MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

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

The defense allowed:
Head of the department
______Olexander OKHRIMENKO
«___»____________2023

Diploma project

for a bachelor's degree

in Educational Program “Manufacturing Engineering”

Program subject area – 131 “Applied Mechanics”

on the topic: «Design and Technological Support for the Production of the "Jaw" Part»

Developed by:
Student of the IV year of study, group MT-93
____ZYAD HAKIM__________________________ _______________
(full name) (signature)

Supervisor:
Associate professor Anatolii SUBIN, Ph.D. _______________

Reviewer:
_Associate professor Olga HOLYAVIK, Ph.D._____ _______________

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

Student _______________
signature

Kyiv – 2023

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“IGOR SIKORSKY KYIV POLYTECHNIC INSTITUTE”
EDUCATION AND RESEARCH INSTITUTE OF MECHANICAL ENGINEERING

Department of Manufacturing Engineering

«APPROVED»
Head of the department

_______Oleksandr OHRIMENKO

«___»____________2023

Assignment for the diploma project

for a bachelor's degree

Program subject area **131. Applied Mechanics _**

Student from group MT-93 ZYAD HAKIM ____________________

1. Topic of the project __Design and Technological Support for the Production of the "Jaw" Part

Project supervisor ______Assoc. Prof. Anatolii SUBIN _________________ ,

approved by the University Order of «___»_________ 2023 №_____

2. Deadline for submission of the project «_16_» __06__2023

3. Task on general engineering issues Overview of the general issues happened with Jaw manufacturing ____

«____» ___ 2023 _____ Head of the ME department Oleksandr OHRIMENKO

4. Tasks on the topic of the diploma project Design a technological process and_ define the technological equipment for the manufacture of parts “ Jaw ”______

5. The list of questions to be developed on the task named in **sect.3**
Review of general issues; explain ways to solve

6. The list of questions to be developed on the task named in **sect.4**
perform standard tasks of designing the operational technological process of manufacturing parts " Jaw "; to design constructions of machine tools for realization of technological process; to determine the cost calculations; to form a set of technological documentation

7. List of the graphic material (indicating mandatory drawings, posters, presentations, etc.) to present the major results of the general engineering issues investigations; design 3-D models and drawings of parts and blanks; to design schemes of performance of technological operations; modeling of G-code operation for its execution on the selected CNC machine; to design assembly drawings of machine tools for realization of technological process; the total number of sheets of the graphic part should be 6-8 sheets

8. Diploma section consultants

Section name	**Task**	**Deadline**	**Supervisor**
Economical	Perform the detail cost calculation	30.05.2023	

TIME SCHEDULE

№	**The stage of the diploma project execution**	**Deadline**	**Notes**
1	Technological section	1 week	
2	Technological section	2 week	
3	Design section	3 week	
4	Design section	4 week	
5	Other sections	5 week	
6	Formalizing of the project sections	6 week	

The assignment has been issued « 15 » 04 2023

Student ZYAD HAKIM

Project supervisor Anatolii SUBIN

Abstract

The explanatory note for my bachelor's diploma project titled "Design and Technological Provision of Jaw Part Manufacturing" comprises of 70 A4-size pages and includes 33 illustrations, 19 tables, and 3 appendices. These appendices present the processing routes and operations, and the control program code for the CNC machine. Throughout the project, I have referenced 59 literature sources, including manuals, guides, handbooks, catalogs, standards, articles, and scientific research.

The graphical part of the project consists of 8 A1-size sheets, showcasing various aspects such as the static study results, detailed drawings, 3D representations of the part and the workpiece, graphical depictions of the technological transitions, and their visualization in the CAM system. Furthermore, assembly drawings of the machine devices and technological transition schemes for two operations are included.

Within the diploma project, I have addressed the following aspects:

- I explored the issue of deformation of the workpiece when machining.
- I proposed an alternative solution to a specific problem, highlighting its advantages and drawbacks.
- I designed a 3D model of the jaw part and provided its detailed drawings.
- I conducted an analysis of the part's functional purpose and working conditions within the assembly.
- I performed a brief analysis of the manufacturability of the part's design.
- I selected the appropriate method for manufacturing the workpiece, developed a 3D model of the workpiece, and created its detailed drawings.
- I justified the selection of technological foundations for all the operations within the manufacturing process.
- I devised the operational technological process for manufacturing the jaw part.
- I determined the required allowances for all the machined surfaces of the workpiece.
- I standardized the technological operations for producing the part.
- I developed the necessary technological documentation, including processing routes, and operations.
- I designed the construction of the machine device and its 3D model, conducting all the necessary calculations to determine the required clamping force.
- I calculated the manufacturing cost of the part.

The attached annex pages at the end of the diploma project include a comprehensive report of the static study conducted on the jaw part using Fusion 360. The study

focused on assessing the structural weaknesses of the part during the drilling of tapped countersunk holes F5 and F6. The study report provides valuable insights into the deformations that occurred and their visual representations.

This diploma project aims to showcase the extensive research, design, and technological considerations involved in the manufacturing process of the jaw part. It presents a comprehensive analysis of various aspects, along with practical solutions and innovative approaches.

Table of Contents

General issues of manufacturing the Jaw

In any manufacturing project, we often face challenges and obstacles that require careful consideration. Our diploma project focused on the manufacturing of the "Jaw" part, where our main aim was to design a manufacturing plan that maximizes efficiency, accuracy, and cost-effectiveness.

To reduce machining costs, it is advantageous to include as many workpiece features as possible during the casting process. However, the jaw part presented a specific challenge. It had 10 tapped countersunk holes with a diameter of 8mm, which were too small to be included in the casting. Consequently, we had to postpone these holes for the machining phase.

One significant issue we encountered, which became the central focus of this diploma project, was the potential deformation during the drilling of holes F5 and F6. The details of the static stress study report related to this issue are provided in the annex section at the end of this report. Addressing this common problem required additional time due to the complex geometry of the part.

In typical cases, reducing cutting forces and using support structures are effective solutions to prevent deformation during drilling. However, these methods were not applicable in our situation. Therefore, we came up with an alternative solution: implementing heat treatment before machining.

By subjecting the workpiece to heat treatment (annealing), our goal was to improve its structural integrity and minimize the risk of deformation during drilling. This approach allowed us to ensure the dimensional accuracy of the final product and mitigate any potential distortions.

<u>Heat treatments</u> consist of a certain number of combined operations of heating and cooling for the purpose of:

a. To improve the characteristics of the materials and make them more favorable to a given use, with the following modifications:

- Increased breaking strength and elastic limit Rem, Re, A % by giving the element better hold.
- Increased hardness, allowing parts to better withstand wear or impact.

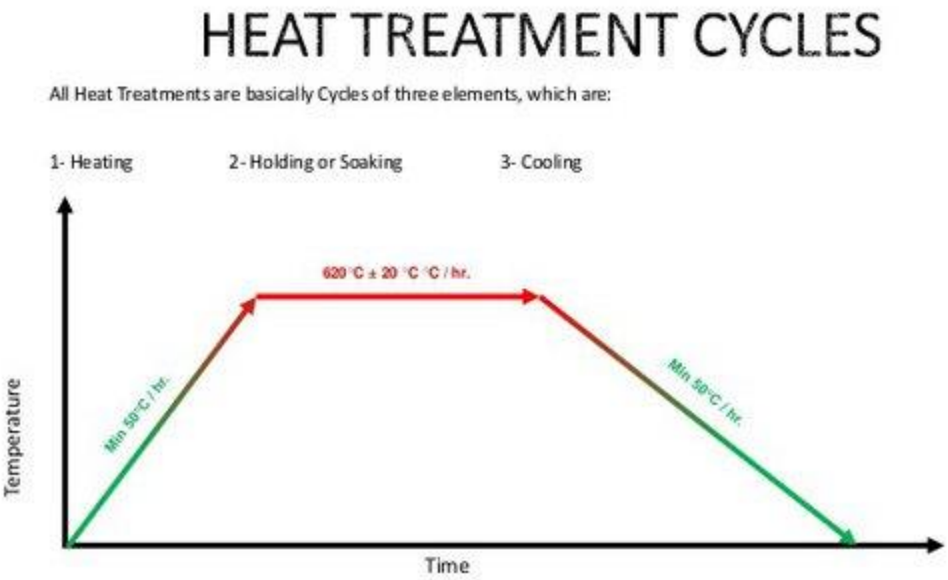
b. To regenerate a metal that has a coarse grain (refining the grains, homogenize the structure) case of materials having undergone forging.

c. To remove the internal stresses (work hardening) of the materials before undergoing cold plastic deformation (stamping, flow forming).

Apart from recrystallization annealing which makes it possible to eliminate strain hardening, heat treatments do not apply to pure metals, but only to a few alloys for which an increase in the elastic limit and a reduction in brittleness are mainly sought. Heat treatments are mainly applied to Carbon steels and Stainless alloy steels, non-ferrous alloys. In general, heat treatments do not change the chemical composition of the alloy.

Definitions and processes of heat treatments

Carrying out a heat treatment on a part means subjecting it to a variation in temperature as a function of time. The heat treatment process consists of:



1: Heating to temperatures above transformation temperatures.

2: Maintains at a set temperature.

3: Cooling with a given speed:
- slow (in the oven, in the air).
- Quite fast (in oil).
- Very fast (in water).

1. Part heating

The first step in any heat treatment is heating the part to the required temperature. The heating must be done very quickly to have low energy consumption and high productivity. There are two options for room heating.

a. By heat transfer:

There are three possibilities:
-By conductivity: The part is heated in a regular oven where it only comes into contact with the floor of the oven, so it receives only a small amount of the expended heat through conductivity.

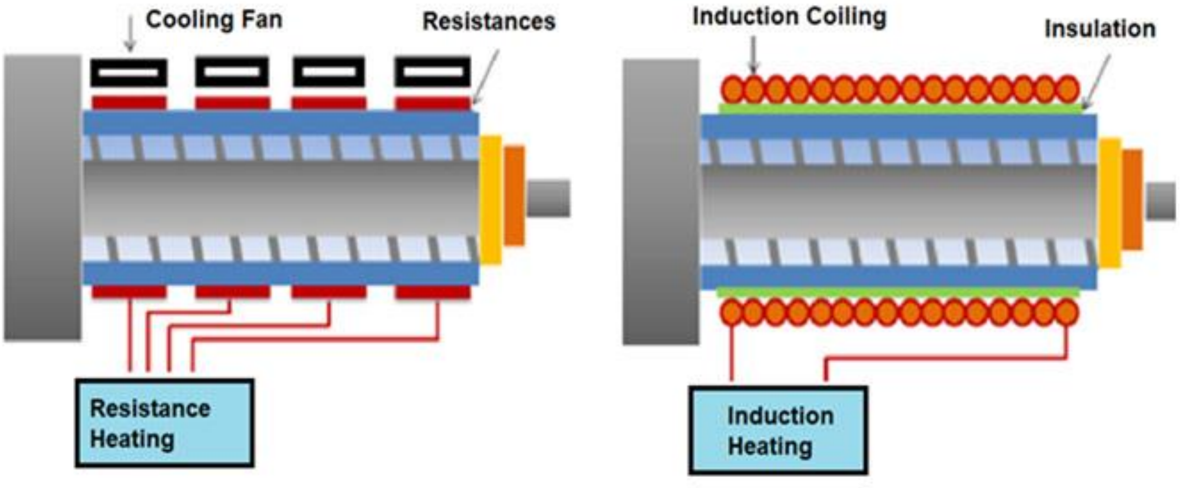
-By convection: In this case, the part is heated by contact with a hot fluid (gas or liquid) that moves and touches the part, transferring a large portion of the expended heat.

-By radiation: The heat absorbed by the walls and roof of the oven is radiated towards the part, which absorbs it. This is the case where the heat input is the most significant.

In most cases, the heating of parts is done simultaneously by convection and radiation.

b. By generating heat within the part:

This is a possibility to heat the part by creating a current flow within it, either by using the part as a conductor in an electrical circuit (resistance heating) or by placing the part in a varying magnetic field (induction heating).



This method is mainly used for small and uniform cross-section parts. Very high heating rates can be achieved. For example, for a part with a Ø 150 mm section, the heating time to reach T = 1200°C is:

- 20 minutes for induction heating.
- 8 minutes for resistance heating.
- 2 to 3 hours for heating in an oven.

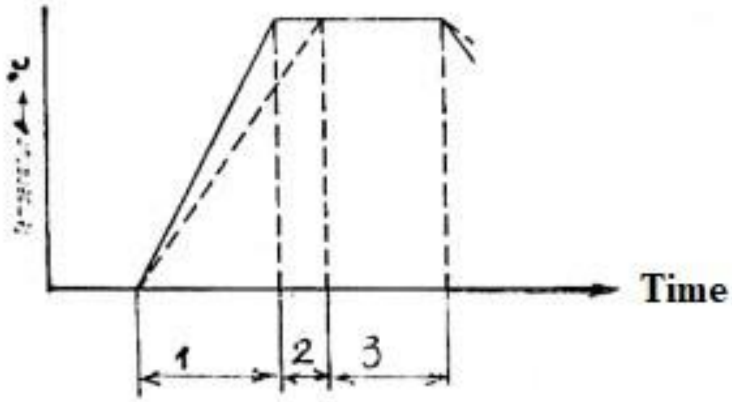
This method is cost-effective only for sections smaller than 150 mm.

The difficulties that may arise during rapid heating are the cracking and elongation of the parts due to the difference in expansion between the outer layer and the core of the part, which creates stresses that can cause cracks at low temperatures and plastic deformations at high temperatures.

Regardless of the heating method used, there is always a temperature difference in different parts of the part, resulting in non-uniform heat distribution.

Figure represents the heating curve for the surface and core of the part, with the curve simplified as a straight line.

During the heating process, three stages can be distinguished:



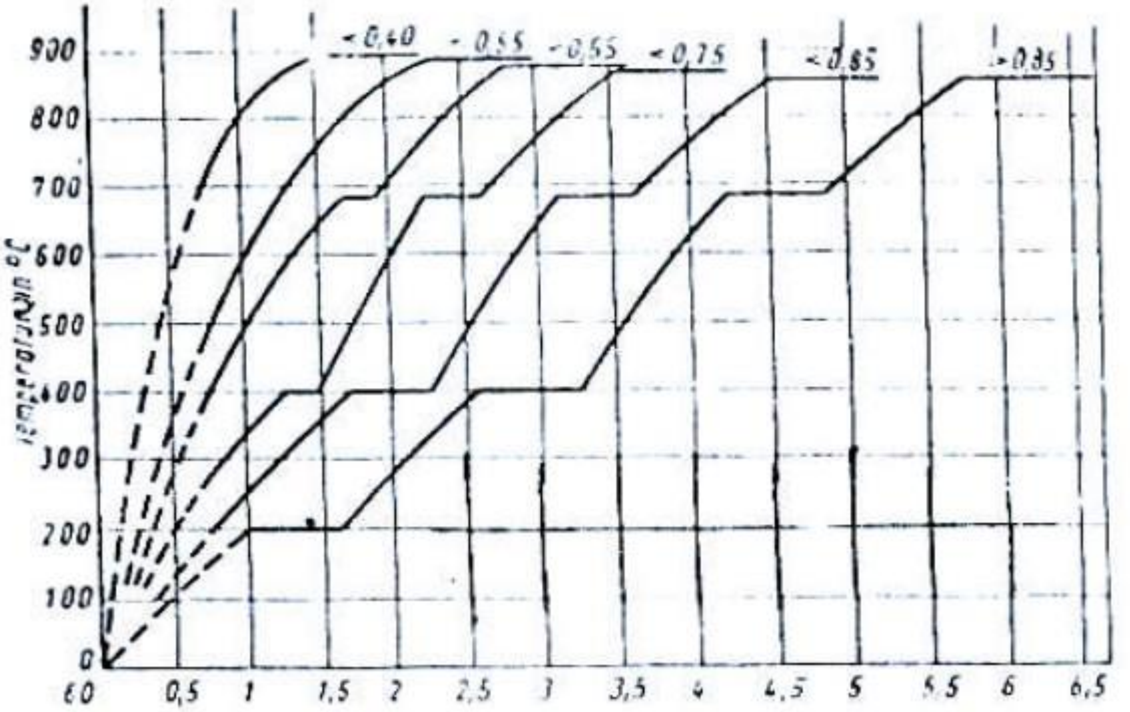
a. Preheating duration: This is the time from the start of heating until the nominal temperature is reached on the surface of the part.
b. Penetration or equalization heating duration: This is the time required to reach the nominal temperature on both the surface and the core of the part.
c. Holding duration: This is the time required to maintain the part at a specific temperature, starting from the temperature reached in the core.

The main factors influencing part heating are diameter (thickness), conductivity, furnace temperature, etc. In general, the heating regime for steels is determined based on the part's diameter and the characteristics defined by the equivalent carbon content (C_{eq}).

$$C_{\text{équivlent}} = C + \frac{Mn}{5} + \frac{Cr}{4} + \frac{Mo}{3} + \frac{Ni}{10} + V + \frac{Si - 0{,}5}{5} + \frac{W}{10} + \frac{Ti}{5} + \frac{Al}{10}$$

For maximum contents up to: 0.9% C, 1.1% Mn, 1.8% Cr, 0.5% Mo, 5.0% Ni, 0.25% V, 1.8% Si, 2% W, 0.4% Ti, 2% Al, it is possible, according to RUHFUS and PLFAUME, to determine the heating duration of the part based on its diameter and C_{eq}.

The steps shown on the curves (Figure 4) aim to reduce the temperature difference between the core and the outer layer of the part (temperature equalization). These curves are valid for tempering and normalizing annealing heat treatments.



Heating times in minutes recommended for normal tempering and quenching based on C_{eq} for a part with a diameter of 60 mm are shown in Figure 4.

For different heating processes, the following speeds can be chosen:

Slow heating: 3 to 10°C/min.
Conventional (normal) heating: 50°C/s.
Rapid heating: > 50°C/s.

2. Heating Conditions for Heat Treatment of Parts

The heating equipment must allow for:

-Reaching and maintaining a specific temperature in all parts of the piece with an accuracy of approximately plus or minus 5°C.
-Preventing any alteration of the metal, particularly decarburization in the case of steels.

-Providing preheating options when the desired temperature is high.

In general, only heating within a closed chamber with automatic temperature control can offer the desired solution.

3. Types of Furnaces and Their Atmospheres

a. Chamber Furnaces:

In chamber furnaces, heating is primarily done through radiation. They have a chamber where the piece to be heated is placed. In some cases, there may be a second chamber above the first one, which recovers some of the generated heat and serves as a preheating chamber.

b. Salt Bath Furnaces:

They offer the following advantages:

Rapid heating: The piece is in contact with the liquid salt on all sides, which is in constant motion.

Uniform heating: Temperature variations within the bath are minimal, resulting in even heating of the piece and reducing the likelihood of deformation.

Preservation of metal properties: The bath, which can be neutral, oxidizing, or reducing, protects the piece from direct contact with atmospheric oxygen.

c. Electric Furnaces:

Electric furnaces can be either chamber furnaces or salt bath furnaces. They are typically heated using metallic resistors made of nickel-chrome for temperatures below 1000°C and silicon for temperatures up to 1300°C. High-temperature electric furnaces with salt baths use electrodes, with the molten salt serving as resistance between the electrodes.

d. Atmospheres:

When heating parts to high temperatures in flame furnaces or electric furnaces, gases react with the metal surface, resulting in oxidation or decarburization of the outer layers of the parts.

Oxidation occurs due to the interaction of the metal with oxygen or water vapor present in the furnace atmosphere. Generally, carbon dioxide ($CO2$) reacts with iron, causing oxidation.

$2\ Fe + O2 \rightarrow 2\ FeO$
$Fe + H2O \rightarrow FeO + H2\uparrow$
$Fe + CO2 \rightarrow FeO + CO\uparrow$

Oxidation leads to metal loss and degradation of the surface layers. At the beginning of heating, these reactions occur on the surface after the formation of an oxide film. This phenomenon spreads through the diffusion of oxygen atoms in the grain boundaries, crossing the scale, and, conversely, through reverse diffusion, iron moves towards the surface.

Decarburization occurs simultaneously at high temperatures through the interaction of carbon atoms in the steel with hydrogen according to the following reactions:

$C + 2\ H2 \rightarrow Fe + CH4\uparrow$
$C + 1/2\ O2 \rightarrow Fe + CO\uparrow$

The intensity of oxidation and decarburization of the steel depends on temperature, chemical composition, and the surrounding environment. To maintain a neutral atmosphere, the following equilibrium must be satisfied:

Oxidation ↔ reduction
Decarburization ↔ carburization

To protect the parts from oxidation and decarburization, chemically neutral gases called "controlled atmospheres" are introduced into the usable space of the furnace. There are several types of controlled atmospheres:

- Endothermic atmosphere: obtained by partial combustion of natural gas, composed of (21% CO + 40% $H2O$ + 2% $CH4$ + 37% $N2$).
- Exothermic atmosphere: obtained by partial combustion of $CH4$, composed of (2% $CO2$ + 2% $H2$ + 96% $N2$).
- Technical nitrogen: composed of ((2 to 4)% $H2$ + 96% $N2$).
- Vacuum heating (from 10-2 to 10-6 mm Hg), often used for special alloys (refractory, stainless, electro-technical).
- Salt bath heating: reserved for cutting tools and small machine components.

4. Cooling of Parts

The crucial factor in determining the cooling process for a part is the desired structural state to be obtained. Of course, rapid cooling is always sought after for higher productivity, but one must consider the risks of cracking and distortion of the parts. The required cooling rate to achieve a specific structural state is determined based on the Time-Temperature-Transformation (TTT) diagram. Cooling is carried out in tanks using water or oil, with the bath maintained at a constant temperature. Warm water is continuously replaced by cold water entering from the bottom of the tank.

Jets are also used to adjust the cooling of parts over their entire surface. Additionally, special chambers are employed where mist is produced by the injection of water and pressurized air.

Technological Process

1. Analysis of the purpose and operating conditions of the part in the Assembly and determining the type of production

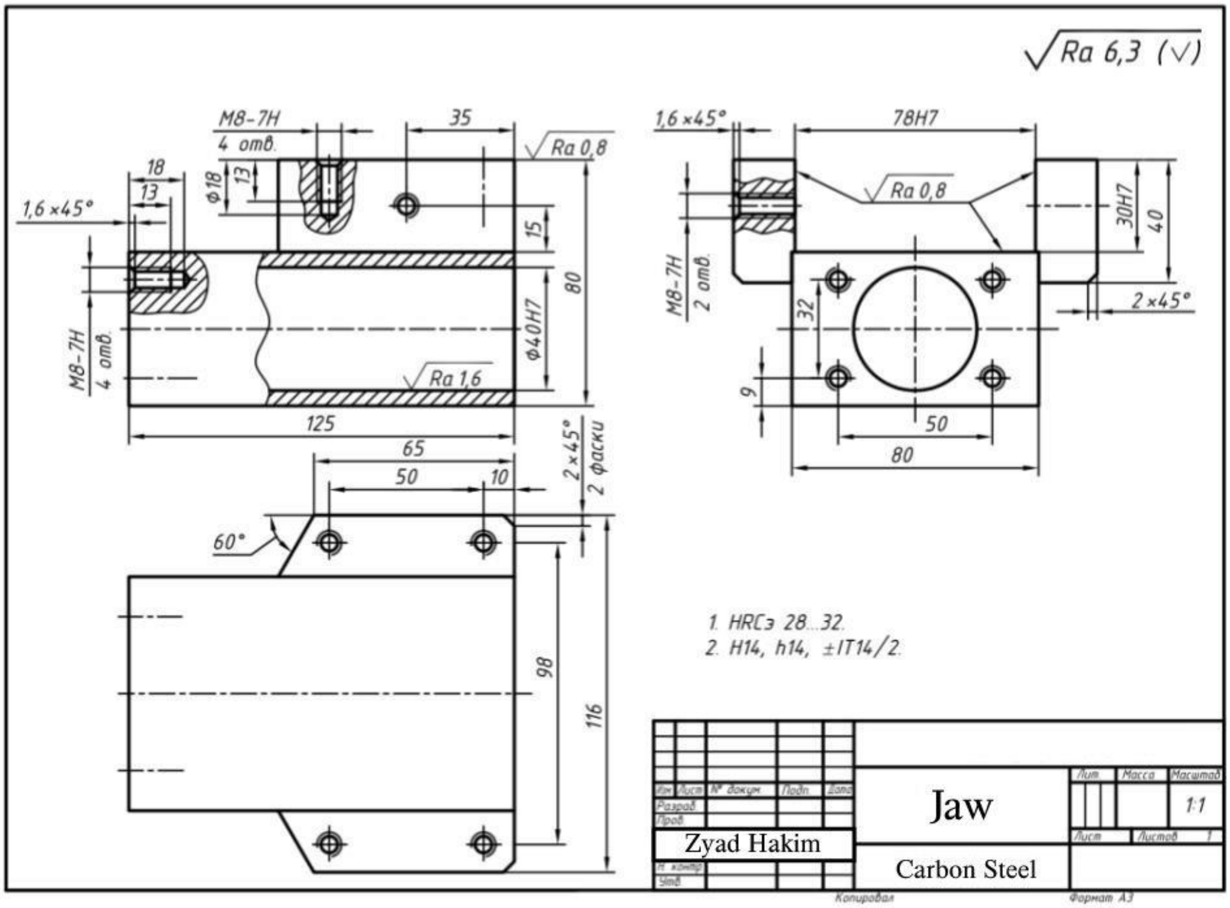


Fig1 – Drawing of the Jaw

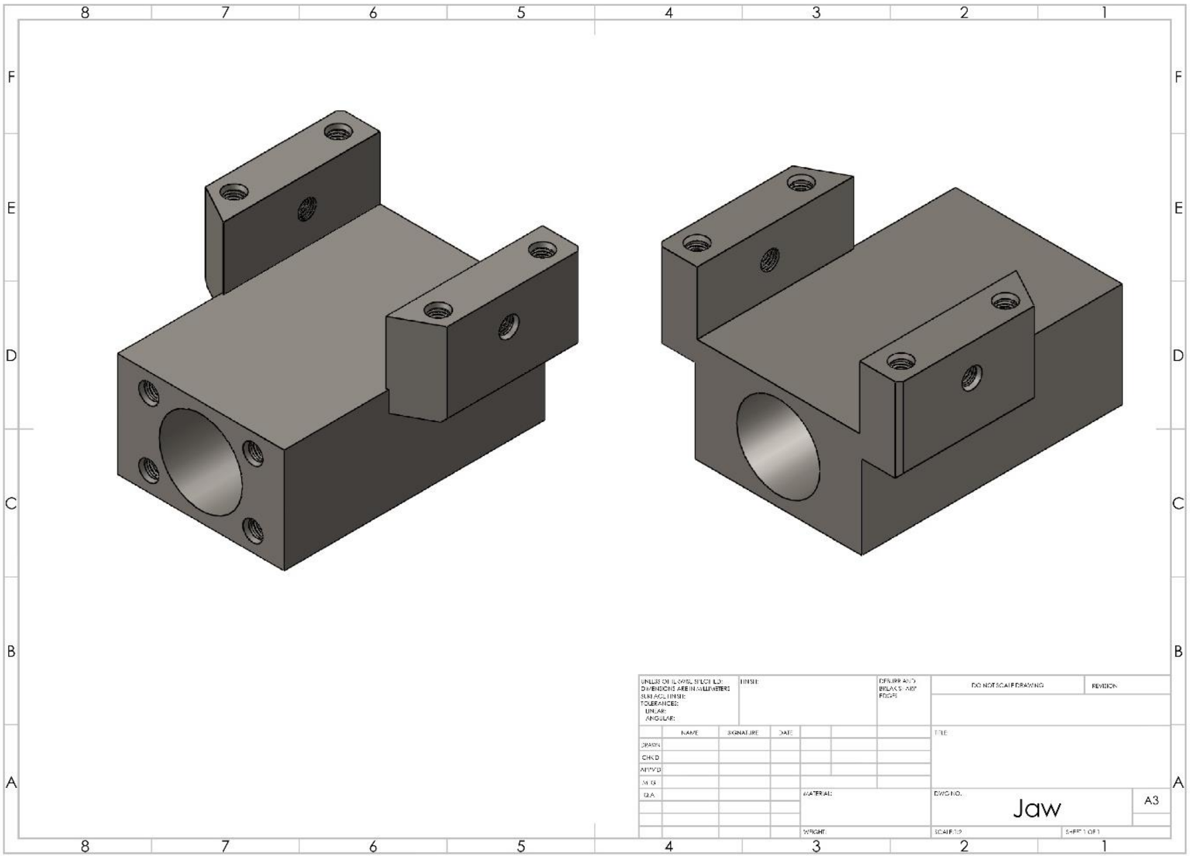


Figure 2 – Jaw 3D drawing

<u>1.1. Analysis of the purpose and operating conditions of the part in the assembly unit</u>

When reviewing the configurations of the part, we can surely deduce that the part in question is categorized as “Body”.

The “Jaw” is a stationary part of the assembly “vise”, where its role comes in the form of securely holding and a workpiece when clamped during machining. Its main function is to cater proper stability, alignment and clamping stability to a workpiece. Rigidity and strength are the essential operating conditions for the Jaw, where it has to be rigid and strong enough to weather the forces exerted during clamping and machining. It is ordinarily manufactured to retain its form and structural integrity under the aforementioned conditions; therefore, a high-quality steel is to be used. The surface finish of the Jaw is fairly important, especially the surfaces that come in contact with a workpiece, as these surfaces need to be smooth and flat in order to achieve a firm Jaw and eliminate any possible chances of slippage or mis-alignment. The Jaw is securely seated on the vise body and mounted on the mounting plating using 4 bolts of M8-7H, while the jaw inserts are mounted on top using a set of same bolt size. *(Please refer to Fig 2, Part 2)*

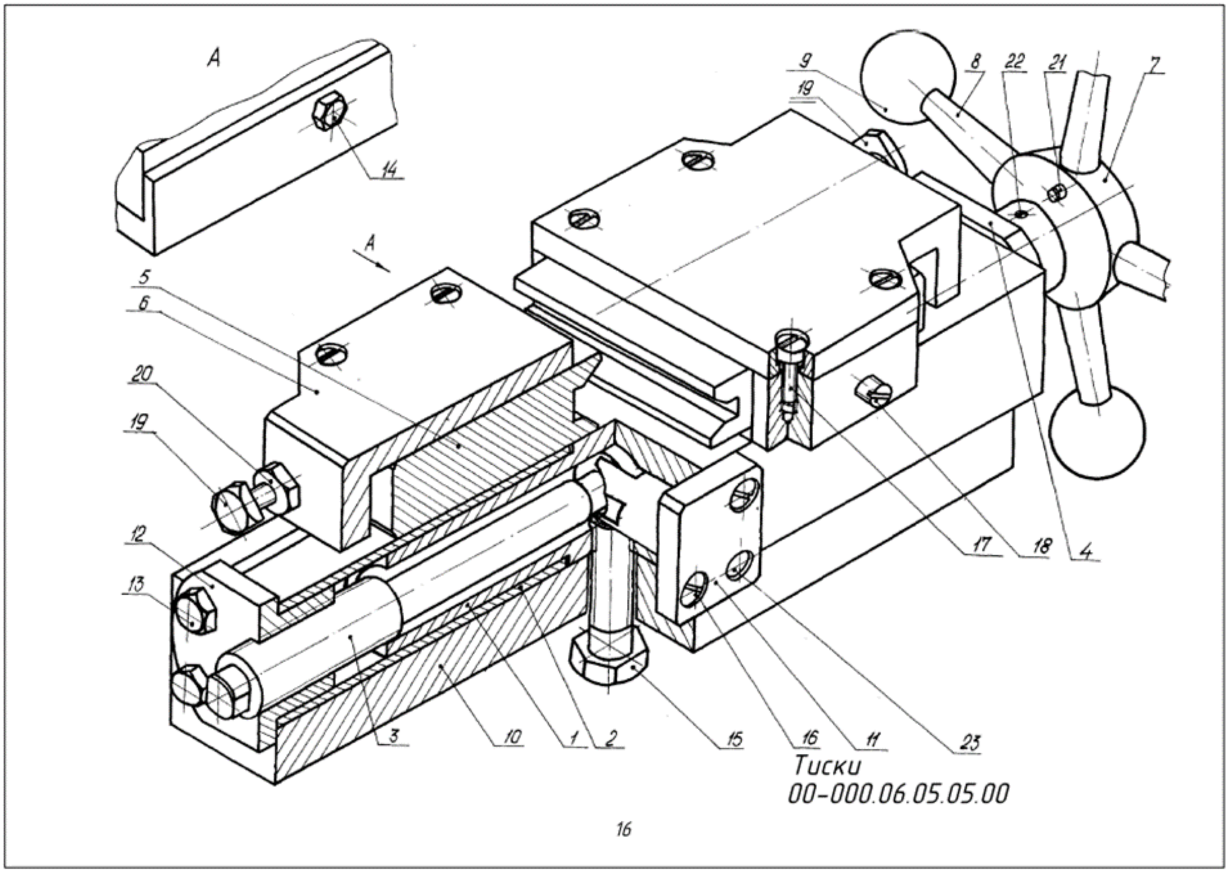


Fig2 – Drawing of the assembly Vise

1.2 Analysis of the material

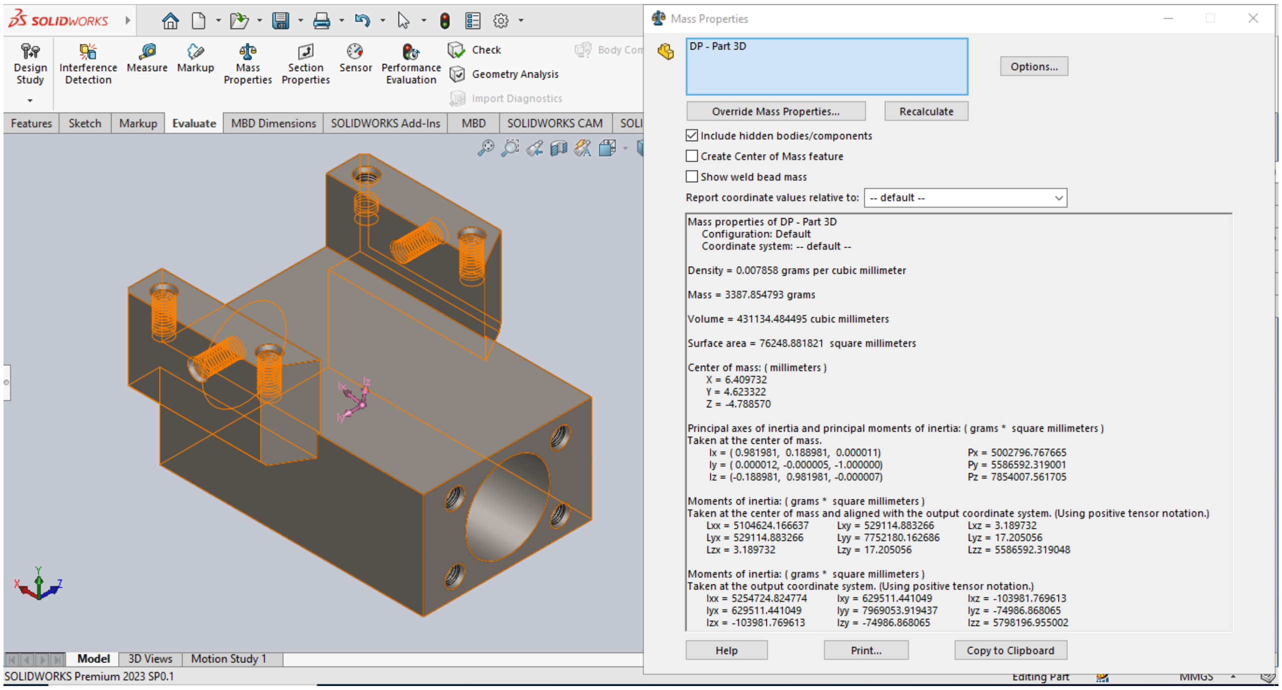
According to the information heretofore mentioned we can say that the material chosen to manufacture the Jaw; “Steel 10 ГОСТ 1050–88” (carbon steel), is a suitable choice. its moderate strength and toughness properties provide adequate durability and reliability for the prerequisite clamping applications. You can find the information regarding chemical composition as well as mechanical properties of the “Carbon Steel” in (Table 1) below.

Table1 – Chemical composition and mechanical properties of Carbon Steel

Chemical composition				
Carbon (C)	Manganese (Mn)	Silicon (Si)	Phosphorus (P)	Sulfur (S)
0.08 - 0.14	0.3 - 0.6	≤ 0.35	≤ 0.035	≤ 0.035
Mechanical properties				
Tensile Strength (MPa)	Yield Strength (MPa)	Elongation (%)	Impact Energy (J)	Hardness (HB)
390 - 540	≥ 215	≥ 24	≥ 39	≤ 187

1.3 Determining the type of production and analysis of its impact on the manufacturing plane.

In order to determine the type of production of the housing we will use the table below. It divides the classes of the production types based on the part mass and production volume.



☑ Include hidden bodies/components
☐ Create Center of Mass feature
☐ Show weld bead mass
Report coordinate values relative to: -- default --

```
Mass properties of DP - Part 3D
    Configuration: Default
    Coordinate system: -- default --

Density = 0.007858 grams per cubic millimeter

Mass = 3387.854793 grams

Volume = 431134.484495 cubic millimeters

Surface area = 76248.881821  square millimeters

Center of mass: ( millimeters )
     X = 6.409732
     Y = 4.623322
     Z = -4.788570

Principal axes of inertia and principal moments of inertia: ( grams *  square millimeters )
Taken at the center of mass.
      Ix = ( 0.981981,  0.188981,  0.000011)              Px = 5002796.767665
      Iy = ( 0.000012, -0.000005, -1.000000)              Py = 5586592.319001
      Iz = (-0.188981,  0.981981, -0.000007)              Pz = 7854007.561705

Moments of inertia: ( grams *  square millimeters )
Taken at the center of mass and aligned with the output coordinate system. (Using positive tensor notation.)
     Lxx = 5104624.166637     Lxy = 529114.883266     Lxz = 3.189732
     Lyx = 529114.883266      Lyy = 7752180.162686    Lyz = 17.205056
     Lzx = 3.189732           Lzy = 17.205056         Lzz = 5586592.319048

Moments of inertia: ( grams *  square millimeters )
Taken at the output coordinate system. (Using positive tensor notation.)
     Ixx = 5254724.824774     Ixy = 629511.441049     Ixz = -103981.769613
     Iyx = 629511.441049      Iyy = 7969053.919437    Iyz = -74986.868065
     Izx = -103981.769613     Izy = -74986.868065     Izz = 5798196.955002
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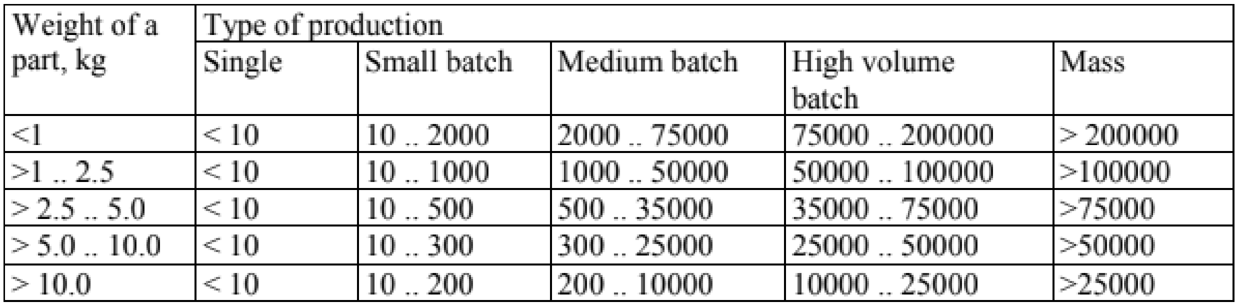
Fig3 – Mass properties

In our case: - Part Mass ≈ 3.39 kg
- Production Volume: 500

Table 2 – Type of production data



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

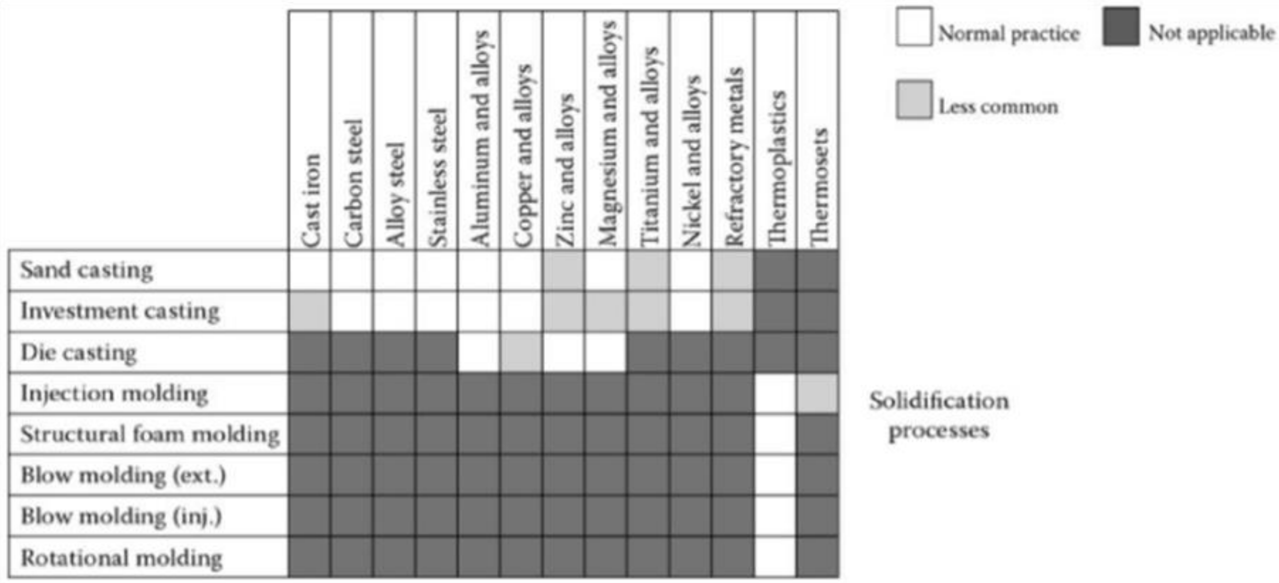
Conclusion: We can safely deduce that the part belongs to the medium batch production type. All further analysis will be based on this revelation.

2. Selection of the base process and design of the blank

To select a base process, we have provided the following necessary information regarding the Jaw:

- Technical Drawing file for geometry aspects
- Component Material
- Production volume per annum (500).

We can identify the base process for the part in hand _ Jaw_. The process selection is based on the material for the casting. the material is Carbon Steel; therefore, we chose the sand-casting process as it is the orderly practice, according Figure 4 as shown below.



□ Normal practice ■ Not applicable ▒ Less common

Solidification processes

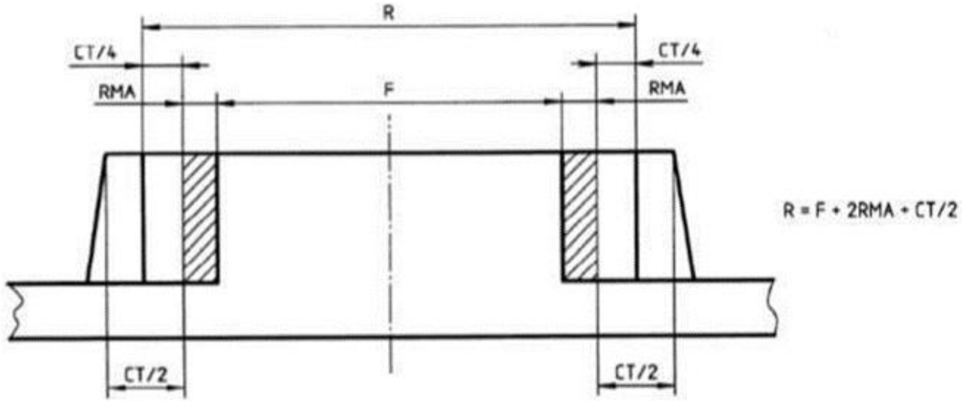
	Cast iron	Carbon steel	Alloy steel	Stainless steel	Aluminum and alloys	Copper and alloys	Zinc and alloys	Magnesium and alloys	Titanium and alloys	Nickel and alloys	Refractory metals	Thermoplastics	Thermosets
Sand casting	□	□	□	□	□	□	▒	□	▒	□	▒	■	■
Investment casting	▒	□	□	□	□	□	▒	▒	▒	□	▒	■	■
Die casting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

Fig 4 – Solidification Processes

When it comes to casting, there are two crucial factors to take into account. Firstly, casting tolerances (CT) must be considered. These tolerances determine the amount of material that should be added to compensate for shrinkage and surface imperfections or defects. It also includes the inclusion of a draft angle.

Another critical aspect in casting is the Required Machining Allowance (RMA), which refers to the additional amount of material that needs to be included for post-machining processes. The RMA is typically added when a polished and smooth finish is desired.

Conforming to “ISO 8062” of Castings, we could safely say that the recommended CT would be CT 10, as for the RMA, the appropriate grade would be F, as per the largest dimension of the part. *(Refer to Table 3 for values.)*
The following Figures (Fig 5) present a visual representation of Casting Tolerances (CT) and Required Machining Allowance (RMA) in relation to raw casting, shedding light on their significance.



R = Raw casting basic dimension

F = Dimension after final machining

RMA = Required machining allowance

CT = Casting tolerance

Fig 5 – CT and RMA in relation to R (ISO 8062)

Table 3 – RMA, CT and Raw casting dimensions

Dimension of the part	**RMA**	**Min limit of size for external features (or max for internal features)**	**CT** ***(mm)***	**Raw casting dimensions** ***(mm)***
125	3	128	3.6	129.8±1.8
80	3	83	3.2	84.6±1.6
50	3	53	2.8	54.4±1.4
48	3	45	2.8	43.6±1.4
Φ40	3	37	2.6	35.4±1.3
40	3	43	2.8	44.6±1.6
18	3	21	2.4	22.2±1.2

*When designing the casting model, certain recommendations should be taken into account, we need to:

- ✓ Optimize the part's orientation to minimize gravitational dimensions, preventing deformations and enhancing casting quality.
- ✓ Place the parting line along the Jaw's symmetry plane to achieve a uniform distribution of material during casting.

✓ Apply 2-5 mm fillets to each corner of the Jaw, improving molten metal flow, reducing stress concentration, and enhancing overall strength.

✓ Implement a 2-degree tapering on all surfaces relative to the parting plane, facilitating easy mold removal after casting.

✓ Limit machining allowance to necessary surfaces, minimizing excess material and reducing post-machining efforts and waste.

✓ Utilize the casting process for critical features, while smaller features can be machined post-casting to achieve desired precision.

✓ Adhere to ISO 8062 standards, specifically CT10 for casting tolerance and RMA grade 3 (F) for machining allowance, ensuring consistent and accurate casting.

✓ Strive for a defect-free final casting by employing proper mold design, gating, and cooling techniques to minimize surface imperfections.

✓ Ensure the casting aligns visually with provided specifications, encompassing dimensions, contours, and overall appearance.

✓ Lastly, consider gentle heating if necessary to alleviate residual stresses and enhance the Jaw's quality and integrity after casting.

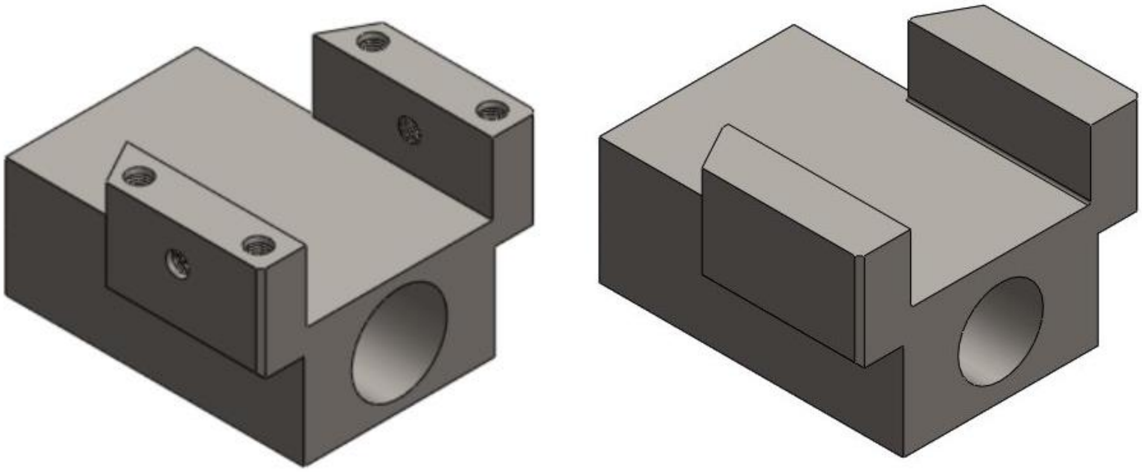


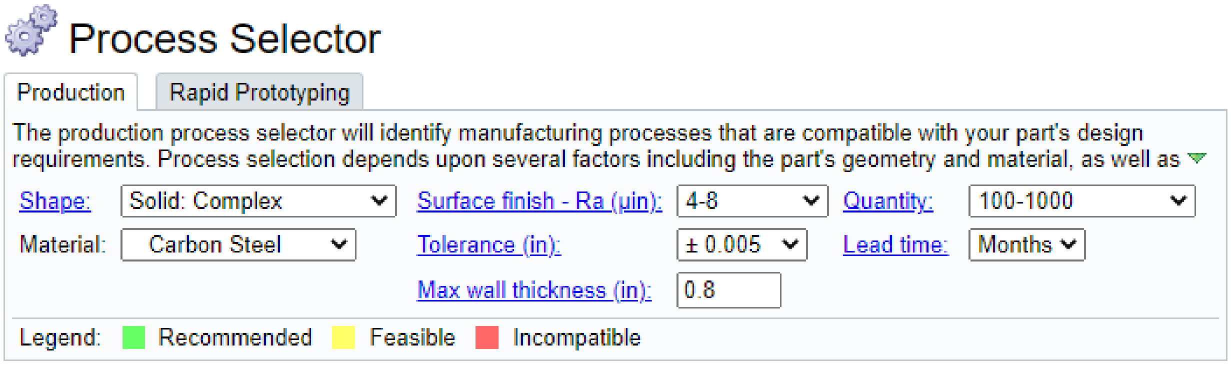
Fig 6 – Workpiece 3d Model vs Casting blank 3D model

2.1 Selection of the base process

In order to select the base process, we shall utilize an online application called “Process Selector” that can be found through “https://www.custompartnet.com”.

Initial data for the process selection:

- Drawing of a part;
- Material of a part – Carbon Steel
- Annual output – 500 pcs (42 per month).



The production process selector will identify manufacturing processes that are compatible with your part's design requirements. Process selection depends upon several factors including the part's geometry and material, as well as

Shape: Solid: Complex
Surface finish - Ra (μin): 4-8
Quantity: 100-1000
Material: Carbon Steel
Tolerance (in): ± 0.005
Lead time: Months
Max wall thickness (in): 0.8

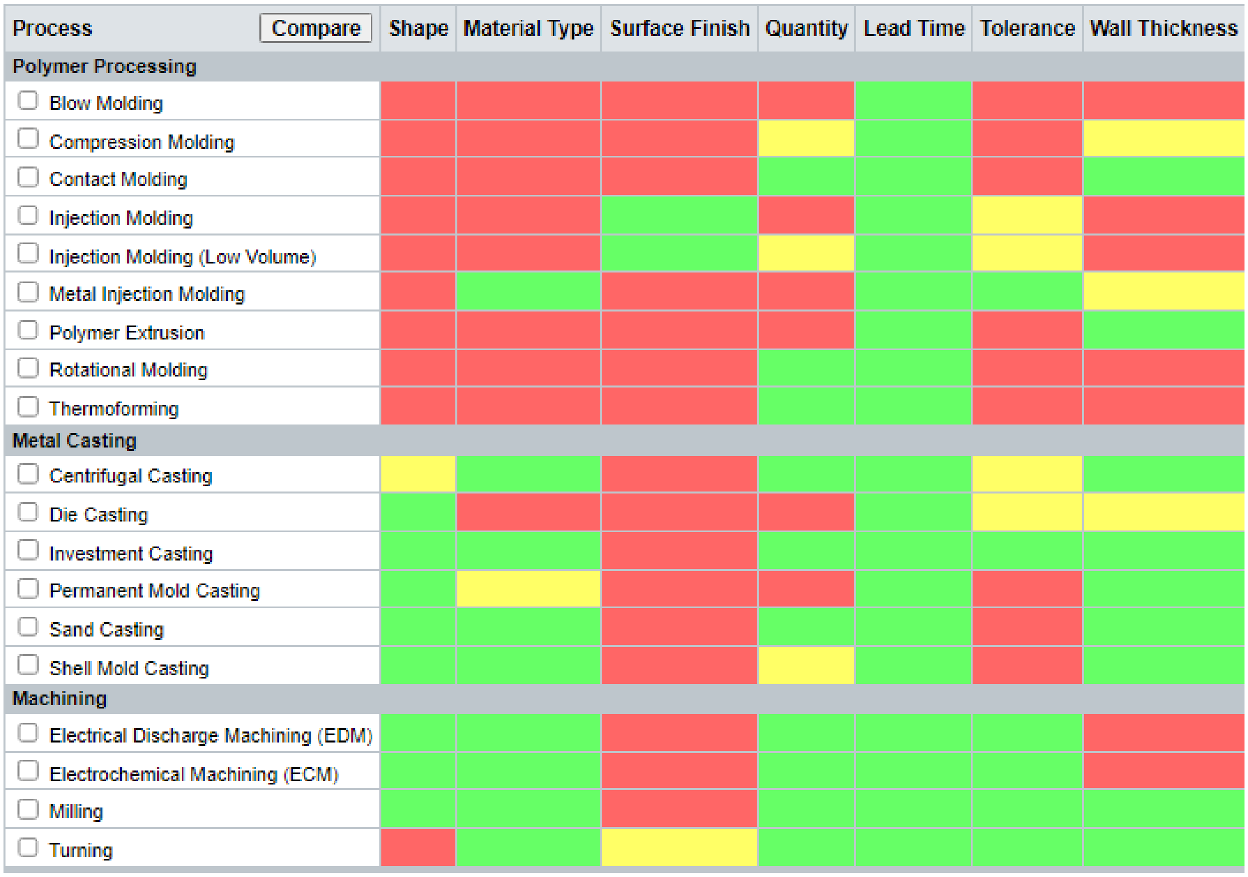
Legend: 🟩 Recommended 🟨 Feasible 🟥 Incompatible

Fig 6 – Process Selector Interface / Data

According to the results (Fig 7 below), the metal casting processes could be applied as base processes, taking into account that we do not consider the final tolerance and surface finish (will be obtained by secondary process). The following processes could be applied:

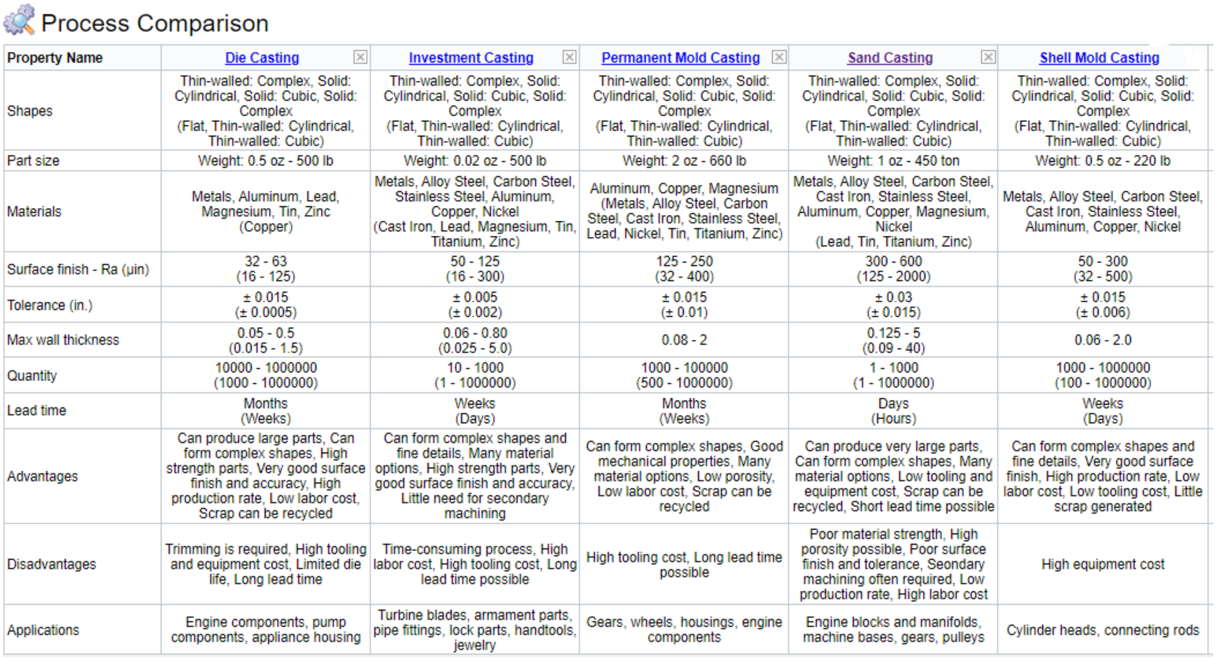
- Centrifugal Casting,
- Die Casting,
- Investment Casting,
- Sand Casting,
- Shell-mold casting.

Among these processes Sand Casting is recommended according to all criteria except surface finish and tolerance. Milling could be recommended as the secondary process. (Refer to Fig 8 for a comparison of possible base processes).



Process	Shape	Material Type	Surface Finish	Quantity	Lead Time	Tolerance	Wall Thickness
Polymer Processing							
☐ Blow Molding	🟥	🟥	🟥	🟥	🟩	🟥	🟥
☐ Compression Molding	🟥	🟥	🟥	🟨	🟩	🟥	🟨
☐ Contact Molding	🟥	🟥	🟥	🟩	🟩	🟥	🟩
☐ Injection Molding	🟥	🟥	🟩	🟥	🟩	🟨	🟥
☐ Injection Molding (Low Volume)	🟥	🟥	🟩	🟨	🟩	🟨	🟥
☐ Metal Injection Molding	🟥	🟩	🟥	🟥	🟩	🟩	🟨
☐ Polymer Extrusion	🟥	🟥	🟥	🟥	🟩	🟥	🟩
☐ Rotational Molding	🟥	🟥	🟥	🟩	🟩	🟥	🟥
☐ Thermoforming	🟥	🟥	🟥	🟩	🟩	🟥	🟥
Metal Casting							
☐ Centrifugal Casting	🟨	🟩	🟥	🟩	🟩	🟨	🟩
☐ Die Casting	🟩	🟥	🟥	🟥	🟩	🟨	🟨
☐ Investment Casting	🟩	🟩	🟥	🟩	🟩	🟩	🟩
☐ Permanent Mold Casting	🟩	🟨	🟥	🟥	🟩	🟥	🟩
☐ Sand Casting	🟩	🟩	🟥	🟩	🟩	🟥	🟩
☐ Shell Mold Casting	🟩	🟩	🟥	🟨	🟩	🟥	🟩
Machining							
☐ Electrical Discharge Machining (EDM)	🟩	🟩	🟥	🟩	🟩	🟩	🟥
☐ Electrochemical Machining (ECM)	🟩	🟩	🟥	🟩	🟩	🟩	🟥
☐ Milling	🟩	🟩	🟥	🟩	🟩	🟩	🟩
☐ Turning	🟥	🟩	🟨	🟩	🟩	🟩	🟩

Fig 7 - Results of the Process Selector



Process Comparison

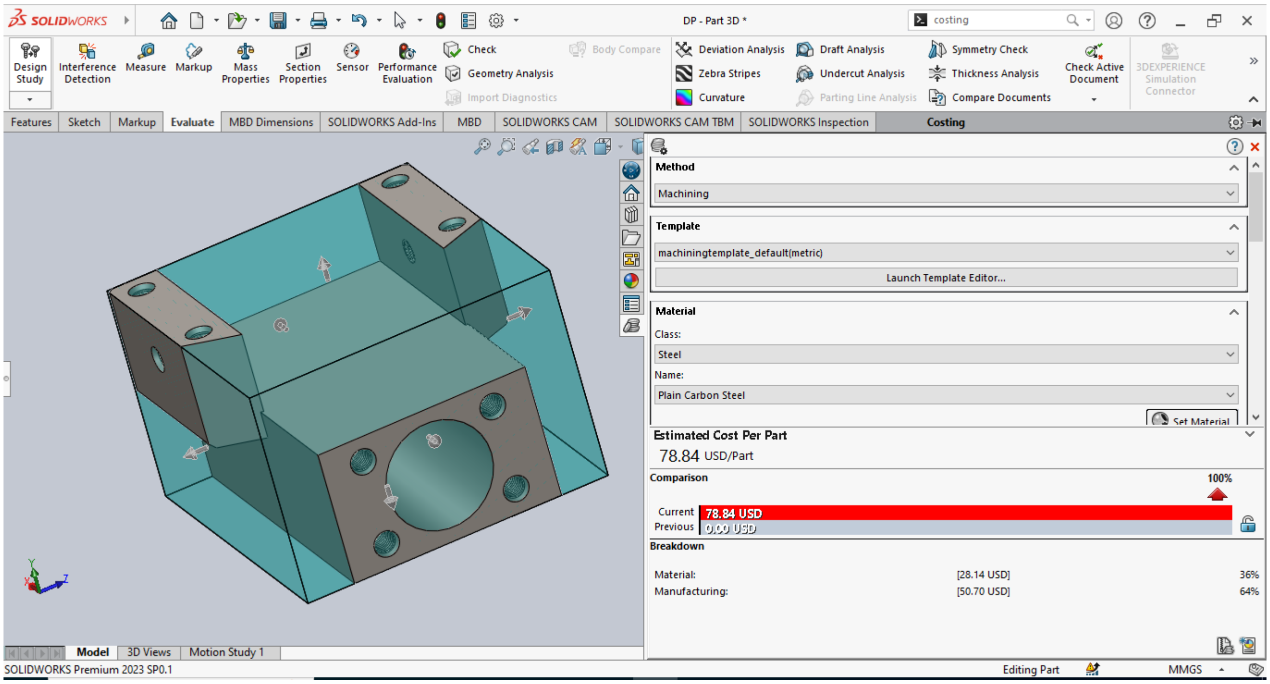
Property Name	Die Casting	Investment Casting	Permanent Mold Casting	Sand Casting	Shell Mold Casting
Shapes	Thin-walled: Complex, Solid: Cylindrical, Solid: Cubic, Solid: Complex (Flat, Thin-walled: Cylindrical, Thin-walled: Cubic)	Thin-walled: Complex, Solid: Cylindrical, Solid: Cubic, Solid: Complex (Flat, Thin-walled: Cylindrical, Thin-walled: Cubic)	Thin-walled: Complex, Solid: Cylindrical, Solid: Cubic, Solid: Complex (Flat, Thin-walled: Cylindrical, Thin-walled: Cubic)	Thin-walled: Complex, Solid: Cylindrical, Solid: Cubic, Solid: Complex (Flat, Thin-walled: Cylindrical, Thin-walled: Cubic)	Thin-walled: Complex, Solid: Cylindrical, Solid: Cubic, Solid: Complex (Flat, Thin-walled: Cylindrical, Thin-walled: Cubic)
Part size	Weight: 0.5 oz - 500 lb	Weight: 0.02 oz - 500 lb	Weight: 2 oz - 660 lb	Weight: 1 oz - 450 ton	Weight: 0.5 oz - 220 lb
Materials	Metals, Aluminum, Lead, Magnesium, Tin, Zinc (Copper)	Metals, Alloy Steel, Carbon Steel, Stainless Steel, Aluminum, Copper, Nickel (Cast Iron, Lead, Magnesium, Tin, Titanium, Zinc)	Aluminum, Copper, Magnesium (Metals, Alloy Steel, Carbon Steel, Cast Iron, Stainless Steel, Lead, Nickel, Tin, Titanium, Zinc)	Metals, Alloy Steel, Carbon Steel, Cast Iron, Stainless Steel, Aluminum, Copper, Magnesium, Nickel (Lead, Tin, Titanium, Zinc)	Metals, Alloy Steel, Carbon Steel, Cast Iron, Stainless Steel, Aluminum, Copper, Nickel
Surface finish - Ra (μin)	32 - 63 (16 - 125)	50 - 125 (16 - 300)	125 - 250 (32 - 400)	300 - 600 (125 - 2000)	50 - 300 (32 - 500)
Tolerance (in.)	± 0.015 (± 0.0005)	± 0.005 (± 0.002)	± 0.015 (± 0.01)	± 0.03 (± 0.015)	± 0.015 (± 0.006)
Max wall thickness	0.05 - 0.5 (0.015 - 1.5)	0.06 - 0.80 (0.025 - 5.0)	0.08 - 2	0.125 - 5 (0.09 - 40)	0.06 - 2.0
Quantity	10000 - 1000000 (1000 - 1000000)	10 - 1000 (1 - 1000000)	1000 - 100000 (500 - 1000000)	1 - 1000 (1 - 1000000)	1000 - 1000000 (100 - 1000000)
Lead time	Months (Weeks)	Weeks (Days)	Months (Weeks)	Days (Hours)	Weeks (Days)
Advantages	Can produce large parts, Can form complex shapes, High strength parts, Very good surface finish and accuracy, High production rate, Low labor cost, Scrap can be recycled	Can form complex shapes and fine details, Many material options, High strength parts, Very good surface finish and accuracy, Little need for secondary machining	Can form complex shapes, Good mechanical properties, Many material options, Low porosity, Low labor cost, Scrap can be recycled	Can produce very large parts, Can form complex shapes, Many material options, Low tooling and equipment cost, Scrap can be recycled, Short lead time possible	Can form complex shapes and fine details, Very good surface finish, High production rate, Low labor cost, Low tooling cost, Little scrap generated
Disadvantages	Trimming is required, High tooling and equipment cost, Limited die life, Long lead time	Time-consuming process, High labor cost, High tooling cost, Long lead time possible	High tooling cost, Long lead time possible	Poor material strength, High porosity possible, Poor surface finish and tolerance, Seondary machining often required, Low production rate, High labor cost	High equipment cost
Applications	Engine components, pump components, appliance housing	Turbine blades, armament parts, pipe fittings, lock parts, handtools, jewelry	Gears, wheels, housings, engine components	Engine blocks and manifolds, machine bases, gears, pulleys	Cylinder heads, connecting rods

Fig 8 – Process Selector / Base processes comparison

2.2 Cost Estimation

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

However, due to unforeseeable circumstances I had to abort that and choose the "Costing" option on Solidworks instead, although it is not 100%, it generally gives an idea of how much a certain workpiece would cost, and in our Jaw detail, the cost per piece came to: 78.84$ / piece.



Method: Machining

Template: machiningtemplate_default(metric)

Material
Class: Steel
Name: Plain Carbon Steel

Estimated Cost Per Part
78.84 USD/Part

Comparison 100%
Current 78.84 USD
Previous 0.00 USD

Breakdown

Material:	[28.14 USD]	36%
Manufacturing:	[50.70 USD]	64%

Fig 9 – SW Costing estimation

2.3 Casting Design

Referring to bullet point "2" - Selection of the base process and design of the blank, and subpoint "2.1" Base Process Selection.
*As a recap:

Initial data for the work piece design (according to the variant):
- Drawing of a part;
- Material of a part – Carbon Steel;
- Base process – Sand Casting;
- Annual output – 500 pcs (42 per month).

CT 10 and RMA grade F according to ISO 8062.

General recommendations to respect for the casting:

- Orientation
- Parting line
- Fillets
- Tapering
- Machining allowance
- Main features vs smaller features
- Tolerances and grades
- Surface quality
- Visual Conformity
- Post-casting steps

All in all, after careful crafting, the following (Fig 10) is the final outcome for the casting blank design.

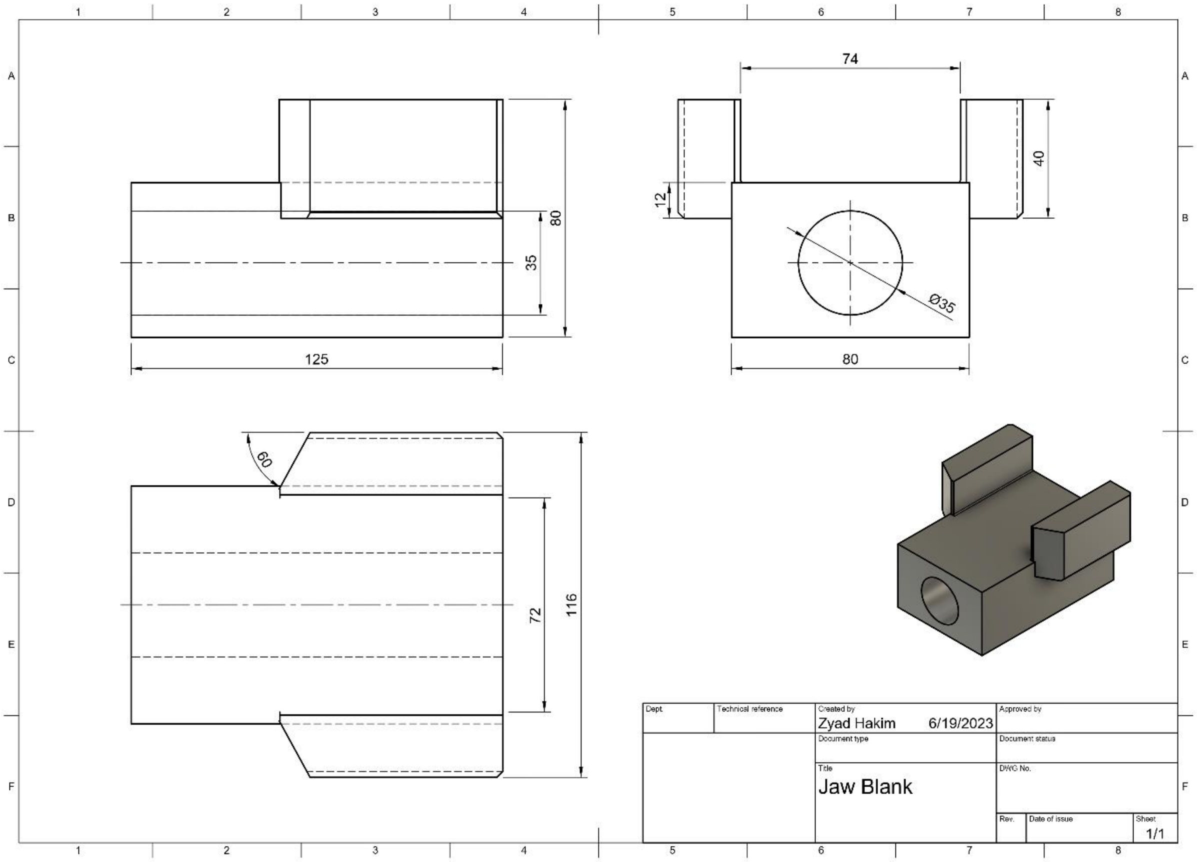


Fig 10 – Jaw casting blank drawing

2.4 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.

2.4.1 Rationale for 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:

- Main functional (design) datum
- Auxiliary functional (design) datum
- Fastening surfaces
- Free surfaces

For further analysis, let’s classify surfaces of a given part according to their purpose (Fig 11).

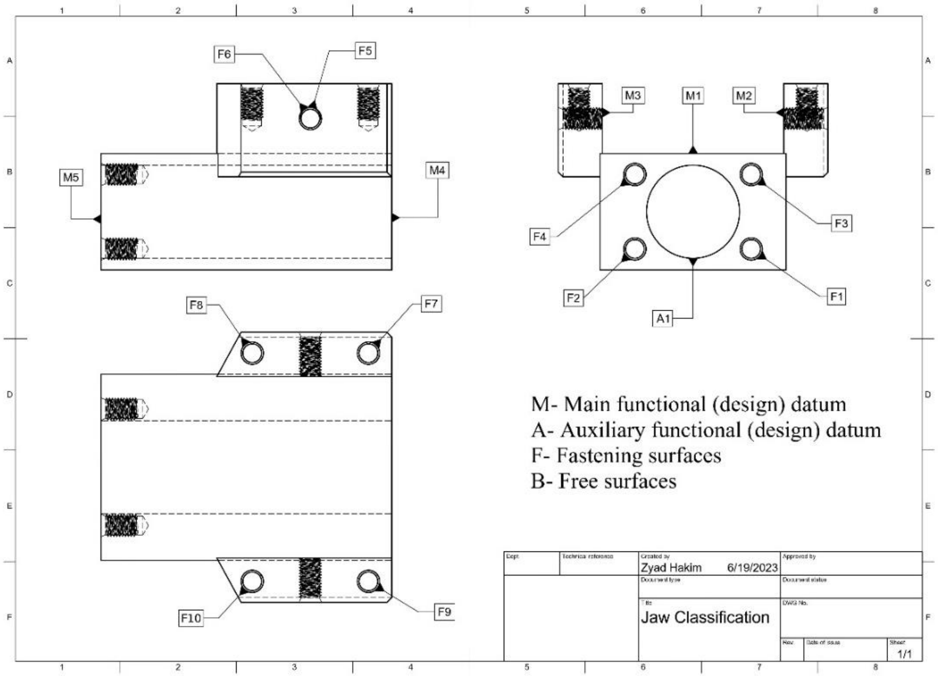


Fig 11 – Classification

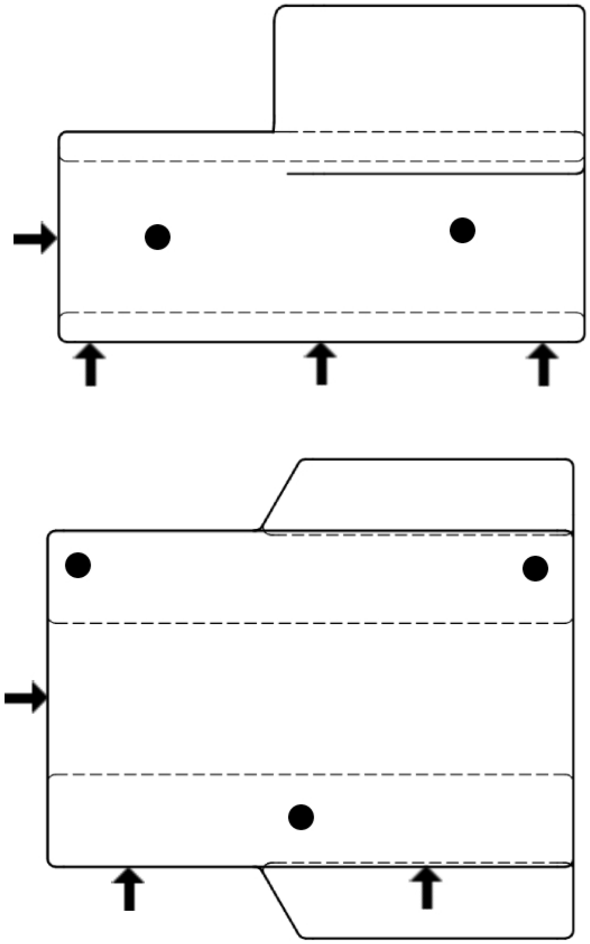


Fig 12 – Locating scheme

The formula for the locating scheme presented in Fig 12 is as follows:

LSGMD =>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,
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 "Jaw" is sufficiently oriented, which allows processing its surfaces with the specified requirements for the spatial position.

In our case GMD remains unchanged.

GMD => Const

Advantages of this locating position:
- Easy to implement
- Ensures the correct placement of untreated surfaces relative to the treated ones

2.4.2 Rationale for the selection of manufacturing datum for the first manufacturing operations

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. 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 (this prevents the occurrence of defects on this surface for further processing), 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.

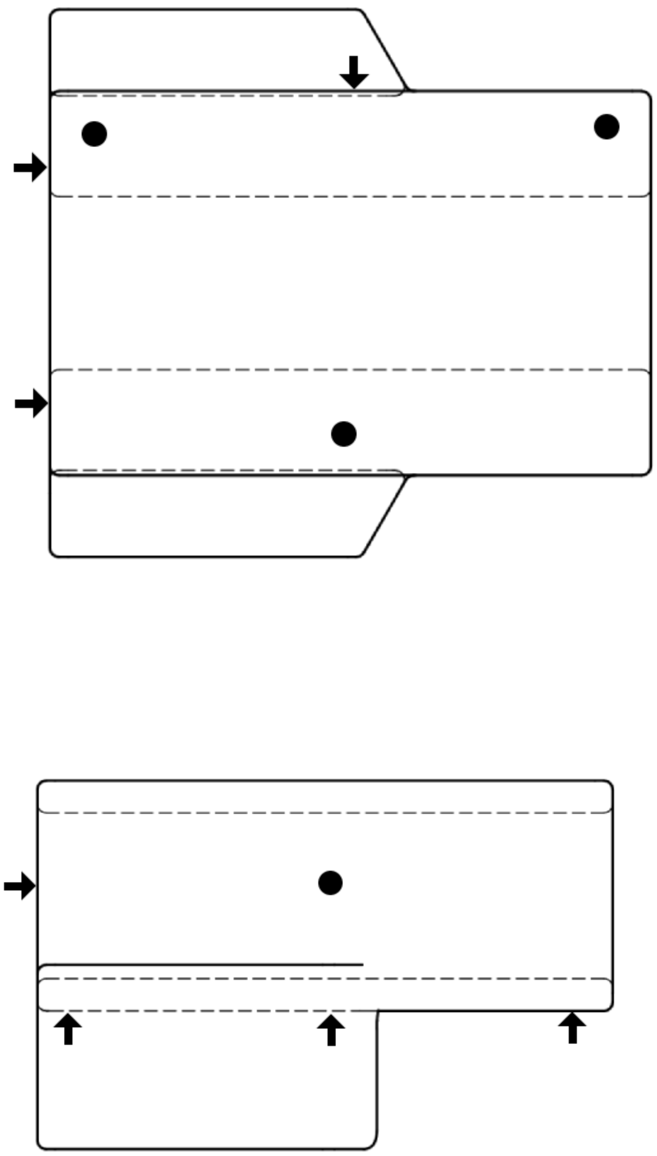


Figure 13 – Locating scheme for second manufacturing position

Advantages:

- provides perpendicularity of the untreated side plane to a datum surface;
- uniform allowance for further processing of the side surfaces used for locating in the first position.

2.5 Conclusion

In conclusion, this part of the project has been successfully completed. The selection of the sand-casting process as the base processing method offers a cost-effective solution for the production of the desired part. The cost estimation indicates that machining alone would amount to approximately $78.84 per piece, but as stated before, this is a preliminary estimation, a detailed estimation which includes the casting as well as machining costs will be addressed later on.

The casting blank design has been developed, taking into account the requirements for sand-casting and subsequent machining processes. This design ensures that the casting provides the necessary geometry and dimensional tolerances to facilitate efficient machining operations.

The locating scheme has also been established, outlining how the workpiece will be securely positioned and held during machining. This scheme ensures proper alignment and stability, contributing to the accuracy and quality of the final machined product.

Moving forward, the focus will shift towards the machining phase of the project. With the casting blank and locating scheme in place, the subsequent machining operations can be carried out to achieve the desired surface finish, roughness accuracy, and overall functional requirements of the part.

Design Section

3 Design of the typical surfaces processing routes

The Jaw can be designed by combining various typical geometric shapes, each serving a specific purpose. These shapes include cylindrical or conical external and internal surfaces, planes, and various shaped surfaces like screws and involutes. Depending on the type of surface, different cutting tools and sequences of surface treatment can be employed to achieve the desired surface accuracy.

The development of machining routes for individual surfaces is one of the initial tasks in the process plan design. This manufacturing process, created in a temporal and spatial context, addresses the challenges of dimensional accuracy, shape, and surface quality for each individual surface. However, it does not encompass the accuracy of the relative positions of the surfaces. This task will be addressed later by establishing locating schemes and dividing the processing stages into modules, including rough, finish, and final stages.

During the development of the manufacturing process, it is crucial to select the most economically viable machining option from several possibilities. Therefore, to save time, it is advisable to utilize standard and proven manufacturing processes for machining the main surfaces of the part.

For the specific Jaw components depicted in Figure 1, typical machining sequences, as well as the achieved accuracy and surface roughness, are presented in Table 4. The surfaces are classified as shown in Figure 11, providing a comprehensive understanding of the different surface characteristics.

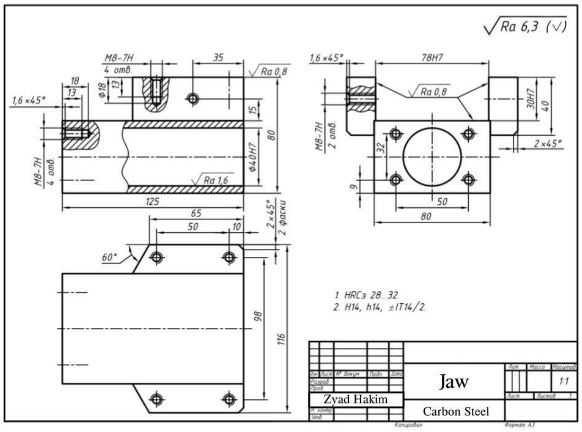


Figure 1 – Drawing

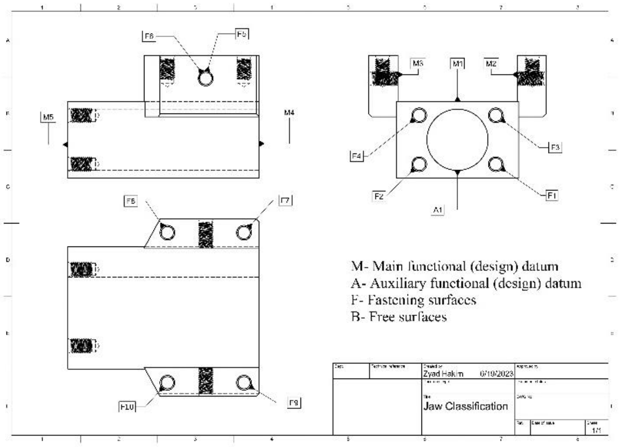


Figure 11 – Surface classification

Table 4 – Processing routes for surfaces of part "Jaw"

Surfaces	IT	Ra	Machining sequence	IT	Ra
	According to drawing			After Machining	
1	2	3	4	5	6
M1, M2	14	0.8	Shoulder rough milling Shoulder finish milling	14	0.8
M1, M3	14	0.8	Shoulder rough milling Shoulder finish milling	14	0.8
M4	14	0.8	Rough milling Finish milling	14	0.8
A2, A5, A6	14		Rough milling Finish milling	14	
F7, F8, F9, F10	14 (7H)		Centering Drilling Countersinking Threading	7H	
F6, F7	14 (7H)		Centering Drilling Countersinking Threading	7H	

A1, A4	14		Rough milling Finish milling	14	
B1	14 (H7)		Centering Drilling Reaming	H7	
F1, F2, F3, F4	14 (7H)		Centering Drilling Countersinking Threading	7H	
A3	14		Rough milling Finish milling	14	
A7, A8	14		Rough milling Finish milling	14	

3.1 Design of manufacturing process plan

The task is to develop the manufacturing process plan that will meet all the requirements of manufacturing accuracy, complexity, and cost.

Let’s consider the following recommendations:

1. Surfaces that are the datums for the subsequent stages of processing should be processed first.

2. Each subsequent manufacturing step or operation must improve the quality characteristics of the treated surfaces

- If this requirement is not met, e.g. when implementing heat treatment, then it is necessary to return to the processing of the workpiece surfaces, which are datum for subsequent processing stages.

3. The roughing must be separated from the next stages of processing by a certain period of time, or aging operations should be provided, especially for critical, large-sized and high-value parts.

4. For timely detection of defects on surfaces where they are not allowed, these surfaces should be processed at the early stages of the manufacturing process.

5. During roughing the first should be processed surfaces that have the highest allowance and the most responsible surfaces

6. Finishing of the most responsible surfaces must be performed at the latest manufacturing steps.

7. The surfaces which least reduce the overall stiffness of the workpiece should be processed first

8. Surfaces with a precise relative spatial position should be processed in one installation

9. Do not change the tool when finishing precise responsible surfaces

10.Fastening surfaces must be processed at the 3rd stage of the manufacturing process, after finishing the related surface

005 Multipurpose

Machine: HAAS UMC-750

A. Install, secure, remove

Position 1

005.01 Rough milling shoulder to the surfaces M1 and M2
005.02 Finish milling shoulder to the surfaces M1 and M2
005.03 Rough milling shoulder to the surfaces M1 and M3
005.04 Finish milling shoulder to the surfaces M1 and M3

005.05 Rough milling shoulder to the surfaces M4
005.06 Finish milling shoulder to the surfaces M4

005.07 Rough milling shoulder to the surfaces M5
005.08 Finish milling shoulder to the surfaces M5

005.09 Center the position of 4 holes F7, F8, F9 and F10
005.10 Drilling the 4 holes F7, F8, F9 and F10 to Diameter 8 depth of 18mm
005.11 Countersink the 4 holes F7, F8, F9 and F10, dimension 1.6x45
005.12 Thread the 4 holes F7, F8, F9 and F10, 7H to depth of 13mm

005.13 Center the position of 4 holes F5 and F6
005.14 Drilling the 2 through holes F5 and F6 to Diameter 8

005.15 Countersink the 4 holes F5 and F6, dimension 1.6x45
005.16 Thread the 4 holes F5 and F6, 7H to depth of 13mm

005.19 Center the position of the hole A1
005.20 Drilling the through hole A1 to diameter 40mm
005.21 Reaming the hole A1 to a final Diameter of 40mm

005.22 Center the position of 4 holes F1, F2, F3 and F4
005.23 Drilling the 4 holes F1, F2, F3 and F4 to Diameter 8 and depth of 18mm
005.24 Countersink the 4 holes F1, F2, F3 and F4, to dimension 1.6x45
005.25 Thread the 4 holes F1, F2, F3 and F4, 7H to depth of 13mm

3.2 Machine selection

The types of machines are determined by the manufacturing processes. For example, if turning is the process, a lathe will be used. The physical size of the machine is considered during the first cut selection.

Machines that cannot meet the maximum power requirement are discounted, unless there are no other options. Machines with far greater power output than required are also discounted, unless they have a higher spindle speed required by an operation.

Capability analysis considers dimensional and geometric accuracy and surface finish. The batch size is the operational factor to be considered. Machines that do not meet the economic batch quantity should be discounted.

After taking into account all the requirements and limitations discussed in the previous chapter, the preliminary selected machine is the HAAS UMC-750 vertical machining center.

The following Figure 14 is the selected machining center, followed by its specifications and qualities.

Fig 14 – HAAS UMC-750

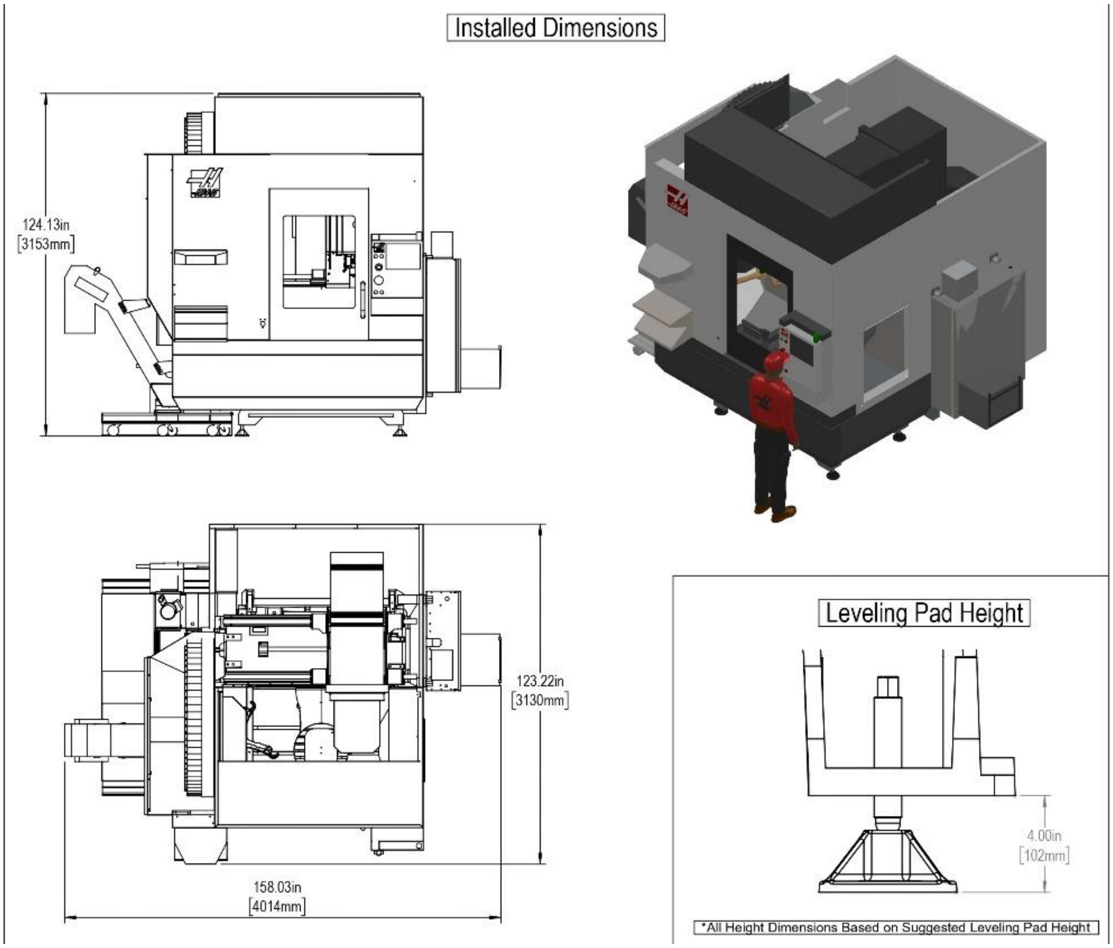


Fig 15 – Technical 2D drawing of HAAS UMC-750

Table 5 – HAAS UMC-750 Specifications

TRAVELS	S.A.E	METRIC
X Axis	30.0 in	762 mm
Y Axis	20.0 in	508 mm
Z Axis	20.0 in	508 mm
Spindle Nose to Platter (~ max)	24.0 in	610 mm
Spindle Nose to Platter (~ min)	4.0 in	102 mm
SPINDLE	S.A.E	METRIC
Max Rating	30.0 hp	22.4 kW
Max Speed	8100 rpm	8100 rpm

Max Torque	90.0 ft-lbf @ 2000 rpm	122.0 Nm @ 2000 rpm
Drive System	Inline Direct-Drive	Inline Direct-Drive
Taper	CT40 | BT40 | HSK-A63	CT40 | BT40 | HSK-A63
Bearing Lubrication	Air / Oil Injection	Air / Oil Injection
Cooling	Liquid Cooled	Liquid Cooled
B AXIS - TILT	S.A.E	METRIC
Travel	120 ° to 35- °	120 ° to 35- °
Max Speed	50 °/sec	50 °/sec
Max Torque	2240 ft-lbf	3037 Nm
Brake Torque	2000 ft-lbf	2712 Nm
C AXIS - ROTATION	S.A.E	METRIC
Travel	360 °	360 °
Max Speed	50 °/sec	50 °/sec
Max Torque	1854 ft-lbf	2514 Nm
Max Part Swing	27.0 in	686 mm
Brake Torque	900 ft-lbf	1220 Nm
PLATTER	S.A.E	METRIC
Platter Diameter	19.70 in	500 mm
Max Weight on Platter	660 lb	300.0 kg
Max Weight on Platter w/Pallet Pool	200 lb	90.7 kg
T-Slot Width	0.626 in to 0.630 in	15.90 mm to 16.00 mm

Number of Std T-Slots	7	7
T-Slot Center Distance	2.48 in	63 mm
FEEDRATES	S.A.E	METRIC
Max Cutting	650 ipm	16.5 m/min
Rapids on X	900 ipm	22.9 m/min
Rapids on Y	900 ipm	22.9 m/min
Rapids on Z	900 ipm	22.9 m/min
AXIS MOTORS	S.A.E	METRIC
Max Thrust X	2750 lbf	12233 N
Max Thrust Y	2750 lbf	12233 N
Max Thrust Z	3400 lbf	15124 N
TOOL CHANGER	S.A.E	METRIC
Type	SMTC	SMTC
Capacity	30+1	30+1
Max Tool Diameter (full)	2.5 in	64 mm
Max Tool Diameter (adjacent empty)	5.0 in	127 mm
Max Tool Length (from gage line)	12 in	305 mm
Max Tool Weight	12 lb	5.4 kg
Tool-to-Tool (avg)	2.8 s	2.8 s
Chip-to-Chip (avg)	3.6 s	3.6 s
GENERAL	S.A.E	METRIC
Coolant Capacity	55 gal	208 L
AIR REQUIREMENTS	S.A.E	METRIC
Air Required	4 scfm @ 100 psi	113 L/min @ 6.9 bar

Inline Air Hose	3/8 in	3/8 in
Coupler (Air)	3/8 in	3/8 in
Air Pressure Min	80 psi	5.5 bar
DIMENSIONS - SHIPPING	S.A.E	METRIC
Domestic Pallet	168 in x 93 in x 110 in	427 cm x 235 cm x 280 cm
Export Pallet	174 in x 92 in x 100 in	442 cm x 234 cm x 254 cm
Weight	14250 lb	6463.8 kg
Export Crate w/70+1 SMTC	168 in 95 in 141 in	427 cm 241 cm 358 cm
Export Crate for Sheet Metal	102 in x 63 in x 28 in	259 cm x 160 cm x 71 cm
Weight for Sheet Metal Crate	1066 lb	484 kg
ELECTRICAL SPECIFICATION	S.A.E	METRIC
Spindle Speed	8100 rpm	8100 rpm
Drive System	Inline Direct-Drive	Inline Direct-Drive
Spindle Power	30.0 hp	22.4 kW
Input AC Voltage (3 Phase) - Low	220 VAC	220 VAC
Full Load Amps (3 Phase) - Low	70 A	70 A
Input AC Voltage (3 Phase) - High*	440 VAC	440 VAC
Full Load Amps (3 Phase) - High*	35 A	35 A

3.3 Tooling selection

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

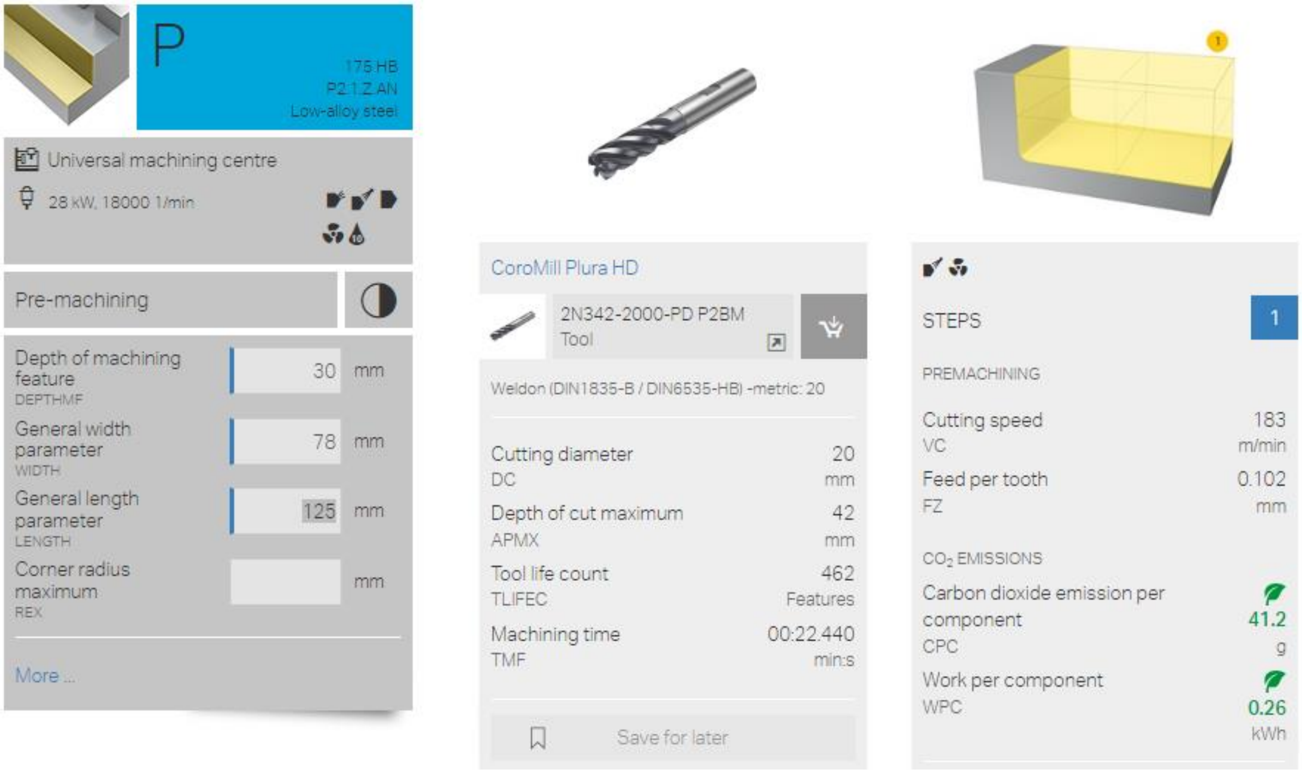
Selection of tooling – If single-piece tooling is being used, then a suitable toolholder should be selected before fully defining the tool geometry and material.

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

Milling:
005.01 – 005.08 / 005.17 – 005.18 / 005.26 – 005.29



P

175 HB
P2.1.Z.AN
Low-alloy steel

Universal machining centre

28 kW, 18000 1/min

Pre-machining

Depth of machining feature DEPTHMF	30	mm
General width parameter WIDTH	78	mm
General length parameter LENGTH	125	mm
Corner radius maximum REX		mm

More ...

CoroMill Plura HD

2N342-2000-PD P2BM
Tool

Weldon (DIN1835-B / DIN6535-HB) -metric: 20

Cutting diameter DC	20 mm
Depth of cut maximum APMX	42 mm
Tool life count TLIFEC	462 Features
Machining time TMF	00:22.440 min:s

Save for later

STEPS 1

PREMACHINING

Cutting speed VC	183 m/min
Feed per tooth FZ	0.102 mm

CO_2 EMISSIONS

Carbon dioxide emission per component CPC	41.2 g
Work per component WPC	0.26 kWh

Fig 16 – CoroMill Plura HD

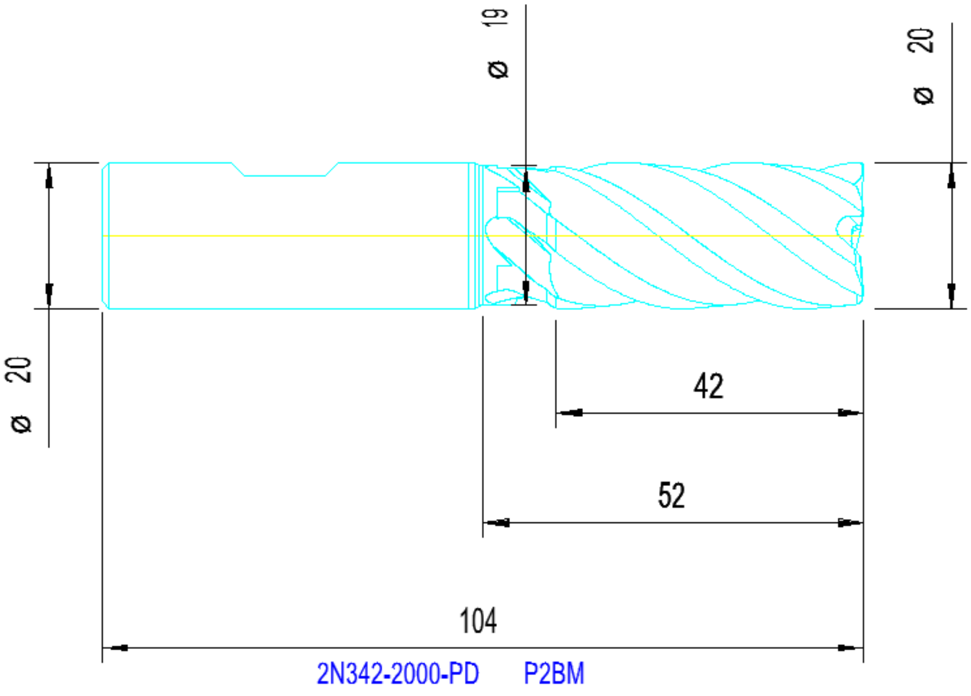
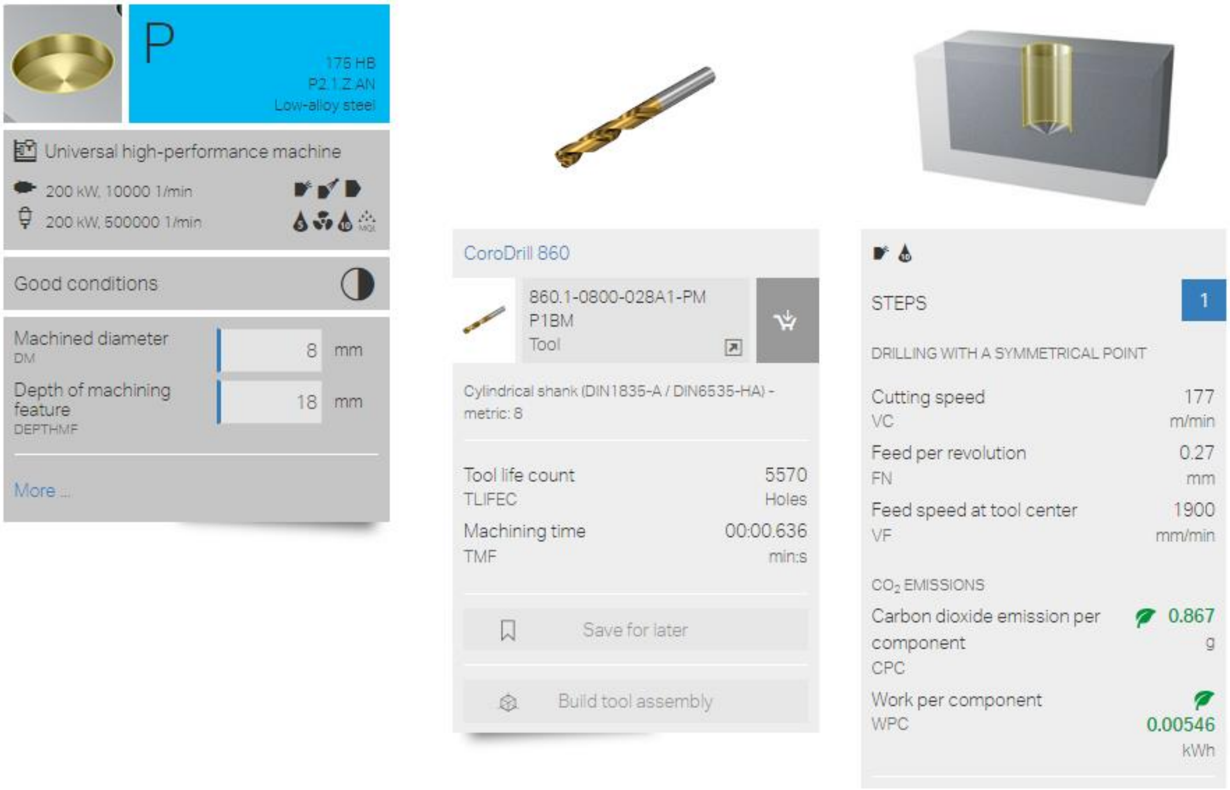


Fig 17 – CoroMill Plura HD 2D drawing

Table 6 – Product Data CoroMill Plura HD N342

Material classification level 1 (TMC1ISO)	PK
Cutting diameter	20 mm
Tolerance class cutting diameter	h10
Cutting diameter face contact	19.5 mm
Corner chamfer	45 deg
Corner chamfer width	0.25 mm
Depth of cut maximum	42 mm
Depth of cut maximum (PFW)	42 mm
Centre cutting capability	FALSE
Depth of cut maximum (FFW)	42 mm
Usable length	52 mm
Peripheral effective cutting edge count	5
Maximum ramping angle (FFW)	7 deg
Connection diameter tolerance	h6
Grade	P2BM
Basic standard group	COROMANT
Coolant entry style code	0: without coolant
Connection diameter	20 mm
Functional length	104 mm
Body diameter (BD1)	19 mm
Body diameter (BD2)	19 mm
Neck diameter	19 mm
Body length (LB1)	52 mm
Body length (LB2)	52.87 mm
Body half taper angle (BHTA1)	0 deg
Body half taper angle (BHTA2)	30 deg
Flute helix angle	38 deg
Radial rake angle (GAMF)	10.5 deg
Axial rake angle (GAMP)	10.5 deg
Maximum regrinds	4
Rotational speed maximum	11,700 1/min
Weight of item	0.403 kg

Drilling: M8-7H
005.09 – 005.10 / 005.13 – 005.14 / 005.22 – 005.23



P
175 HB
P2.1.Z.AN
Low-alloy steel

Universal high-performance machine
200 kW, 10000 1/min
200 kW, 500000 1/min

Good conditions

Machined diameter DM: 8 mm
Depth of machining feature DEPTHMF: 18 mm

CoroDrill 860
860.1-0800-028A1-PM
P1BM
Tool

Cylindrical shank (DIN1835-A / DIN6535-HA) - metric: 8

Tool life count TLIFEC: 5570 Holes
Machining time TMF: 00:00.636 min:s

STEPS 1

DRILLING WITH A SYMMETRICAL POINT

Cutting speed VC: 177 m/min
Feed per revolution FN: 0.27 mm
Feed speed at tool center VF: 1900 mm/min

CO_2 EMISSIONS
Carbon dioxide emission per component CPC: 0.867 g
Work per component WPC: 0.00546 kWh

Fig 18 – CoroDrill 860

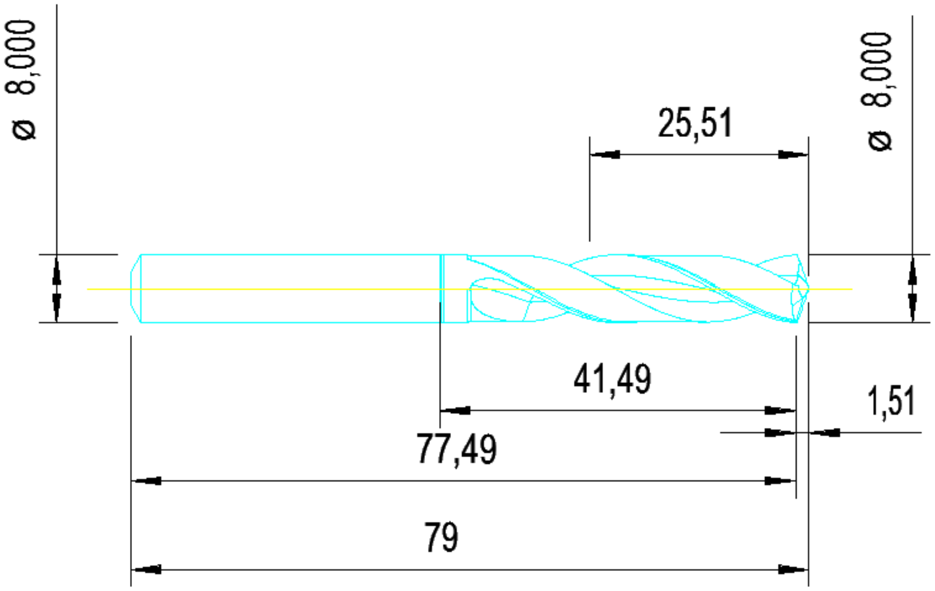
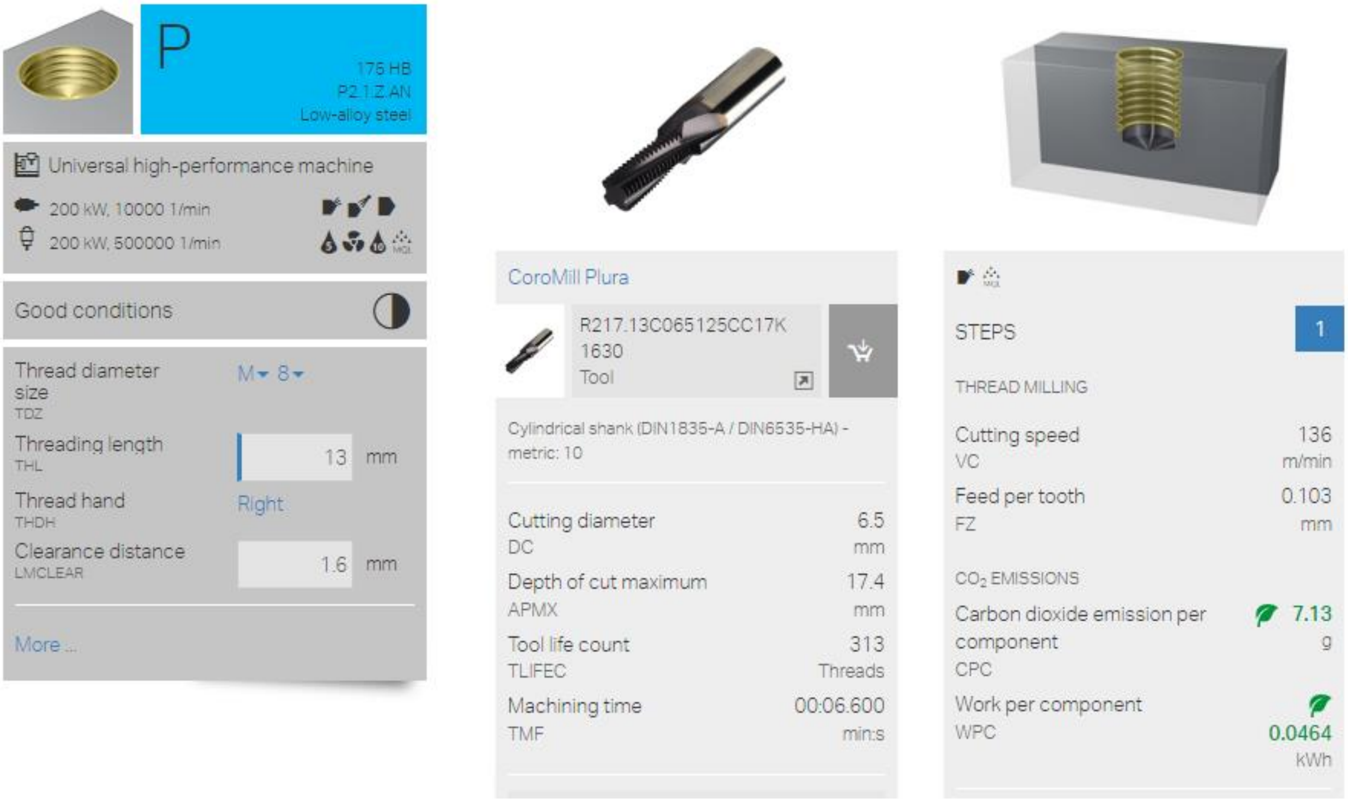


Fig 19 – CoroDrill 860 2D drawing

Table 7 – Product Data CoroDrill 860

Material classification level 1	P
Cutting diameter	8 mm
Achievable hole tolerance	H8
Usable length	25.3 mm
Usable length diameter ratio	3.162
Adaptive interface machine direction	Cylindrical shank -metric: 8
Connection diameter tolerance	h6
Grade	P1BM
Substrate	HC
Coating	PVD TiAlSiN+TiSiN
Basic standard group	DIN 6537 K
Coolant entry style code	4: axial concentric entry on circle
Connection diameter	8 mm
Point angle	147 deg
Point length	1.185 mm
Overall length	79 mm
Functional length	77.7 mm
Chip flute length	41 mm
Maximum regrinds	3
Rotational speed maximum	9,947 1/min
Weight of item	0.047 kg
Release date	1/12/2022
Release pack id	22.1

Threading: M8-7H
005.12 / 005.16 / 005.25



P
175 HB
P2.1.Z.AN
Low-alloy steel

Universal high-performance machine
200 kW, 10000 1/min
200 kW, 500000 1/min

Good conditions

Thread diameter size TDZ	M 8	
Threading length THL	13	mm
Thread hand THDH	Right	
Clearance distance LMCLEAR	1.6	mm

More ...

CoroMill Plura

R217.13C065125CC17K 1630
Tool

Cylindrical shank (DIN1835-A / DIN6535-HA) - metric: 10

Cutting diameter DC	6.5 mm
Depth of cut maximum APMX	17.4 mm
Tool life count TLIFEC	313 Threads
Machining time TMF	00:06.600 min:s

STEPS 1

THREAD MILLING

Cutting speed VC	136 m/min
Feed per tooth FZ	0.103 mm

CO_2 EMISSIONS

Carbon dioxide emission per component CPC	7.13 g
Work per component WPC	0.0464 kWh

Fig 20 – CoroMill Plura R217

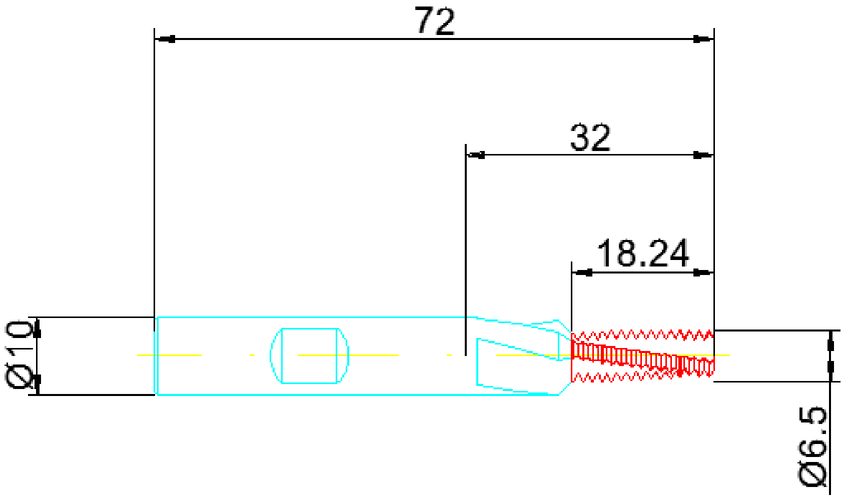


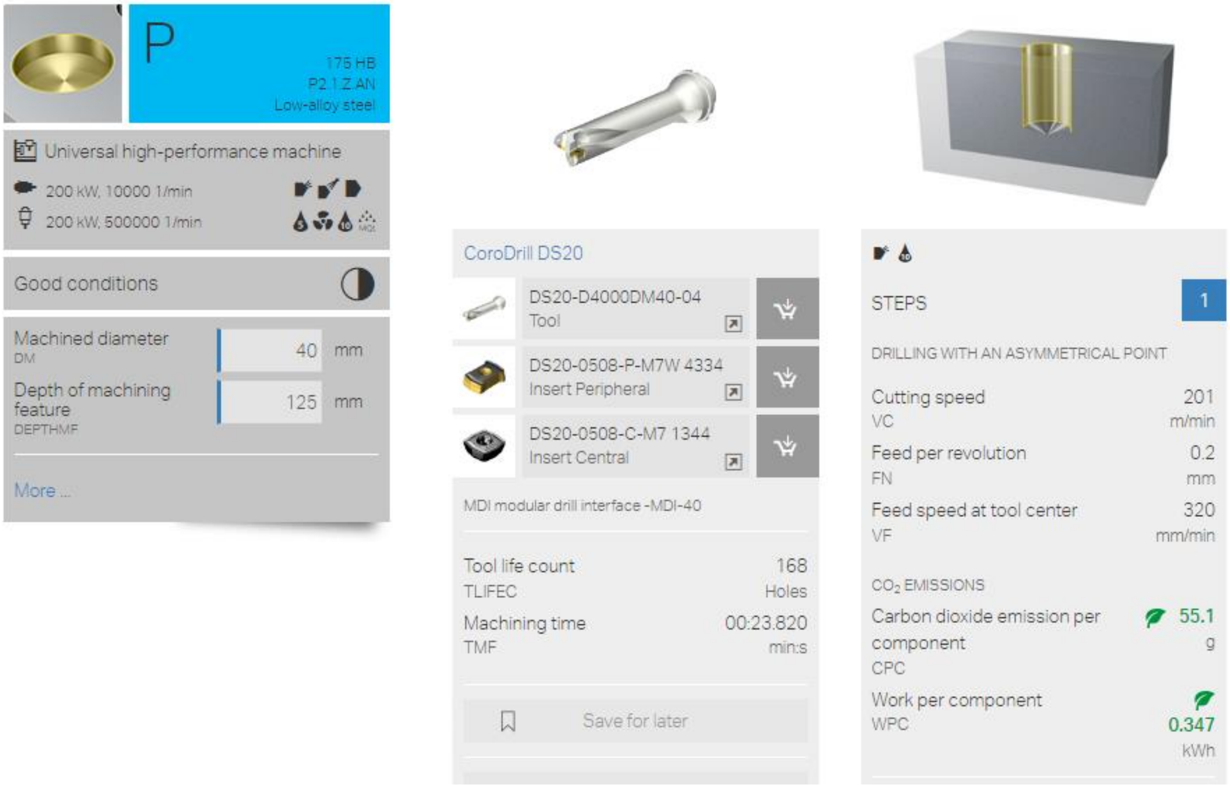
Fig 21 – CoroMill Plura R217 2D drawing

Table 8 - Product Data CoroMill Plura R217

Material classification level 1	PMKNSH
Thread form type	M60
Thread type	INT
Thread diameter size	M8X1.25
Thread pitch	1.25 mm

Cutting diameter 1	6.5 mm
Cutting diameter 2	6.5 mm
Maximum cutting diameter	10 mm
Countersink angle	90 deg
Basic standard group	COROMANT
Depth of cut maximum	17.35 mm
Usable length	18.24 mm
Adaptive interface machine dir.	Cylindrical shank -metric: 10
Connection diameter tolerance	h6
Grade	1630
Substrate	HC
Coating	PVD TiAlN
Coolant entry style code	1: axial concentric entry
Coolant pressure	20 bar
Peripheral effective cutting-edge count	3
Connection diameter	10 mm
Functional length 1	72 mm
Functional length 2	54.65 mm
Body diameter	10 mm
Neck diameter	10 mm
Body length	17.35 mm
Flute helix angle	10 deg
Rotational speed maximum	80,000 1/min
Weight of item	0.073 kg
Release date	9/19/2012
Release pack id	12.2

Drilling: 40H7
005.20


P
175 HB
P2.1.Z.AN
Low-alloy steel

Universal high-performance machine
200 kW, 10000 1/min
200 kW, 500000 1/min

Good conditions

Machined diameter DM	40	mm
Depth of machining feature DEPTHMF	125	mm

More ...

CoroDrill DS20

DS20-D4000DM40-04
Tool

DS20-0508-P-M7W 4334
Insert Peripheral

DS20-0508-C-M7 1344
Insert Central

MDI modular drill interface -MDI-40

Tool life count TLIFEC	168 Holes
Machining time TMF	00:23.820 min:s

Save for later

STEPS 1

DRILLING WITH AN ASYMMETRICAL POINT

Cutting speed VC	201 m/min
Feed per revolution FN	0.2 mm
Feed speed at tool center VF	320 mm/min

CO_2 EMISSIONS

Carbon dioxide emission per component CPC	55.1 g
Work per component WPC	0.347 kWh

Fig 22 – CoroDrill DS20

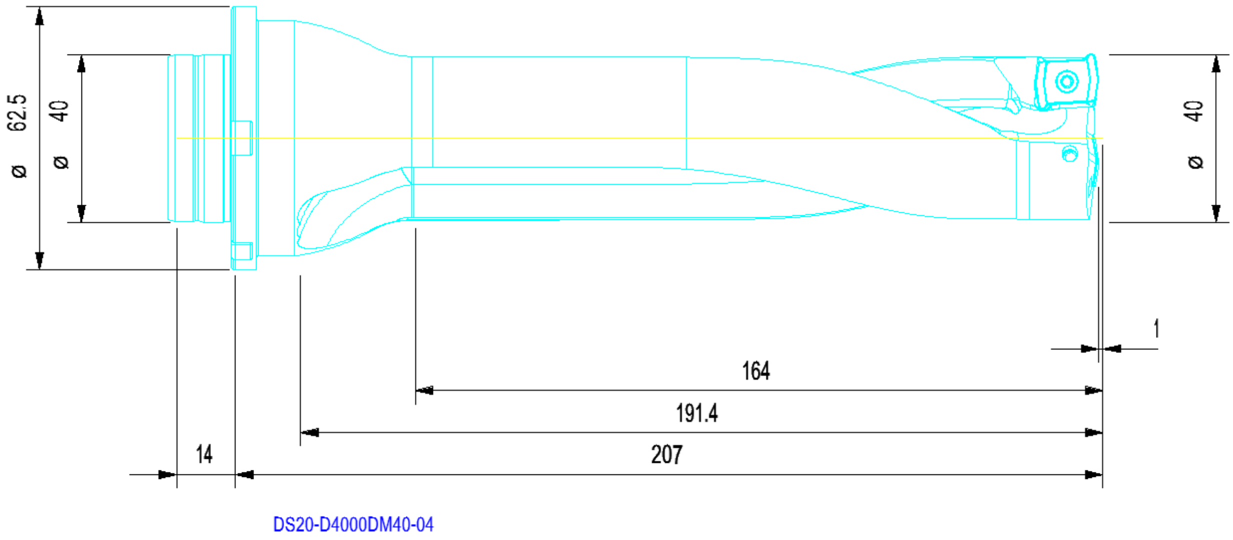


Fig 23 – CoroDrill DS20 2D drawing

Table 9 – Product Data CoroDrill DS20

Cutting diameter	40 mm
Achievable hole tolerance lower	0 mm
Achievable hole tolerance upper	0.35 mm
Usable length	161.002 mm
Usable length diameter ratio	4.025
Maximum adjustment limit	0.72 mm
Clamping type code	S
Torque	2 Nm
Adaptive interface machine direction	MDI modular drill interface -MDI-40
Coolant entry style code	4: axial concentric entry on circle
Coolant pressure	10 bar
Connection diameter	40 mm
Tool cutting edge angle	81 deg
Point length	1.002 mm
Overall length	222 mm
Functional length	205.998 mm
Body length (LB1)	164 mm
Rotational speed maximum	9,000 1/min
Weight of item	1.49 kg
Release date	9/24/2019
Release pack id	19.2

Modular fixture design

The primary goal of the fixture design is to provide stable and precise positioning of the Jaw part during machining, minimizing vibrations, deflections, and distortions that could affect the final product's quality. The design process takes into account various factors such as the geometry and dimensions of the Jaw part, the machining operations involved, the cutting forces applied, and the accessibility of the tooling. By carefully considering these factors, we can develop a fixture that optimizes the machining process and ensures consistent and accurate results.

The table vise stands out as the optimal choice for the fixture design due to its exceptional characteristics and functionality. With its sturdy construction and robust clamping mechanism, the table vise provides a secure and stable Jaw on the Jaw part during machining operations. Its adjustable jaws offer versatility in accommodating different Jaw part sizes and shapes, ensuring compatibility with various design iterations. Furthermore, the table vise allows for precise positioning and alignment, enabling accurate machining and minimizing dimensional errors. Its user-friendly design and easy mounting options make it a practical and efficient solution for the fixture setup. By utilizing a table vise, we can achieve the necessary stability, accessibility, and repeatability required for successful machining of the Jaw part. In order to visualize the practical implementation of the table vise in the fixture design, let us visualize the following figures.

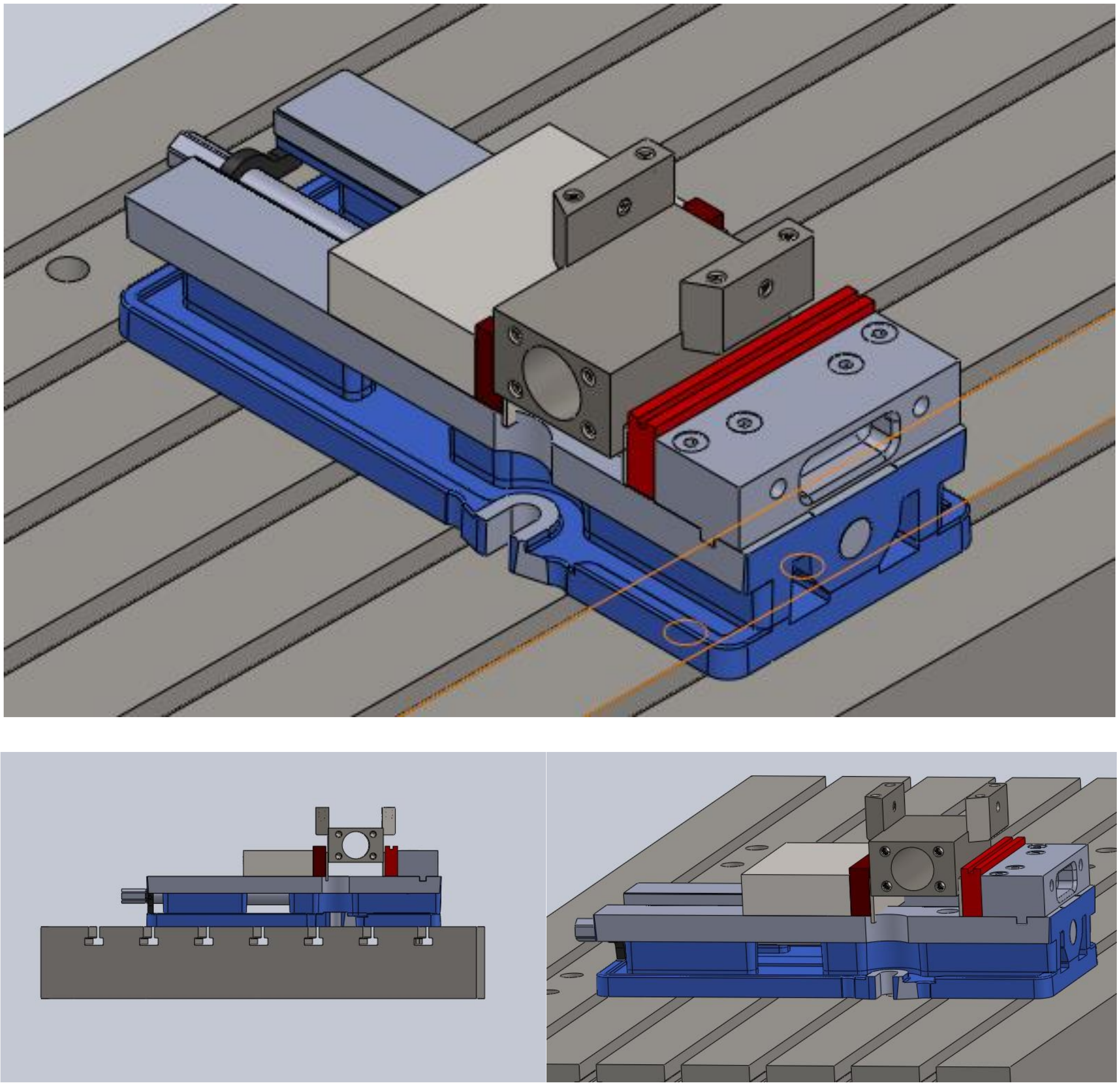


Figure 24 – Illustrations of the Jaw on the table vise

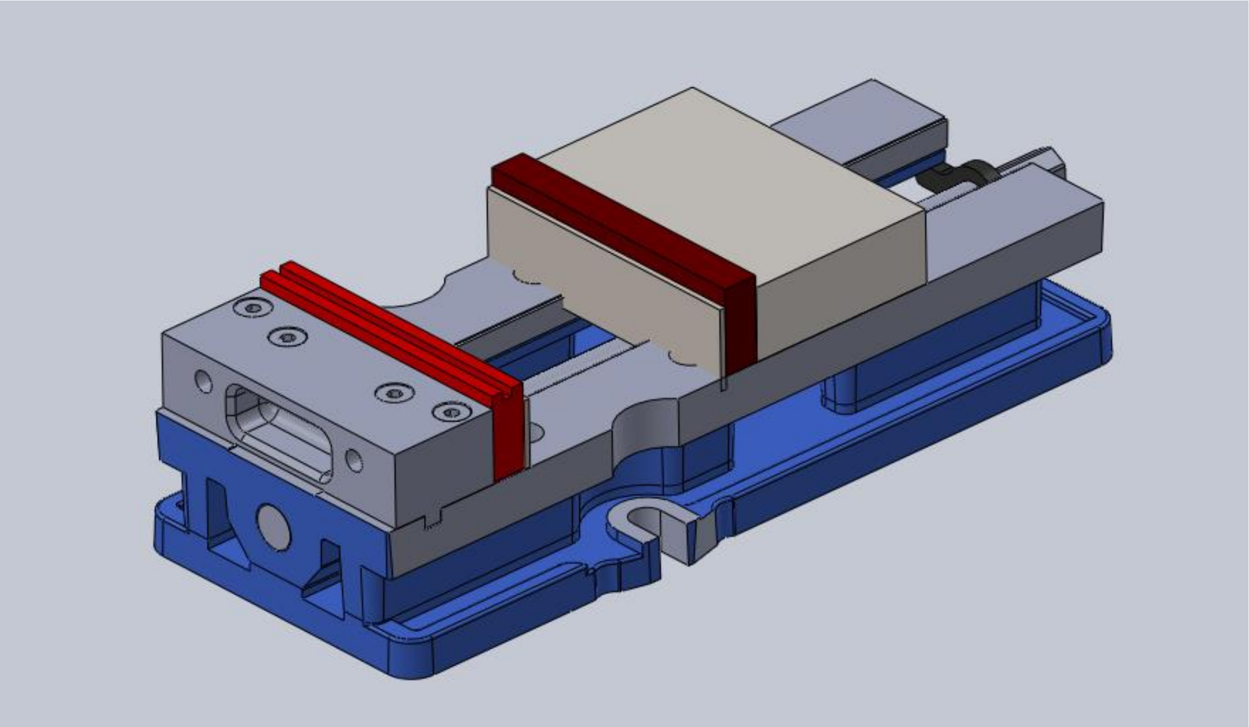
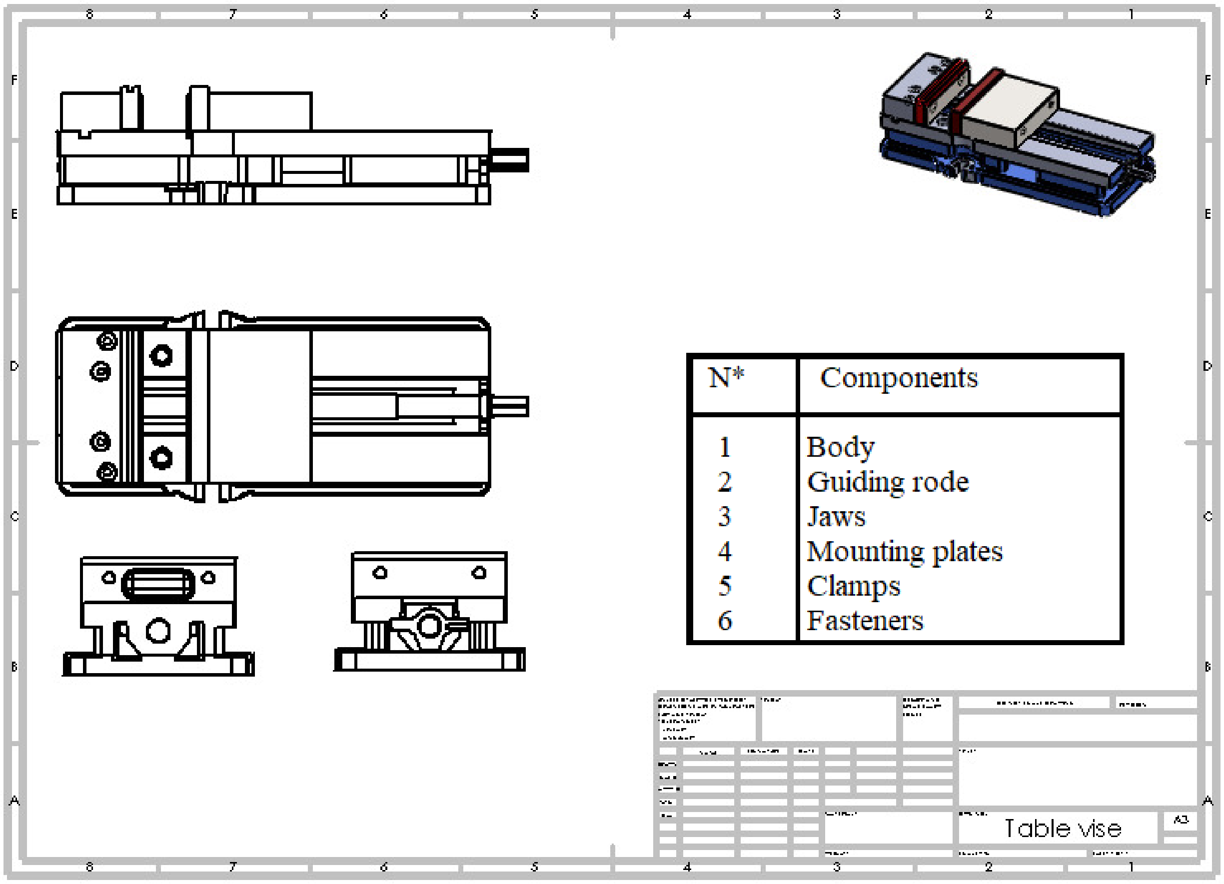


Figure 25 – Table vise 3D model



N*	Components
1	Body
2	Guiding rode
3	Jaws
4	Mounting plates
5	Clamps
6	Fasteners

Figure 26 – 2D drawing of the table vise

In response to the decision not to proceed with the table vise fixture design, an alternative solution was developed to meet the specific requirements of the project. The newly designed fixture, dedicated to securing the jaw part during machining, takes into consideration the need for clearances and unobstructed access to the machining areas. The design ensures that the fixture itself does not interfere with the machining process or impede the movement of the CNC machine. By focusing solely on providing a stable and secure hold for the jaw, the alternative fixture offers a streamlined and efficient solution tailored to the unique needs of the project.

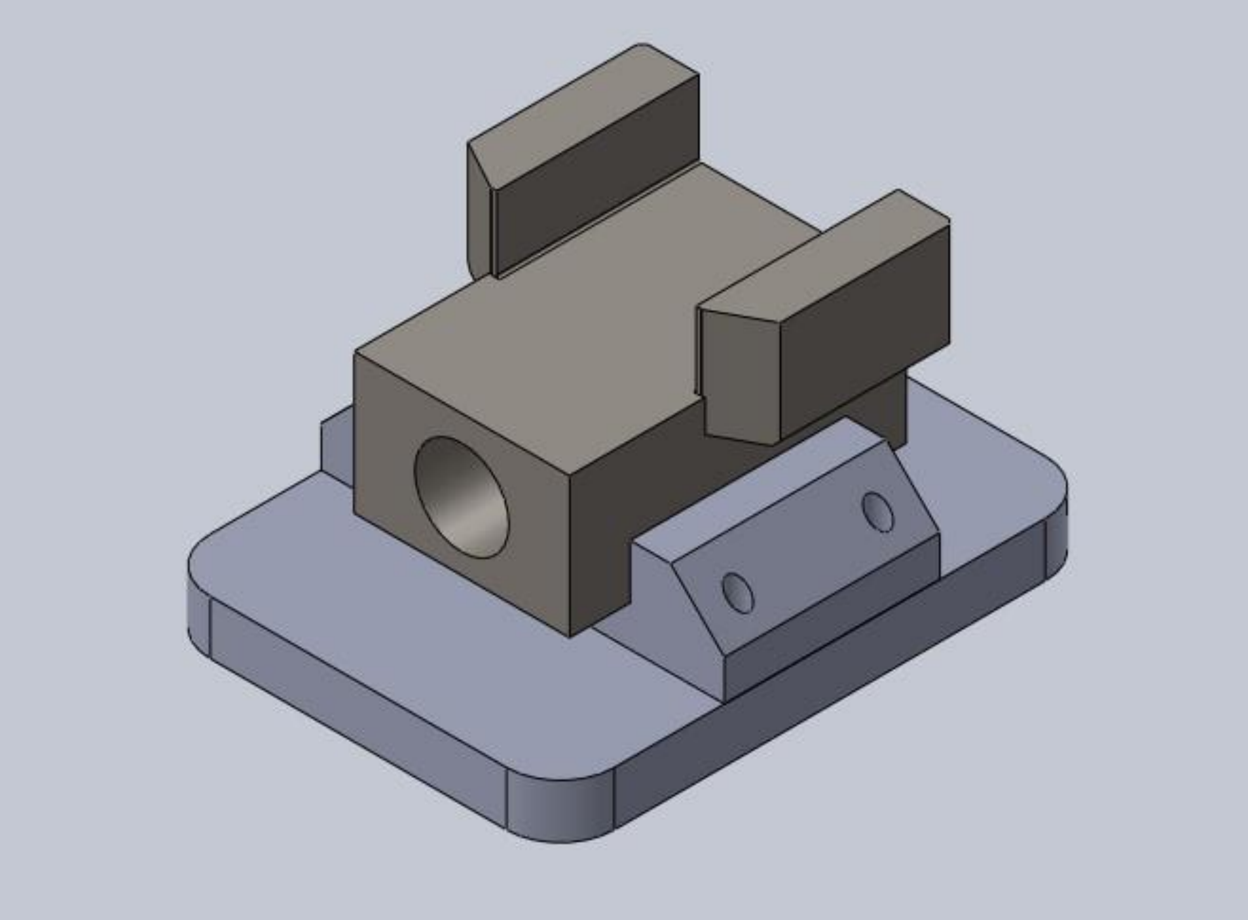
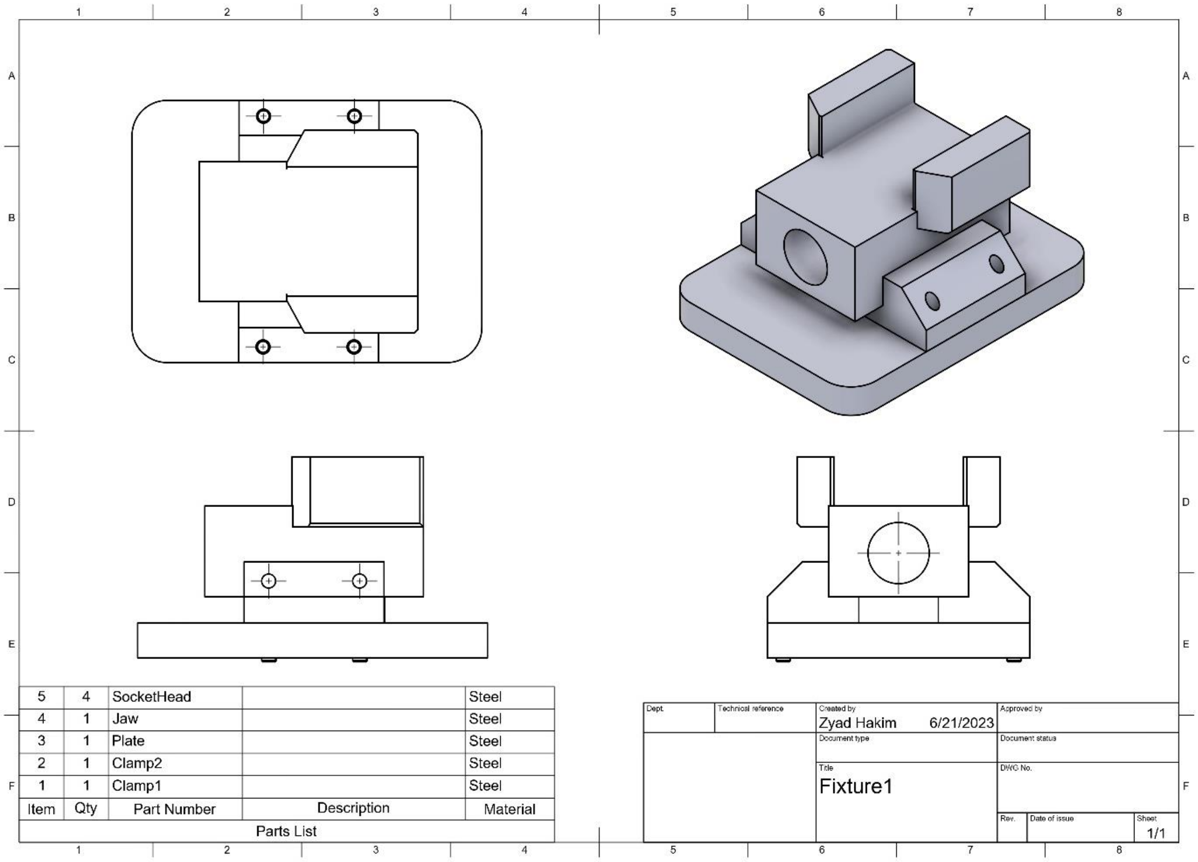


Figure 27 – New Fixture design



Item	Qty	Part Number	Description	Material
5	4	SocketHead		Steel
4	1	Jaw		Steel
3	1	Plate		Steel
2	1	Clamp2		Steel
1	1	Clamp1		Steel

Parts List

Dept.	Technical reference	Created by Zyad Hakim 6/21/2023	Approved by
		Document type	Document status
		Title Fixture1	DWG No.
			Rev. / Date of issue / Sheet 1/1

Figure 28 – 2D drawing of the Fixture design

In order to demonstrate the practical implementation of the fixture, the following images provide a visual representation of how the fixture effectively holds the jaw part in place, allowing for controlled and stable machining operations.

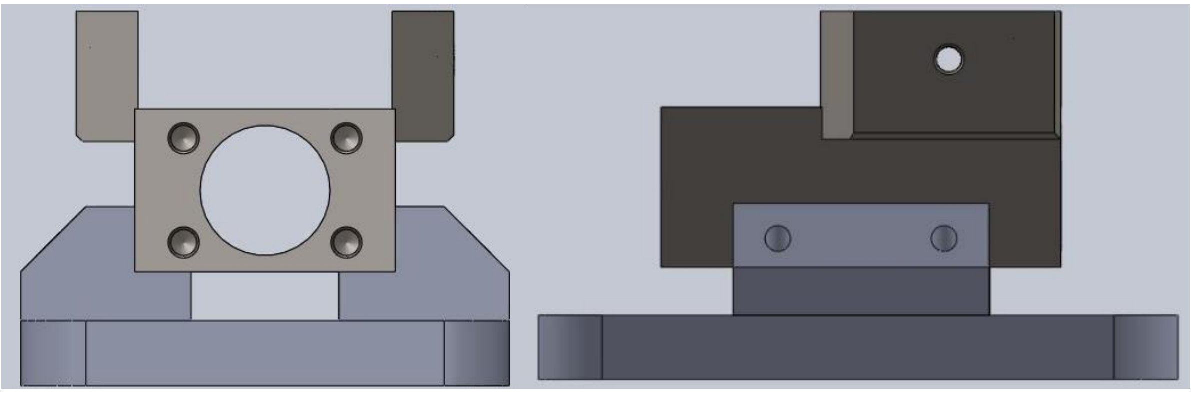


Figure 29 – Illustration of Jaw on the Fixture

In addition to the new fixture design, we also developed a simplified alternative design for machining the Jaw part. This design involved using four corner clamps and a base plate. The corner clamps were positioned at the corners of the workpiece, securely holding it in place. The base plate provided a stable foundation for the clamps and ensured proper alignment.

This simplified fixture design offered advantages such as easy setup and reduced complexity. By using only four corner clamps and a base plate, we achieved a straightforward and cost-effective solution without compromising machining accuracy.

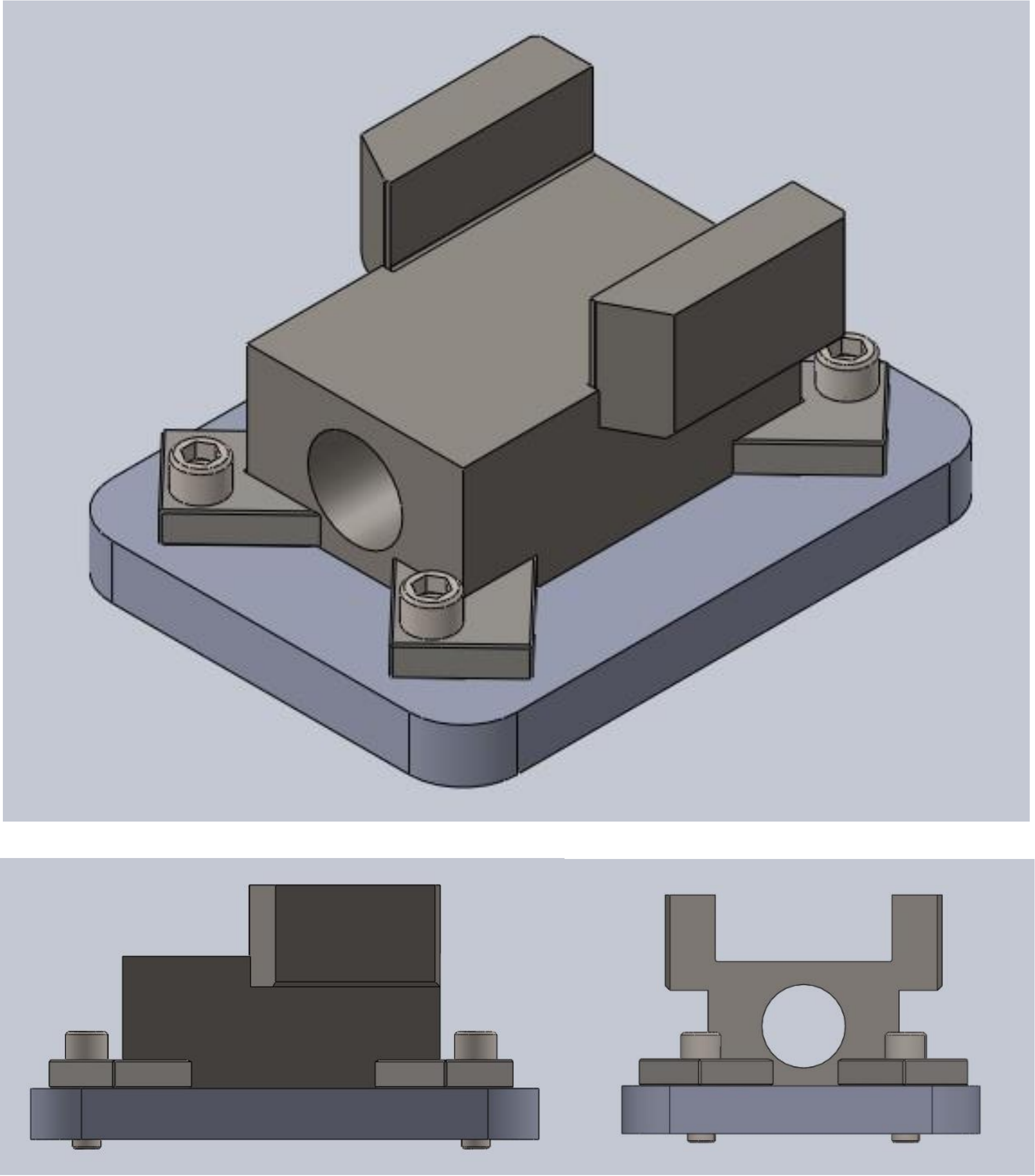
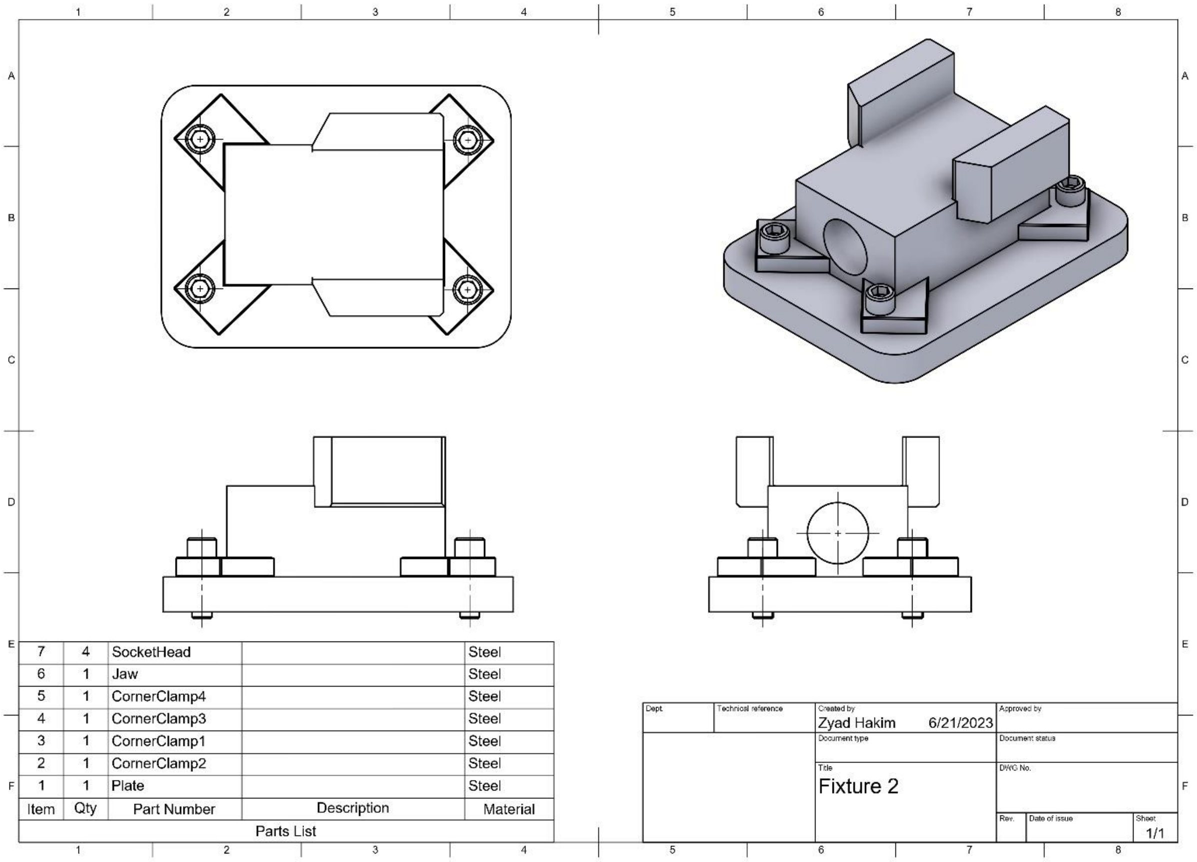


Figure 30 – Corner clamps Fixture



Item	Qty	Part Number	Description	Material
7	4	SocketHead		Steel
6	1	Jaw		Steel
5	1	CornerClamp4		Steel
4	1	CornerClamp3		Steel
3	1	CornerClamp1		Steel
2	1	CornerClamp2		Steel
1	1	Plate		Steel

Parts List

Dept
Technical reference
Created by Zyad Hakim 6/21/2023
Approved by
Document type
Document status
Title Fixture 2
DWG No.
Rev.
Date of issue
Sheet 1/1

Figure 31 - Corner clamps Fixture Drawing

Clamping force calculation

The clamping force of a fixture refers to the amount of force applied by the fixture to securely hold and immobilize the workpiece during machining or manufacturing operations. It is the force that resists any movement or displacement of the workpiece caused by cutting forces, vibrations, or other external factors.

Calculating the clamping force is essential to ensure that it is sufficient to resist the cutting forces and external loads encountered during the machining process. By determining the required clamping force, one can select an appropriate clamping mechanism, verify the fixture's load-bearing capacity, and make any necessary adjustments to ensure the workpiece remains securely held throughout the operation.

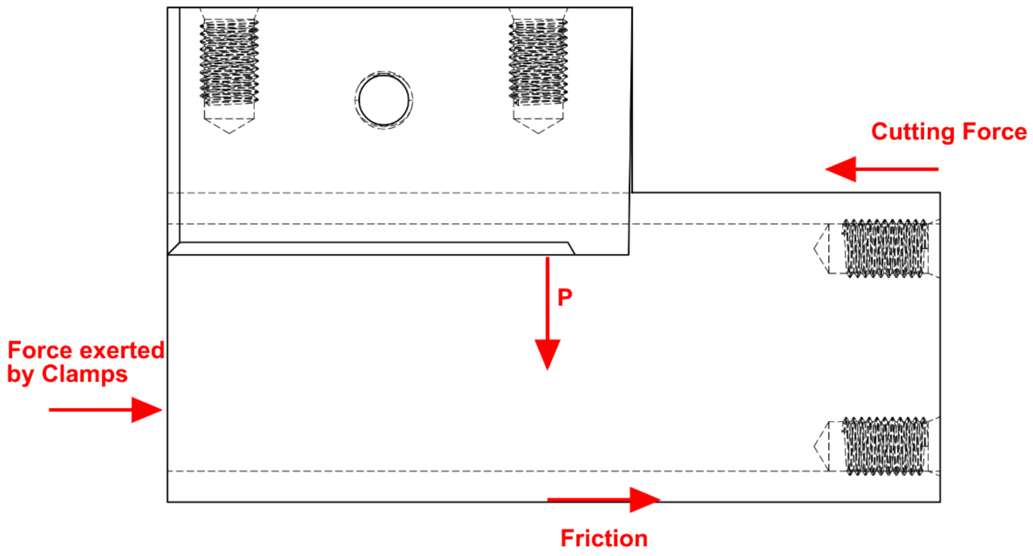
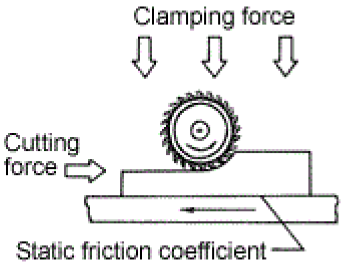


Figure 32 - Forces

In order to calculate the clamping force, we can use the method below:



$$\text{Required clamping force} = \frac{\text{Cutting force (lbs)}}{\text{Static friction coefficient}} \times \text{Safety factor (usually 2)}$$

Contact surfaces	Friction coefficient (Dry)	Friction coefficient (Lubricated)
Steel on steel	15	12
Steel on cast iron	19	10
Cast iron on cast iron	30	19

The highest forces would be encountered when rough machining the surfaces M1, M2 and M3 with a 20mm end mill and a depth of cut of 2mm along the X-axis. We assume a cutting force of 500 N along the X-axis.

As a result, we can determine that the clamping force required would be as follows:

Units

○ lbs

● N

Cutting Force (N)

500 N

Static Friction Coefficient

0.2

Safety Factor

2

1

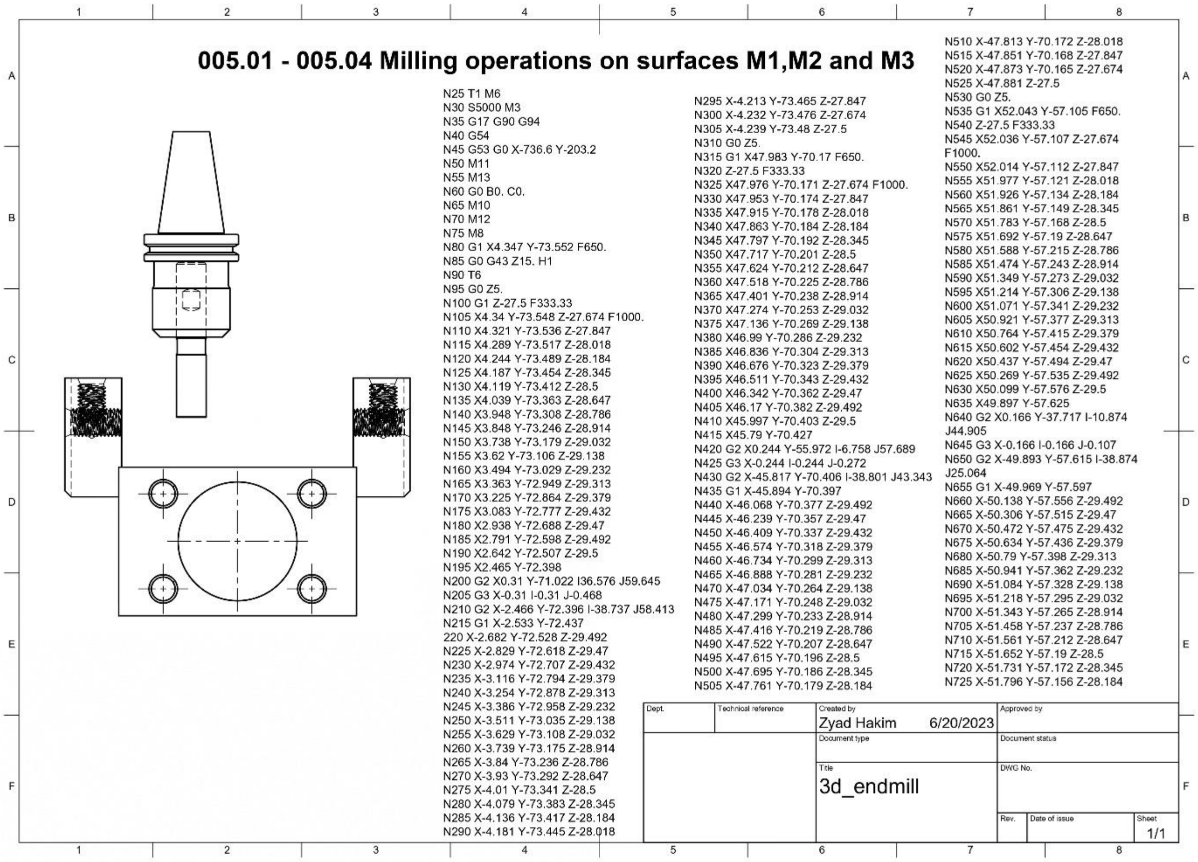
Required Clamping Force (N)

5,000 N

Figure 33 – Required Clamping force N

Post process generation

Once all the necessary technological processes have been completed, we can proceed to simulate the machining and generate the post-process NC code. This allows us to visualize and analyze the entire machining operation. In the following images, you will find a depiction of the machining process along with the corresponding NC code. These visuals provide a clear representation of how the toolpaths are executed and how the machine will precisely carry out each operation. This simulation and NC code generation are crucial steps in ensuring the accuracy and efficiency of the machining process.



005.01 - 005.04 Milling operations on surfaces M1,M2 and M3

```
N25 T1 M6
N30 S5000 M3
N35 G17 G90 G94
N40 G54
N45 G53 G0 X-736.6 Y-203.2
N50 M11
N55 M13
N60 G0 B0. C0.
N65 M10
N70 M12
N75 M8
N80 G1 X4.347 Y-73.552 F650.
N85 G0 G43 Z15. H1
N90 T6
N95 G0 Z5.
N100 G1 Z-27.5 F333.33
N105 X4.34 Y-73.548 Z-27.674 F1000.
N110 X4.321 Y-73.536 Z-27.847
N115 X4.289 Y-73.517 Z-28.018
N120 X4.244 Y-73.489 Z-28.184
N125 X4.187 Y-73.454 Z-28.345
N130 X4.119 Y-73.412 Z-28.5
N135 X4.039 Y-73.363 Z-28.647
N140 X3.948 Y-73.308 Z-28.786
N145 X3.848 Y-73.246 Z-28.914
N150 X3.738 Y-73.179 Z-29.032
N155 X3.62 Y-73.106 Z-29.138
N160 X3.494 Y-73.029 Z-29.232
N165 X3.363 Y-72.949 Z-29.313
N170 X3.225 Y-72.864 Z-29.379
N175 X3.083 Y-72.777 Z-29.432
N180 X2.938 Y-72.688 Z-29.47
N185 X2.791 Y-72.598 Z-29.492
N190 X2.642 Y-72.507 Z-29.5
N195 X2.465 Y-72.398
N200 G2 X0.31 Y-71.022 I36.576 J59.645
N205 G3 X-0.31 I-0.31 J-0.468
N210 G2 X-2.466 Y-72.396 I-38.737 J58.413
N215 G1 X-2.533 Y-72.437
220 X-2.682 Y-72.528 Z-29.492
N225 X-2.829 Y-72.618 Z-29.47
N230 X-2.974 Y-72.707 Z-29.432
N235 X-3.116 Y-72.794 Z-29.379
N240 X-3.254 Y-72.878 Z-29.313
N245 X-3.386 Y-72.958 Z-29.232
N250 X-3.511 Y-73.035 Z-29.138
N255 X-3.629 Y-73.108 Z-29.032
N260 X-3.739 Y-73.175 Z-28.914
N265 X-3.84 Y-73.236 Z-28.786
N270 X-3.93 Y-73.292 Z-28.647
N275 X-4.01 Y-73.341 Z-28.5
N280 X-4.079 Y-73.383 Z-28.345
N285 X-4.136 Y-73.417 Z-28.184
N290 X-4.181 Y-73.445 Z-28.018
N295 X-4.213 Y-73.465 Z-27.847
N300 X-4.232 Y-73.476 Z-27.674
N305 X-4.239 Y-73.48 Z-27.5
N310 G0 Z5.
N315 G1 X47.983 Y-70.17 F650.
N320 Z-27.5 F333.33
N325 X47.976 Y-70.171 Z-27.674 F1000.
N330 X47.953 Y-70.174 Z-27.847
N335 X47.915 Y-70.178 Z-28.018
N340 X47.863 Y-70.184 Z-28.184
N345 X47.797 Y-70.192 Z-28.345
N350 X47.717 Y-70.201 Z-28.5
N355 X47.624 Y-70.212 Z-28.647
N360 X47.518 Y-70.225 Z-28.786
N365 X47.401 Y-70.238 Z-28.914
N370 X47.274 Y-70.253 Z-29.032
N375 X47.136 Y-70.269 Z-29.138
N380 X46.99 Y-70.286 Z-29.232
N385 X46.836 Y-70.304 Z-29.313
N390 X46.676 Y-70.323 Z-29.379
N395 X46.511 Y-70.343 Z-29.432
N400 X46.342 Y-70.362 Z-29.47
N405 X46.17 Y-70.382 Z-29.492
N410 X45.997 Y-70.403 Z-29.5
N415 X45.79 Y-70.427
N420 G2 X0.244 Y-55.972 I-6.758 J57.689
N425 G3 X-0.244 I-0.244 J-0.272
N430 G2 X-45.817 Y-70.406 I-38.801 J43.343
N435 G1 X-45.894 Y-70.397
N440 X-46.068 Y-70.377 Z-29.492
N445 X-46.239 Y-70.357 Z-29.47
N450 X-46.409 Y-70.337 Z-29.432
N455 X-46.574 Y-70.318 Z-29.379
N460 X-46.734 Y-70.299 Z-29.313
N465 X-46.888 Y-70.281 Z-29.232
N470 X-47.034 Y-70.264 Z-29.138
N475 X-47.171 Y-70.248 Z-29.032
N480 X-47.299 Y-70.233 Z-28.914
N485 X-47.416 Y-70.219 Z-28.786
N490 X-47.522 Y-70.207 Z-28.647
N495 X-47.615 Y-70.196 Z-28.5
N500 X-47.695 Y-70.186 Z-28.345
N505 X-47.761 Y-70.179 Z-28.184
N510 X-47.813 Y-70.172 Z-28.018
N515 X-47.851 Y-70.168 Z-27.847
N520 X-47.873 Y-70.165 Z-27.674
N525 X-47.881 Z-27.5
N530 G0 Z5.
N535 G1 X52.043 Y-57.105 F650.
N540 Z-27.5 F333.33
N545 X52.036 Y-57.107 Z-27.674
F1000.
N550 X52.014 Y-57.112 Z-27.847
N555 X51.977 Y-57.121 Z-28.018
N560 X51.926 Y-57.134 Z-28.184
N565 X51.861 Y-57.149 Z-28.345
N570 X51.783 Y-57.168 Z-28.5
N575 X51.692 Y-57.19 Z-28.647
N580 X51.588 Y-57.215 Z-28.786
N585 X51.474 Y-57.243 Z-28.914
N590 X51.349 Y-57.273 Z-29.032
N595 X51.214 Y-57.306 Z-29.138
N600 X51.071 Y-57.341 Z-29.232
N605 X50.921 Y-57.377 Z-29.313
N610 X50.764 Y-57.415 Z-29.379
N615 X50.602 Y-57.454 Z-29.432
N620 X50.437 Y-57.494 Z-29.47
N625 X50.269 Y-57.535 Z-29.492
N630 X50.099 Y-57.576 Z-29.5
N635 X49.897 Y-57.625
N640 G2 X0.166 Y-37.717 I-10.874
J44.905
N645 G3 X-0.166 I-0.166 J-0.107
N650 G2 X-49.893 Y-57.615 I-38.874
J25.064
N655 G1 X-49.969 Y-57.597
N660 X-50.138 Y-57.556 Z-29.492
N665 X-50.306 Y-57.515 Z-29.47
N670 X-50.472 Y-57.475 Z-29.432
N675 X-50.634 Y-57.436 Z-29.379
N680 X-50.79 Y-57.398 Z-29.313
N685 X-50.941 Y-57.362 Z-29.232
N690 X-51.084 Y-57.328 Z-29.138
N695 X-51.218 Y-57.295 Z-29.032
N700 X-51.343 Y-57.265 Z-28.914
N705 X-51.458 Y-57.237 Z-28.786
N710 X-51.561 Y-57.212 Z-28.647
N715 X-51.652 Y-57.19 Z-28.5
N720 X-51.731 Y-57.172 Z-28.345
N725 X-51.796 Y-57.156 Z-28.184
```

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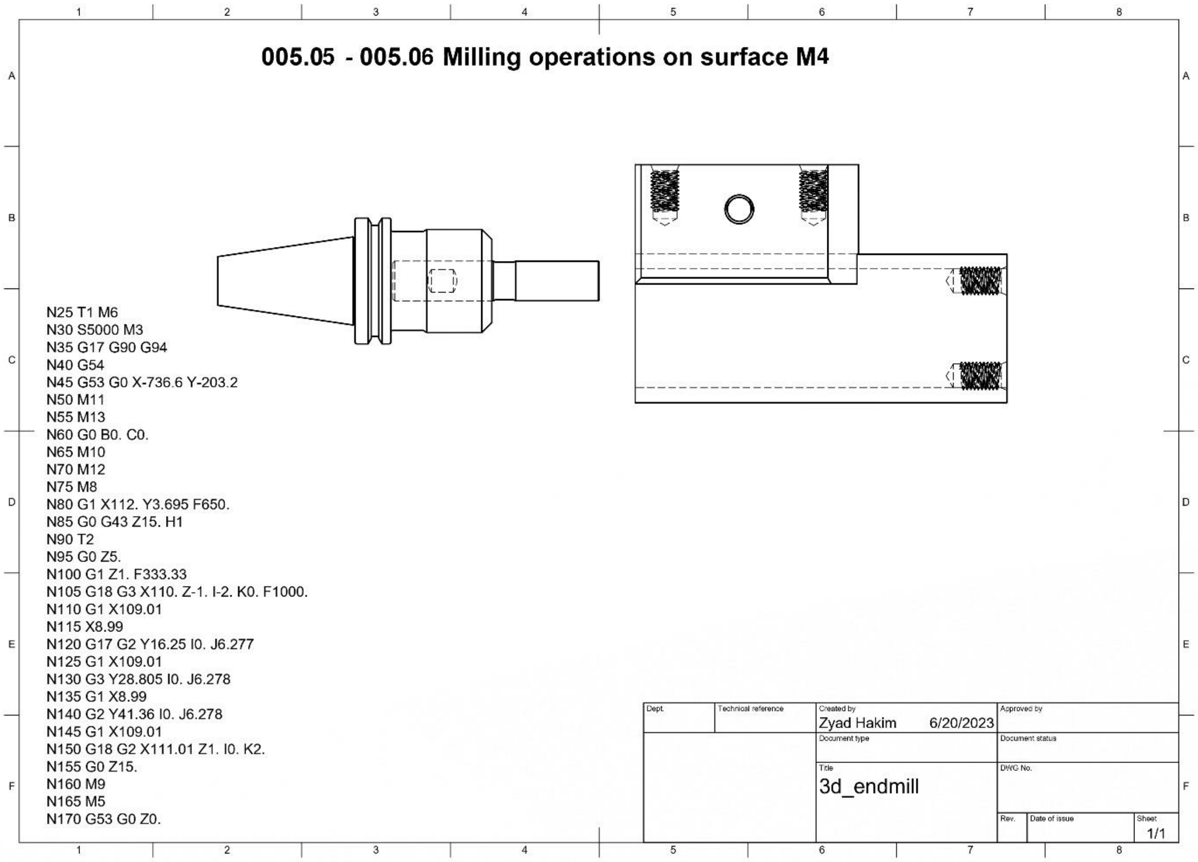

005.05 - 005.06 Milling operations on surface M4

```
N25 T1 M6
N30 S5000 M3
N35 G17 G90 G94
N40 G54
N45 G53 G0 X-736.6 Y-203.2
N50 M11
N55 M13
N60 G0 B0. C0.
N65 M10
N70 M12
N75 M8
N80 G1 X112. Y3.695 F650.
N85 G0 G43 Z15. H1
N90 T2
N95 G0 Z5.
N100 G1 Z1. F333.33
N105 G18 G3 X110. Z-1. I-2. K0. F1000.
N110 G1 X109.01
N115 X8.99
N120 G17 G2 Y16.25 I0. J6.277
N125 G1 X109.01
N130 G3 Y28.805 I0. J6.278
N135 G1 X8.99
N140 G2 Y41.36 I0. J6.278
N145 G1 X109.01
N150 G18 G2 X111.01 Z1. I0. K2.
N155 G0 Z15.
N160 M9
N165 M5
N170 G53 G0 Z0.
```

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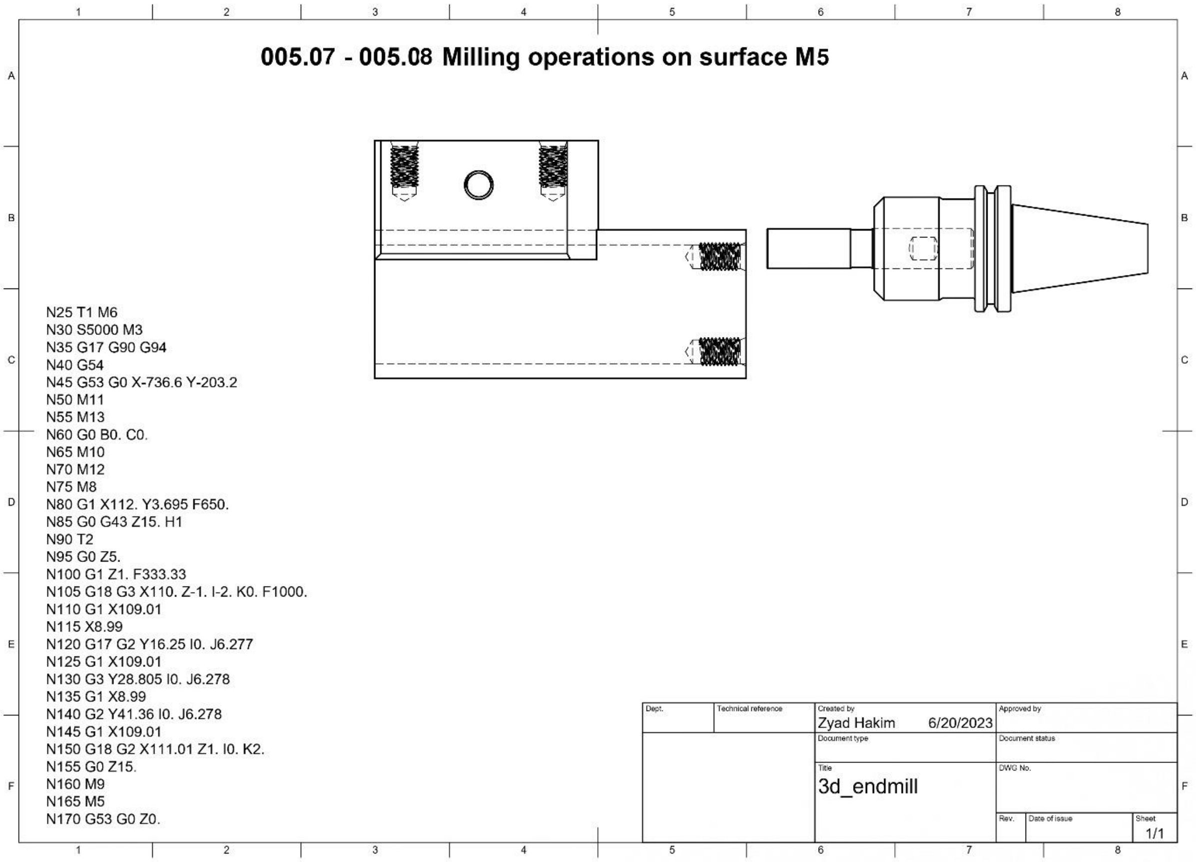

005.07 - 005.08 Milling operations on surface M5

```
N25 T1 M6
N30 S5000 M3
N35 G17 G90 G94
N40 G54
N45 G53 G0 X-736.6 Y-203.2
N50 M11
N55 M13
N60 G0 B0. C0.
N65 M10
N70 M12
N75 M8
N80 G1 X112. Y3.695 F650.
N85 G0 G43 Z15. H1
N90 T2
N95 G0 Z5.
N100 G1 Z1. F333.33
N105 G18 G3 X110. Z-1. I-2. K0. F1000.
N110 G1 X109.01
N115 X8.99
N120 G17 G2 Y16.25 I0. J6.277
N125 G1 X109.01
N130 G3 Y28.805 I0. J6.278
N135 G1 X8.99
N140 G2 Y41.36 I0. J6.278
N145 G1 X109.01
N150 G18 G2 X111.01 Z1. I0. K2.
N155 G0 Z15.
N160 M9
N165 M5
N170 G53 G0 Z0.
```

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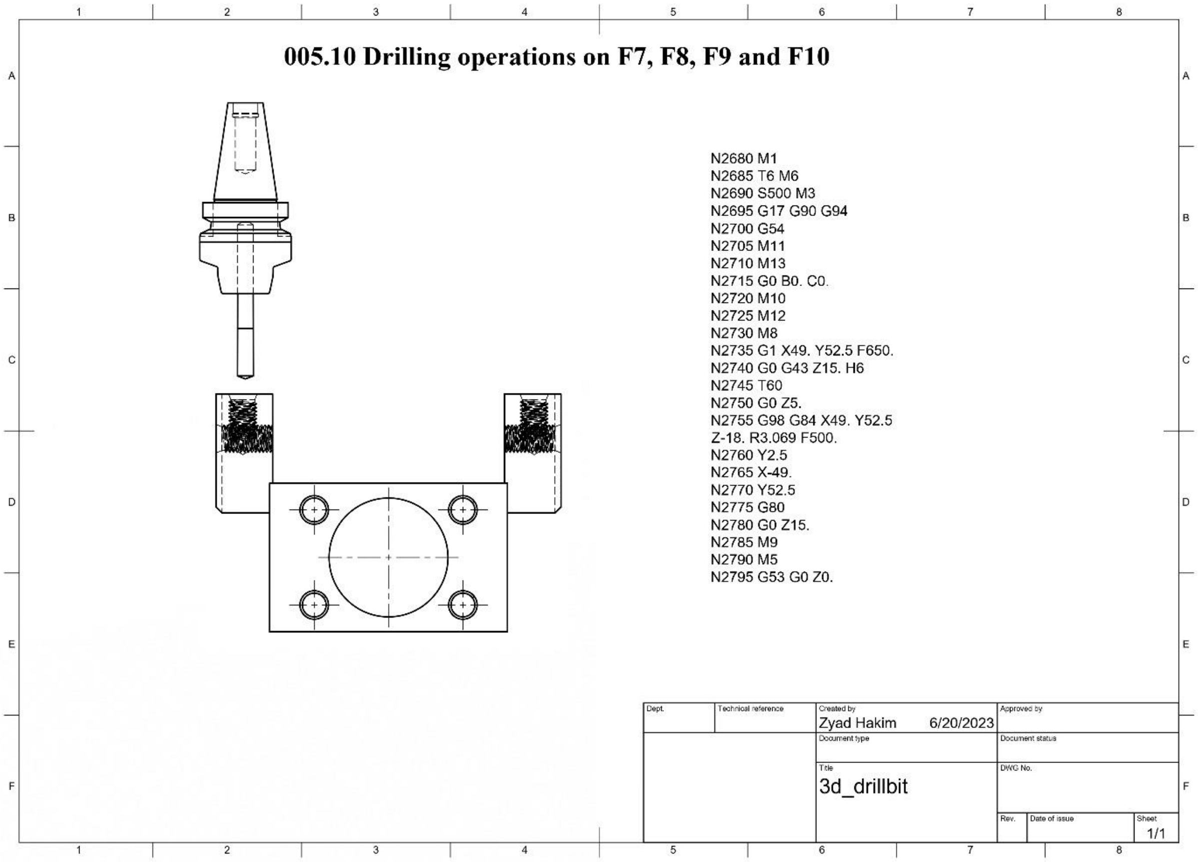

005.10 Drilling operations on F7, F8, F9 and F10

```
N2680 M1
N2685 T6 M6
N2690 S500 M3
N2695 G17 G90 G94
N2700 G54
N2705 M11
N2710 M13
N2715 G0 B0. C0.
N2720 M10
N2725 M12
N2730 M8
N2735 G1 X49. Y52.5 F650.
N2740 G0 G43 Z15. H6
N2745 T60
N2750 G0 Z5.
N2755 G98 G84 X49. Y52.5
Z-18. R3.069 F500.
N2760 Y2.5
N2765 X-49.
N2770 Y52.5
N2775 G80
N2780 G0 Z15.
N2785 M9
N2790 M5
N2795 G53 G0 Z0.
```

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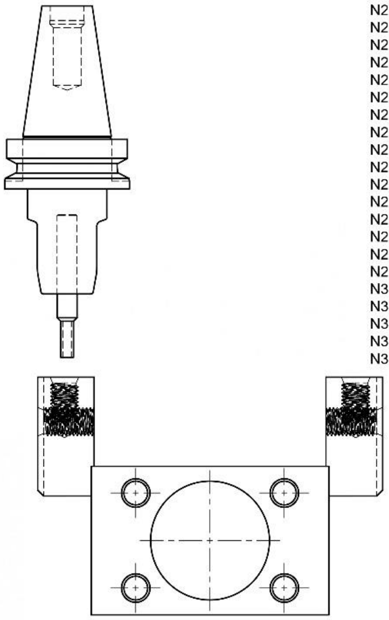
005.12 Tapping operations the holes F7, F8, F9 and F10



```
N2920 M1
N2925 T6 M6
N2930 S500 M3
N2935 G17 G90 G94
N2940 G54
N2945 M11
N2950 M13
N2955 G0 B0. C0.
N2960 M10
N2965 M12
N2970 M8
N2975 G1 X49. Y52.5 F650.
N2980 G0 G43 Z15. H6
N2985 T1
N2990 G0 Z5.
N2995 G98 G84 X49. Y52.5 Z-18. R3.069 F500.
N3000 Y2.5
N3005 X-49.
N3010 Y52.5
N3015 G80
N3020 G0 Z15.
```

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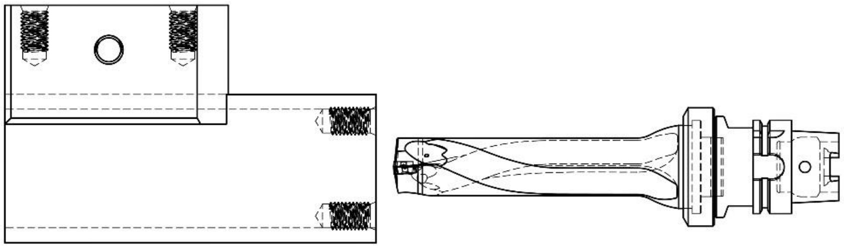
005.20 Drilling the through hole A1



```
N25 T4 M6
N30 S500 M3
N35 G17 G90 G94
N40 G54
N45 G53 G0
X-736.6 Y-203.2
N50 M11
N55 M13
N60 G0 B0. C0.
N65 M10
N70 M12
N75 M8
N80 G1 X59. Y26.
F650.
N85 G0 G43 Z15.
H4
N90 G0 Z5.
N95 G98 G84 X59.
Y26. Z-126. R4.
F2000.
N100 G80
N105 G0 Z15.
```

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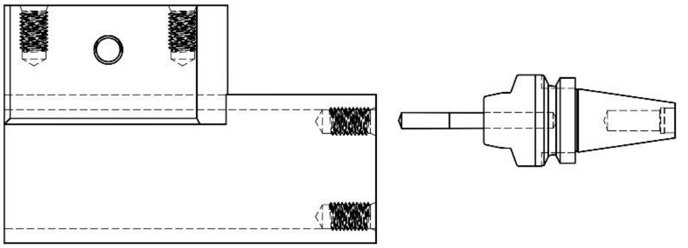
005.23 Drilling operations on F1, F2, F3 and F4



```
N175 M1
N180 T2 M6
N185 S5000 M3
N190 G17 G90 G94
N195 G54
N200 M11
N205 M13
N210 G0 B0. C0.
N215 M10
N220 M12
N225 M8
N230 G1 X84. Y42. F650.
N235 G0 G43 Z15. H2
N240 T60
N245 G0 Z5.
N250 G98 G81 X84. Y42. Z-19. R2.069 F1000.
N255 Y10.
N260 X34.
N265 Y42.
N270 G80
N275 G0 Z15.
N280 M9
N285 M5
N290 G53 G0 Z0.
```

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		Document type	Document status		
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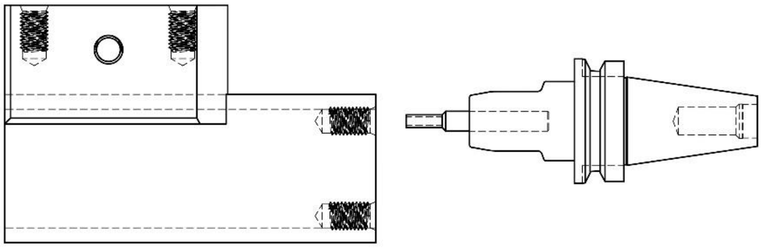
005.25 Tapping operations on holes F1, F2, F3 and F4



```
N415 M1
N420 T3 M6
N425 S500 M3
N430 G17 G90 G94
N435 G54
N440 M11
N445 M13
N450 G0 B0. C0.
N455 M10
N460 M12
N465 M8
N470 G1 X84. Y42. F650.
N475 G0 G43 Z15. H3
N480 T1
N485 G0 Z5.
N490 G98 G84 X84. Y42. Z-19. R2.069 F500.
N495 Y10.
N500 X34.
N505 Y42.
N510 G80
N515 G0 Z15.
```

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Economical Section

5 Manufacturing cost calculations

I- Sand casting Cost estimation

The cost estimation for sand casting involves considering various factors such as material costs, labor expenses, and additional overheads. To determine the approximate cost, mathematical equations are used based on the specific parameters of the sand casting process. By understanding and applying these equations, we can gain valuable insights into the financial aspects of sand casting production. Let's explore the mathematical equations involved in sand casting cost calculation and how they contribute to evaluating the overall manufacturing expenses.

Mathematical equations for calculating sand casting cost:

The total cost of casting the Jaw part is calculated using the following formula:

$$C_{total} = C_{material} + C_{labor} + C_{energy}$$

1. Material cost is calculated using the formula:

$$C_{material} = C_{direct} + C_{indirect}$$

Where: C_{direct} is the direct material cost $= P_{metal} \times W_{cast} \times f_m \times f_p$

And:
P_{metal} = price of the metal used in USD/kg
W_{cast} = weight of the cast part in kg
f_m = metal loss factor during melting (1.01–1.12) *
f_p = metal loss factor during pouring (1.01–1.07) *

$C_{indirect}$ is the indirect material cost $= C_{mold\ sand} + C_{core\ sand} + C_{miscellaneous}$

$C_{mold\ sand}$ is the mold sand mixture (with activator and binder) cost =

$$P_{mold\ sand} \times f_{recycle} \times f_r \times f_{mold\ rej} \times W_{mold\ sand}$$

Where:

$P_{mold\ sand}$ = price of mold sand mixture USD/kg *
$f_{recycle}$ = sand recycling factor (0.1–1.0) *
f_r = casting rejection factor (1–1.12) *
$f_{mold\ rej}$ = mold rejection factor (1–1.10)

$W_{mold\ sand}$ is the weight of sand mold in kg $= \rho_{mold\ sand} \times V_{mold\ sand}$

$\rho_{mold\ sand}$ = mold density in $^{kg}/_{m^3}$
$V_{mold\ sand}$ is the total volume of the mold sand in m^3

$$= V_{flask} - V_{cast} - V_{gating} - V_{feeder} - V_{core}$$

V_{flask} = volume of the flask in m^3
V_{cast} = volume of the Jaw in m^3
V_{gating} = volume of the entire gating system in m^3
V_{feeder} = volume of the feeders in m^3
V_{core} = volume of the core(s) in m^3

$C_{core\ sand}$ is the core sand mixture (with activator and binder) cost

$$= P_{core\ sand} \times f_{recycle} \times f_r \times f_{core\ rej} \times W_{core\ sand}$$

$P_{core\ sand}$ = price of core sand mixture USD/kg *

$W_{core\ sand}$ is the weight of sand core in kg = $\rho_{core\ sand} \times V_{core\ sand}$

$\rho_{mold\ sand}$ = mold density in $^{kg}/_{m^3}$
$V_{mold\ sand}$ is the total volume of the mold sand in m^3
$f_{core\ rej}$ = core rejection factor (1–1.10)

$C_{miscellaneous}$ = miscellaneous materials cost—coatings, lubricants, blasting media, …

2. labor cost is calculated by equation:

$$C_{labor} = C_{labor\ highly\ qualified} + C_{labor\ technical}$$

Where:

$$C_{labor\ highly\ qualified} = f_r \times (\sum m\, f_{design\ rej} \times S_{high\ qualification} \times l_{design\ HQ} \times t_{design})/n_{parts}$$

f_r = factor for casting rejection (depends on the material and the tolerances) (1–1.12) *
m = number of designs
$f_{design\ rej}$ = rejection factor for the design (1–1.2)

$S_{high\ qualification}$ = salary per hour of the highly qualified worker
$l_{design\ HQ}$ = number of highly qualified workers involved in the design
t_{design} = time spent in the design in h
n_{parts} = number of parts produced from the design/activity

$C_{labor\ technical}$ is the technical labour cost

$$= f_r \times (\sum n\, f_{activity\ rej} \times S_{technical} \times l_{activity} \times t_{activity})/n_{parts}$$

$f_{activity\ rej}$ = rejection factor for activity i: $f_{core\ rej}$= 1.0–1.2; $f_{mold\ rej}$= 1.0–1.1;
$f_{activity\ rej}$ = 1 for other activities *
n = number of activities
S_{labor} = salary per hour of the technician
$l_{activity}$ = number of technicians involved in certain activity
$t_{activity}$ = time spent in certain activity in h

3. Energy cost is calculated by:

$$C_{energy} = C_{melting} + C_{holding} + C_{heat\ treatments}$$

where:

$C_{melting}$ is the cost of the melting process $= P_{energy} \times E_{melting} \times W_{metal}/\ {}^{units}/_{batch}$

P_{energy} = price of the energy in USD/kWh

$E_{melting}$ is the energy required by the electric arc furnace for melting the metal in ${}^{kWh}/_{t}$ metal

W_{metal} = weight of metal needed (including 30% extra for the feeder and gating system) in tons

$C_{holding}$ is the cost of holding the material at a certain temperature

$$= P_{energy} \times E_{holding} \times t_{holding}/\ {}^{units}/_{batch}$$

$t_{holding}$ = time that the holding process takes in min

$E_{holding}$ is the energy required to keep the temperature of the melt constant during holding time ${}^{kWh}/_{t}$ per min

$C_{heat\ treatments}$ = the cost of the heat treatments:

$$C_{stress\ relieving} = P_{energy} \times E_{stress\ relieving} / \ {}^{units}/_{batch}$$

$E_{stress\ relieving}$ = the energy required for stress relieving in kWh per batch

$$C_{annealing} = P_{energy} \times E_{annealing} / \ {}^{units}/_{batch}$$

$E_{annealing}$ = the energy required for annealing in kWh per batch

$$C_{preheating\ \&\ cooling} = P_{energy} \times E_{preheating\ \&\ cooling} / \ {}^{units}/_{batch}$$

$E_{preheating\ \&\ cooling}$ = the energy required for preheating and cooling in kWh per batch

$C_{other\ energy}$ = the cost of the other energy used for running the plant

Most of the processes mentioned (melting, holding and HT) produce several parts at the same time while others, such as machining produce individual parts, therefore, the processes that obtain several parts per batch will be divided by the number of parts processed.

II- Machining cost estimation

Machining cost estimation plays a crucial role in evaluating the expenses associated with the machining process. To determine the machining cost, mathematical equations are utilized based on factors like cutting parameters, machining time, tooling costs, and machine utilization. These equations provide valuable insights into the financial implications of machining operations and aid manufacturers in making informed decisions regarding cost optimization strategies. In this section, we will explore the mathematical equations employed in machining cost calculation and their significance in assessing the overall manufacturing costs.

Mathematical equations for calculating machining cost:

The total cost of casting the Jaw part is calculated using the following formula:

$$C_{total} = C_{m\ energy} + C_{m\ labor} + C_{tooling} + C_{overheads}$$

1. The cost of machining energy:
$C_{m\ energy}$ is the energy required for machining the metallic part:

$C_{m\ energy}$ = the cost of the machining process per part

$$= P_{energy} + E_{machining} + t_{machining}$$

$E_{machining}$ = the energy required to machine a part in kWh
$t_{machining}$ = the time required to machine the part in h

2. Machining labor cost formula will be approximately the same as in the casting cost calculation, with few adjustments along the way:

$$C_{labor} = C_{labor\ highly\ qualified} + C_{labor\ technical}$$

3. The cost of tooling is calculated using the Equation:

$$C_{tooling} = C_{updates} + C_{consumables} + C_{maintenance} + C_{machining}$$

where:

$C_{updates}$ = cost of software updates

$$C_{updates} = \sum^{nup} P_{updates}/n_x$$

n_x = number of updates
$P_{updates}$ = price of software updates
n_x = amount of design, machined parts, etc. produced

$C_{consumables}$ = the cost associated to consumables for the use of tooling in USD
$C_{maintenance}$ = the cost of the equipment maintenance in USD
$C_{machining}$ = the cost of machining in USD per part **
** *will depend on surface and dimensional tolerance*.

4. Overheads

The expenses related to overheads will be calculated using formula:

$$C_{overheads} = C_{administration} + C_{depreciation}$$

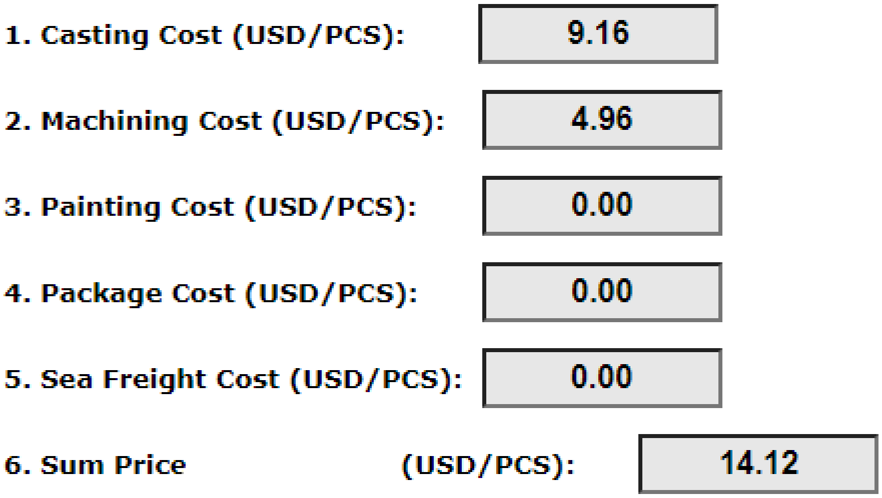
where:

$C_{administration}$ = the administration of the whole business in % of the cast part cost.
$C_{depreciation}$ = the depreciation cost of the entire plant in % of the cast part cost.

Despite reaching out to several companies and manufacturers for assistance, the responses received were limited or non-existent, which further hindered the acquisition of specific cost details. However, to provide a glimpse into the cost estimation process, a screenshot from a cost estimator provided by a reputable foundry in the UK has been included.

It is important to note that these estimations are based on available resources and should be interpreted as general approximations rather than precise figures. The actual costs associated with manufacturing the Jaw part may vary significantly depending on various contextual factors, regional variations, market dynamics, and other unique considerations specific to each manufacturing operation.

While efforts have been made to provide insights into the cost calculations, further research and validation could be of great use to refine and enhance the accuracy and reliability of the estimations within the specific context of the Jaw part manufacturing process.



1. Casting Cost (USD/PCS): 9.16
2. Machining Cost (USD/PCS): 4.96
3. Painting Cost (USD/PCS): 0.00
4. Package Cost (USD/PCS): 0.00
5. Sea Freight Cost (USD/PCS): 0.00
6. Sum Price (USD/PCS): 14.12

Figure 34 – Manufacturing cost estimation

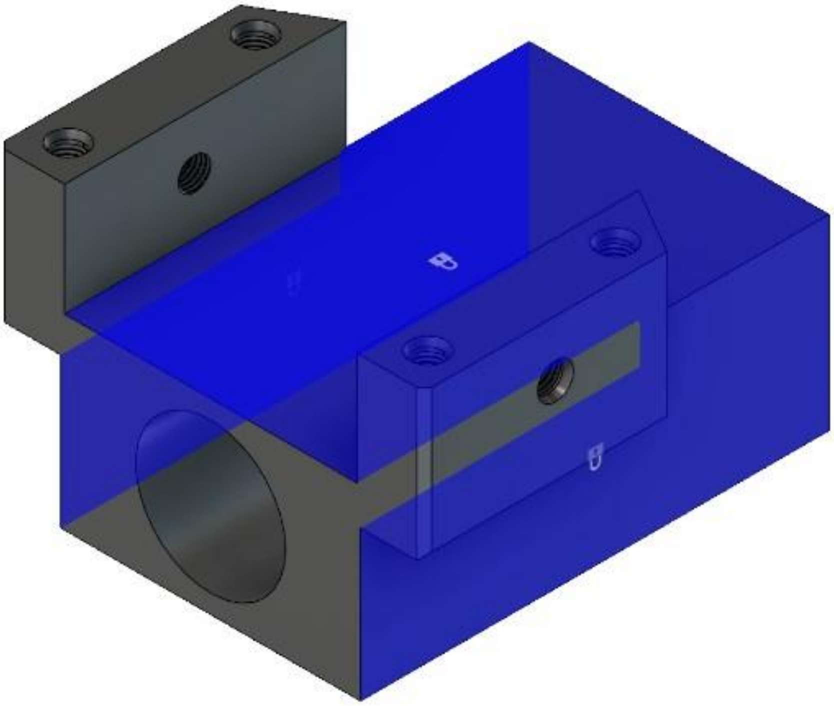
Annex

Static Stress Study Report

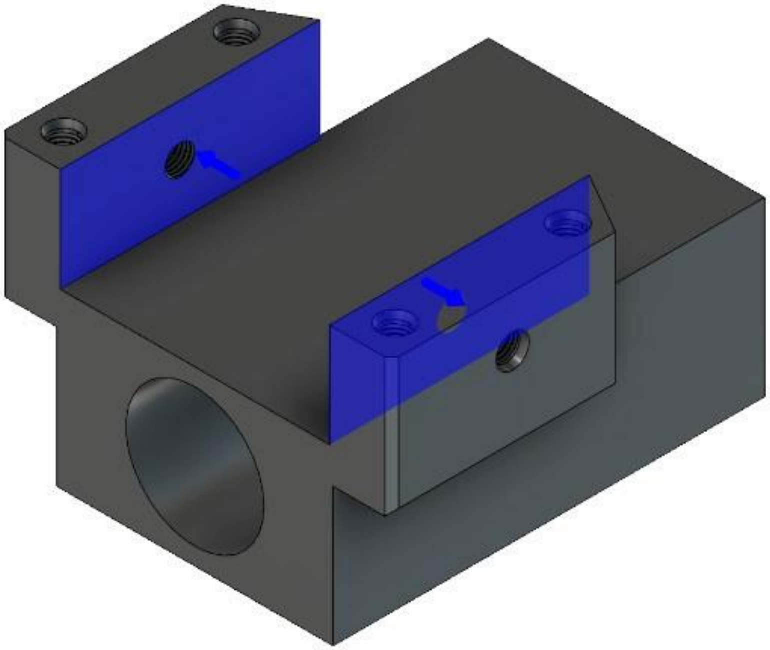
The static stress study was performed on the Jaw workpiece using Fusion 360. The study focused on analyzing the structural behavior and stress distribution of the component.

To ensure accurate analysis, a mesh was created for the study. The average element size for solids was set at 10% of the model size. The mesh elements were ordered as parabolic, and curved mesh elements were generated to capture the geometry accurately. The maximum turn angle on curves was limited to 60 degrees, and the maximum adjacent mesh size ratio was set at 1.5. The maximum aspect ratio was limited to 10 to maintain mesh quality. Additionally, a minimum element size of 20% of the average size was enforced.

The following are figures depicting the surfaces that were fixed to represent the work-holding of the part in the initial Fixture model, as well as surfaces that the simulated forces are applied based on the visual analysis of the part’s geometry.

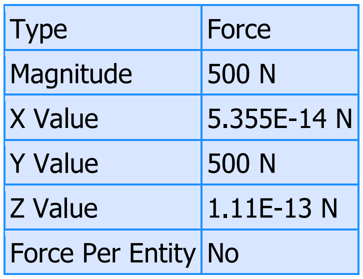


Fixed Surfaces



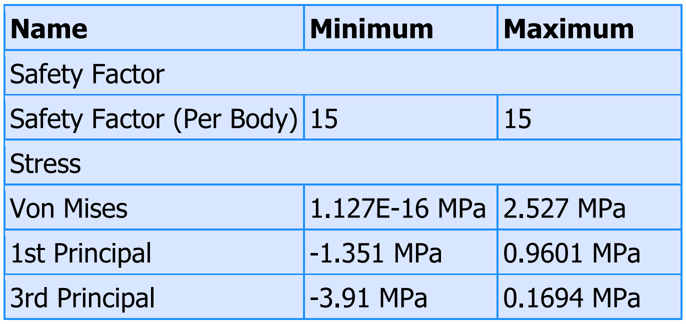
Simulated forces on the surfaces

The simulated loads/forces were as follows:



Type	Force
Magnitude	500 N
X Value	5.355E-14 N
Y Value	500 N
Z Value	1.11E-13 N
Force Per Entity	No

Results:



Name	**Minimum**	**Maximum**
Safety Factor		
Safety Factor (Per Body)	15	15
Stress		
Von Mises	1.127E-16 MPa	2.527 MPa
1st Principal	-1.351 MPa	0.9601 MPa
3rd Principal	-3.91 MPa	0.1694 MPa

Normal XX	-1.513 MPa	0.2955 MPa
Normal YY	-2.9 MPa	0.8582 MPa
Normal ZZ	-2.469 MPa	0.6891 MPa
Shear XY	-0.3812 MPa	0.3747 MPa
Shear YZ	-1.015 MPa	1.312 MPa
Shear ZX	-0.3766 MPa	0.2654 MPa
Displacement		
Total	0 mm	5.601E-04 mm
X	-2.169E-05 mm	1.383E-05 mm
Y	-5.083E-04 mm	5.095E-04 mm
Z	-4.706E-05 mm	2.329E-04 mm
Reaction Force		
Total	0 N	60.51 N
X	-11.92 N	3.597 N
Y	-54.65 N	58.41 N
Z	-18.41 N	17.54 N
Strain		
Equivalent	0	2.023E-05
1st Principal	-3.863E-08	9.783E-06
3rd Principal	-2.276E-05	0
Normal XX	-1.365E-06	1.468E-06
Normal YY	-9.557E-06	3.633E-06
Normal ZZ	-7.5E-06	3.292E-06
Shear XY	-4.72E-06	4.639E-06
Shear YZ	-1.256E-05	1.624E-05
Shear ZX	-4.662E-06	3.286E-06
Contact Force		
Total	0 N	0 N
X	0 N	0 N
Y	0 N	0 N
Z	0 N	0 N

Summary:

The static stress study report provides a summary of the results for the analyzed part. Here is a summary of the key findings:

Safety Factor:

The safety factor for the entire body is consistent at 15, indicating a sufficient margin of safety.

Stress:

The Von Mises stress ranges from 1.127E-16 MPa to 2.527 MPa.
The 1st Principal stress ranges from -1.351 MPa to 0.9601 MPa.
The 3rd Principal stress ranges from -3.91 MPa to 0.1694 MPa.
Normal stresses in the XX, YY, and ZZ directions range from -2.469 MPa to 0.8582 MPa.

Shear:

Shear stresses in the XY, YZ, and ZX directions range from -0.3812 MPa to 1.312 MPa.

Displacement:

Total displacement ranges from 0 mm to 5.601E-04 mm.
Displacement in the X direction ranges from -2.169E-05 mm to 1.383E-05 mm.
Displacement in the Y direction ranges from -5.083E-04 mm to 5.095E-04 mm.
Displacement in the Z direction ranges from -4.706E-05 mm to 2.329E-04 mm.

Reaction Force:

Total reaction force ranges from 0 N to 60.51 N.
Reaction forces in the X direction range from -11.92 N to 3.597 N.
Reaction forces in the Y direction range from -54.65 N to 58.41 N.
Reaction forces in the Z direction range from -18.41 N to 17.54 N.

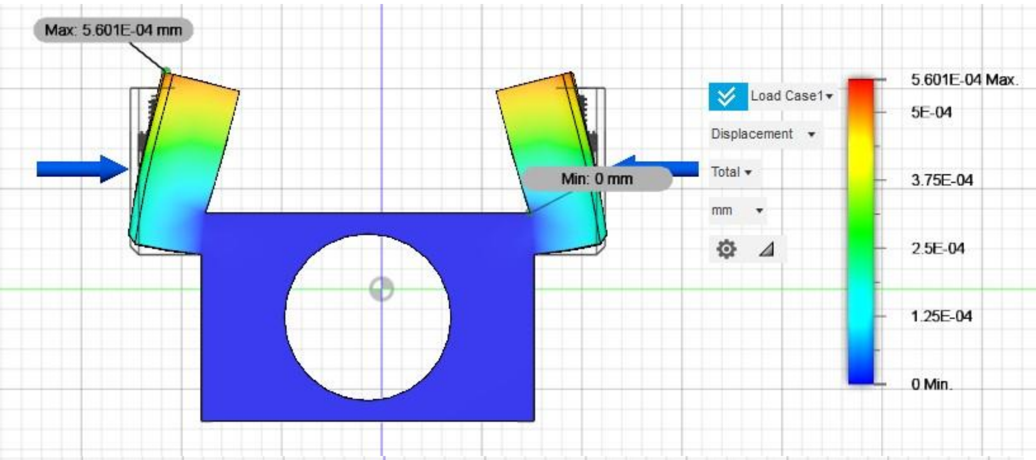
Strain:

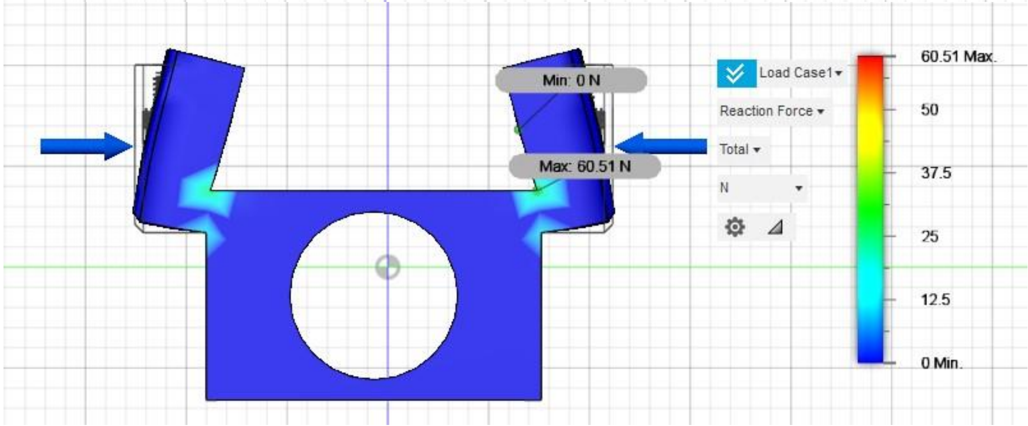
The equivalent strain ranges from 0 to 2.023E-05.
The 1st Principal strain ranges from -3.863E-08 to 9.783E-06.
The 3rd Principal strain ranges from -2.276E-05 to 0.
Normal strains in the XX, YY, and ZZ directions range from -7.5E-06 to 3.633E-06.

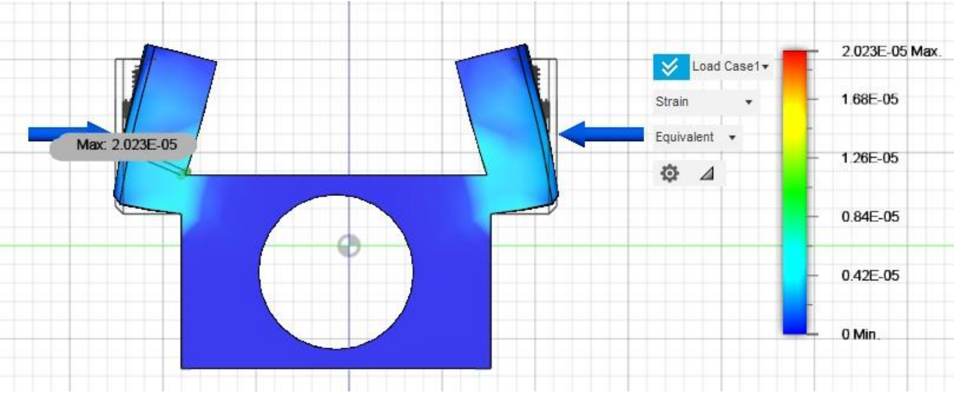
Contact Force:

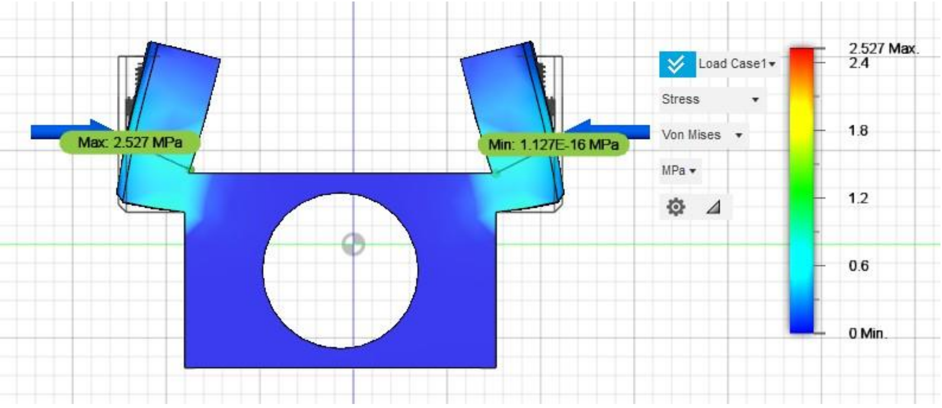
There are no contact forces observed in the analysis.

These results provide insights into the stress distribution, displacements, reaction forces, and strains within the part. They are valuable in evaluating the structural integrity and performance of the analyzed component.


Max: 5.601E-04 mm
Min: 0 mm
Load Case1
Displacement
Total
mm
5.601E-04 Max.
5E-04
3.75E-04
2.5E-04
1.25E-04
0 Min.


Min: 0 N
Max: 60.51 N
Load Case1
Reaction Force
Total
N
60.51 Max.
50
37.5
25
12.5
0 Min.


Max: 2.023E-05
Load Case1
Strain
Equivalent
2.023E-05 Max.
1.68E-05
1.26E-05
0.84E-05
0.42E-05
0 Min.


Max: 2.527 MPa
Min: 1.127E-16 MPa
Load Case1
Stress
Von Mises
MPa
2.527 Max.
2.4
1.8
1.2
0.6
0 Min.

Resources

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