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

EDUCATIONAL AND RESEARCH
INSTITUTE OF MECHANICAL ENGINEERING
Department of Manufacturing Engineering

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Head of the department

____ Oleksandr OKHRIMENKO

"___"_____________2025

Diploma project

for a bachelor's degree

According to the educational and professional program

«Manufacturing Engineering»

In the specialty 131 «Applied mechanics»

on the topic: « Technological preparation of a manufacturing process to produce a part "Bottom plate" »

Developed by:
the student of 4th year of study, group MT-13
Muoneke Kingsley Chinoye ______________ __________
(full name) (signature)

Academic supervisor PhD, associate professor Medvedev Vadym ___ __________
(position, academic degree, academic title, surname and initials) (signature)

Reviewer Ph.D, associate professor Kholavik Olga ________________ __________
(position, academic degree, academic title, surname and initials) (signature)

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

Kyiv – 2025

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

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

APPROVED
Head of the department
_______ Oleksandr OKHRIMENKO
«___»____________2025 р.

ASSIGNMENT
for the diploma project to the student

_______ ______________Muoneke Kingsley Chinoye_______________
(full name)

1. Topic of the diploma project « Technological preparation of a manufacturing process to produce a part “Bottom plate”»

project supervisor Medvedev Vadym, PhD, associate professor
(full name, academic degree, academic title)

approved by the University Order dated 29.05.2025 р. № 1835-с

2. The deadline for the student to submit a diploma project «13» June 2025

3. Initial data for the project:
Drawings of the product “Bottom plate”;
Material: S235JR (A36);
Production Volume: 4000 units per batch

4. The content of the explanatory note, a list of tasks to be developed

Chapter 1. Optimization of the hole boring process
Chapter 2. Manufacturing process planning
Chapter 3: Fixture design
Chapter 4. Economic calculations

5. A list of graphic and illustrative material
- Presentation of the Chapter 1 results: 1 sheet A1
- Drawing of a part and a blank – 1 sheet A1
- Manufacturing operation presentation – 2 sheets A1
- Drawing of the workpiece clamping device – 3 sheet A1
- Presentation of the project – 5-10 PowerPoint slides

6. Consultants for chapters of the project

Chapter	Surname, initials, and position of consultant	Signature, date	
		Issued the task	Accepted the task
1	-	-	-
2			
3			
4			

7. Issue date of the assignment: 19 May 2025

CALENDAR PLAN

No	Stages of the diploma project implementation	The deadline for the stages of the diploma project	Notes
1	Chapter 1. Optimization of the hole boring process	25 May 2025	
2	*Presentation of the Chapter 1 results: 1 sheet A1*	25 May 2025	
3	*Drawing of a part and a blank – 1 sheet A1*	25 May 2025	
4	Chapter 2. Manufacturing process planning	31 May 2025	
5	*Manufacturing Operations Presentation - 2 sheets of A1 Format*	31 May 2025	
6	*Results of NC-program development – 1 sheet A1*	31 May 2025	
7	Chapter 3: Fixture design	7 June 2025	
8	*Drawing of the workpiece clamping device – 1 sheet A1*	7 June 2025	
9	Chapter 4. Economic calculations	10 June 2025	
10	Presentation	10 June 2025	

Student *Muoneke Kingsley CHINOYE*

Supervisor *Vadym MEDVEDEV*

Abstract

This thesis presents the development of a comprehensive manufacturing process plan for a Bottom Plate component used in stamping die assemblies. From the choice of raw materials to the last surface grinding step, the study covers every crucial facet of production.

The Bottom Plate's geometry, purpose, and production requirements are examined. Its dimensions are 530 × 400 × 75 mm. A proposed process path includes surface grinding, CNC milling, radial drilling, and vertical milling. Dimensional information, surface finish specifications, and the proper cutting tools are used to support each machining process.

To guarantee repeatable accuracy during CNC machining, special attention is paid to the fixture and clamping system design. For the best workpiece location, a hydraulic clamping arrangement with diamond and cylindrical locating pins was chosen (presented theoretically). Tool life, torque, and spindle speed are adjusted to the material properties of carbon steel 3 while cutting parameters and forces are computed empirically.

Additionally, established economic models are used to generate estimates of machining time and cost. The outcomes attest to the suggested procedure's cost-effectiveness and technical viability. In the framework of contemporary process planning for precision metal components, this work illustrates the combination of CAD modeling, empirical computations, and fixture design.

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CHAPTER 1

1.1 Analysis of the Purpose and Operating Conditions of the Bottom Plate in the Assembly Unit Introduction

This study focuses on the design and manufacturing properties of the Bottom Plate, a form of prismatic part. Classifying the part according to its function and physical characteristics, assessing its material qualities, identifying characteristics that can impair production efficiency, and identifying the best manufacturing practices are the objectives of this analysis.

It is crucial to comprehend these elements to make sure the component satisfies performance, durability, as well as affordability. After describing the part's categorization and planned use, the report evaluates its material type, chemical makeup, and physical characteristics, including density and linear shrinkage. The report concludes by outlining the relevant manufacturing procedures and analyzing how design elements affect production choices.

1.1.2 Analysis of the Part's Working Conditions in the Assembly Unit

One essential part of a die used in cold sheet metal stamping is the bottom plate. Forming, bending, and cutting the Support Base part are all steps in the sequential stamping process. The entire stamping system is built to operate on a press that can exert over 80 tons of force (Ghosh & Mallik, 1986), guaranteeing the consistent transformation of sheet metal during automated production. This plate, as well as additional normalized parts such as the top plate, bottom plate, guide bushings, and guide columns, contributes to the die structure. In particular, the bottom plate acts as the die's basis and supports its functioning components. Its reference surface is a portion of its surface that is attached to the press. Another is utilized for the functional parts of the stamping tool.

The bottom plate remains stationary throughout the press operation, but the top plate, which is connected to the press slide, moves up and down to drive the punch and permits the sequential stamping operations.

The bottom plate features slots that are 25 mm wide and are intended to be fastened to the press using M24 screws. These grooves serve as positioning guides and can also be used to replace the bolt heads with T-slot nuts or specially designed clamps.

The Ø45H7 holes for connecting guide columns allow the upper and lower sides of the die to be perfectly aligned. Die installation is made easier because the punch is already calibrated concerning the matrix. After being inserted into the upper plate, the guide sleeves move smoothly along these columns.
Additionally, two Ø12H7 holes are used to locate the holder (basing), and eight Ø13 mm holes are used to secure it to the lower plate.

A 12 x 30 mm and two 14 x 20 mm grooves are used to remove debris from the cutting (falling) region.

The plate can be transferred, usually with lifting bolts, using the four M16–7N threaded holes provided. extra holes on the die assembly allow for the installation of extra functional components.

(Description provided above is based on the Supervisor's Example on the analysis and working conditions of the Bottom plate in the assembly unit)

A sketch of the "Bottom Plate" portion is shown in Figure 1.1.

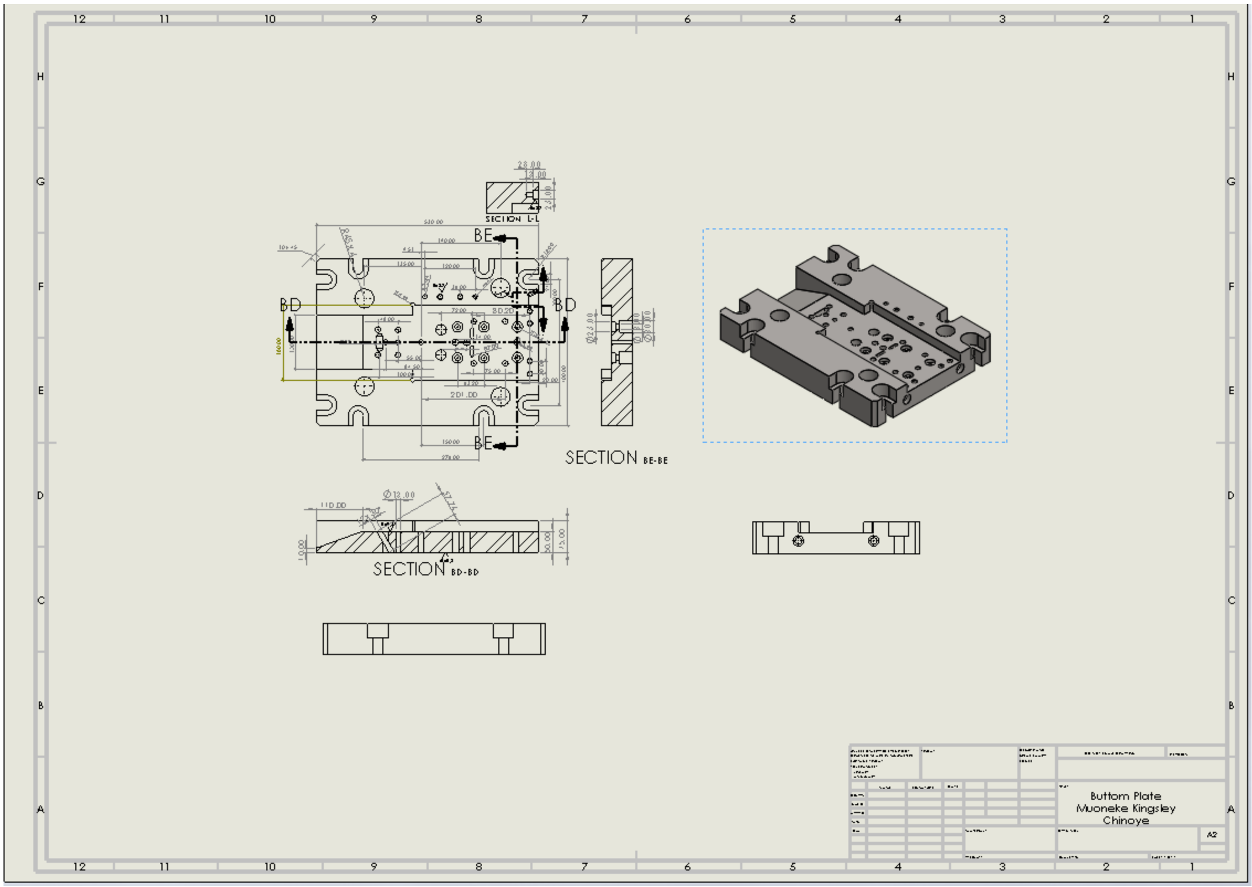


Fig.1

1.1.3 Analysis of the Material

The Bottom Plate is structurally made of **Carbon Steel – Steel 3 (Ст3)**, classified as a **low-carbon steel** under the standard **GOST 380-94**. In CAD-based selection systems, it is typically referred to as **Plain Carbon Steel**.

Chemical Composition *(Reference: Modulus Metal – **AISI 1030 Carbon Steel Chemical Composition**)*:

Element	Percentage (%)
C	0.20
Si	0.07
Mn	0.50
Cr	0.30
S	0.05
P	0.04
Cu	0.30
Ni	0.30
As	0.08
Fe	Balance

Material Model Name: Ст 3 ГОСТ 380-94
CAD Material Name: Plain Carbon Steel
Density: 0.01 g/mm³
Mass of the Part: 91660.40 g
Physical and Mechanical Properties:

- **Density**: 0.01 g/mm³
- **Yield Strength** (σ^{T}): 215 MPa
- **Ultimate Tensile Strength** (σ^{B}): 460 MPa
- **Linear Shrinkage**: 1.5–2%

(citations: https://www.modulusmetal.com/aisi-1030-carbon-steel-chemical-composition/)

1.1.4 Machinability

Carbon Steel – Steel 3 (Ст3 ГОСТ 380-94), with a **Brinell Hardness of HB 124** and a **yield strength of approximately 400 MPa** in hot-rolled form, offers **good machinability** characteristics under standard manufacturing conditions.

Machinability Coefficients:

- With **carbide tools**: $K_{vt \cdot sp} = 1.8$
- With **high-speed steel (HSS)** tools: $K_{v\beta \cdot st} = 1.6$

These values indicate that Ст3 is well-suited for machining operations such as **turning, drilling, and milling**.

Machining Recommendations:

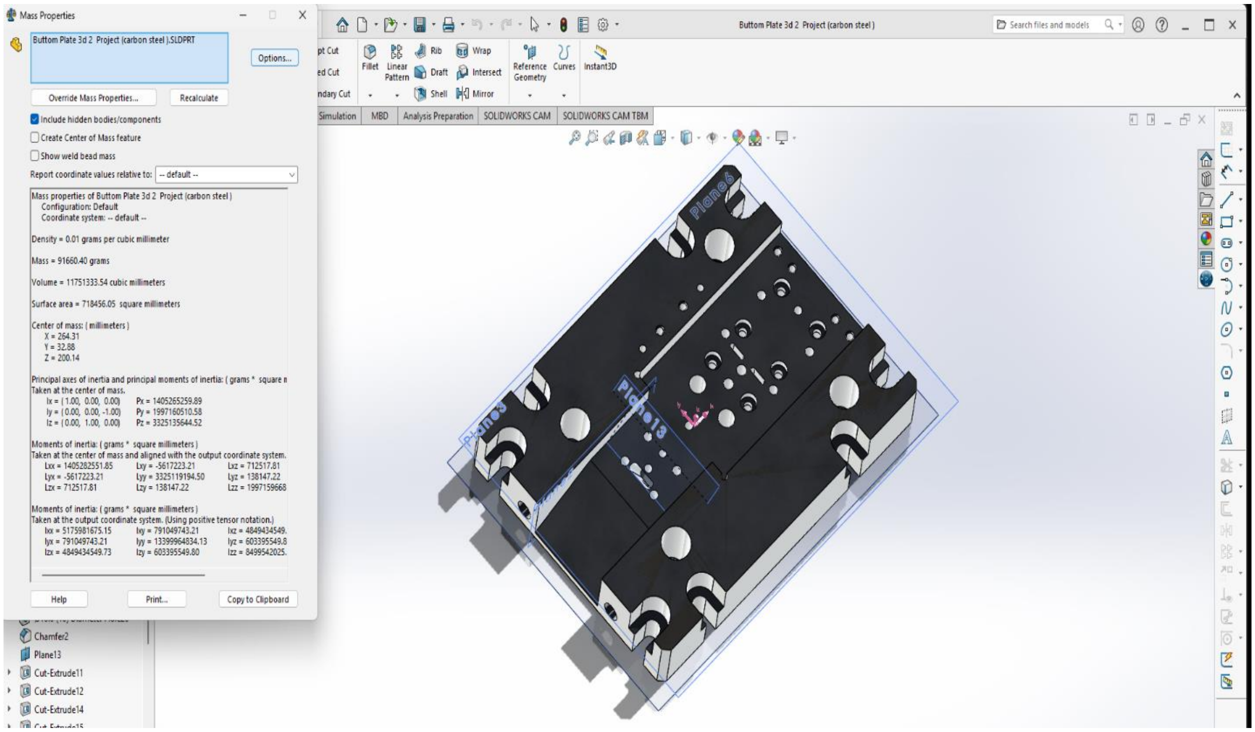
- **Tool Material**: Prefer **carbide tools** for enhanced tool life and productivity.
- **Coolant**: Use appropriate **cutting fluid** to reduce heat and improve surface finish.
- **Cutting Conditions**: Employ **moderate feed rates and speeds**, especially when using HSS tools to minimize tool wear.

Citation:

Modulus Metal. *Chemical composition and properties of AISI 1030 carbon steel*. Retrieved from: https://www.modulusmetal.com/aisi-1030-carbon-steel-chemical-composition/

Retrieved from: https://www.modulusmetal.com/aisi-1030-carbon-steel-chemical-composition/

Figure 1.2 shows some Material Properties based on the CAD design of this model



1.2 Determining the Production Type

For the Bottom Plate, the Medium Production volume is selected, given the large mass (91.66 kg) and size of the bottom plate density – 0.01 grams per cubic millimeter),
Batch production will likely be the most suitable choice for medium-volume production. And a Production Type is suggested based on the table below,

Production Type Table
Figure

Weight of a part, kg	Type of production				
	Single	Small batch	Medium batch	High volume batch	Mass
> 5.0 .. 10.0	< 10	10 .. 300	300 .. 25000	25000 .. 50000	>50000

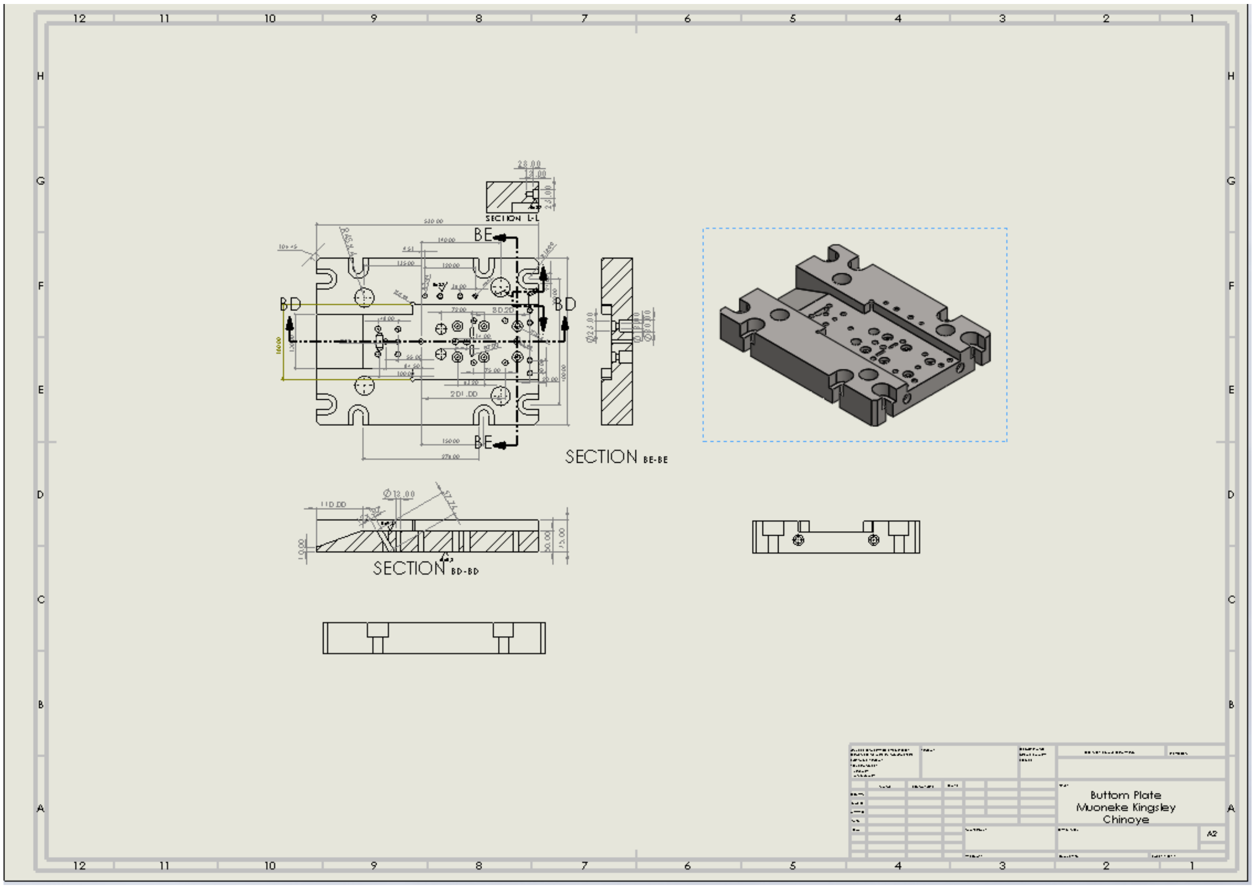
Alternatives Bottom Plate Production types based on Conditions and requirements

If **Precision and Complexi**ty are key, CNC machining is highly recommended, but high precision

- If the shape is suitable for molding and you're focused on optimization of cost at medium volume, die casting could be considered.
- For simpler geometries in sheet metal, stamping is also an efficient recommendation

Production Quantity: 25000 (based on the table used)
Conclusion. For medium-volume production, batch production using CNC machining, die casting, or stamping would likely provide the right balance of flexibility, cost, and efficiency.

1.3 Design of the Blank Figure 1.3



This section outlines the engineering decisions behind the blank design for the Bottom Plate, focusing on material selection, forming method, blank dimensions, manufacturing readiness, and the required process route.

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1. Material Selection

Chosen Material: Carbon Steel 3 (Ст3 ГОСТ 380-94)

The selection of Carbon Steel 3 ensures a balance of machinability, structural strength, and cost-efficiency, making it suitable for medium-volume manufacturing of structural components such as the bottom plate.

Mechanical Properties:

- **Yield Strength:** ~215 MPa
  → Prevents permanent deformation under load.

- **Tensile Strength:** ~460 MPa
  → Maintains structural integrity under applied stress.
- **Hardness:** ~124 HB
  → Provides moderate wear resistance without compromising machinability.

Physical Properties:

- **Density:** ~7.85 g/cm^3
  → Adds mass and stability during machine operation.
- **Thermal Conductivity:** ~50 W/m·K
  → Supports heat dissipation during machining, reducing distortion.

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2. Selection of Blank Type and Base Form

According to the process structure that will later be introduced in sections 1.5 and 1.6 (the process structure and route will be explained in detail in the following sections), the forming method must be compatible with the geometry and production needs of the bottom plate.

- **Part Dimensions:** 530 mm × 400 mm × 75 mm
- **Selected Forming Process:** Hot Rolling

Why Hot Rolling?

- Easily produces flat plates of large thickness.
- 75 mm thick hot-rolled plates are commercially available (tolerance table is present in , which shows tolerance and allowance for all Processes).
- Reduces reliance on casting or forging.
- Simplifies procurement and provides a consistent, machineable structure.

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3. Blank Dimensions, Geometry, and Tolerances

- **Initial Blank Geometry:** Flat, rectangular solid.
- **Features:** No internal machining (groves/holes) is present at this stage.
- **Final Machined Size:** 530 × 400 × 75 mm

- **Workpiece Dimensions Before Machining (more details about dimensions in section 1.3, table 2,3):**
    - Length: 533 mm
    - Width: 403 mm
    - Height: 78 mm

Machining Allowances:

- Based on analytical calculation methods
- Allowances are applied per surface to account for surface defects, roughness, and final tolerance.

Rolling Tolerances (per EN 10051 standard):

- **Thickness Tolerance (75 mm):** ±3.5 mm (Class B or C)
- **Width Tolerance:** ±10 mm
- **Length Tolerance:** ±15 mm

These tolerances ensure the rolled blank remains within machinable limits before final finishing.

Note: The current thesis does not go into detail on hot rolling diagrams or deformation physics, as these vary by rolling mill and standard.

Dimensional Matrix –
Dimension Matrix gives the linear dimensions of the workpiece and is denoted using l for linear dimensions, d – diameter, and f- chamfers. More details are explained in section 1.5 for Processing routes

Table 1

Category	Dimension No.	Value (mm)

Length (l)	l1	400
Length (l)	l2	530
Length (l)	l3	13
Length (l)	l4	28
Length (l)	l5	230
Length (l)	l6	130
Length (l)	l7	180
Length (l)	l8	110
Length (l)	l9	10
Length (l)	l10	24
Length (l)	l11	37
Length (l)	l14	30
Length (l)	l15	20
Length (l)	l16	12
Length (l)	l17	30
Length (l)	l19	34
Length (l)	l20	14
Length (l)	l21	10
Length (l)	l25	20
Length (l)	l26	32
Length (l)	l27	20
Length (l)	l29	75
Length (l)	l30	50-0.1
Length (l)	l33	35
Length (l)	l34	25
Diameter (d)	d1	25
Diameter (d)	d3	45H7

Diameter (d)	d4	12
Diameter (d)	d5	10
Diameter (d)	d6	25
Diameter (d)	d7	15

Diameter (d)	d8	13
Diameter (d)	d9	13
Diameter (d)	d10	12
Diameter (d)	d11	13
Diameter (d)	d13	10
Diameter (d)	d15	25
Diameter (d)	d19	20
Diameter (d)	d20	30
Diameter (d)	d21	20
Threaded Feature	M1	M16-7N
Threaded Feature	M2	M10-7N
Threaded Feature	M3	-
Threaded Feature	f1	10×45°
Threaded Feature	f2	1×45°
Threaded Feature	f3	1.6×45°

4. Manufacturing Readiness and Secondary Operations

The rolled blank provides a strong starting point for subsequent machining operations. These operations will be discussed in detail in section 1.5 **Design of the Typical Surface Processing Routes (Table)**. Specific machining operations are also linked to section 1.5,1.6 of this thesis, where full process steps are presented.

Determination of Allowance and Tolerance Treatment for a Part
Both functional requirements and empirical machining data are used to support the dimensional tolerances allocated to the machined and blank features. To ensure that the final tolerance of 6 µm (from 75.00 to 74.94 mm) complies with IT8 criteria, a progressive reduction in material allowance is performed for the main surface (75 mm), from rough milling to surface grinding. For stamping die assembly, this guarantees correct base alignment and contact fit.

The manufacturing process for holes like Ø45H7 consists of drilling, boring, countersinking, and final reaming. This results in a tolerance band of 25 µm (45.000–45.025 mm), which is in line with ISO H7 class. Tolerance stack-up principles and machining process capacity have been used to analytically verify the cumulative allowances (ΔΣ) and consequent size restrictions in Tables A and B. The tolerance method is both economically and functionally viable for the bottom plate design since the values meet the machining standards and surface roughness grades specified by GOST 25346-89 and ISO 286.

Table 2
Table A - Allowance Calculation for Surface 75 mm

Operation Step	Grade	Rz (µm)	Ey (µm)	ΔΣ (µm)	Zmin (µm)	Tolerance (µm)	Size Max (mm)	Size Min (mm)
Stock	-	400	400	1486.61	-	-	82.6	82.6
Rough Milling	13	125	120	2366.61	89.2	80	76.53	76.13
Semi-finish Milling	12	32	50	472.2	4.46	140	75.66	75.46
Finish Milling	10	10	15	226.46	0.18	140	75.23	75.11
Grinding	8	5	10	105.05	0.05	90	75.00	74.94

Table 3

Table B - Determination of allowances by analytical method for 45H7+0.025 mm

Table B - Allowance Calculation for Hole Ø45H7

Operation Step	Grade	Rz (μm)	Ey (μm)	ΔΣ (μm)	Zmin (μm)	Tolerance (μm)	Size Max (mm)	Size Min (mm)
Drilling	12	63	80	-	71.98	80	43.5	25
Boring	10	50	70	501.2	60.47	80	44.16	44.00
Countersinking	9	40	40	440.6	2.42	80	44.68	44.62
Reaming Ø45H7	7	3.2	5	320.1	0.07	80	45.025	45.00

Machining Allowance and Tolerance: For determining the Model tolerance and allowance
Table 4

No.	Part Size (mm)	Tolerance (mm)	Allowance (mm)	Machining Allowance	(mm)Workpiece Size (mm)
1	400	8.0	+5.3/-2.7	+4.3/+4.3	408.6
2	530	8.0	+5.3/-2.7	+4.7/+4.7	539.4
3	130	5.6	+3.7/-1.9	-3.5/-3.5	123.0
4	230	6.3	+4.2/-2.1	+4.7/+4.3	239.0
5	180	6.3	+4.2/-2.1	-3.8/-3.8	172.4
6	110	5.6	+3.7/-1.9	+4.7/+0	114.7
7	10	4.5	+3/-1.5	+3.5/+3.5	17.3
8	50-0.1	5.0	+3.3/-1.7	+3.8/+3.5	57.3
9	75	5.0	+3.3/-1.7	+3.8/+3.8	82.6

10	135	5.6	+3.7/-1.9	+4.3/+3.5	142.8
11	110	5.6	+3.7/-1.9	+4.3/+3.8	118.1

1.4 Locating the Workpiece During the Manufacturing Process

To guarantee dimensional precision and geometric consistency throughout all machining operations, precise and repeatable workpiece positioning is crucial in process planning and fixture design. The primary objective of a locating system, as stated by Peter Scallan in Process Planning: The Design/Manufacture Interface, is to limit a workpiece's six degrees of freedom (three translational and three rotational) while it is being processed.

Operation 010 – Vertical Milling: A vice is used to locate the part, which is sitting on its lower plane. Two rotational and three translational degrees of freedom are constrained by this configuration. Firm clamping removes the last degree of freedom.

Operation 020 – CNC Vertical Milling: The portion is based on the lower plane inside a CNC fixture, just like operation 010. The fixture's design eliminates the remaining degrees of freedom, guaranteeing complete positional restriction when cutting.

Operation 015 – Radial Drilling: The part is located against three surfaces—the bottom and two adjacent vertical sides. This configuration eliminates all six degrees of freedom and enables accurate hole placement. To keep the part in this state during the drilling cycle, mechanical grips are used to clamp it.

Operation 030 – Vertical Milling: In this operation, the part is installed on locating fingers (cylindrical and relieved pins) and located using the bottom plane and precision holes. When paired with mechanized grips, this arrangement provides exceptional repeatability and the total elimination of all degrees of freedom during machining.

Operation 035 – Radial Drilling: Once more, precision pins (fingers) identify the bore holes and support the part on the lower plane, and automated grips restrain it.

1.4.1 Alternative Locating Principles

Locating the scheme selection based on the manufacturing datum (MD)

The general algorithm of substantiation of manufacturing datum (MD) includes two stages:
- Rationale for the choice of general manufacturing datum (GMD)
- Rationale for the choice of manufacturing datum for the first manufacturing operations

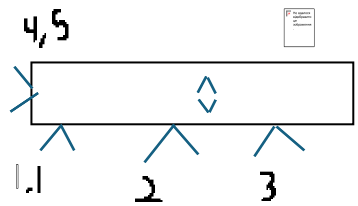
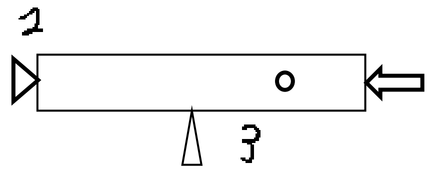
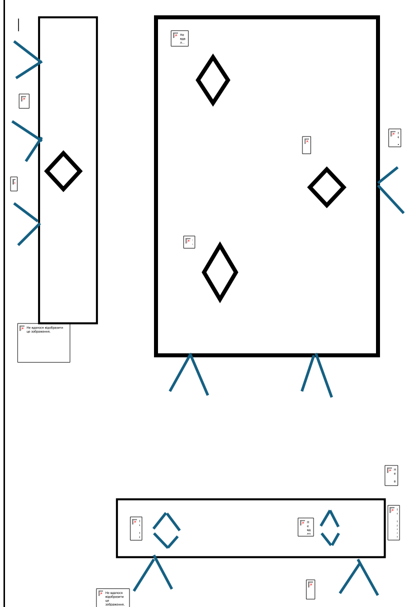
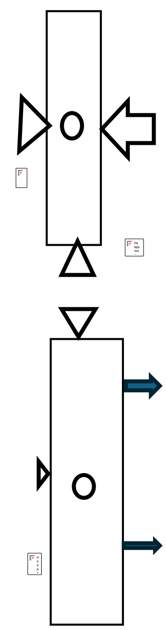
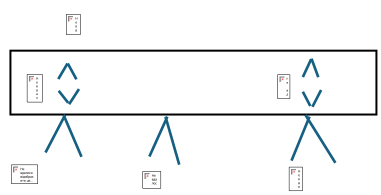
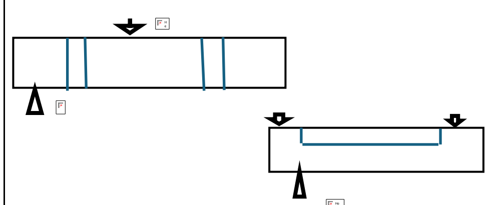
1.4.1 Rationale for the choice of general manufacturing datum
General manufacturing datum (GMD) is a set of datum surfaces that can be

used to perform all operations of the manufacturing process or most of it.
The initial data to justify the choice of GMD are the working drawing of the part. To solve the problems of the first stage, it is necessary to classify the surfaces
of the part for their intended purpose.
The design of any part can be represented as a set of four types of surfaces:
1. Main functional (design) datum
2. Auxiliary functional (design) datum
3. Fastening surfaces
4. Free surfaces

The formula for the locating scheme is presented as follows:
LSGMD =>S(3) +DS (2)+ O(1),
where S (3) – setting datum, deprives the workpiece of 3 degrees of freedom, DS (2) – double support datum, deprives the workpiece of 2 degrees of freedom, and O (1) – support datum, deprives the workpiece of 1 degree of freedom.

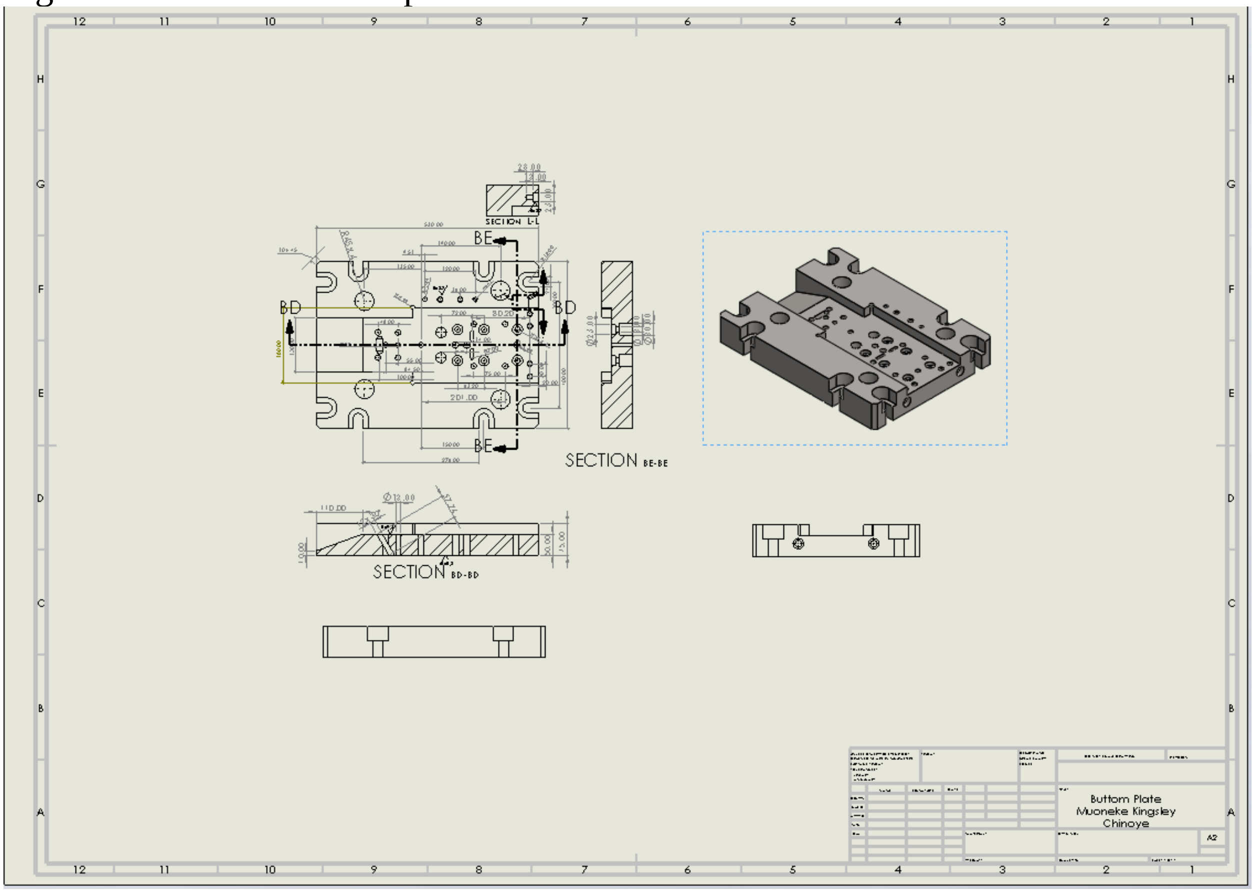
The table below depicts the locating scheme used for the Bottom Plate, Table 5

Operation code	Locating scheme	Installation diagram

010 Vertical Milling 020 CNC vertical Milling		
015 Radial Drilling		
025 Vertical Milling with CNC, 030 Vertical Milling, 035 Radial Drilling		

1.5 **Design of the typical surface processing routes (table)**

Fig of Solidworks Bottom plate



In manufacturing engineering, the process route represents the structured sequence of technological operations required to transform a raw blank into a finished part. It defines the order of machining operations and the specific surfaces involved, while considering applicable tolerances and allowances, the machines used, and the parameters maintained throughout the manufacturing process.
A well-developed process route ensures efficiency, precision, and repeatability in production.

This section presents a **technological process route for the Bottom Plate**
Before the processing route is introduced shortly, a dimensional matrix is introduced, which holds the diameter, chamfer, and length of this model
(This section presents a dimensions matrix that's helpful, specifically developed for the Bottom Plate. Before detailing the process steps, the part is introduced as a *complex prismatic component* — a type that typically involves intricate geometric features and precise dimensional requirements.

dimensional matrix Form1, Fig x1 from section 1.3

Introduction to the Dimensional Matrix and Technological (Operational) Process Table

The dimensional matrix plays a critical role in process planning by enabling engineers to compare key geometric and functional features of a part. In this project, the dimensional matrix, typically presented in the Table below, lists essential parameters such as overall dimensions (length = y1, y2, etc.), hole diameters (d1, d2, …), threaded features (M1, M2), and chamfers (f1, f2). These parameters are used to identify linear parts that are being processed in the dimensional process route

Dimensional Matrix -

Category Length	Dimension No.	Value (mm)
1	l1	400
2	l2	530
3	l3	13
4	l4	28
5	l5	230
6	l6	130
7	l7	180
8	l8	110
9	l9	10
10	l10	24
11	l11	37
12	l14	30
13	l15	20
14	l16	12

15	l17	30
16	l19	34
17	l20	14
18	l21	10
19	l25	20
20	l26	32
21	l27	20
22	l29	75
23	l30	50-0.1
24	l33	35
25	l34	25
Diameter (d)	d1	25
Diameter	d3	45H7
Diameter	d4	12
Diameter	d5	10
Diameter	d6	25
Diameter	d7	15
Diameter	d8	13
Diameter	d9	13
Diameter	d10	12
Diameter	d11	13
Diameter	d13	10
Diameter	d15	25
Diameter	d19	20
Diameter	d20	30
Diameter	d21	20

Threaded Feature	M1	M16-7N
Threaded Feature	M2	M10-7N
Threaded Feature	M3	-
Threaded Feature	f1	10×45°
Threaded Feature	f2	1×45°
Threaded Feature	f3	1.6×45°

Dimensional matrix table 2 or Operational Process table
This Dimensional matrix involves the Process codes alongside the dimensions that would be machined

Operation Codes Matched to Dimensions - Bottom Plate, Table 6

Operation Code	Operation	Dimension No.	Bottom P
010	Vertical Milling	l1, l2, l6, l7, l8, l30, l33, l34	+
015	Radial Drilling	d1, d6, d15	+
020	CNC Vertical Milling	l3, l4, l5, l10, l11, l14, l15, l16, l17, l20, l21, l25, l26, l27	+
025	CNC Vertical Milling	d3	+
030	Radial Drilling	d8, d9, d10, d11, d13, d19, d20, d21	+
035	Surface Grinding	Face 2	+

For Clarity: when considering Process 010, vertical milling, we can see the dimension list, and when we cross-check with the dimensional matrix from section 1.3, we can confirm the exact linear dimensions

- **Linear and feature dimensions** (e.g., **y1, y2, y3** referred to as length on the table DMT)
- Hole diameters (e.g., d1, d2, d3, …)
- Threaded holes (e.g., M1, M2, M3)

- Chamfers and bevels (e.g., f1, f2, …)

The Technological Process Route Table

The technological Process Route Table shows the sequential process and steps taken in machining the bottom plate. Also, defines the necessary geometric and feature-based specifications of the Bottom Plate and the Process carried out concerning its dimensions. This construction integrates key surface and dimensional elements found in the Bottom Plate. It includes:

Table 7

Operation Code	Operation Name	Machine	Tools Used	Surfaces Machined	Controlled Parameters	Steps / Description	Function / Purpose	Before Machining (Allowance / Tolerance)	After Machining (Final Tolerance Achieved)
005	Procurement / Blank Preparation	—	—	—	Initial blank: 530 mm × 400 mm × 75 mm; Carbon Steel 3; machining allowance included	Prepare and inspect the blank; confirm the material and dimensions	Provides machinable stock material	Machining allowance per surface (see Tables 2.3–2.5)	Prepared a blank with nominal dimensions for all surfaces
010	Vertical Milling	Vertical Milling Machine, Model 6A56	End Mill, Caliper	1, 3, 4, 2, 5, 6	y1 = 400 mm (surface 4), y2 = 530 mm (surface 6), Chamfer f1	Mill datum surfaces; Maintain key dimensions; Apply chamfers	Establishes datums and dimensional limits	Allowance ~+3.8 mm; Tolerance: ±0.1 mm on y1, y2	y1 = 400 mm ±0.1 mm; y2 = 530 mm ±0.1 mm; chamfer 15×45° ±0.1°
015	Radial Drilling	Radial Drilling	Twist drills, Tap,	Holes d1, Thread	d1, M1, f2	Drill and tap holes;	Forms functional and	Allowance ~+2 mm;	d1: Ø45H7;

		Machine, Model 2554	Countersink	M1, Chamfer f2		Chamfer edges	fastening features	Thread M1: 6H fit; Chamfer ±0.1 mm	Thread M1: ISO metric; Chamfer f2 = 1×45°
020	CNC Vertical Milling (1)	CNC Milling Machine, Model 6560 MF3	Drills, Reamer, End/Face Mill, Countersink	Surface 7, Surface 8, Grooves, Holes d3–d5	d3–d5, f4; Precise surface creation (7, 8); Grooves	Precision machining of faces and holes; Apply chamfers	Refines and defines critical geometry	Allowance ~+2.5 mm on precision surfaces; f4: ±0.05 mm	d3–d5: Ø14H7; Chamfer f4: 1×45° ±0.05°; Smooth surface 7, 8
025	CNC Vertical Milling (2)	CNC Milling Machine, Model 6560 MF3	Drills, Taps, Countersink, Spot facer	Grooves, Holes d6–d16, Threads M2, Chamfers f3	d6–d16, M2, f3	Finish hole drilling, slotting, threading, and countersinking	Completes secondary holes, threads, and grooves	Threads M2: 6H; Hole diameters d6–d16: H7; Allowance ~2 mm	d6–d16: Ø13H7; M2: M12×1.75-6H; f3 = 1×45° ±0.1°
030	Radial Drill Press Operation	Vertical Milling Machine, Model 6A56	End Mill, Caliper	Slot d17 (depth l23)	Slot depth l23	Cut slot d17 to a specific depth	Creates a central slot feature	Slot d17 rough cut; Tolerance: ±0.2 mm depth	Slot d17: 12 mm wide × l23 deep ±0.2 mm
035	Surface Grinding (Flat Grinding)	Radial Drilling Machine, Model 2554	Twist drills, Tap, Countersink, Spot facer	Threads M3, Chamfers f5, Holes d2, d18–d21	d2, d18–d21, M3, f5	Thread holes, chamfer, and spot-face as needed	Final threaded holes and finishing touches	Thread M3: 6H; Holes H7; Chamfers ±0.1 mm	Thread M3: M10×1.5-6H; d18–d21: Ø12H7; Chamfer f5 = 1×45°

Section 1.6 – Design of the Operational Manufacturing Process Plan

This section describes the sequential flow of activities from procurement to finishing and describes the detailed manufacturing procedures needed to make the Bottom Plate component. The processes are predicated on the specific machining methods, machine kinds, and cutting instruments needed to generate the necessary features and dimensions.
It also highlights the equipment and tools required, and how the item is strategically machined at each step. Ensuring that each surface and feature on the part is manufactured with the proper accuracy, finish, and order is the aim.

Preparing the Blank and First Setup Procurement 005
The part begins as a raw carbon steel blank (Ст3), which is obtained from the hot rolling Process, also known as Procurements in Operation code 005, and other operations are listed below

In the Following Processes, the Type III Vernier Calliper is recommended, which complies with GOST 166-89 (the USSR/Russian standard for mechanical calipers), has a 0–500 mm range, and a 0.05 mm resolution.

1. 005 Procurement.
2. 010 Vertical milling.
3. 015 Radial drilling
4. 020 CNC vertical milling machine.
5. 025 Vertical milling machine with CNC.
6. 030 Vertical milling
7. 035 Radial drilling
8. 040 Surface grinding
9. 045 Surface grinding.

Operation 005: Procurement (Hot Rolling)
Purpose: Preparation of the blank out of carbon steel that is 530x400x75 mm in size
Process: Hot rolling is used to get the blank to a rough size so that it can be machined further.

Considerations: Allowance is made for future milling; surface scale may still be present (allowance and hot rolling of specific dimensions are dependent on the manufacturer's standard or the User`s)

010 Vertical milling.

Equipment: vertical milling machine model 6A56.

Equipment: special device.

Tool: end mill.

Measuring tool: Type III Vernier Calliper, 0–500 mm range, 0.05 mm resolution, GOST 166–89

A. Place and remove the workpiece.
    1. Mill the surface 1 beforehand.
    2. Mill the surface 1 completely.
    3. Mill surface 3.
    4. Mill surface 4, ensuring dimension l1.

B. Place the workpiece.
    5. Mill surface 2 beforehand.
    6. Mill the surface 2 completely.
    7. Mill surface 5.
    8. Mill surface 6, ensuring dimension L2.
    9. . Mill 4 chamfers f1.

015 Radial drilling.

Equipment: radial drilling machine model 2554.

Equipment: special device.

Tools: twist drills, taps, countersinks.

Measuring tool: Type III Vernier Calliper, 0–500 mm range, 0.05 mm resolution, GOST 166–89.

A. Place and remove the workpiece.

1. Drill 2 holes d1 to a depth of l3.
2. Countersink 2 chamfers f2
3. Drill 2 holes for the M1 thread; 4. Cut the M1 thread to a depth of l4

B. Place the workpiece.
5. Drill 2 holes d1 to a depth of l3.
6. Countersink 2 chamfers f2
7. Drill 2 holes for the M1 thread
8. Cut the M1 thread to a depth of l4

020 CNC vertical milling machine.

Equipment: CNC vertical milling machine model 6560MF3.
Equipment: special device.
Tools: spiral drills, countersink, reamer, milling cutters, countersink
Measuring tools: Type III Vernier Calliper, 0–500 mm range, 0.05 mm resolution, GOST 166–89, plug gauges.

A. Place and remove the workpiece.
1. Drill 4 holes d3.
2. Ream 4 holes d3
3. Countersink 4 holes d3.
4. Ream 4 holes d3
5. Countersink 4 chamfers f4.
6. Drill d4.
7. Drill 2 holesd5 to a depth of l34.
8. Mill surface 7 preliminarily, maintaining dimensions l5, l6, l7
9. Mill surface 7 finally
10. Fine milling of surface 7, ensuring dimension l30 + allowance for further processing.
11. Mill surface 8 at an angle l, ensuring dimensions l8, l9.
12. Mill 4 grooves, ensuring dimensions l10, l11.
13. Mill 4 grooves, ensuring dimensions l12, l13, r1, l33.

025 Vertical milling machine with CNC.

Equipment: CNC vertical milling machine model 6560MF3; special attachment.
Tools: twist drills, taps, countersinks, end mills, reamers, countersinking, countersinks.
Measuring tools: Type III Vernier Calliper, 0–500 mm range, 0.05 mm resolution, GOST 166–89, plug gauges.

A. Place and remove the workpiece.

1. Drill 2 holes d6.
2. Drill 2 holes d7
3. Drill 8 holes d8.
4. Drill 4 holes d9
5. Drill 3 holes d10
6. Drill 3 holes d10.
7. Countersink 3 holes d10
8. Ream 3 holes d10
9. Drill 4 holes d11.
10. Drill 6 holes d12
11. Drill 16 holes, d13.
12. Ream 16 holes d13 to a depth of l14.
13. Drill 22 holes for the M2 thread.
14. Countersink 22 chamfers f3.
15. Cut the M2 thread to a depth of l15.
16. Drill 3 holes for the grooves.
17. Drill 4 holes d14 for the groove.
18. Mill the groove l16xl17.
19. Mill 2 grooves l19xl20 with an angle l2.
20. Countersink 8 holes d15 to a depth of l21
21. Countersink 4 holes d16 to a depth of l22.

030 Vertical milling
Equipment: vertical milling machine model 6A56
Equipment: special device.
Tool: end mill.
Measuring tool: calliper ShTs-I-200-0.05 GOST 166-89.

1. Mill the groove

035 Radial drilling
Equipment: radial drilling machine model 2554
Equipment: special device
Tools: spiral drills, tap, countersink, countersink
Measuring tools: calliper ShTs-II-125-0.05 GOST 166-89.

A. Place and remove the workpiece.

1. Drill 4 holes
-Countersink 4 chamfers f5
-Cut the thread
-Countersink 2 holes
-Countersink 4 holes d19 to a depth of l25
-Countersink 8 holes d20 to a depth of l26
-Countersink 4 holes d21 to a depth of l27
-Countersink 4 holes

040 Surface grinding
Equipment: surface grinding machine model 3D725
Equipment: magnetic plate 7208-0055 GOST 17519-87
Tool: Circle K300x100x203 ST GOST 2424-83
Measuring tool: calliper ShTs-II-125-0.05 GOST 166-89
A. Place and remove the workpiece.
1. Grind surface 1.

045 Surface grinding.
Equipment: surface grinding machine model 3D725
Equipment: magnetic plate 7208-0055 GOST 17519-87
Tool: Circle K 300x100x203 ST GOST 2424-83
Measuring tool: calliper ShTs-II-125-0.05 GOST 166-89

A. Place and remove the workpiece.
1. Grind surface 2 to ensure size l29.

Manufacturing/ Machining Operations and Operations involved

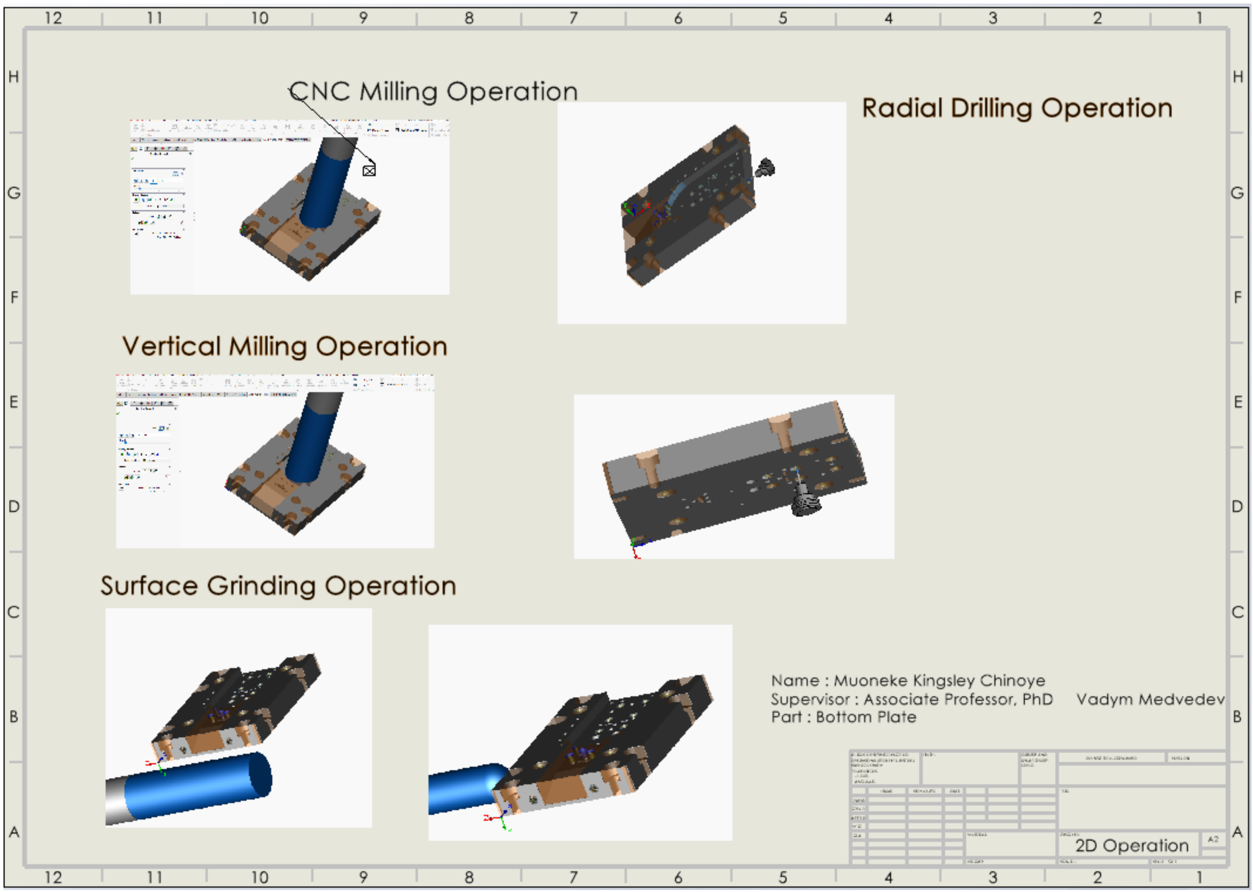


Fig.3

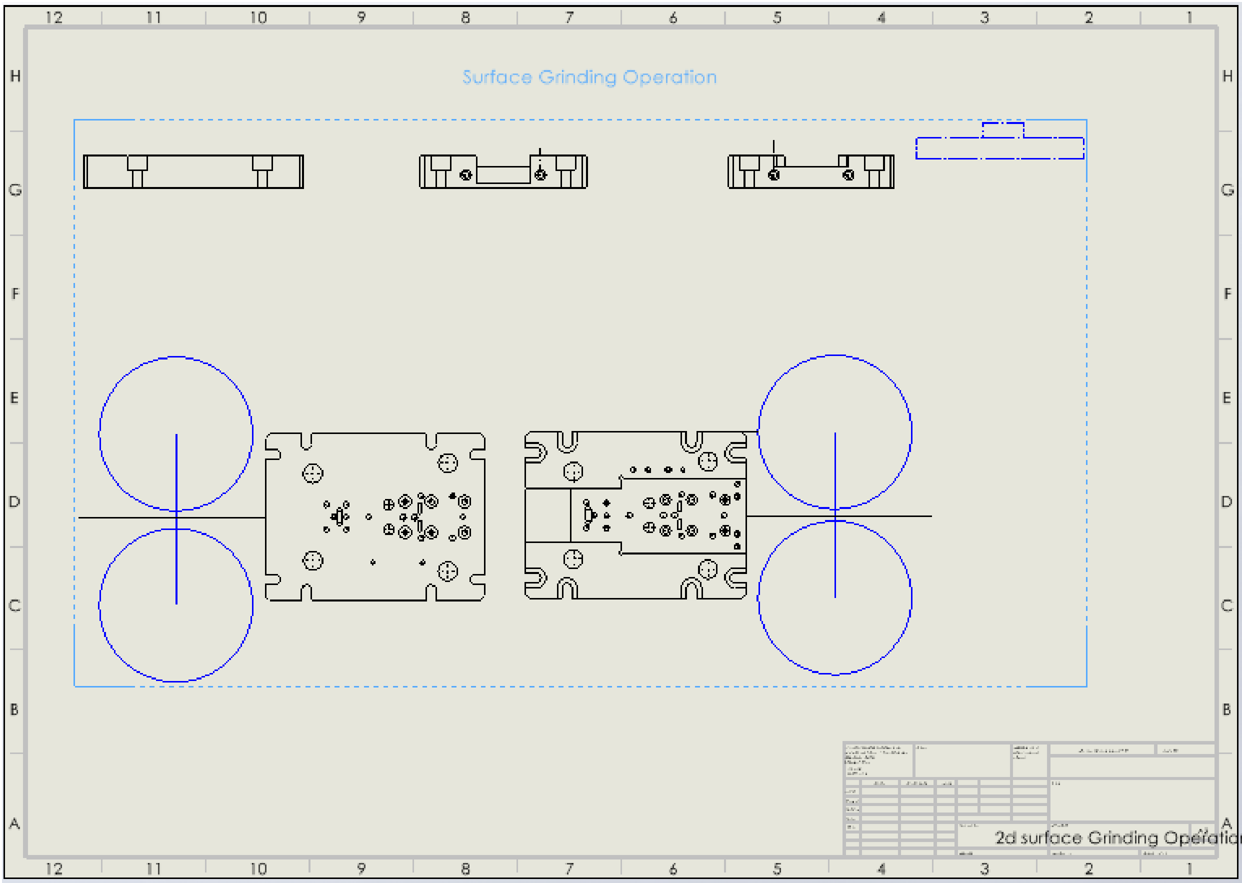


Fig.4

The Figure tries to illustrate the Surface Grinding Operation 035 (based of 2d sketch)

Surface Description

1.7 Short Description of Manufacturing Equipment

This section introduces the primary machines and tools used in the manufacturing of the Bottom Plate, based on the design and process route from sections 1.3 and 1.5 of this bachelor's Thesis. Each machine is responsible for specific operations necessary for shaping, drilling, and finishing the part.
But first, we begin with the classification of the equipment used in this bachelor's Thesis, based on Peter Scallan`s method of classification, to give an introductory overview

Peter Scallan's Model – Machining Resource Categories

Peter Scallan (in *Process Planning: The Design/Manufacture Interface*) generally classifies machine resources into the following:

Tool Classification and **Machining Classification**
We would be considering only cases in tool classification that correspond to this Bachelor Thesis, already selected Processes (covered in section 1.5, Processing Route table). The following classifications are as follows

1. Tools: Consumable tools
2. Work holding or durable tools

1. Consumable Tools
These are worn-out tools that are frequently changed. They have a direct hand in material cutting, molding, or finishing.

Drilling holes with twist or spiral drills (Ops 015, 020, 025, 030, 035)

For rough and final milling (Ops 010, 020, 025, 030), end mills and milling cutters are used.

Taps: used for internal thread cutting (Ops 015, 035)

Reamers: to enhance tolerance and finish holes (Ops 020, 035)

To chamfer the edges of holes, use countersinks (Ops 015, 020, 030, 035).
For fine surface grinding, a K 300x100x203 ST grinding wheel is utilized (Ops 035, 045).

2. **Work holding or durable tools**

During machining, these tools are used to hold and place the workpiece securely. They are reused throughout operations and are not consumed during the process.

Various milling and drilling operations (Ops 010, 015, 020, 025, 030) use a special fixture or clamping device.

The item is held firmly during surface grinding by a magnetic plate (Model 7208-0055) (Ops 035, 045).

Associated Measuring Tools
These tools are crucial for dimensional control, even if they are neither cutting nor clamping equipment:

example: Vernier calipers (GOST 166-89, ShTs-I, ShTs-II, and ShTs-III).

Factors in the Selection of Machine Equipment

1. Based on machines' physical size, construction, and power, these in turn will be factors in determining the speeds and feeds available and the maximum depth of cut the machine is capable of.

2. The number and type of tools available for production equipment are under consideration.

3. Machining Accuracy: Machining within the dimensional requirement (Peter Scallan´s Process planning)

Technological operations and recommended tools shaping/forming,
Before the manufacturing and machining take place, which involves abrasion, a form of material removal, the first approach is the selection of Hot Rolling, using rolling mills.
Hot rolling was selected to obtain the 75mm height and a 530mm (length obtained through further processing), (for more understanding on rolling operation see Goetsch, 1991, chapter 4 of Peter Scallan´s Process Planning) which is part of **casting, shaping/forming, machining, joining, and surface processes.**

Machining Equipment
Three categories of machining techniques exist: cutting, abrasive, and non-traditional procedures.
Tools involved:

- Twist drills, spiral drills
- End mills, milling cutters
- Taps, countersinks, reamers

(For a more detailed explanation, see Peter Scallan`s Process Planning)

1. CNC Vertical Milling Machine (Operation 020 & 025)

The CNC vertical milling machine (model 6560MF3) plays a critical role in operations 020 and 025, handling complex milling and drilling tasks on surface 7 and other detailed areas. It is equipped with tools such as spiral drills, countersinks, reamers, milling cutters, and special devices. Key tasks include:

- Drilling, reaming, and countersinking multiple hole patterns (e.g., d3, d4, d5)
- Pre and final milling of surface 7 while maintaining dimensions like l5 to l30
- Milling angled surfaces (e.g., surface 8 at angle ÿ)
- Machining grooves with precise dimensions (l10–l13, r1, l33)

Measuring tools used: ShTs-I-125-0.05 and ShTs-III-250-800-0.05 (GOST 166-89), plug gauges.

2. Conventional Vertical Milling Machine (Operation 010 & 030)

A conventional vertical milling machine (model 6A56) is applied during operations 010 and 030. This machine is intended for initial and intermediate surface preparation, such as:

- Milling surfaces 1, 2, and 3 completely
- Machining the groove d17 to depth l23

Tools: end mills and measuring devices like ShTs-I-200-0.05 and ShTs-I-125-0.05 calipers per GOST 166-89. It is often operated with a special device for stable clamping.

3. Radial Drilling Machine (Operation 015 & 035)

The radial drilling machine (model 2554) is responsible for creating a wide variety of holes across multiple surfaces. Used in operations 015 and 035, this machine supports:

- Drilling holes of various diameters (e.g., d6–d21)
- Tapping and countersinking M2 and M3 threads
- Milling grooves of different geometries and angles

Tools: twist drills, taps, countersinks, reamers. Measuring: calipers (ShTs-II-125-0.05, GOST 166-89) and plug gauges. A special clamping device is used for securing large plates.

4. Surface Grinding Machine (Operation 035)

For the final finishing stages (operation 035), a surface grinding machine (model 3D725) is used in combination with a magnetic plate (model 7208-0055, GOST 17519-87). This setup ensures precise flatness and surface finish for surfaces 1 and 2.
Grinding is done using a K 300x100x203 ST wheel (GOST 2424-83), with a dimensional precision verified using caliper ShTs-II-125-0.05 (GOST 166-89).

Fig.5

(for illustration purposes of a type of vertical milling machine, source: http://twentywheels.com/view/9266-2000_haas_vf___3_cnc_vertical_milling_machine.html)

Set Up for CNC Machine Tool

In operation 020, a CNC vertical milling machine is used to machine T-grooves on the bottom plate. Accurate T-slot formation requires precise control over cutting settings and tool trajectories, which CNC machining provides in contrast to manual procedures. Tight dimensional tolerances and homogeneity are necessary for these slots, which are used as locating or clamping channels in machine bases and fixtures.

Setup for the Machine
A CNC vertical milling machine with an automated tool changer (ATC) is utilized for this task. After a first slotting operation with a normal end mill, a T-slot cutter (also called a T-slot end mill) is used.

Common characteristics of CNC machines:

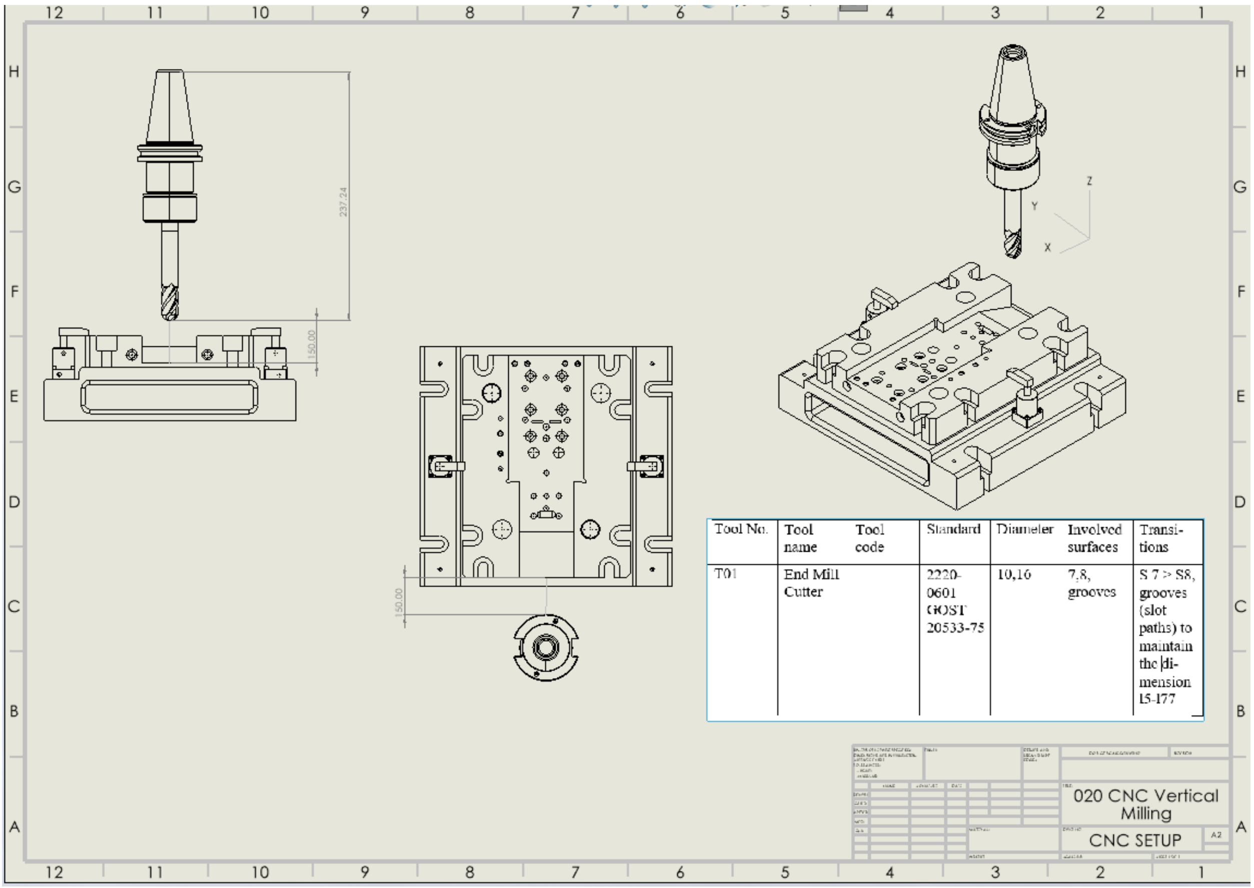
Controlling the spindle speed allows for different cutting speeds.

Feed rates that can be adjusted for reliable material removal

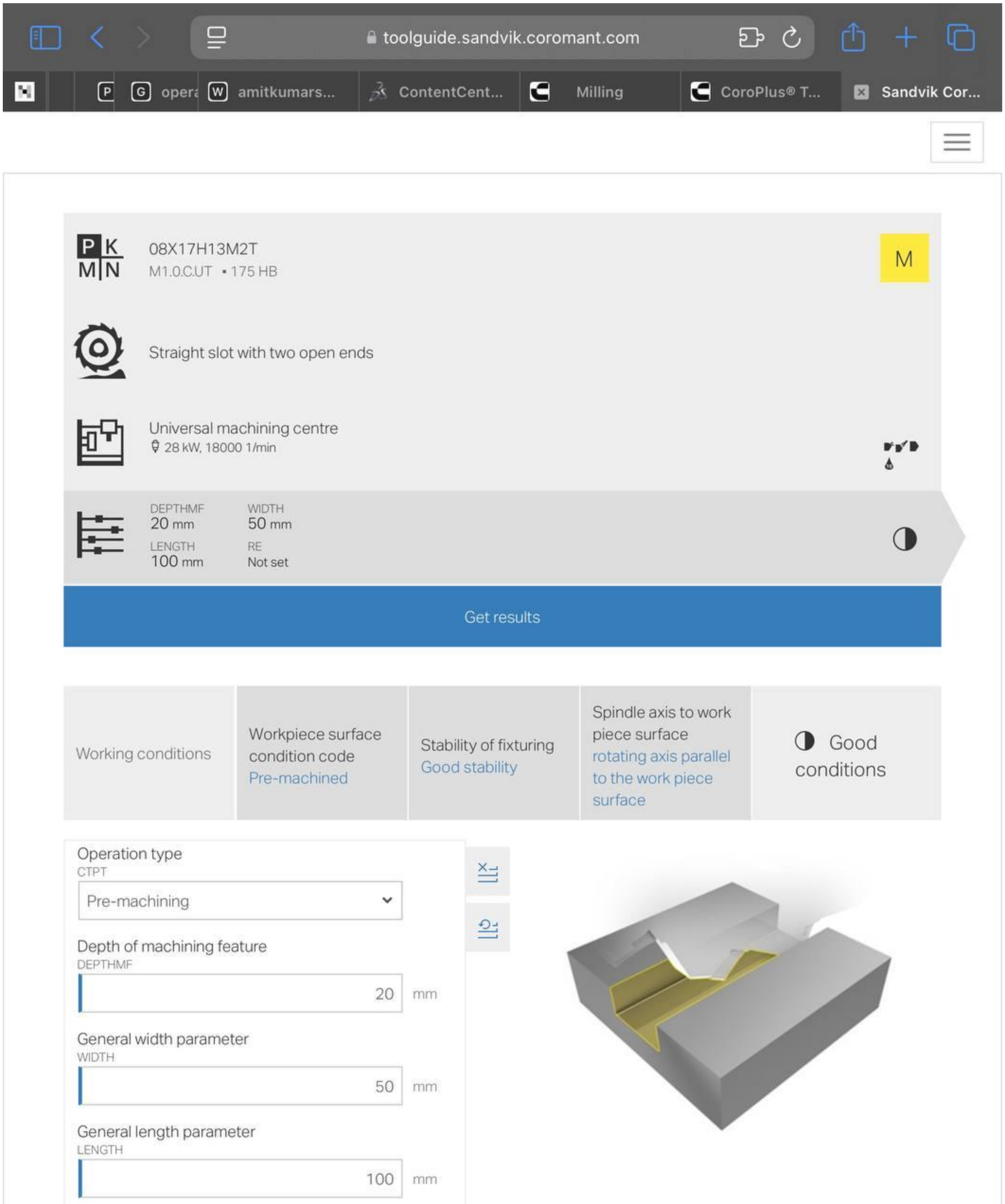
Tool placement with high accuracy (±0.01 mm)

Three-axis control to ensure accurate slot geometry

Note: For Simulation Purposes, the Sandvik Cormorant tool Guide website was conducted and also used in the selection and revision for endmill (https://www.sandvik.coromant.com/en-gb/tools/coroplus-toolguide)



Tool No.	Tool name	Tool code	Standard	Diameter	Involved surfaces	Transi-tions
T01	End Mill Cutter		2220-0601 GOST 20533-75	10,16	7,8, grooves	S 7 > S8, grooves (slot paths) to maintain the di-mension l5-l77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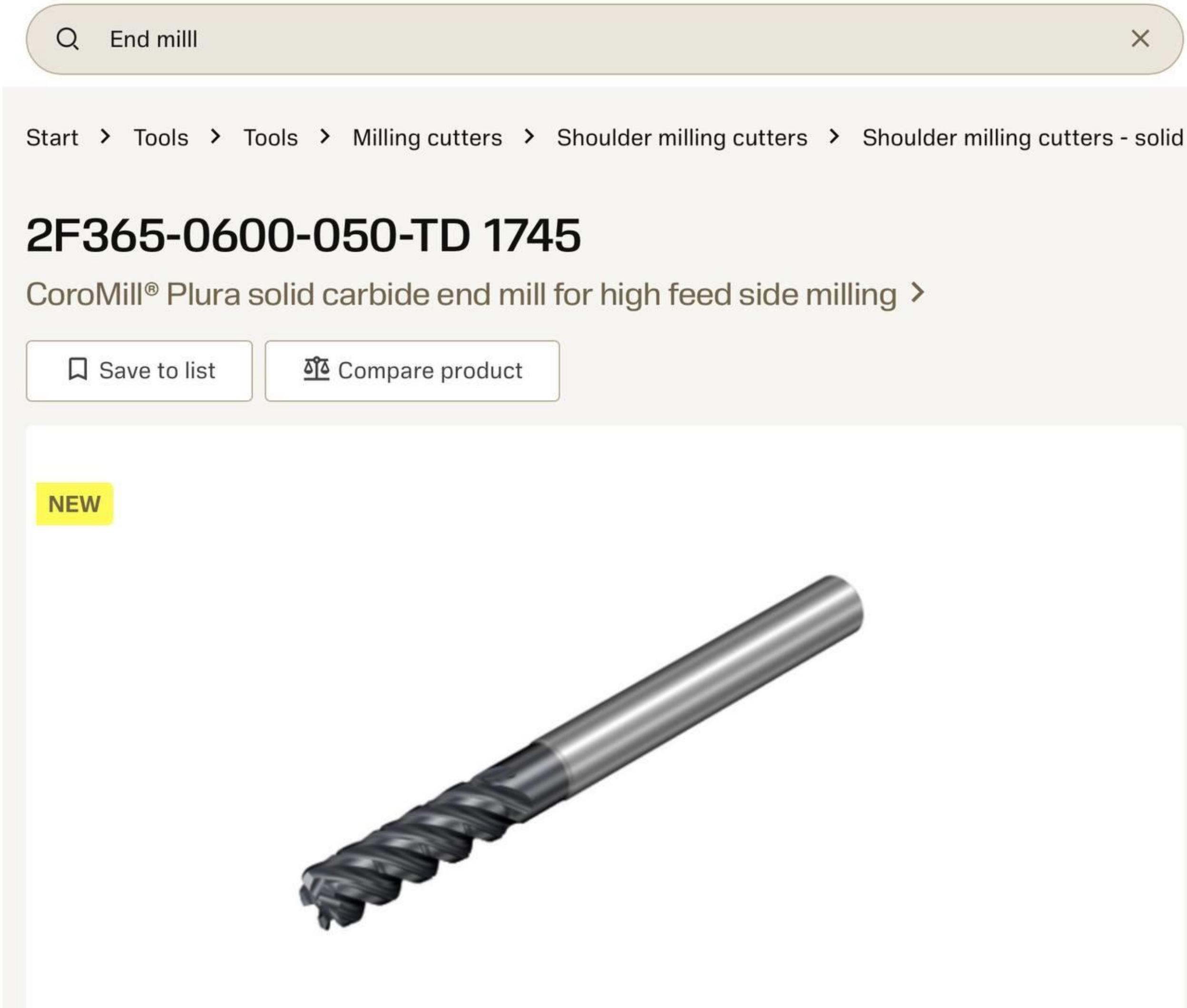
amitkumars...
ContentCent...
Milling
CoroPlus® T...
Sandvik Cor...
08X17H13M2T
M1.0.C.UT • 175 HB
M
Straight slot with two open ends
Universal machining centre
28 kW, 18000 1/min
DEPTHMF
20 mm
WIDTH
50 mm
LENGTH
100 mm
RE
Not set
Get results
Working conditions
Workpiece surface condition code
Pre-machined
Stability of fixturing
Good stability
Spindle axis to work piece surface
rotating axis parallel to the work piece surface
Good conditions
Operation type
CTPT
Pre-machining
Depth of machining feature
DEPTHMF
20
mm
General width parameter
WIDTH
50
mm
General length parameter
LENGTH
100
mm



Note: at the end of this bachelor's thesis, the G-code file is included, which contains the G-code data generated from SolidWorks that can be used for CNC Setup for all CNC involved Processes 020 AND 025

1.8 Cutting Tools and Cutting Conditions Selection

The cutting tools, cutting conditions, and setup decisions used in the machining of the Bottom Plate are covered in this section. The technological process plan, cutting condition formulas verified by international machining standards (such as ISO 8688), and values modified for medium carbon steel (σ = 460 MPa) are the basis for the selections. These characteristics support the machining time and cost estimates in Section 1.9 of this Bachelor Thesis .

1.8.1 Work Holding and Setup Devices

Operation	Machining Type	Work Holding / Setup Devices Used
010 – Vertical Milling	Cutting	Compound machine presses (chosen based

		on the parts configurations)
020 – CNC Vertical Milling	Cutting	Compound machine presses (very important for part geometry)
015 – Vertical Drilling	Cutting	Mechanized grips (for workpiece securing)
025 – CNC Vertical Milling	Cutting	Setting fingers and mechanized grips
030 – Radial Drilling	Cutting	Setting fingers and mechanized grips
035 – Surface Grinding	Abrasive	Magnetic table (Model 7208-0057, GOST 2424-83)

1.8.2 Cutting Tool Selection

- Ø25 mm Twist Drill (GOST 2301-3652) – Operation 015
- Ø11 mm Twist Drill (GOST 2301-3583) – Pre-reaming for Ø12H7 Hole
- Countersink Ø11.79 mm (GOST 12489-71)
- Ø14.95 mm Twist Drill – For M16-7N thread hole
- Ø12 mm Machine Reamer (GOST 16087-70)
- HSS End Mills – For groove and face milling (025)
- Ø25 mm Countersink – Large chamfering (025)
- Grinding wheel K 300x100x203 ST (GOST 2424-83) – Finishing of operation (035)
- Taps – For threads (M16-7N, M2, M3)

1.8.3 Measuring Instruments

The accuracy and accessibility of surfaces were taken into consideration when choosing measurement instruments. Basic geometric surfaces are measured with calipers and Digital/vernier calipers (GOST 166-89) for critical hole dimensions like Ø45H7, Ø12H7, and Ø10H7; plug gauges were used.
ISO formulae were used to determine the parameters. The values assist dimensional accuracy for Bottom Plate Part 4 and match machine specifications (6560MF3, 2554).

1.8.4 Empirical Basis for Cutting Condition Calculations

Utilizing the formulas from ISO 8688 (Machinery's Handbook)
$V = C \cdot D^q$
$n = (1000 \times V) / (\pi \times D)$
$Mkr = 10 \times Cm \times D^q \times S^y \times Kp$
$N = (Mkr \times n) / 9750$
Constants: C = 15–30, Cm = 0.035, q = 0.4, y = 0.8, Kp = 0.7–1.0

1.8.5 Cutting Conditions – Calculations

Radial Drilling (015):
Tool: Ø25 mm Twist Drill
Feed: 0.4 mm/rev | Speed: 209 rpm | Torque: 72.5 N·m | Power: 1.5 kW | Tool Life: 50 min
CNC Milling (025):
Ø11 mm: 0.22 mm/rev | 281 rpm | 8.7 N·m
Ø11.79 mm: 0.35 mm/rev | 435 rpm | 1.37 N·m
Ø14.95 mm: 0.28 mm/rev | 347 rpm | 14.9 N·m

1.8.6. Sample Calculation – Tool Life and Torque (Operation 015)

For Operation 015 (Radial Drilling) using a Ø25 mm twist drill and carbon steel Ст3 (σ = 460 MPa), the following calculations are performed based on standard machining equations:
The formula for cutting speed (ISO 8688/Machines Handbook) is $V = C \cdot D^q$.
Where: $V = 22 \times 25^{0.4} \approx 16.43$ m/min, C = 22 (for the HSS drill), D = 25 mm, and q = 0.4
$n = (1000 \times V) / (\pi \times D) = (1000 \times 16.43) / (\pi \times 25) \approx 209.3$ rpm is the spindle speed.
The torque $Mkr = 10 \times Cm \times D^q \times S^y \times Kp$ is the calculation.
Where: $Mkr = 10 \times 0.0345 \times 25^{2.0} \times 0.4^{0.8} \times 0.7 \approx 72.52$ N·m, where Cm = 0.0345, D = 25, q = 2.0, S = 0.4 mm/rev, y = 0.8, and Kp = 0.7
$N = (Mkr \times n) / 9750 = (72.52 \times 209.3) / 9750 \approx 1.55$ kW is the power.

Tool Life:
Applying the simplified empirical assumption for HSS in carbon steel, Taylor's Tool Life Equation:
For HSS, $T = (C / V)^{1/m}$, where $m \approx 0.2$
Considering the empirical constant for steel drilling, $C \approx 80$:
≈ 50 min $T = (80 / 16.43)^5$

(Machinery's Handbook, 31st Ed, ISO 8688 – Tool life testing, Sandvik Coromant Technical Guide, GOST 166-89 – Caliper Standards, GOST 10903-77 – Twist Drill Standards)

1.9 Time and Cost Calculations

This section uses a few chosen operations (015 – Radial Drilling and 025 – CNC Vertical Milling) as example cases to estimate the total machining time and unit cost for producing the Bottom Plate. The computations are based on empirical models and common machining economics cost estimating concepts, including workspace allocation, equipment depreciation, energy consumption, and modifications for preliminary and auxiliary time. Better planning and resource optimization are made possible by these insights.

1.9.1 Machining Time Calculation

The following formula is used to determine the artificial machine time (Tsht):

Tsht = (To + Tv) × (1 + a_otd + a_obsl)
Where:
To = 36.87 min (Basic cutting time)
Tv = 21.8 min (Auxiliary machine time)
a_otd + a_obsl = 10% overhead rate = 5.86 min
Tsht = 62.11 min
Xer is the seriality coefficient that modifies the preparation and final time (Tp.z):
Tp.z = 57.1 min; Xer = 1.3
Adjusted Tv.f = 28.34 min
Total batch time for 3 parts:
T_batch = Tp.z + Tsht × 3 = 57.1 + (62.11 × 3) = 243.43 min

1.9.2 Machining Cost Estimation

The artificial time (Tsht = 21.95 min) is used to calculate the unit cost of machining using typical engineering economic models. The following parameters and constants are employed. Parameters used include

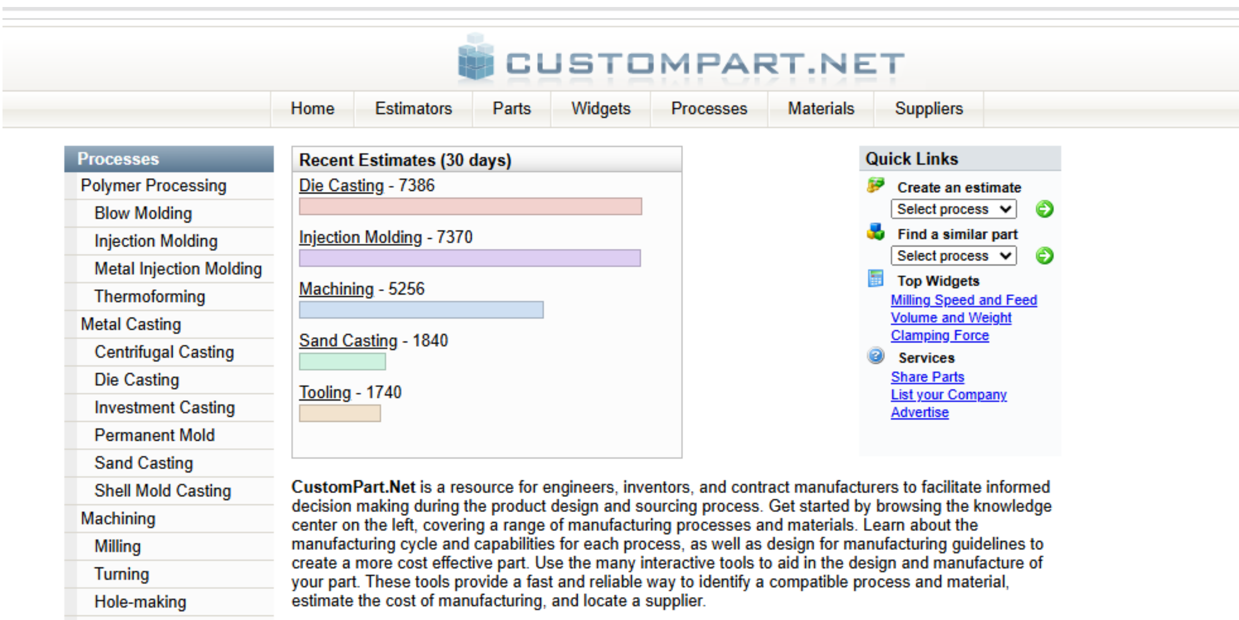
Equipment cost (F): 95,000 UAH
Depreciation rate (Na): 15%
Equipment cost rate (Sto): 0.0023 UAH/min
Annual maintenance (Nm, Ne): 245 UAH, 80 UAH
Repair coefficients (Km, Ke): 40, 18
Tool cost rate (Zu): 0.0057 UAH/min
Electric motor power (N): 10 kW
Load factor (ψzo): 0.71
Electricity rate (Se): 0.32 UAH/kWh
Production floor cost (Np): 50 UAH/m²
Floor space (Ps): 39 m²
Effective hours (k): 3620 h/year
Normative efficiency (En): 0.15

Cost Breakdown by Unit for Each Part, Table 8

Cost Component	Value (UAH)
Depreciation Cost (Ao)	1.90
Tech Equipment Cost (Ato)	0.05
Repair & Maintenance (Ro)	1.14
Cutting Tool Cost (I)	0.03
Power Consumption (Pae)	0.008
Production Area Cost (Pp)	0.20

Other Overhead	0.014
Total Cost per Part (C)	3.342

Alternative cost estimation:https://www.custompartnet.com/, Fig.6



Economic Efficiency

Applying the formula for comparative cost efficiency:
$(C_2 + En \times Co_2) - (C_1 + En \times Co_1)$ makes up E.
$E = (3.342 + 0.15 \times 9.6)$ if $C_2 = 3.342$, $Co_2 = 9.6$; $C_1 = 2.03$, $Co_1 = 2.6$ $0.15 \times 2.6 + 2.03 = 2.362$ UAH/part

Conclusion

About 90.45 minutes are needed for each part, and 243.43 minutes are needed for a three-piece batch. Depreciation, tooling, electricity, and workspace are all included in the predicted 3.342 UAH cost per part. The cost-effectiveness and efficiency of the process route are confirmed by an economic benefit of 2.362 UAH/part.

References

(Machinery's Handbook, 31st Edition, ISO 15531 – Industrial Automation Systems, DIN 8765 – Cost estimation for machine tools, Ukrainian State Standardized Industrial Cost Models)

Chapter 2 – Fixture Design and Clamping Force

2.1 Development of Fixture Design

For high-precision CNC vertical milling and drilling operations (020 and 025), the fixture is designed to safely accommodate a Bottom Plate (530x400x75 mm). Repeatability, process dependability, and resistance to cutting pressures produced during grooving, drilling, and reaming are all guaranteed by the design.

Functional Requirements:
The fixture must:
- Accurately position the workpiece for machining of holes and grooves on Surface 7
- Prevent displacement due to axial, radial, and circumferential cutting forces
- Allow tool access to critical dimensions (e.g., d3-d5, l5-l30)
- Be mountable to a CNC table (model 6560MF3)

Locating Scheme:
A 3-2-1 locating scheme is applied: (more details in section 1.4)
- 3 points on the bottom surface of the workpiece (supporting Surface 2)
- 2 cylindrical pins entering positioning holes D12H7 and D13
- 1 end stop to prevent sliding along the X-axis

This deprives the part of 5 degrees of freedom; the 6th is eliminated by top clamping.
Clamping Concept:
The use of the hydraulic clamp system is implemented:
- 2 Clamp arms exert pressure in a vertical direction.
- Backing supports absorb axial force components
- Fastening elements (e.g., M16-7N bolts) secure the workpiece
Fixture Body:
The fixture base mounts on CNC T-slots. Locating pins are dowelled for repeatability. Clearance is controlled within 0.05 mm.
Resistance to Cutting Forces:
- Axial forces (Px), radial forces (Py), and tangential forces (Pz)
- Frictional resistance at clamps and supports neutralizes displacement

A labeled layout diagram can further illustrate the fixture structure.
The design of the fixture is supported by a force-balance analysis, which assumes that a part during milling is subjected to
- Circumferential cutting force (Pz): tool rotation
- Radial force (Py): side deflection tendency
- Axial force (Px): thrust along the spindle
(These forces are balanced to avoid machining errors and other errors in manufacturing)

To ensure full restraint, the workpiece is supported and located based on:

Locating System:
- Base support (3 hardened pads): counters vertical load and tilt
- Cylindrical pin + cut pin: inserted into holes (e.g., Ø12H7 and Ø13), restraining lateral movement and rotation
- End stop or surface contact: eliminates the final degree of freedom
- This setup removes all 6 degrees of freedom (3 translational, 3 rotational) — matching the force-diagram basis in standard fixture design

Load Resistance :
- Clamping friction (Ftr2): vertical hydraulic clamps apply normal force, generating friction against lift
- Support friction (Ftr1): side reactions from contact pads resist radial movement

Forces acting from the tool side are decomposed:
- Pz and Px try to lift or adjust the plate
- Py attempts to make a lateral movement

These are counteracted by:

$$F\_total\_resist = \mu * N + \mu 1 * R$$

Where:

$\mu = 0.25$, $\mu 1 = 0.20$

N = normal clamping force

R = support reaction

Design :
- The locating holes lessen reliance on human alignment and make fixture reloading easier. Relief pins are positioned inside the fixture body to guarantee repeatability. Hydraulic clamps deliver force directly over non-machined zones.

2.2 Estimation of Clamping Force

Finding the least necessary clamping force to stop the Bottom Plate model from moving during CNC machining—specifically, the milling of grooves and reaming of holes during operations 020 and 025, while considering all active and reactive forces is the aim of this computation. The effects of these forces tend to cause movement or a slight adjustment to the base of the fixture

2.2.1 Forces Acting on the Workpiece

During milling and reaming, the workpiece is subjected to:
- Px: Axial force (in the spindle direction)
- Py: Radial force (lateral cutting force)
- Pz: Circumferential/tangential force (tool rotation effect)

2.2.2 Reaction Forces and Friction Resistance

Movement resistance is supplied by
- Ftr: Frictional force at the clamp-tool area
- Ftr1: Friction in the support-contact areas

- F_{tr2}: Friction from hydraulic clamping arms

The friction resistance equation :

$$Py \leq Ftr + Ftr1$$

Where:

$Ftr = \mu * N$ (clamping friction)

$Ftr1 = \mu 1 * R$ (support friction)

$\mu = 0.25$, $\mu 1 = 0.20$ (steel-on-steel contact)

2.2.3 Input Parameters from Process

Precalculated cutting values
- Radial Force (Py): 4260 N (from milling and groove machining)
- Support Reaction (R): presumed to disperse uniformly across three support points
- Safety Coefficient (k): 1.5

2.2.4 Required Clamping Force Calculation

To prevent upward/lateral displacement:

$$F\_clamp = (Py * k) / \mu = (4260 * 1.5) / 0.25 = 25{,}560 \text{ N}$$

This is the minimum total clamping force needed for the hydraulic system.
If two hydraulic arms are used:

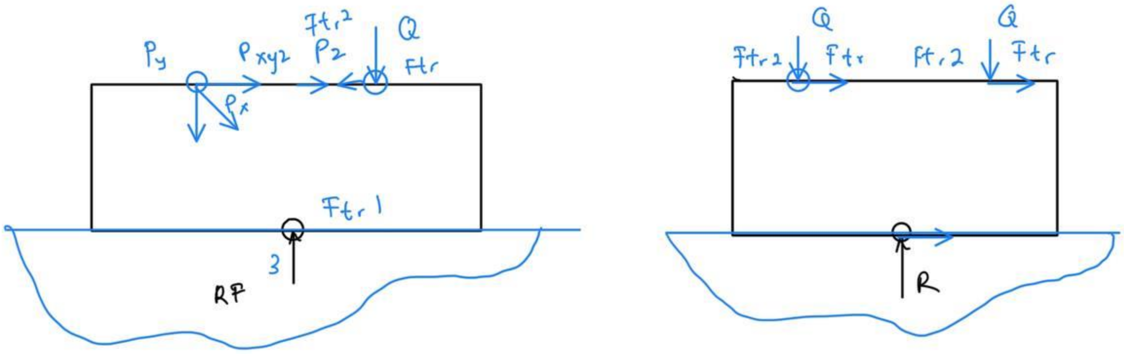
$$F\_per\ clamp = 25{,}560 / 2 = 12{,}780 \text{ N}$$

2.2.5 Clamp Capacity and Safety

Selected clamps:
- Model: Standard hydraulic clamps
- Rated force per arm: 15,000 N
- Total provided: 30,000 N.

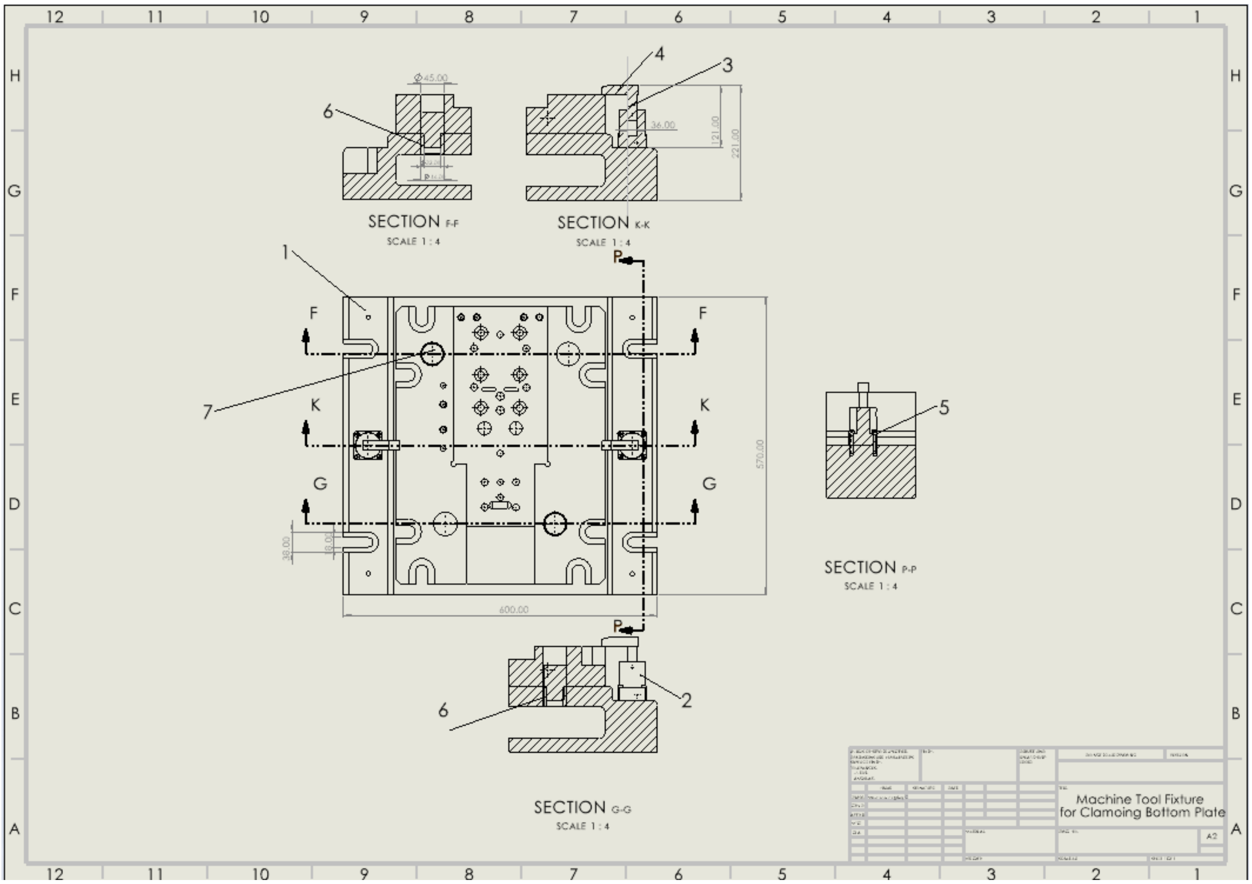
Clamping Force Scheme, Fig.6

RE



Machine tool fixture for clamping the workpiece
This section explains the work holding mechanism used in clamping the workpiece and bottom plate during the process 020 CNC vertical milling machine and the 025 Vertical milling machine with CNC.
The work holding mechanism used for the manufacture of the bottom 530x400x75 mm plate is the hydraulic clamping system.

Fig.7

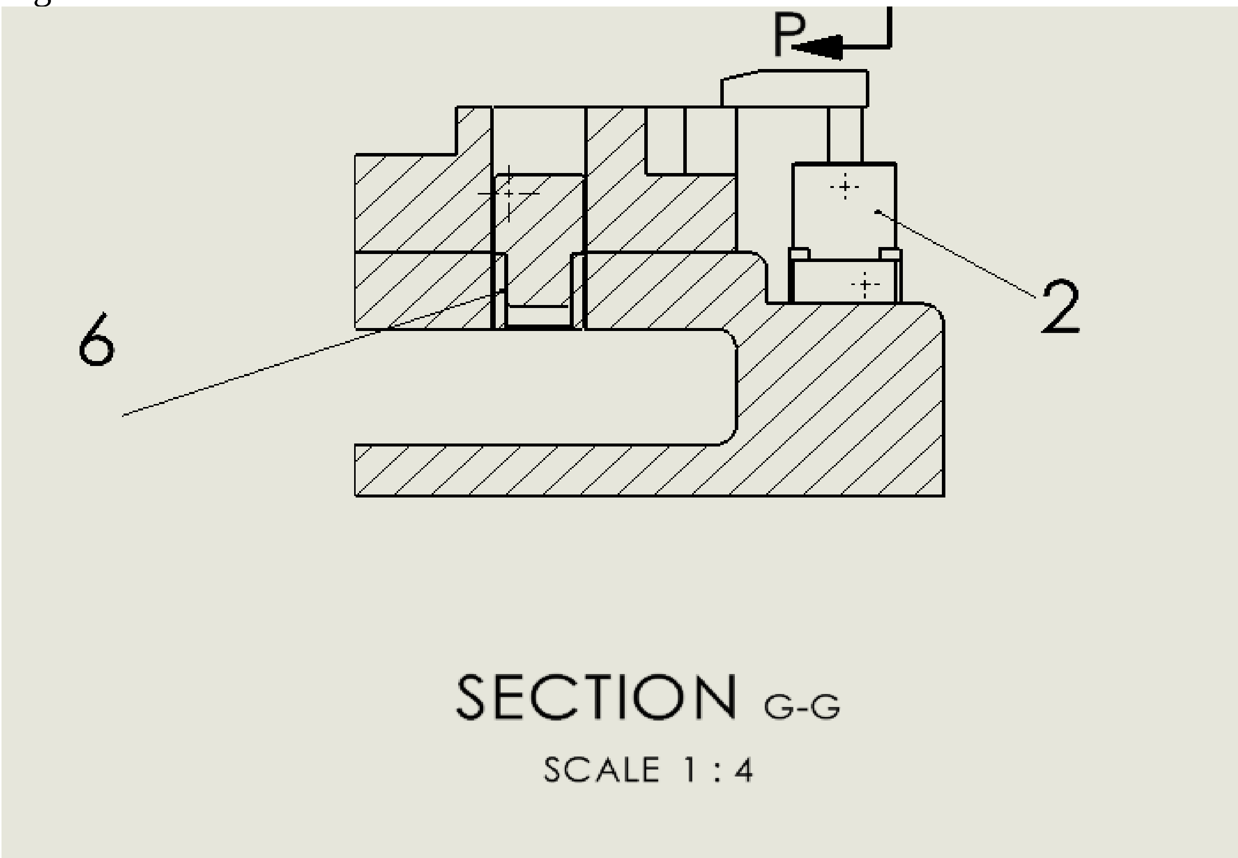


Design and Purpose Analysis

During milling operations, the bottom plate is held firmly in place by the **hydraulic clamp 36-cylinder size**, which guarantees stability, precision, and repeatability. It saves setup time, maintains constant pressure throughout the machining process, and produces strong clamping force with little physical effort. This makes it perfect for precise operations like those needed for the bottom plate because it improves surface smoothness, reduces vibration or movement, and increases operator safety**.**

Assembly: the bottom plate, which is fixed by two hydraulic clamps**, 2** (as seen in the figure.8 that keeps it in fixtured during machining to withstand applied forces and ensure repeatability during the machining operation, considering the model weight of approximately 90kg), which are then fixtured to a custom base plate **1**, that is attached to a CNC machine base plate with the use of a total of 8 M12 mounting screws **5** with length of 40 mm, four for each clamps.

Fig.8



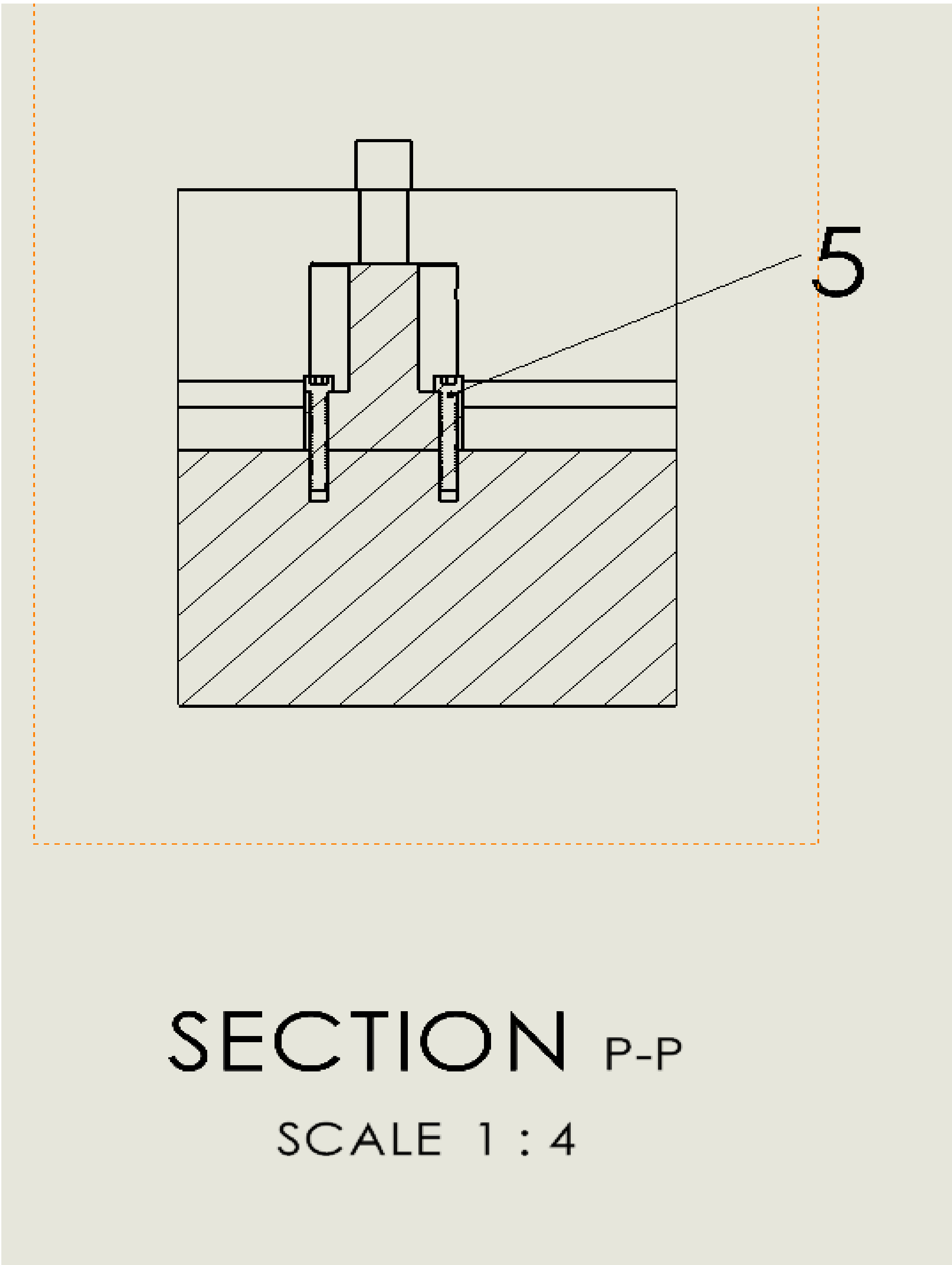


Fig.9

In figure.7, pin **7,** locating pin can be seen**,** which is used to locate the workpiece by overcoming the degrees of freedom, and the pins are inserted into a custom bushing **6** for proper fitting, so that the bottom plate is located onto the base plate **1 at the 45H7** hole

Working Principle of Hydraulic Clamp

The hydraulic clamp **2** uses Pressurized hydraulic fluid to produce a powerful and consistent clamping force. This mechanism pushes a piston **3** that stretches the clamp arm **4** onto the bottom plate by pumping fluid into a cylinder with a 36 mm diameter.

The following formula is used to get the force

$F=P\times A$

The calculation of clamping force using the standard formula:

$F = P \times A$

Where:

- F is the clamping force (N)
- P is the hydraulic pressure (Pa)
- A is the piston area, calculated by $A = \pi \times D^2 / 4$
- D is the piston diameter (36 mm = 0.036 m)

Calculation for N Force

Based on Previous calculations, to achieve a force around 14,000 newtons

We calculate the Piston area, which is 36 mm in cylinder size

$A = \pi \times (0.036)^2 / 4 = 1.018 \times 10^{-3}\ m^2$

$P = F / A = 14{,}000 / 1.018 \times 10^{-3} \approx 13{,}754{,}130$ Pa

Step 3: Convert pressure to MPa:

P = 13,754,130 Pa/1,000,000= 13.75 MPa

In conclusion, the system needs to run at a pressure of about 13.75 MPa to provide a clamping force of 14,000 N utilizing a 36 mm diameter hydraulic cylinder.

References (for 3d models:https://www.3dfindit.com/en/digitaltwin/pneumatic-swing-clamping-cylinder?path=medan%2Fair_cylinders%2Fclamp_cylinders%2Fmas_masd_mats_matsd%2Fmas_asmtab.prj&varsettransfer=AAAB2HiclZE7D4IwEIB3fwWym0KcTM5LCKAxKZTQBuJYtEMTxISH_2Fn2R_2BghOdbn77vEtd7CMWCiOWewIWVHd9YVWd1wAV7U69fraODfVdmPeur7rIFDdKBMPZ1xvPCAvnnp8qEZc_2

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Xv8Rw3Ju5RZOxnIxtyykIN3TeG55FlrOxP9SxriFRL7XJJ_2Bv4QNNnp2Q)

Chapter 3: Features of Calculating Cutting Modes

Features For Calculating Cutting Modes
In this section, we will be highlighting the Features for calculating cutting mode from Prof. A. Chandrashekhar - Milling operations TA 102 Workshop Practice and Process 010 would be used as an example; further reference would be indicated respectively, especially for assumed or uncalculated data parameters

Purpose: Finding the ideal machining parameters that guarantee effective material removal, tool longevity, and the required surface quality is the goal of examining cutting mode features and choosing the right cutting speed, feed rate, depth of cut, and tool engagement variables are essential for balancing productivity and dimensional accuracy in manual milling processes like Operation 010.

1. Cutting Speed (Vc): Cutting Speed is defined as the peripheral speed of the cutter **(**Prof. A. Chandrashekhar**)**

Formula:
$Vc = (\pi \times D \times N) / 1000$ [m/min]
• D: Diameter of cutter (mm)
• N: Spindle speed (rpm)

Operation 010 Application:
Using Milling cutter2214-0515 T15K6 assuming tool has a diameter, D = 50 mm and Vc = 100 m/min,
$N = (1000 \times 100) / (\pi \times 50) = 636.62$ rpm

2. Feed (f)

Feed is the movement of the workpiece relative to the cutter.

Three types are defined:
• Feed per tooth: $F1 = f / (z \times N)$ [mm/tooth]
• Feed per revolution: $F2 = F1 \times z$
• Feed per minute: $f = F1 \times z \times N$

Operation 010 Application:

We assumed the tool has 6 teeth with a feed of 0.12
Let F1 = 0.12 mm/tooth, z = 6, N = 636.62 rpm:
f = 0.12 × 6 × 636.62 = 458.36 mm/min

3. Depth of Cut (d)

The thickness of material removed in one pass of the cutter.
we use the roughing parameter 6.3 in machining while ensuring 400mm and decided depth of cut 0.3
Operation 010 Setup:
Roughing cut: d = 0.3 mm

4. Width of Cut (w)

The width of the surface that contacts the cutter, perpendicular to the feed
we assumed the Partial face cut: w = 40 mm

5. Material Removal Rate (MRR)

Formula:
MRR = w × d × f [mm^3/min]

Operation 010 Calculation:
MRR = 40 × 3 × 458.36 =55003.2 mm^3/min

6. Machining Time (t)

Formula:
t = L / f [min]
L: length of cut = bottom plate length or model + approach + overtravel
L = 530 + 20 + 20 = 570 mm

t = 570 / 458.36 ≈ 1.24 min

7. Surface Roughness (Ra)

Based on drawing data, the recommended surface roughing is Ra = 6.3 µm (roughing finish)

8. Influence of Tool Material (T15K6 Carbide)

We assumed the tool used in Operation 010 — milling cutter 2214-0515 T15K6 — is a carbide-tipped end mill, compliant with GOST 26595–85.

Carbide (especially grade T15K6) allows:
• Higher cutting speed (Vc up to 100–120 m/min)
• Reduced tool wear
• Better chip control and stable cutting in steel

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