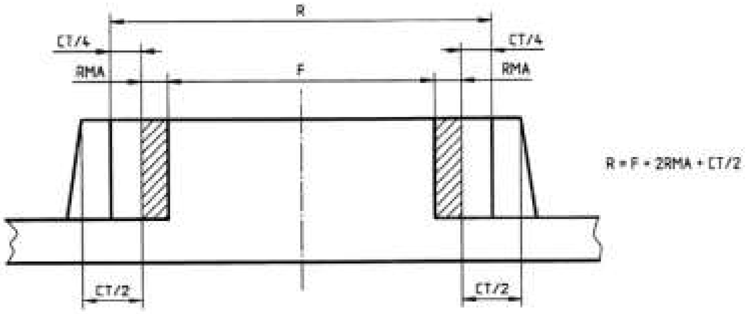
According to the Geometry of the part as well as the chart above, we choose the Sand Casting as our base process moving on.

2.2.2. Casting Tolerance and Required Machining Allowance calculations

To select the required machining allowance (RMA) grade, we can refer to Table B.1 in [ISO 8062]. This table recommends grade E for sand casting machine-molded with Grey Cast Iron. Based on Table 1 in the same reference, and considering the part's largest dimension of 175mm (as per drawing), the required machining allowance for RMA grade F is 1.4mm.

To estimate the casting tolerance (CT) grade for long production runs, we can refer to Table A1 in [ISO 8062]. This table suggests CT grade 10 for sand casting with Iron.

The selection of RMA and CT grades, along with their locations on the part, are further illustrated in the sketches presented in Fig.4.



R = Raw casting basic dimension

F = Dimension after final machining

RMA = Required machining allowance

CT = Casting tolerance

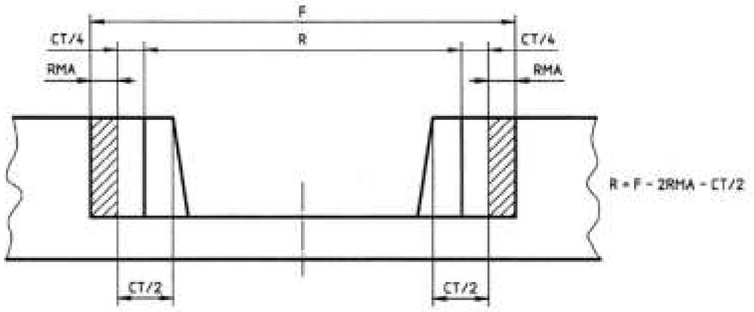


Fig.4. CT an RMA illustration

Table.3. CT and RMA Tolerances

Dimension	RMA	Min limit of size for external features (or max for internal features)	CT	Raw Casting Dimension
100	1.4	102.8	3.2	104.4±1.6
⌀35.5	1.4	32.7	2.6	31.4±1.3
⌀35	1.4	32.2	2.6	30.9±1.3
⌀30	1.4	27.2	2.6	25.9±1.3
12	1.4	14.8	2.2	15.9±1.1
⌀10	1.4	7.2	2	6.1±1.0
⌀8.5	1.4	5.7	2	4.7±1.0

⌀6	1.4	3.2	2	2.2±1.0

Effective casting design is crucial for producing high-quality parts. Here are the key considerations we implemented for the sand-casted “Corps that direct”:

- The workpiece is positioned to minimize its height within the mold. This reduces the distance molten metal travels, minimizing the risk of solidification issues like shrinkage porosity.
- The parting line, where the mold separates, coincides with the plane of symmetry. This simplifies mold design and core placement.
- Sharp corners in the casting design are avoided. Instead, radii of 0.5-5mm are used. This improves casting integrity by reducing stress concentration points that could lead to cracking.
- A draft angle of 2° is applied to all walls perpendicular to the parting line. This facilitates easier removal of the cast part from the mold after solidification.
- The machining allowance (RMA) is added only to surfaces that will require secondary machining processes. This minimizes material waste and optimizes casting efficiency.
- The main hole of the “Corps that direct” is formed using cores. This allows for the creation of this feature during the casting process itself.
- Small features like additional holes are created using secondary processes like drilling or machining after casting. This is because small features are more challenging to achieve consistently and precisely during casting.

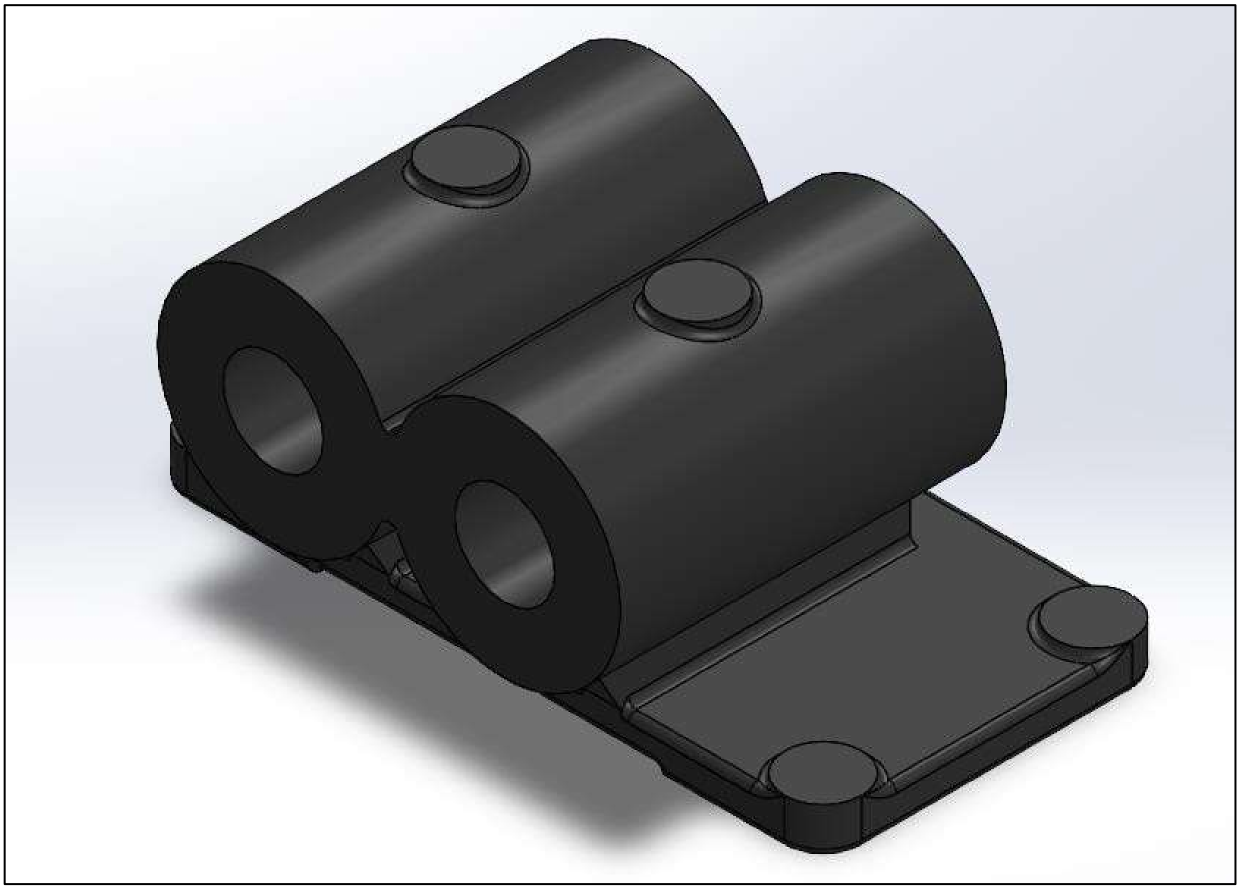


Fig.5. 3D Model of the Casting Blank

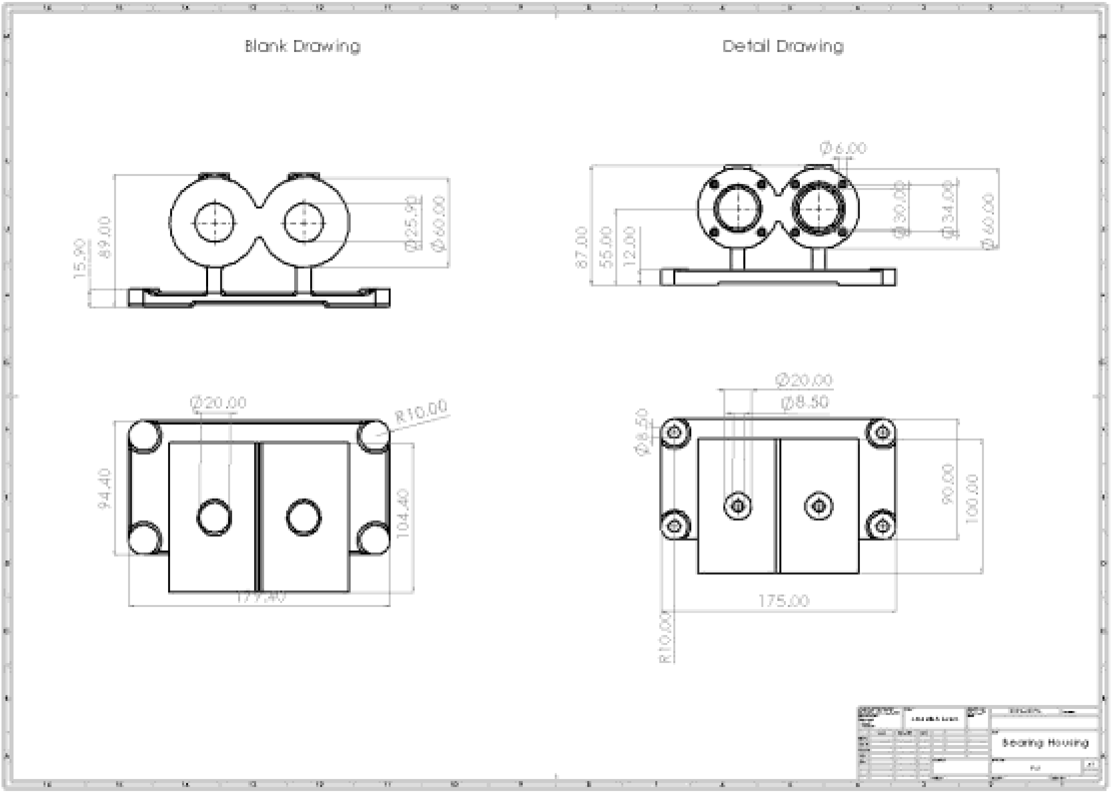


Fig.6. Technical 2D drawing of the Blank

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)

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:

1. Main functional (design) datum

2. Auxiliary functional (design) datum
3. Fastening surfaces
4. Free surfaces

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

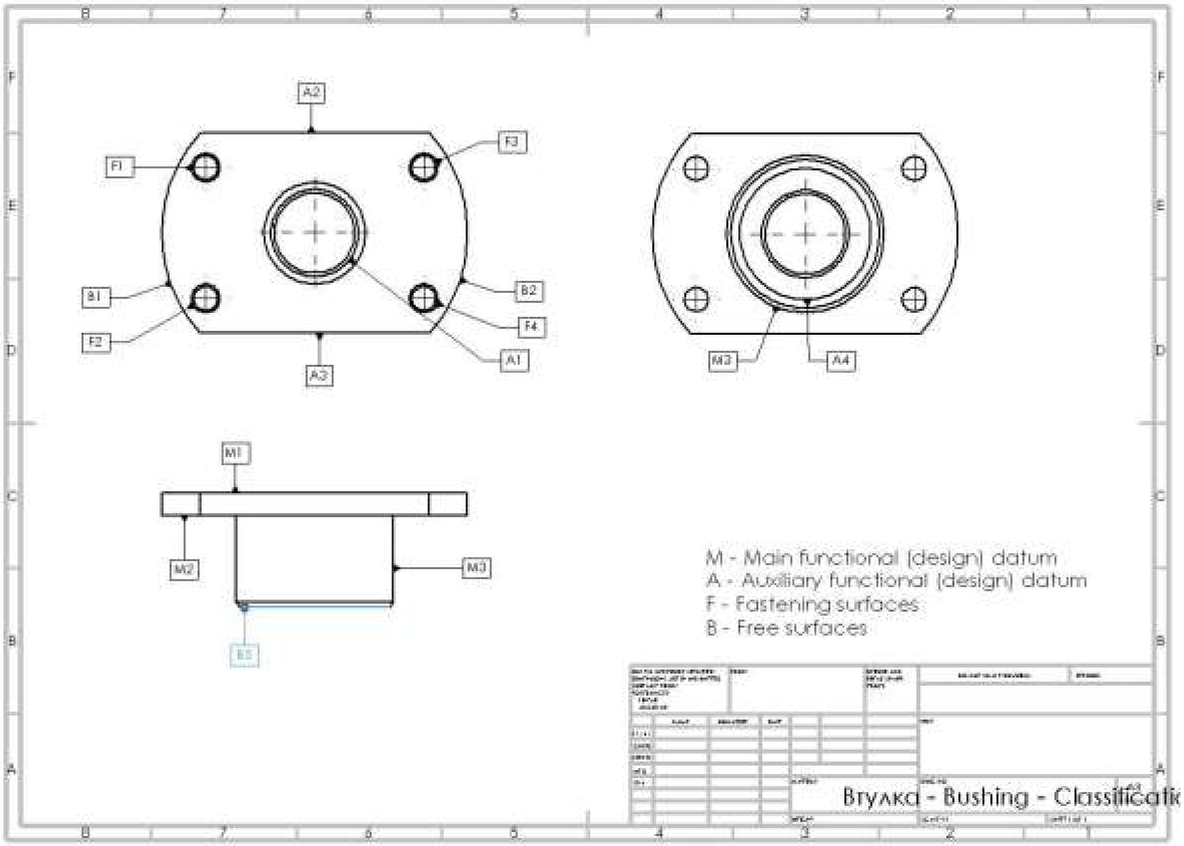


Fig.7. Surfaces Classification

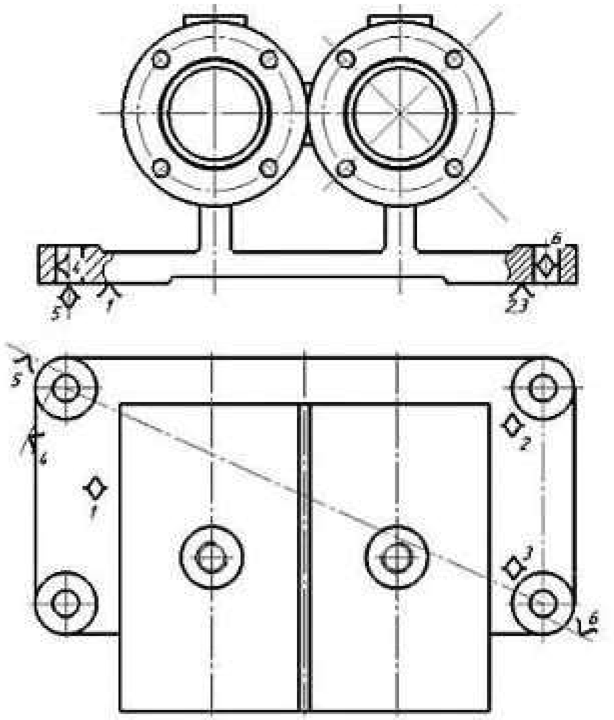


Fig.8. GMD Locating scheme

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

$$\text{��}_{\text{�MD}} = \text{�}(3) + \text{��}(2) + \text{��}(1)$$

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 “Corps that direct” is sufficiently oriented, which allows processing its surfaces with the specified requirements for the spatial position. In our case GMD remains unchanged.

$$\text{���} = \text{�����}$$

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.9.1.

Advantages:

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

Disadvantages:

- Blocks processing the workpiece from 3 holes.
- forms an uneven allowance for the main holes of the “Corps that direct” for the next stages of processing.

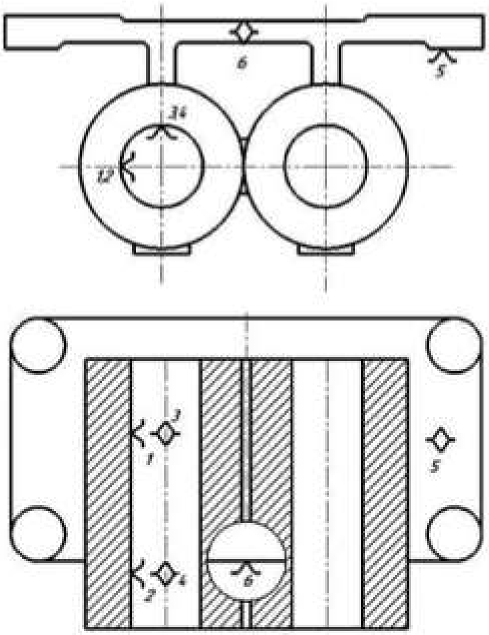


Fig.9. Locating scheme for first manufacturing operation MD

Conclusion: The GMD locating scheme 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 and holes. Therefore, we will use the general manufacturing scheme.

2.4. Design of the typical surfaces processing routes

The design of a part can be broken down into fundamental geometric shapes that work together to achieve the part's overall function. Common elements include cylindrical or conical surfaces (both internal and external), flat planes, and specialized shapes like screw threads or involute gears.

The type of surface directly influences the selection of cutting tools used during machining. Different tools provide varying levels of precision for each surface. Consequently, the machining process involves a specific sequence of operations to achieve the desired final geometry and accuracy for each surface.

This rewrite clarifies the connection between geometric shapes in part design and the corresponding machining processes needed to create them. It also highlights the role of surface type in tool selection and the importance of a defined machining sequence.

The first step in designing a process plan for machining is developing machining routes for individual surfaces. This initial plan focuses on creating a sequence of operations that achieves the desired dimensional accuracy, shape, and quality for each surface on the part. However, this initial plan doesn't consider how precisely these surfaces are positioned relative to each other.

Relative position accuracy refers to how accurately different surfaces are located in relation to one another. This crucial aspect is addressed later in the process planning stage by defining locating schemes. These schemes specify how the part will be positioned and secured during machining. Additionally, the overall machining process is divided into stages: roughing, finishing, and final operations. Each stage uses specific tools and techniques to progressively achieve the desired surface quality.

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.

For our part, presented in Fig.10, selected typical machining sequences as well as achieved accuracy and roughness of working surfaces are given in Table.4. The surfaces classification is given in Fig.11.

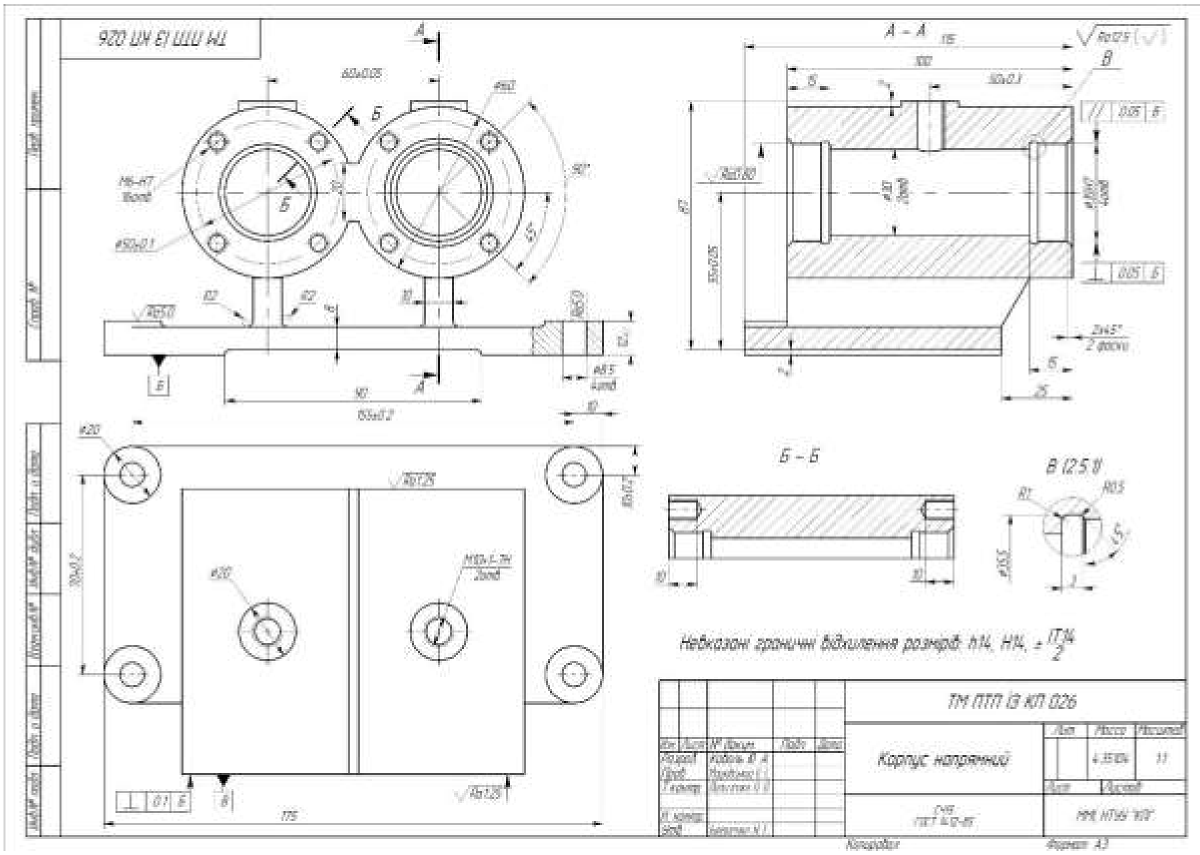


Fig.10. The part "Corps that direct"

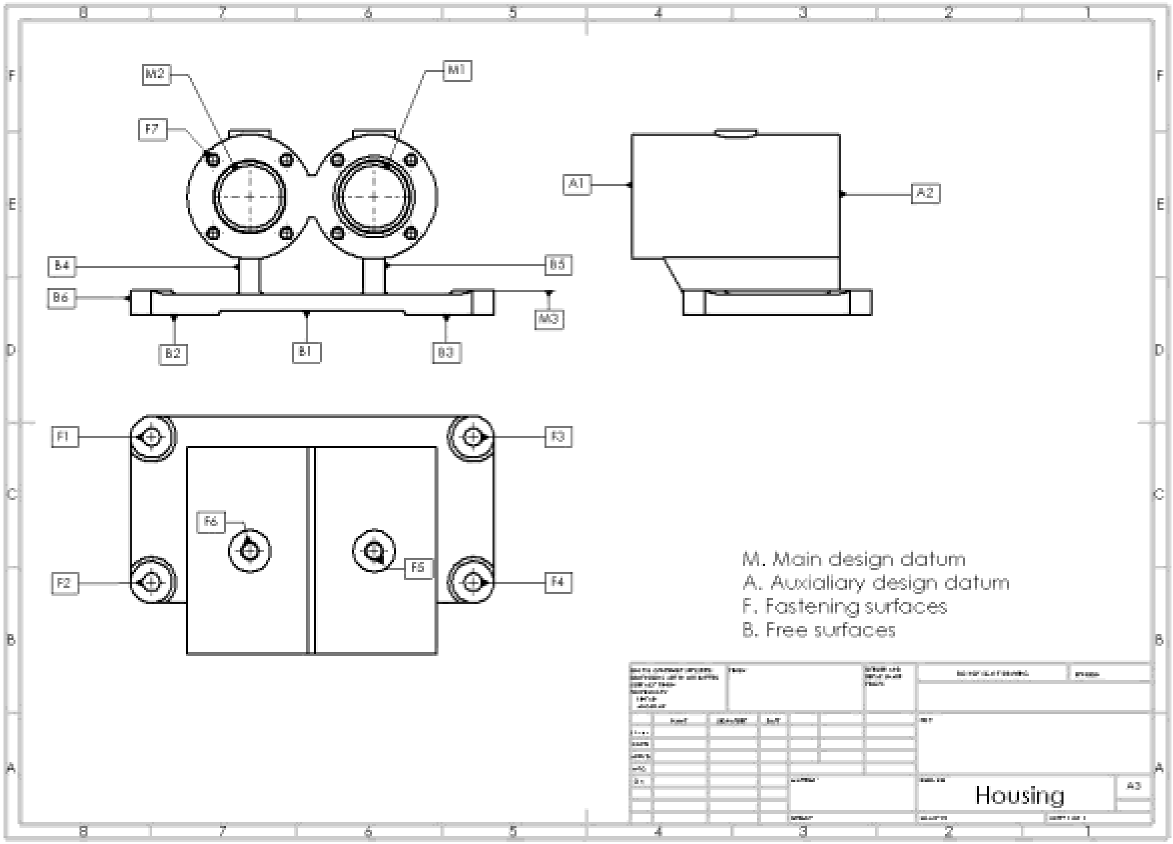


Fig.11. Surfaces Classification

Table.4. Machining Sequences

Surfaces	IT	Ra	Machining sequence	IT	Ra
	According to Drawing			After machining	
1	2	3	4	5	6
2xM1	14	2.5	Rough Boring Finish Reaming	14	2.5
4xM2	H7	0.8	Rough Counterboring Finish Reaming Countersinking	H7	0.8
A1	14	1.25	Rough Milling Finish Milling	14	1.25
A2	14	1.25	Rough Milling Finish Milling	14	1.25

M3	14	5	Rough Milling Finish Milling	14	5
F1, F2, F3, F4	14	5	Centering Drilling Reaming	14	5
F5, F6	7H		Centering Drilling Tapping	7H	-
16xF7	H7	-	Centering Drilling Tapping	H7	-

2.5. Design of the operational manufacturing process plan

We will develop a possible variant of the manufacturing process plan based on: analysis of working conditions and technical requirements to the part, type of production, geometry of the workpiece, and surfaces processing routes, while considering the following recommendations:

- Surfaces that are datums for subsequent stages of processing should be processed first.
- Each subsequent manufacturing step or operation must improve the quality characteristics of the treated surfaces. If not, revisit processing datum surfaces (e.g., after heat treatment).
- Separate roughing from finishing with time or aging, especially for critical, large, or high-value parts.
- Process surfaces early to detect defects where they're not allowed.
- During roughing, prioritize surfaces with the highest allowance and those most critical. Finish critical surfaces last.
- Process surfaces with minimal impact on overall stiffness first.
- Achieve precise relative positioning by processing surfaces in one installation.
- Avoid tool changes during finishing of precise, critical surfaces.
- Process fastening surfaces after finishing related surfaces, typically in the 3rd stage.

005 Multipurpose

Machine: HURCO VMX30Ui

A. Install, Secure, Remove

Position 1

005.01 Rough and Finish Milling of the Surface M3 to dimension 12mm and Ra5.0
005.02 Center the Position of the 4 holes “F1, F2, F3 and F4” according to the drawing
005.03 Drill the holes “F1, F2, F3 and F4” through* to a diameter Ø8.5 and Ra5.0

005.04 Center the holes F5 and F6
005.05 Drill the holes F5 and F6 to dimension ØM10
005.06 Tap the holes F5 and F6 to dimension 7H

Position 2 – Turn the table 90 degrees on axis x clockwise

005.07 Rough and Finish Milling the surface A1 to dimension’
005.08 Center 8 holes F7 on surface A1 according to dimension on sketch
005.09 Drill the 8 holes F7 to a dimeter Ø5.5 and a depth of 10mm
005.10 Tap the 8 holes F7 according to spec H7

005.11 Rough boring and Finish Reaming the 2 holes M1 to diameter Ø30
005.12 Rough Counterboring the holes 2 holes M2 to diameter Ø35
005.13 Finish Reaming the 2 holes M2 to finish H7
005.14 Countersinking the 2 holes M2 to dimension 2x45 degrees

Position 3 – Turn the table 180 degrees on axis x counterclockwise

005.15 Rough and Finish Milling the surface A2 to dimension
005.16 Center 8 holes F7 on surface A1 according to dimension on sketch
005.17 Drill the 8 holes F7 to a dimeter Ø5.5 and a depth of 10mm
005.18 Tap the 8 holes F7 according to spec H7

005.19 Rough Counterboring the holes 2 holes M2 to diameter Ø35
005.20 Finish Reaming the 2 holes M2 to finish H7
005.21 Countersinking the 2 holes M2 to dimension 2x45 degrees

2.6 Machine and Tooling Selection

2.6.1. Machine Selection

Machine selection is crucial for efficient, high-quality manufacturing. Each process (turning, milling, etc.) requires specialized machines. For example, turning often uses lathes for workpiece rotation and cutting tool control.

Machine size matters. Machines unable to handle the workpiece dimensions at any stage are usually discounted, with exceptions for limited options.

Power is another factor. Machines lacking the minimum power for cutting are eliminated. However, a machine with significantly higher power might be considered if it offers a crucial high spindle speed for specific operations.

Machine capability analysis ensures the machine can meet quality standards. This includes dimensional/geometric tolerances and desired surface finish, which impacts the final product's functionality.

Batch size is important. Machines that can't handle the production volume efficiently are not ideal. Automated loading/unloading machines might be necessary for high-volume production.

Considering these factors, we can safely denounce that “Hurco VMX30Ui” is more than capable of fulfilling all requirements.

Table.5. Specsheet of the Hurco VMX30Ui Machine

Feature	Specification
Travels & Capacity	
X, Y, Z Axis Travel	30 in (762 mm) x 20 in (508 mm) x 20.5 in (520 mm)
A-Axis Travel	+30° / -110°
C-Axis Travel	360°
Spindle Nose to Table (Min-Max)	3.5 in (90 mm) / 24 in (610 mm)
Table Diameter	9.8 in (248 mm)
Max. Weight on Table	440 lbs (200 kg)
T-Slot Size	6 x 0.48 in x 60° (6 x 12 mm x 60°)
Spindle	
Max. Spindle Speed	12,000 rpm
Peak Spindle Motor Power	18 hp @ 600 rpm (13.4 kW @ 600 rpm)

Tool Changer	
Tool Type	CAT, BT, DIN 40
Number of Tools	40 (Optional: Up to 240)
Max Tool Diameter	3.0 in (76 mm)
Max Tool Length	11.8 in (300 mm)
Max Tool Weight	15.4 lb (7 kg)
Feedrates	
Rapid Traverse X,Y,Z Axis	1496 in/min (38 m/min)
Max Programmable Feedrate	1260 in/min (32 m/min)
Rapid Traverse A,C Axis	25 rpm
Size	
Max. Operating Floor Space	155 x 156 in (3936 x 3950 mm)
Machine Height	112.2 in (2850 mm)
Machine Weight	11,640 lbs (5280 kg)
Electrical	As per local specifications (consult machine manual)
Sources	https://www.hurco.com/Specifications/Pages/Machine-Data-Sheet.aspx?Model=VMX30Ui&Company=HUS

Fig.12. The CNC Machine Hurco VMX30Ui

2.6.2. Tooling Selection and Cutting Conditions

Evaluation of process and machine selections – Provided the selection of processes and machines is satisfactory, the range of tools that can be used should be 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 of specific 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 toolholder 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:

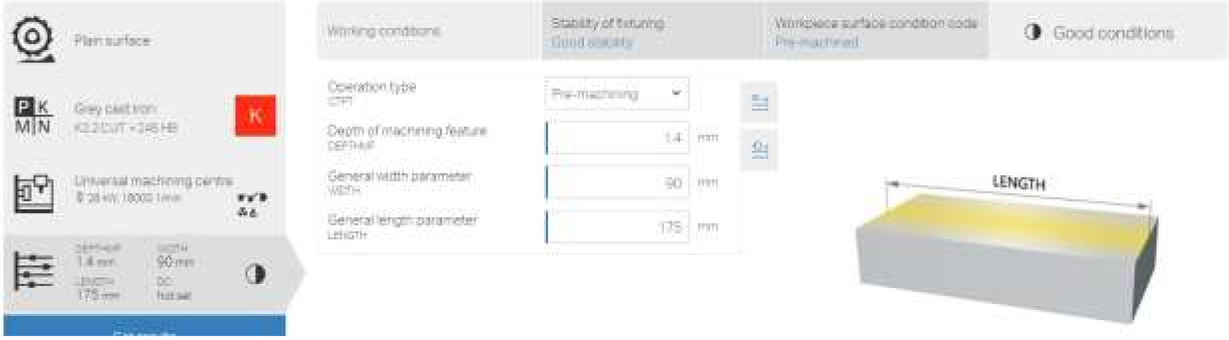
- Select clamping system;
- Select toolholder type and size;
- Select insert shape;
- Select insert size;
- Determine tool edge radius;
- Select insert type;
- Select tool material.

***Tool selection for the manufacturing steps

005.01 Rough and Finish Milling of the Surface M3 to dimension 12mm and Ra5.0

Allowance = 1.4
Radial Cut width = 10

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



Plain surface

Grey cast iron

Universal machining centre

DEPTHMF 1.4 mm

WIDTH 90 mm

LENGTH 175 mm

DC Not set

Working conditions

Stability of fixturing: Good stability

Workpiece surface condition code: Pre-machined

Good conditions

Operation type: Pre-machining

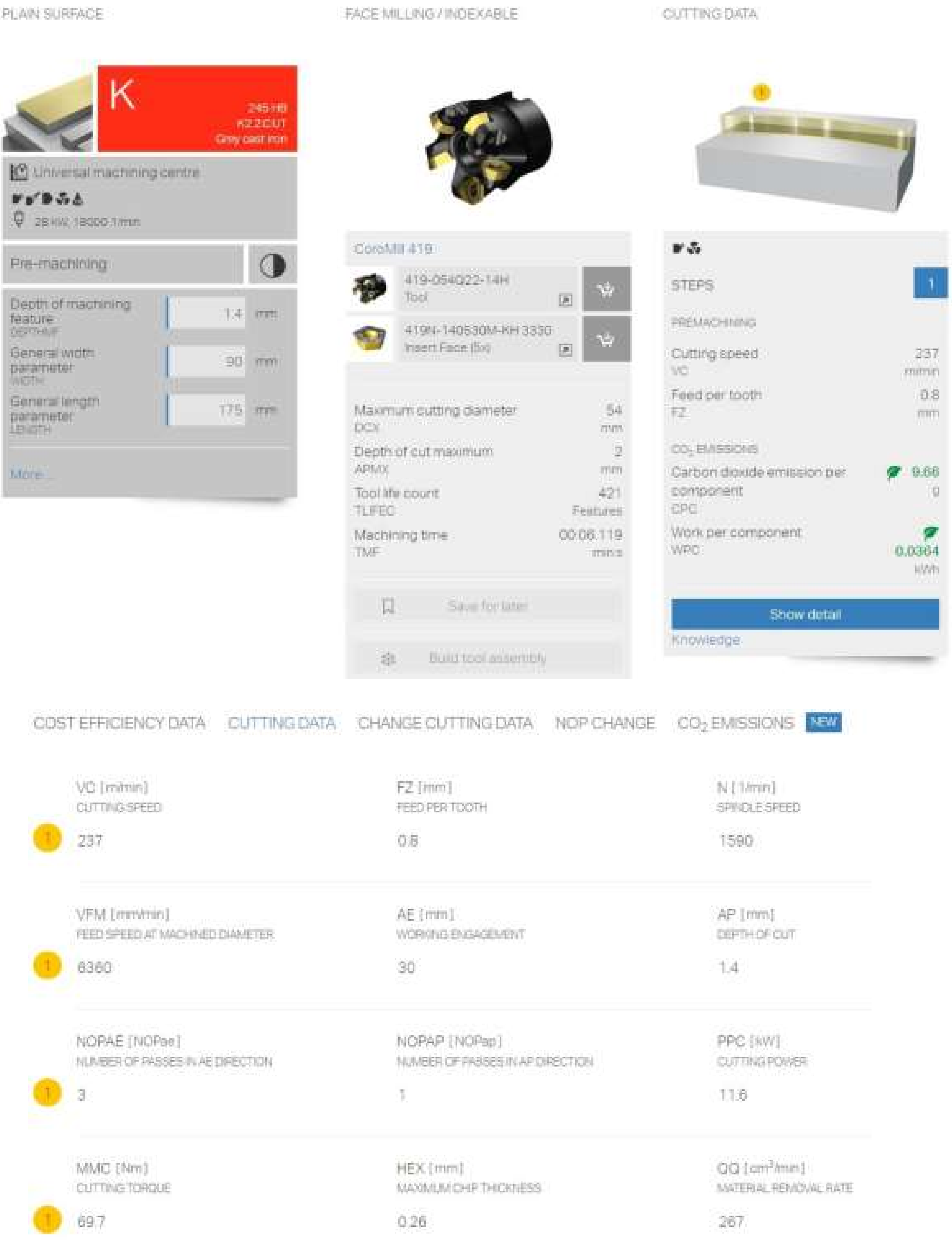
Depth of machining feature DEPTHMF: 1.4 mm

General width parameter WIDTH: 90 mm

General length parameter LENGTH: 175 mm

Fig.13. Initial Data

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



245 HB
K2.2.C.UT
Grey cast iron

Universal machining centre

28 kW, 18000 1/min

Pre-machining

Depth of machining feature DEPTHMF: 1.4 mm

General width parameter WIDTH: 90 mm

General length parameter LENGTH: 175 mm

CoroMill 419

419-054Q22-14H Tool

419N-140530M-KH 3330 Insert Face (5x)

Maximum cutting diameter DCX: 54 mm

Depth of cut maximum APMX: 2 mm

Tool life count TLIFEC: 421 Features

Machining time TMF: 00:06.119 min:s

STEPS: 1

PREMACHINING

Cutting speed VC: 237 m/min

Feed per tooth FZ: 0.8 mm

CO$_2$ EMISSIONS

Carbon dioxide emission per component CPC: 9.66 g

Work per component WPC: 0.0304 kWh

VC [m/min] CUTTING SPEED	FZ [mm] FEED PER TOOTH	N [1/min] SPINDLE SPEED
237	0.8	1590
VFM [mm/min] FEED SPEED AT MACHINED DIAMETER	AE [mm] WORKING ENGAGEMENT	AP [mm] DEPTH OF CUT
6360	30	1.4
NOPAE [NOPae] NUMBER OF PASSES IN AE DIRECTION	NOPAP [NOPap] NUMBER OF PASSES IN AP DIRECTION	PPC [kW] CUTTING POWER
3	1	11.6
MMC [Nm] CUTTING TORQUE	HEX [mm] MAXIMUM CHIP THICKNESS	QQ [cm^3/min] MATERIAL REMOVAL RATE
69.7	0.26	267

Fig.14. Recommended Cutting Tool and Cutting Data

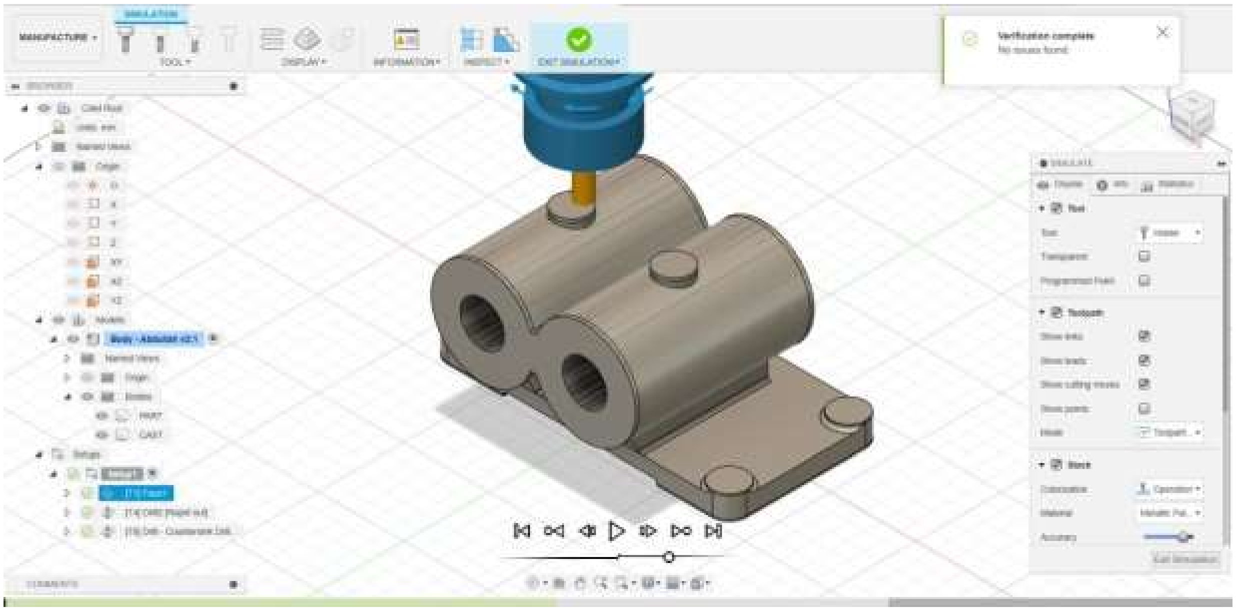
2.7. Post Process and Simulation

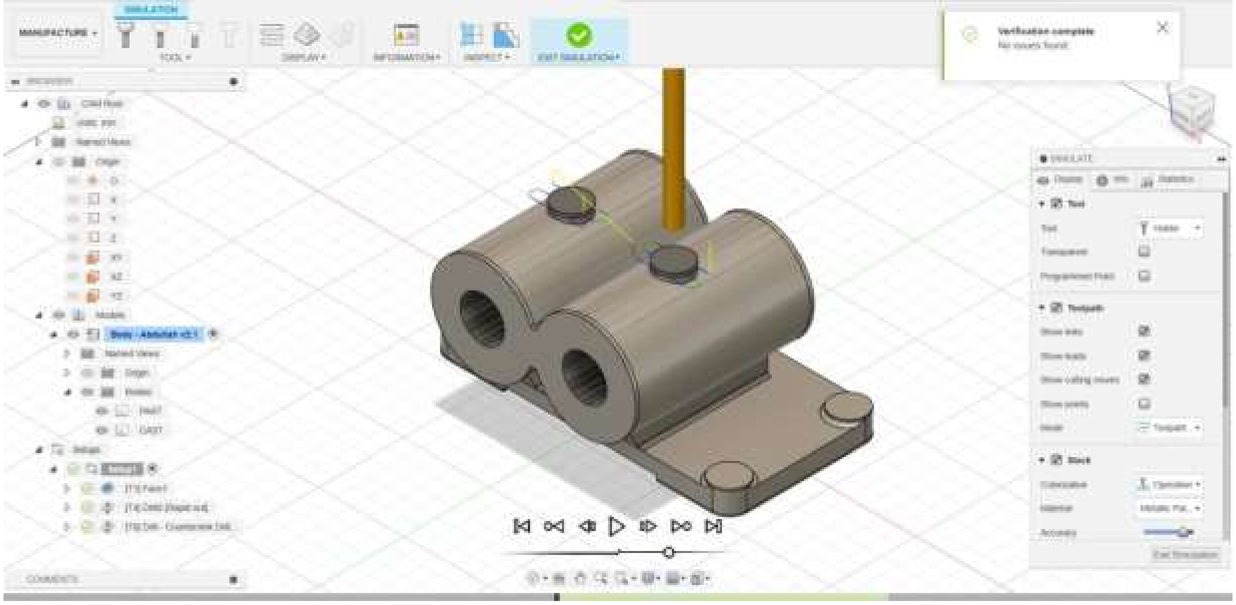
After doing all the necessary analysis on the drawing and part, designing the 3D Model as well as the Casting Blank, we can now safely start working on the Simulation of the machining, this step is crucial to figure out machinability and workability of certain features.

The Simulation will be performed on the software Autodesk Fusion 360, as it has options to simulate our chosen CNC Machine and generate NC Code for that specific machine.

Following are screenshots from the software, all machining steps taken are based on the previous chapters, mainly includes the steps detailed in "2.5. Manufacturing Process Plan".

AS for the Post Process CNC "G" Code, it will be attached at the end of the document as an Annex.





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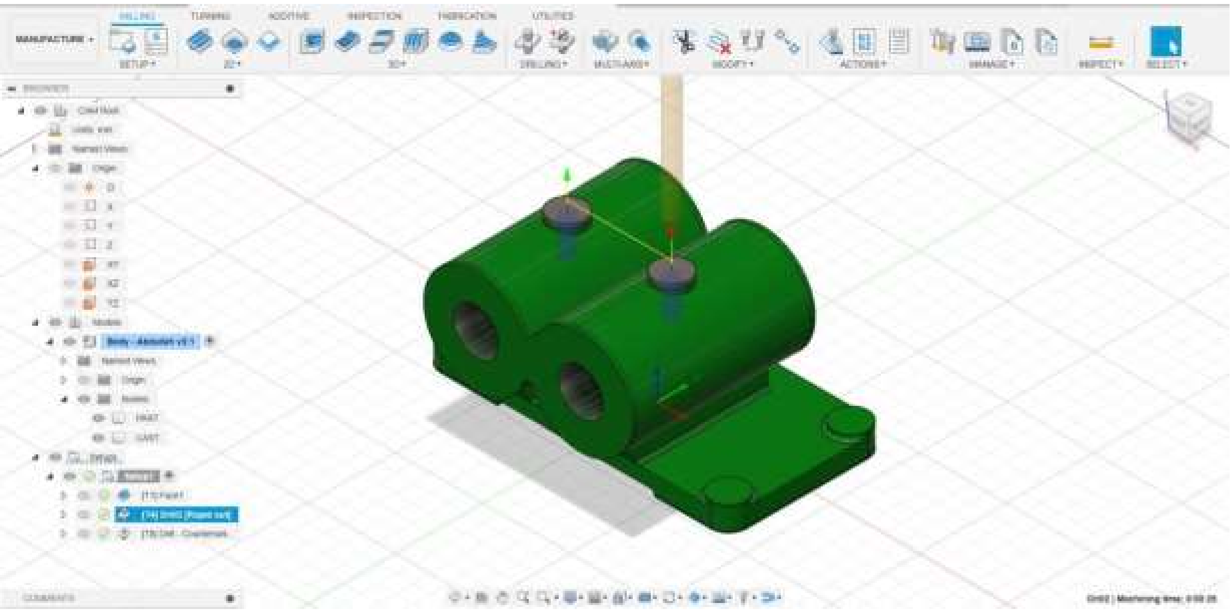

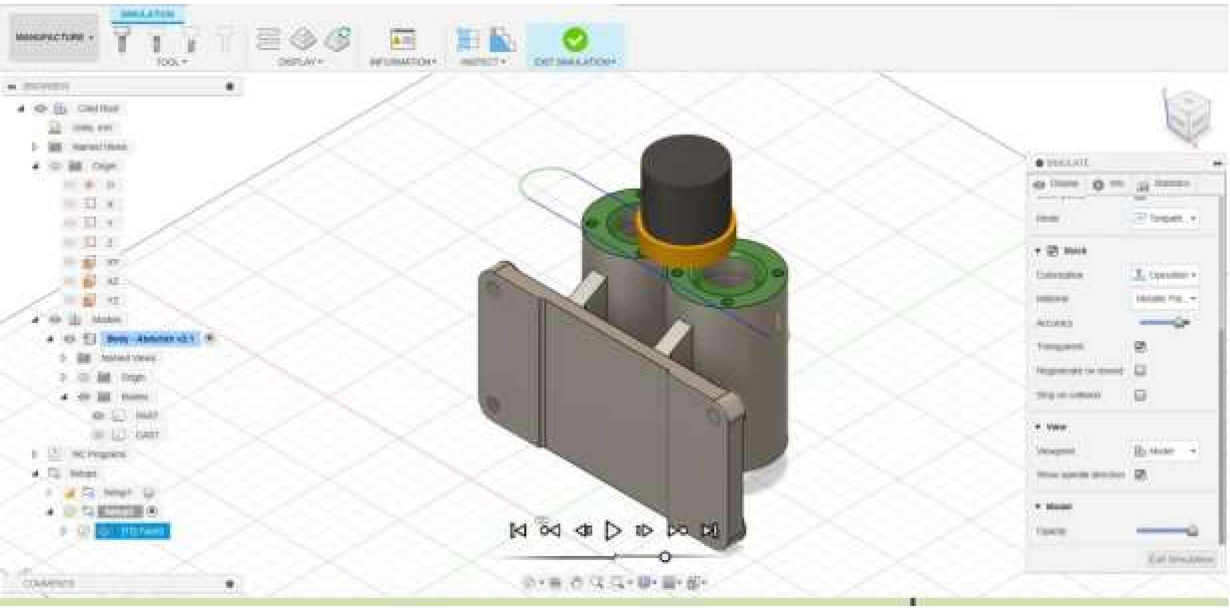
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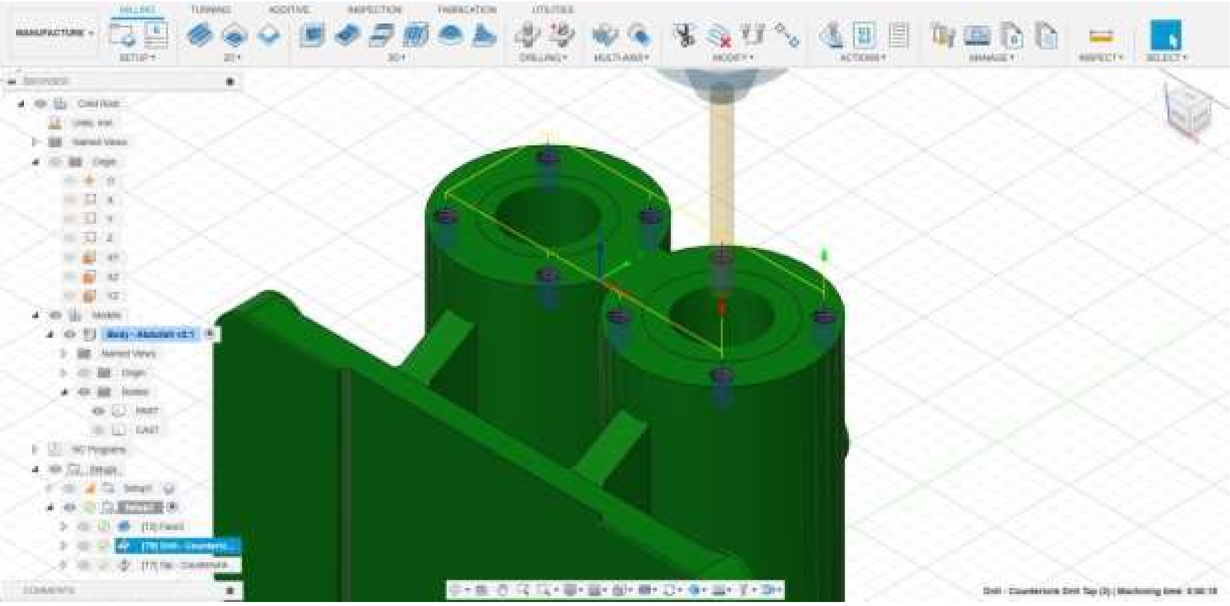
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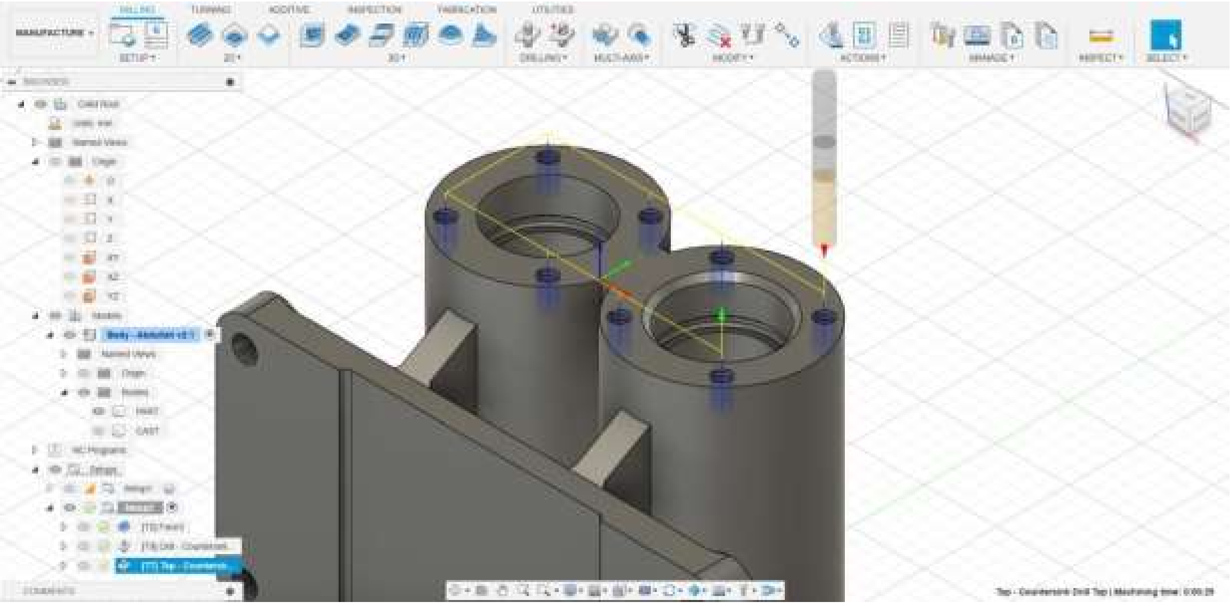
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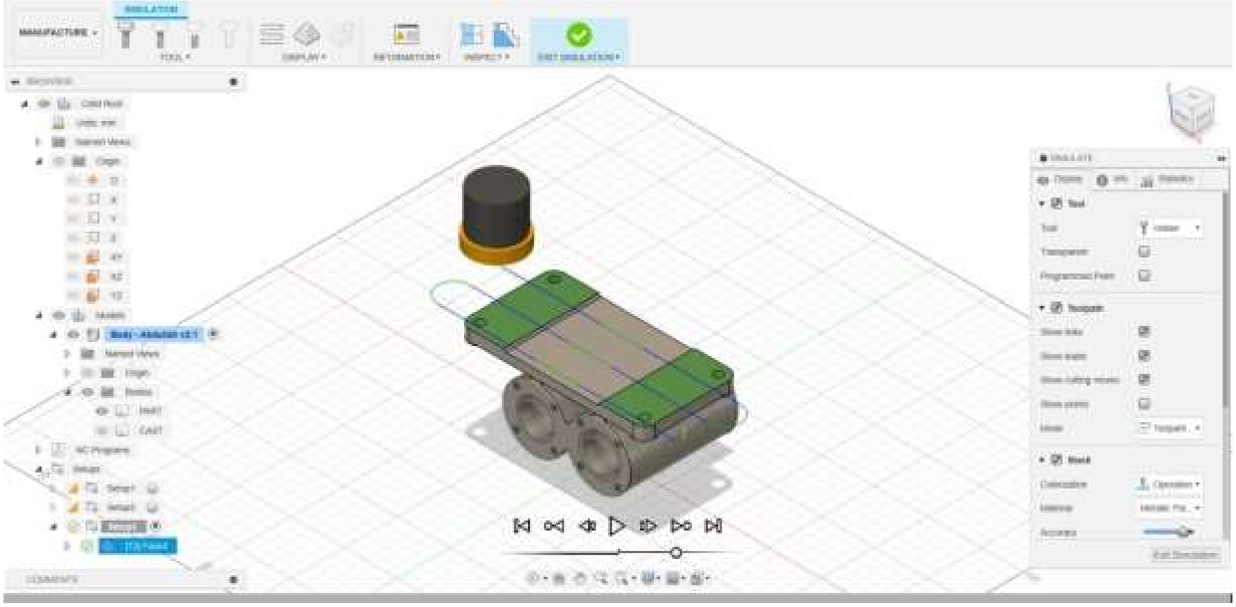
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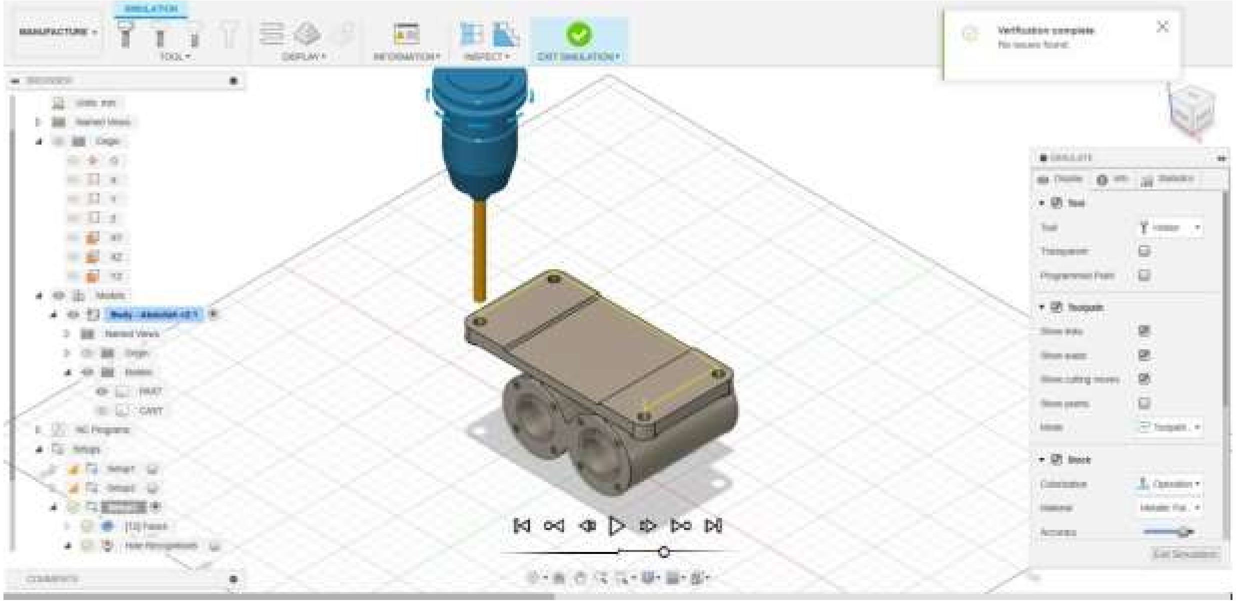

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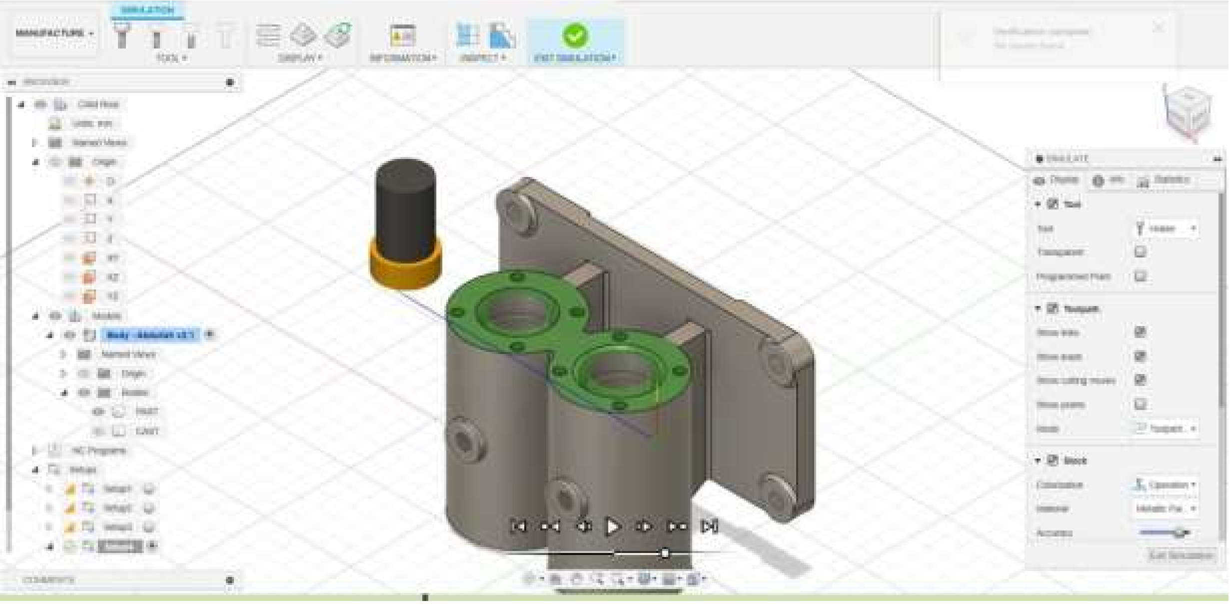

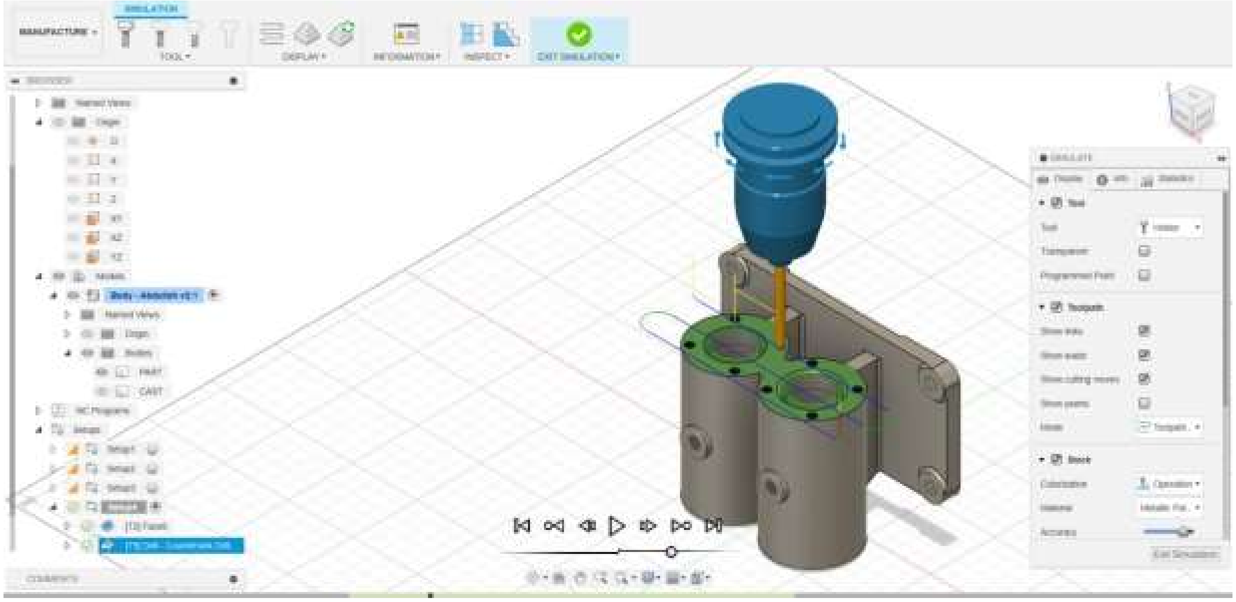
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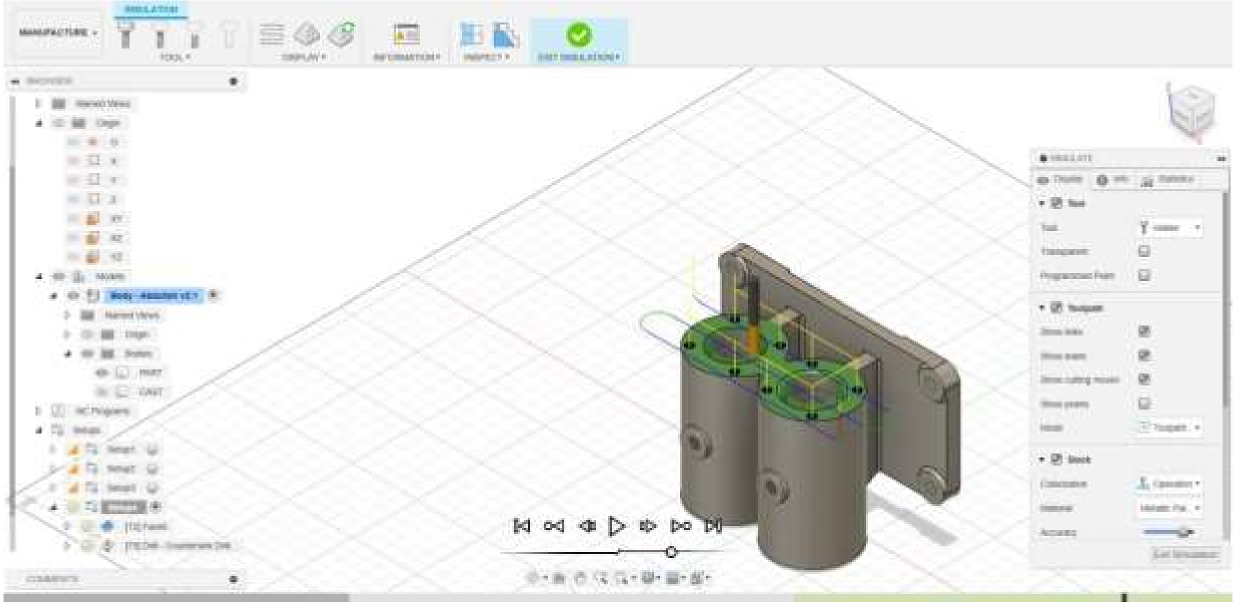
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CHAPTER 3: Fixture Design

3.1. Purpose of the Fixture

This project focuses on designing a fixture for the machining of a “Corps that direct”, which features 2 large cylinders on a platform. The primary goal of this fixture is to ensure the precise and repeatable machining of this part, maintaining high levels of dimensional accuracy and alignment. The customized fixture design aims to improve the manufacturing process by enhancing productivity and ensuring the quality of the machined parts.

The purpose of this report is to detail the design process and specifications of the fixture, targeting the machining requirements of a part with complex features. It provides a comprehensive overview of the fixture design, including conceptualization, engineering drawings, and manufacturing considerations. This document is intended as a reference, offering necessary information to support the evaluation, approval, and implementation phases of the project.

3.2. Possible Fixture designs and solutions

The manufacturing process of the “Corps that direct” necessitates having a Fixture design that will be used in each of the machining sequences, based on the specific requirements of the locating datum. To accommodate these requirements, we have come up with one possible design that can be identified as an optimal solution for the operations on a 5-axis CNC Machine, which is the “The Table Vise”.

This Fixture, the table vise, offers maximum security of the part on the table, as well as repeatability for each of the machining operations. Detailed drawings and images of the fixture designs will be provided in the following figures, illustrating the specific applications in the machining sequence of the “Corps that direct” part.

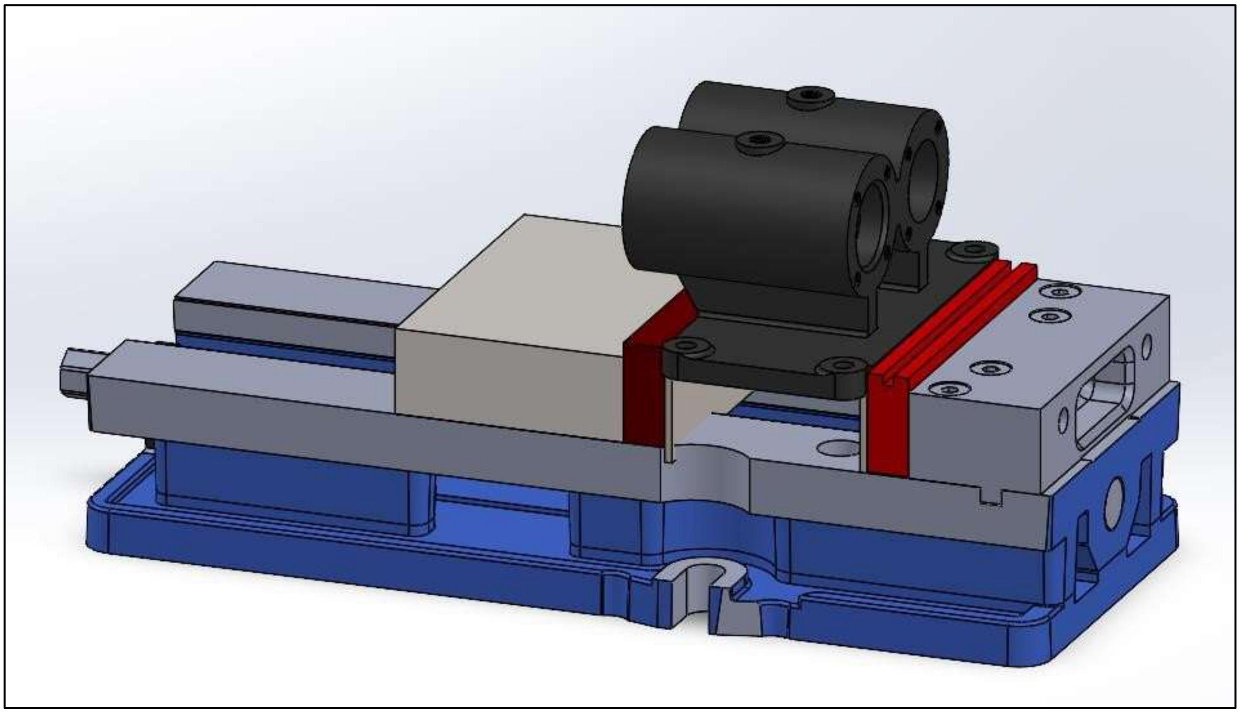


Fig.19. Vise 3D

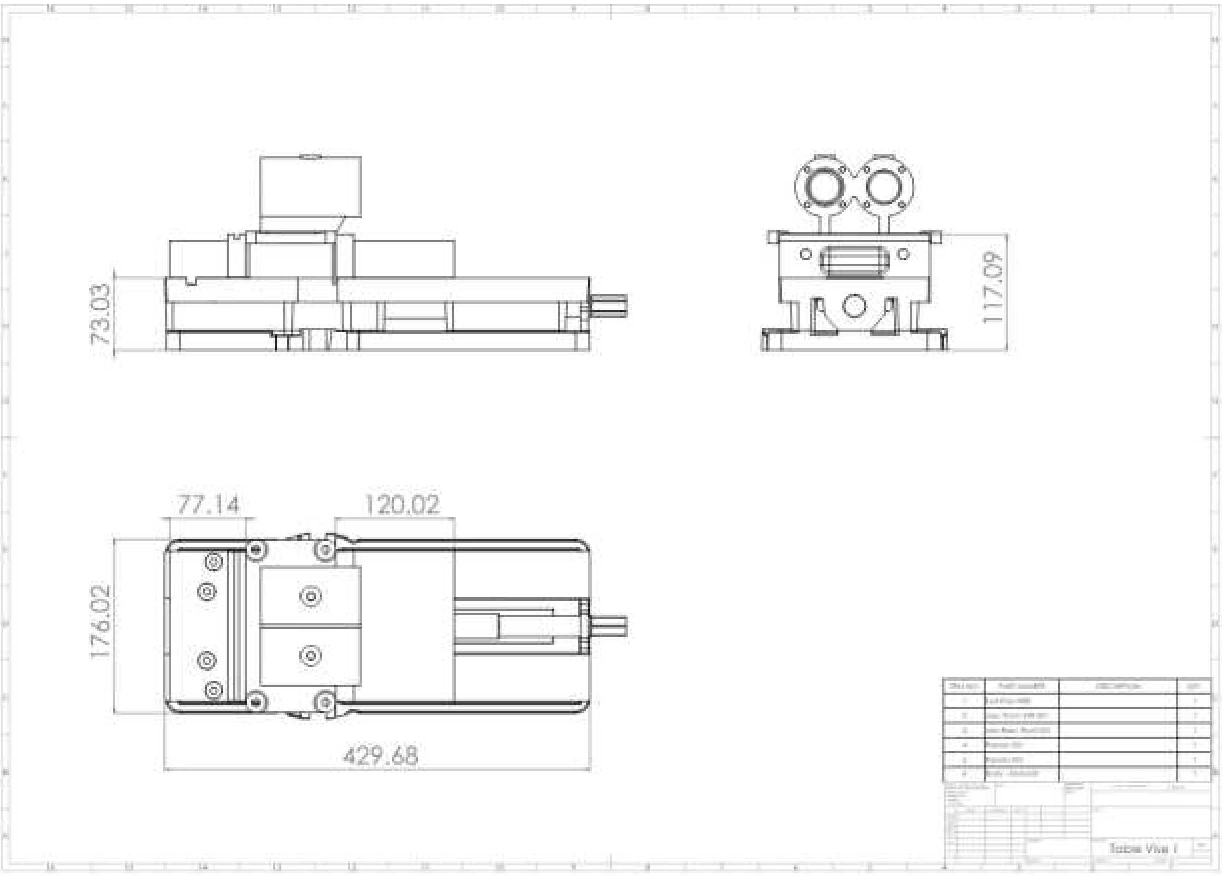


Fig.20. Drawing of the Vise

3.3. Clamping Force calculation

3.3.1. Vise Fixture

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.

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

$$\text{[illegible]} = \text{[illegible]} \Big/ \text{[illegible]}$$

To determine the cutting force, apply:

$$\text{[illegible]} = 4.5 \times \text{[illegible]} \times \text{[illegible]} \times \text{[illegible]} \times \text{[illegible]} \Big/ \text{[illegible]}$$

Where:

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

The cutting speed can be calculated using:

$$\text{[illegible]} = \pi \times \text{[illegible]} \times \text{[illegible]} \Big/ 60{,}000$$

For an example, assuming a cutting speed of 0.942 (units will vary based on input parameters) and plugging in the values into the cutting force formula yields:

$$\text{[illegible]} = 4.5 \times \text{[illegible]} \times \text{[illegible]} \times \text{[illegible]} \times \text{[illegible]} \Big/ \text{[illegible]}$$

After calculating the cutting force, divide this by the coefficient of friction (assumed here to be 0.3) to find the clamping force. Consequently:

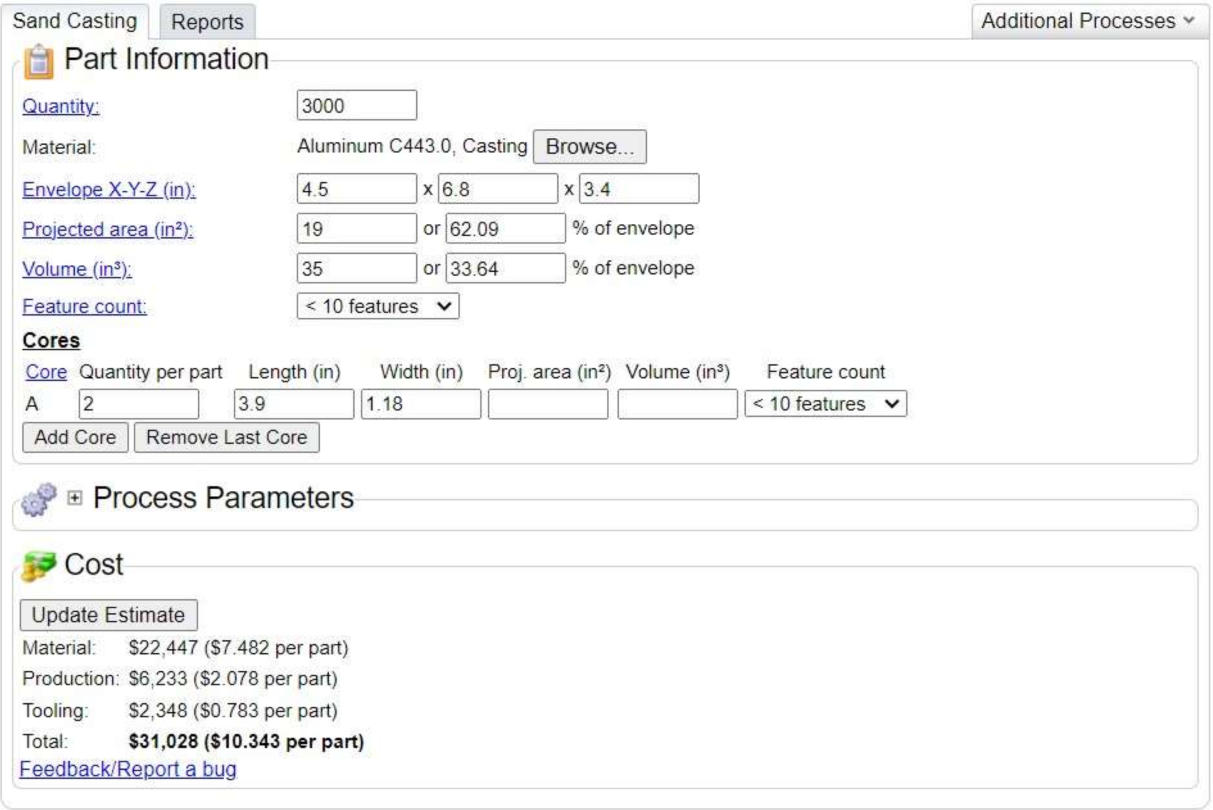
Given a cutting force of 843 N in our example.
The resulting clamping force would be 2810 N

CHAPTER 4: Economical Section

4.1. Cost Estimation

In order to estimate the casting cost, we could utilize an online website called "Cost Estimator" that can be found through "https://www.custompartnet.com/".

The one disadvantage of this tool, is that the complexity of our part can't be taken into consideration as there are no options to detail or upload the 3D model for visual inspection. In addition to that, all Units on this website are set to imperial, therefore conversions to Metric units have been done to adjust to this obstacle, below are the final Cost estimations.



Part Information

Quantity: 3000
Material: Aluminum C443.0, Casting
Envelope X-Y-Z (in): 4.5 x 6.8 x 3.4
Projected area (in²): 19 or 62.09 % of envelope
Volume (in³): 35 or 33.64 % of envelope
Feature count: < 10 features

Cores

Core	Quantity per part	Length (in)	Width (in)	Proj. area (in²)	Volume (in³)	Feature count
A	2	3.9	1.18			< 10 features

Cost

Material:	$22,447 ($7.482 per part)
Production:	$6,233 ($2.078 per part)
Tooling:	$2,348 ($0.783 per part)
Total:	**$31,028 ($10.343 per part)**

Fig.15. Sand Casting Cost Estimation

Stock Information

Part quantity: 3000

Defect rate (%): 3

Run quantity: 3093

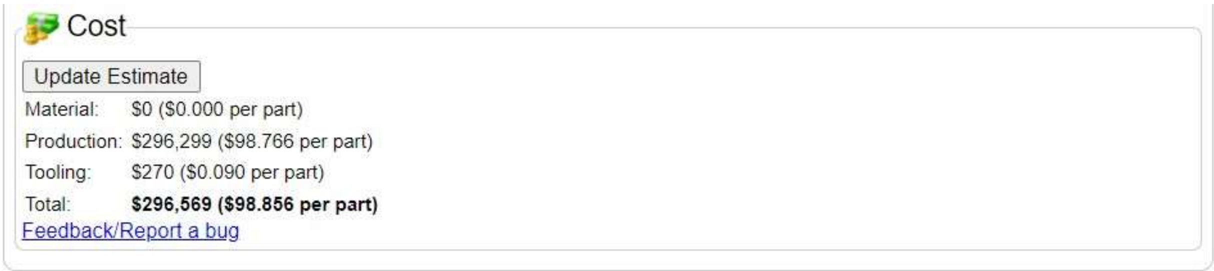
Material: Ductile iron: Grade 80-55-06

Workpiece: Prefabricated part

LxWxH (in): 4.5 x 6.8 x 3.4

Weight (lb): 9

Fig.16. Stock Information for Machining cost estimation



Cost

Material: $0 ($0.000 per part)

Production: $296,299 ($98.766 per part)

Tooling: $270 ($0.090 per part)

Total: **$296,569 ($98.856 per part)**

Fig.17. Cost Estimation for Machining Sequences

Overall, the tally cost of producing 5000 parts will be the sum of sand-casting costs and machining costs, as following:

$$C_T = C_C + C_m = 31{,}028 + 296{,}569 = \$327{,}597$$

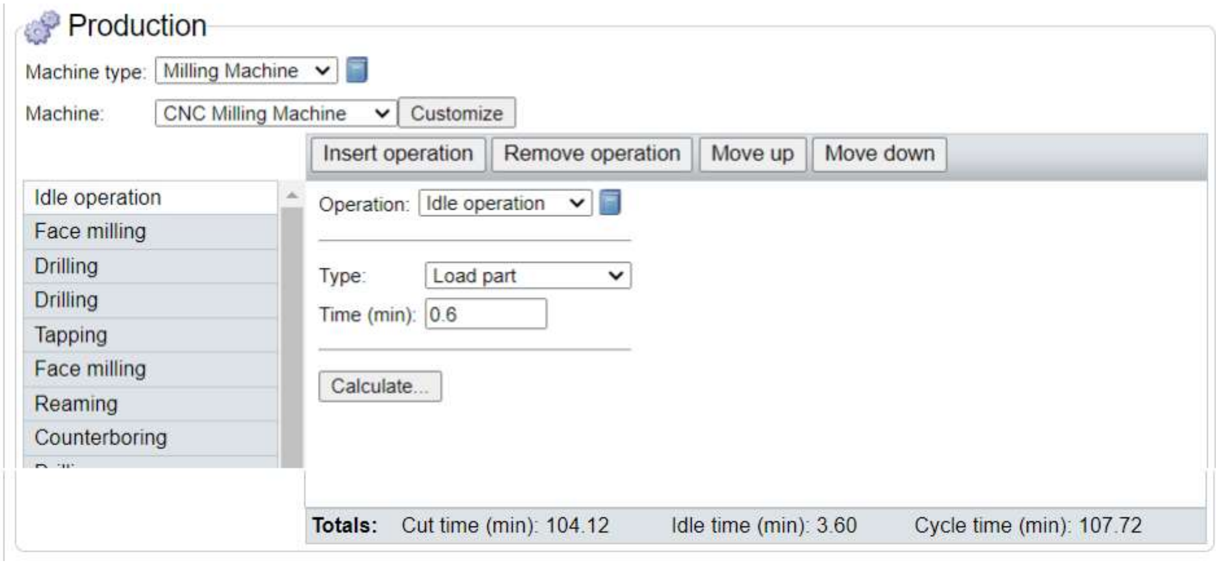
C_T: Total Cost ; C_C: Cost of Casting ; C_m: Cost of Machining

Which accords to roughly: ~$109.19per 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.



Machine type: Milling Machine
Machine: CNC Milling Machine

Idle operation
Face milling
Drilling
Drilling
Tapping
Face milling
Reaming
Counterboring

Operation: Idle operation
Type: Load part
Time (min): 0.6

Totals: Cut time (min): 104.12 Idle time (min): 3.60 Cycle time (min): 107.72

Fig.18. Time Estimation

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

The Cut Time for a total of 104.12 min
The Idle Tie for a total of 3.60 min

Therefore, the Cycle Time will be 107.72 min.

REFERENCES

- Custompartnet : https://www.custompartnet.com
- Hurco CNC Machines: https://www.hurco.com/
- Castings - System of dimensional tolerances and machining allowances ISO 8062
- Sandvik Coromant : https://www.sandvik.coromant.com
- Jig and Fixture Design – Edward G. Hofmann
- Solidworks Guide
- CAD Websites
    - https://www.mcmaster.com
    - https://grabcad.com
    - https://www.3dcontentcentral.com

ANNEX

```
%
O00510
(Using high feed G1 F650. instead of G0.)
(T1 D=10. CR=0. - ZMIN=88.996 - flat end mill)
(T4 D=9. CR=0. TAPER=118deg - ZMIN=65.996 - drill)
(T8 D=10. CR=0. TAPER=118deg - ZMIN=65.996 - drill)
N10 G90 G94 G17
N15 G21
N20 G53 G0 Z0.


(Face1)
N25 T1 M6
N30 S9702 M3
N35 G17 G90 G94
N40 G54
N45 M8
N50 G1 X-14.621 Y-29.766 F650.
N55 G0 G43 Z105.996 H1
N60 T4
N65 G0 Z95.996
N70 G1 Z89.996 F1068.58
N75 G18 G3 X-15.621 Z88.996 I-1. K0. F3205.74
N80 G1 X-44.571
N85 X-45.106
N90 G17 G2 Y-23.083 I0. J3.342
N95 G1 X-15.086
N100 G3 Y-16.4 I0. J3.342
N105 G1 X-15.091
N110 X-45.101
N115 G18 G3 X-46.101 Z89.996 I0. K1.
N120 G0 Z95.996
N125 G1 X14.429 Y-29.766 F650.
N130 Z89.996 F1068.58
N135 G2 X15.429 Z88.996 I1. K0. F3205.74
N140 G1 X44.379
N145 X44.914
N150 G17 G3 Y-23.083 I0. J3.342
N155 G1 X14.894
N160 G2 Y-16.4 I0. J3.342
N165 G1 X14.899
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N170 X44.909
N175 G18 G2 X45.909 Z89.996 I0. K1.
N180 G0 Z105.996
N185 M9
N190 M5
N195 G53 G0 Z0.

(Drill2)
N200 M1
N205 T4 M6
N210 S970 M3
N215 G17 G90 G94
N220 G54
N225 M8
N230 G1 X29.904 Y-21.55 F650.
N235 G0 G43 Z105.996 H4
N240 T8
N245 G0 Z95.996
N250 G98 G81 X29.904 Y-21.55 Z65.996 R93.996 F130.98
N255 X-30.096
N260 G80
N265 G0 Z105.996
N270 M9
N275 M5
N280 G53 G0 Z0.

(Drill - Countersink Drill Tap)
N285 M1
N290 T8 M6
N295 S2911 M3
N300 G17 G90 G94
N305 G54
N310 M8
N315 G1 X29.904 Y-21.55 F650.
N320 G0 G43 Z105.996 H8
N325 T1
N330 G0 Z95.996
N335 G98 G73 X29.904 Y-21.55 Z65.996 R93.996 Q2.5 F436.59
N340 X-30.096
N345 G80
N350 G0 Z105.996

N355 M5
N360 M9
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N365 G53 G0 Z0.
N370 G53 G0 X0. Y0.
N375 M30

%
%
O00515
(Using high feed G1 F650. instead of G0.)
(T2 D=50. CR=0. - ZMIN=-2.2 - face mill)
(T7 D=6. CR=0. - ZMIN=-12.2 - right hand tap)
(T9 D=6. CR=0. TAPER=118deg - ZMIN=-12.2 - drill)
N10 G90 G94 G17
N15 G21
N20 G53 G0 Z0.

(Face3)
N25 T2 M6
N30 S5000 M3
N35 G17 G90 G94
N40 G54
N45 M8
N50 G1 X90.01 Y-12.375 F650.
N55 G0 G43 Z15. H2
N60 T9
N65 G0 Z5.
N70 G1 Z2.8 F333.33
N75 G18 G3 X85.01 Z-2.2 I-5. K0. F1000.
N80 G1 X-85.01
N85 G17 G2 Y17.9 I0. J15.138
N90 G1 X85.01
N95 G18 G2 X90.01 Z2.8 I0. K5.
N100 G0 Z15.
N105 M9
N110 M5
N115 G53 G0 Z0.

(Drill - Countersink Drill Tap 2)
N120 M1
N125 T9 M6
N130 S4851 M3
N135 G17 G90 G94
N140 G54
N145 M8
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N150 G1 X47.678 Y-5.678 F650.
N155 G0 G43 Z15. H9
N160 T7
N165 G0 Z5.
N170 G98 G73 X47.678 Y-5.678 Z-12.2 R2.8 Q1.5 F436.59
N175 X12.322
N180 X-12.322
N185 X-47.678
N190 Y29.678
N195 X-12.322
N200 X12.322
N205 X47.678
N210 G80
N215 G0 Z15.
N220 M9
N225 M5
N230 G53 G0 Z0.

(Tap - Countersink Drill Tap)
N235 M1
N240 T7 M6
N245 S500 M3
N250 G17 G90 G94
N255 G54
N260 M8
N265 G1 X47.678 Y29.678 F650.
N270 G0 G43 Z15. H7
N275 T2
N280 G0 Z5.
N285 G98 G84 X47.678 Y29.678 Z-12.2 R2.8 F500.
N290 X12.322
N295 X-12.322
N300 X-47.678
N305 Y-5.678
N310 X-12.322
N315 X12.322
N320 X47.678
N325 G80
N330 G0 Z15.
N335 M5
N340 M9
N345 G53 G0 Z0.
N350 G53 G0 X0. Y0.
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N355 M30


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O00520
(Using high feed G1 F650. instead of G0.)
(T2 D=50. CR=0. - ZMIN=-1. - face mill)
(T5 D=9.525 CR=0. TAPER=90deg - ZMIN=-5.25 - spot drill)
(T6 D=8.5 CR=0. TAPER=118deg - ZMIN=-15.554 - drill)
N10 G90 G94 G17
N15 G21
N20 G53 G0 Z0.


(Face4)
N25 T2 M6
N30 S5000 M3
N35 G17 G90 G94
N40 G54
N45 M8
N50 G1 X119.733 Y-53.033 F650.
N55 G0 G43 Z15. H2
N60 T5
N65 G0 Z5.
N70 G1 Z4. F333.33
N75 G18 G3 X114.733 Z-1. I-5. K0. F1000.
N80 G1 X112.51
N85 X19.99
N90 X-19.99
N95 X-112.51
N100 G17 G2 Y-22.917 I0. J15.058
N105 G1 X-19.99
N110 X19.99
N115 X112.51
N120 G3 Y7.2 I0. J15.058
N125 G1 X19.99
N130 X-19.99
N135 X-112.51
N140 G18 G3 X-117.51 Z4. I0. K5.
N145 G0 Z15.
N150 M9
N155 M5
N160 G53 G0 Z0.
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(Spotdrill - Spotdrill Drill)
N165 M1
N170 T5 M6
N175 S5000 M3
N180 G17 G90 G94
N185 G54
N190 M8
N195 G1 X77.5 Y-48.6 F650.
N200 G0 G43 Z15. H5
N205 T6
N210 G0 Z5.
N215 G98 G81 X77.5 Y-48.6 Z-5.25
R4. F333.33
N220 Y21.4
N225 X-77.5
N230 Y-48.6
N235 G80
N240 G0 Z15.
N245 M9
N250 M5
N255 G53 G0 Z0.


(Drill - Spotdrill Drill)
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N260 M1
N265 T6 M6
N270 S5000 M3
N275 G17 G90 G94
N280 G54
N285 M8
N290 G1 X77.5 Y-48.6 F650.
N295 G0 G43 Z15. H6
N300 T2
N305 G0 Z5.
N310 G98 G73 X77.5 Y-48.6 Z-
15.554 R4. Q2.125 F1000.
N315 Y21.4
N320 X-77.5
N325 Y-48.6
N330 G80
N335 G0 Z15.

N340 M5
N345 M9
N350 G53 G0 Z0. N355
G53 G0 X0. Y0. N360
M30
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%
%
O00525
(Using high feed G1 F650. instead of G0.)
(T2 D=30. CR=0. - ZMIN=-15. - face mill)
(T7 D=6. CR=0. - ZMIN=-25. - right hand tap)
(T9 D=6. CR=0. TAPER=118deg - ZMIN=-25. - drill)
N10 G90 G94 G17
N15 G21
N20 G53 G0 Z0.
(Face6)
N25 T2 M6
N30 S5000 M3
N35 G17 G90 G94
N40 G54
N45 M8
N50 G1 X76.402 Y-36.68 F650.
N55 G0 G43 Z15. H2
N60 T9
N65 G0 Z5.
N70 G1 Z-12. F333.33
N75 G18 G3 X73.402 Z-15. I-3. K0. F1000.
N80 G1 X-73.402
N85 X-75.01
N90 G17 G2 Y-16.57 I0. J10.055
N95 G1 X75.01
N100 G3 Y3.54 I0. J10.055
N105 G1 X75.
N110 X-75.
N115 G18 G3 X-78. Z-12. I0. K3.
N120 G0 Z15.
N125 M9
N130 M5
N135 G53 G0 Z0.
(Drill - Countersink Drill Tap 3)
N140 M1
N145 T9 M6
N150 S4851 M3
N155 G17 G90 G94
N160 G54
N165 M8
N170 G1 X-47.896 Y5.678 F650.
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N175 G0 G43 Z15. H9

N180 T7

N185 G0 Z5.

N190 G98 G73 X-47.896 Y5.678 Z-25. R-10. Q1.5 F436.59

N195 X-12.54

N200 X12.322

N205 X47.678

N210 Y-29.678

N215 X12.322

N220 X-12.54

N225 X-47.896

N230 G80

N235 G0 Z15.

N240 M9

N245 M5

N250 G53 G0 Z0.

(Tap - Countersink Drill Tap 2)

N255 M1

N260 T7 M6

N265 S500 M3

G90 G94

N275 G54

N280 M8

N285 G1 X-47.896 Y5.678 F650.

N290 G0 G43 Z15. H7

N295 T2

N300 G0 Z5.

N305 G98 G84 X-47.896 Y5.678 Z-25. R-10. F500.

N310 X-12.54

N315 X12.322

N320 X47.678

N325 Y-29.678

N330 X12.322

N335 X-12.54

N340 X-47.896

N345 G80

N350 G0 Z15.

N355 M5

N360 M9

N365 G53 G0 Z0.

N370 G53 G0 X0. Y0.

N375 M30


%
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