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VYSOKÉ UČENÍ TECHNICKÉ V BRNĚ

**FACULTY OF MECHANICAL ENGINEERING**

FAKULTA STROJNÍHO INŽENÝRSTVÍ

**INSTITUTE OF MANUFACTURING TECHNOLOGY**

ÚSTAV STROJÍRENSKÉ TECHNOLOGIE

**COMPARISON OF MACHINING PROCESSES OF  
SELECTED ROTATING PARTS IN TERMS OF CNC AND  
CONVENTIONAL PRODUCTION TECHNOLOGY**

SROVNÁNÍ PROCESŮ OBRÁBĚNÍ VYBRANÉ ROTAČNÍ SOUČÁSTI Z HLEDISKA CNC A KLASICKÉ  
VÝROBNÍ TECHNOLOGIE

**MASTER'S THESIS**

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**AUTHOR**

AUTOR PRÁCE

Bc. Mahmoud J. B. Itmaizi

**SUPERVISOR**

VEDOUCÍ PRÁCE

doc. Ing. Josef Chladil, CSc.

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# Assignment Master's Thesis

Institute: Institute of Manufacturing Technology  
Student: **Bc. Mahmoud J. B. Itmaizi**  
Degree program: Manufacturing Technology  
Branch: Manufacturing Technology and Management in Industry  
Supervisor: **doc. Ing. Josef Chladil, CSc.**  
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As provided for by the Act No. 111/98 Coll. on higher education institutions and the BUT Study and Examination Regulations, the director of the Institute hereby assigns the following topic of Master's Thesis:

## **Comparison of machining processes of selected rotating parts in terms of CNC and conventional production technology**

### **Brief Description:**

Technology of production of rotating parts in relation to the volume of production, production equipment for machining rotating surfaces, technology for piece production and serial production, technology of production of rotating parts in terms of costs.

### **Master's Thesis goals:**

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Production equipment for machining rotating surfaces.  
Choice of representative, including technology for piece production and series production.  
Technology of production of rotating parts in terms of costs.

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STEPHENSON, D. A., AGAPIOU, J. S. Metal Cutting Theory and Practice. 3. Baton Rouge: CRC Press, 2016. ISBN 9781466587533. doi:10.1201/9781315373119

TSCHÄTSCH, H. Applied machining technology. Dordrecht: Springer, 2009, xvii, 398 s. ISBN 9783-642-01006-4.

QUESADA, R. Computer numerical control: machining and turning centers. Upper Saddle River: Pearson Prentice Hall, 2005, 548 s. ISBN 0-13-048867-4.



Deadline for submission Master's Thesis is given by the Schedule of the Academic year  
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In Brno,

L. S.

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Ing. Jan Zouhar, Ph.D.  
Director of the Institute

---

doc. Ing. Jaroslav Katolický, Ph.D.  
FME dean

## **ABSTRAKT**

Tato diplomová práce zkoumá rotační součásti a jejich obráběcím procesem. V první části začíná představením nejběžnějších obráběcích technologií, dále popisuje obráběcí stroje používané pro obrábění rotační součásti a porovnává CNC a ruční stroje. Poté jsou popsány nákladové faktory. Ve druhé části práce je krok za krokem ukázán plný obráběcí proces dvou typů rotačních součástí (hřídel a kotoučů), následuje strojní čas na obrábění a diskuze o preferovaných strojích podle velikosti výroby.

### **Klíčová slova**

Rotační součásti, Obrábění, Strojní čas, Obráběcí operace, Soustružení

## **ABSTRACT**

This thesis researches the rotating parts, and their machining process. In the first part it starts by showing the most common machining technologies, then describes the machine tools used for machining of rotating parts and comparison between CNC and manual machines. After that cost factors are described. In the second part of the thesis, the full machining process of two types of rotating parts (shafts and discs) is shown step by step. following that the machining time needed and a discussion about preferred machines based on size of production.

### **Keywords**

Rotating parts, machining, machine time, machining operations, turning

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## **BIBLIOGRAPHIC QUOTATION**

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## PROHLÁŠENÍ

Prohlašuji, že jsem diplomovou práci na téma Srovnání Procesů Obrábění Vybrané Rotační Součásti Z Hlediska CNC a Klasické Výrobní Technologie vypracoval samostatně s využitím uvedené literatury a podkladů, na základě konzultací a pod vedením vedoucího práce.

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místo, datum

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Mahmoud Itmaizi

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## INTRODUCTION

This thesis investigates the machining of rotating parts. In general, rotating parts are parts with rotational surfaces caused by machining, for example: shafts, pins, and discs It is split into two main parts theoretical and practical.

The first part of the thesis consists of the theory for the types of rotating parts, different production processes and machines (CNC/manual). Then comparing conventional machine tools and CNC machining tools to identify the difference between them. This part will also describe the cost factors and method of calculating and measuring machining times.

The second part consists of the machining process step by step for two profiles (a shaft and a disc) then calculation of estimated machining time for the selected machined profiles. then suggest the best option for the machine types for these profiles at different production sizes.

## 1 THEORY

In this chapter we will have a look on processes used to create rotational surfaces, and the machine tools needed to produce them. Then we will have a look at the comparison in terms of CNC and conventional machines. After that we will discuss the cost factors as well as the machining time calculation methods.

In the next main chapter, we are going to have a look at the manufacturing process for specific rotating parts (a Shaft and a Disc) and look at their manufacturing process.

### Rotating Parts:

In the context of machining a rotating part is a part generated by a rotating cutting tool or workpiece around an axis resulting in a rotational surface. Such rotating parts can have the following shapes: shafts, discs, bushings, pins... etc. This type of surface is commonly made by machining operations such as turning, drilling, milling and grinding.



Figure 1.1 Small Head Locating Pin [1]



Figure 1.2 Shaft [2]

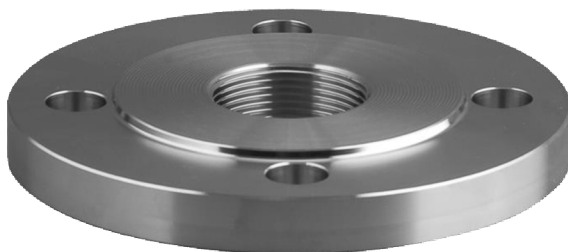


Figure 1.3 Discs (flange) [3]



Figure 1.4 Bushings [4]



## 1.1 Machining Technologies:

There are two main ways for making of rotational surfaces, first we have rotation of the workpiece and the technology for this method is called turning. Second is rotation of cutting tool the Technologies for this method are drilling and milling. In this chapter we will have a look into these technologies.

### 1.1.1 Turning

Turning is the machining process done on a lathe machine where a cutting tool is used to remove material from a rotating workpiece. The workpiece is held in the lathe, which rotates the workpiece on its axis, while the cutting tool is moved along the surface of the workpiece to remove material and create the desired shape. Turning is commonly used to create cylindrical shapes, such as shafts, rods, pins, disks... etc.

There are many turning operations like facing, taper turning, chamfering, facing, grooving, drilling and boring. In the diagram below we can see some of these operations:

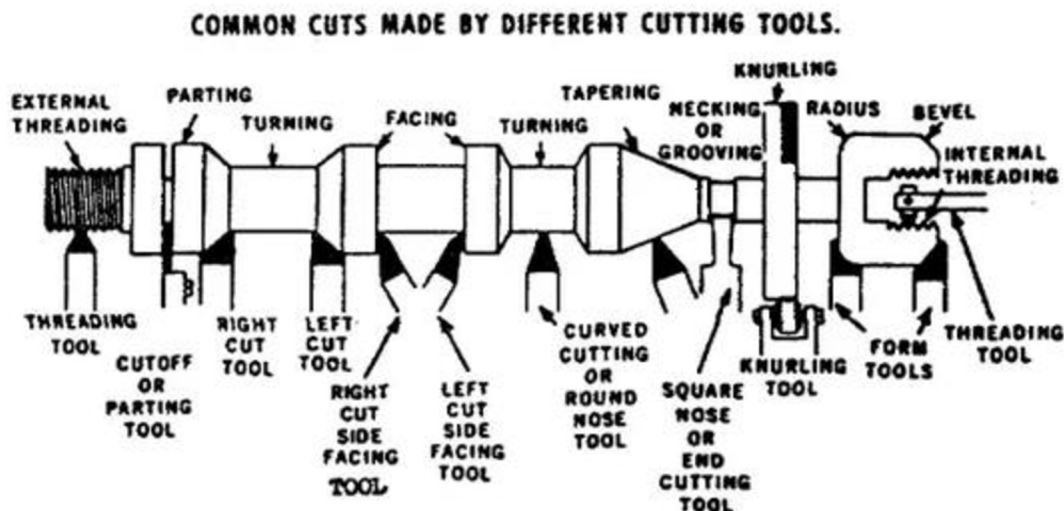


Figure 1.5 Basic turning operations. [ 5]

Turning can be used to create rotational surfaces with a high degree of accuracy and precision. This is because the rotational axis of the workpiece is fixed, allowing for precise control of the shape and dimensions of the rotational surface created. The process of turning involves several key variables, including the rotational speed of the workpiece, the feed rate of the cutting tool, and the depth of cut. These variables can be adjusted to control the size, shape, and surface finish of the rotational surface being created. In general, the most important factor is the feed rate. So higher feed rates can lead to faster material removal rates but may also result in a rougher surface finish. On the other hand, lower feed rates can result in a smoother surface finish but may take longer time to create the desired shape. [ 6]

**Cutting conditions:**

Feed rate:

$$f = \frac{l}{n} \quad (1.1)$$

Where:

- $f$ -feed rate per revolution[mm]
- $l$  -mached length per minute [mm.min<sup>-1</sup>]  
(also called feed rate per minute  $V_f$ )
- $n$ -number of revolutions per minute[ $\text{min}^{-1}$ ]

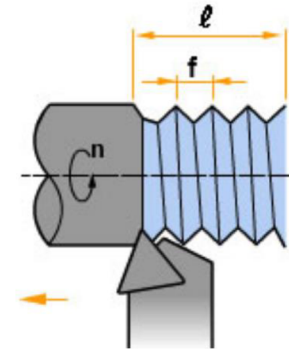


Figure 1.6 Feed per revolution [7]

Cutting speed:

$$v_c = \frac{\pi \cdot D \cdot n}{1000} \quad [\text{m} \cdot \text{min}^{-1}] \quad (1.2)$$

where

- $v_c$ -cutting speed[m.min<sup>-1</sup>]
- $D$ -diameter[mm]
- $n$ -number of revolutions per minute[ $\text{min}^{-1}$ ]

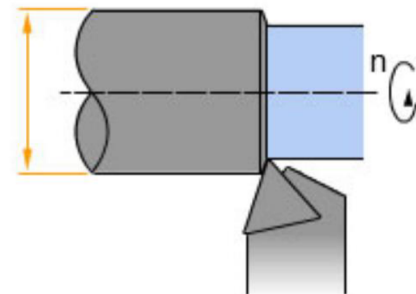


Figure 1.7 Rotational speed  $n$  [7]

Depth of cut  $a_p$ :

The depth of cut is decided by machining allowance and shape of the work piece, power and rigidity of the machine and tool rigidity.

The depth of cut should never be larger than the main cutting edge length of the insert.

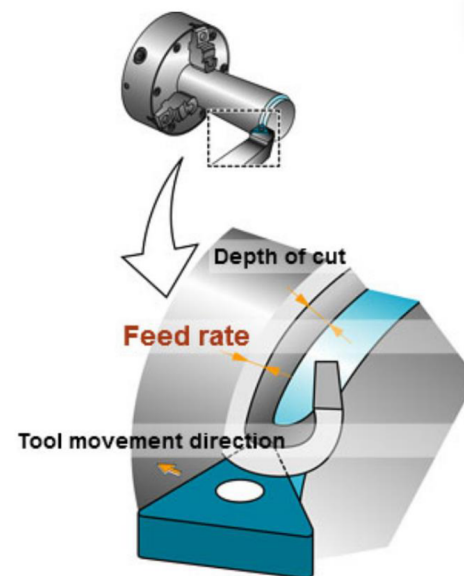


Figure 1.8 Depth of cut [7]

**Surface roughness:**

The geometrical shape on the workpiece surface produced by the cutting edge is called surface roughness. Turning actually forms a helical groove on the part. To estimate the groove height, we use the theoretical roughness equation as follows [7]:

$$H = \frac{f^2 \cdot 1000}{8 \cdot R_e} [\mu\text{m}] \tag{1.3}$$

Where:

Re-nose radius of the cutting insert [mm]

H-Theoretical roughness [ $\mu\text{m}$ ]

f- feed rate per revolution [mm]

This equation gives a rough estimate of Ra value (the exact value is of course only got by actual measurement of the surface). The actual finish will depend on the tool wear, the quality of the machine, vibrations, cutting speed...etc. To improve the surface finish, you can either reduce the feed rate or increase the nose radius. [ <https://cadem.com/insert-nose-radius-chart-turning/>]

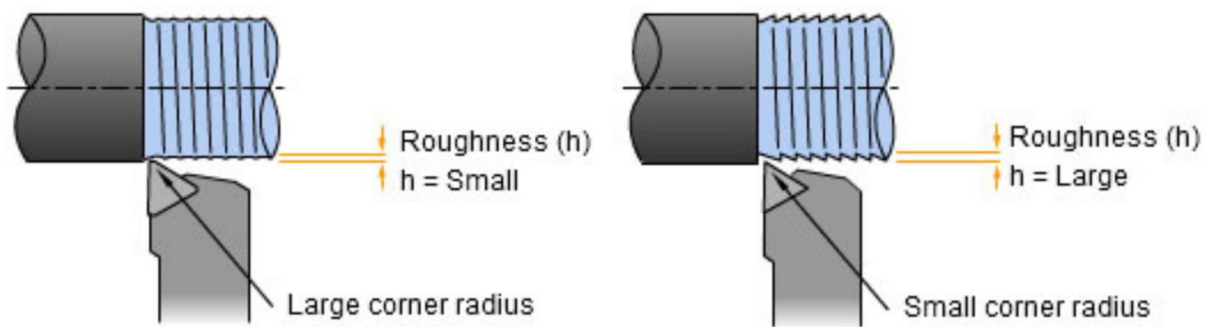


Figure 1.9 Effect of nose radius of the tool on the surface roughness [7]

**Tooling types based on materials:**

There are two main tool materials that are the most used for turning operations:

**High-speed Steel(HSS):**

High-speed steel contains elements like Tungsten and Vanadium. Cutting tools made using this material are known for their extreme hardness, strength, and wear/heat resistance. [8] Figure 1.10



**Carbide:**

Carbide lathe cutting tools are hard and brittle. Therefore, they are compatible with virtually all materials. However, they are expensive, making their use limited for single piece manufacturing. [9] Figure 1.11



### 1.1.2 Milling

Milling is a machining operation that involves removing material from a workpiece using a rotating cutting tool. The cutting tool, known as a milling cutter. The cutter moves along various axes while rotating at high speeds to shape the workpiece according to the desired geometry, while the work piece is typically held in place on a table by a holding device. One of the primary advantages of milling is its ability to create complex shapes and features.

Milling operations can be of all shapes and types to generate a wide variety of shapes, for example mills can drill holes and thread them, or make slots, chamfers... and so on.

common face milling operations:

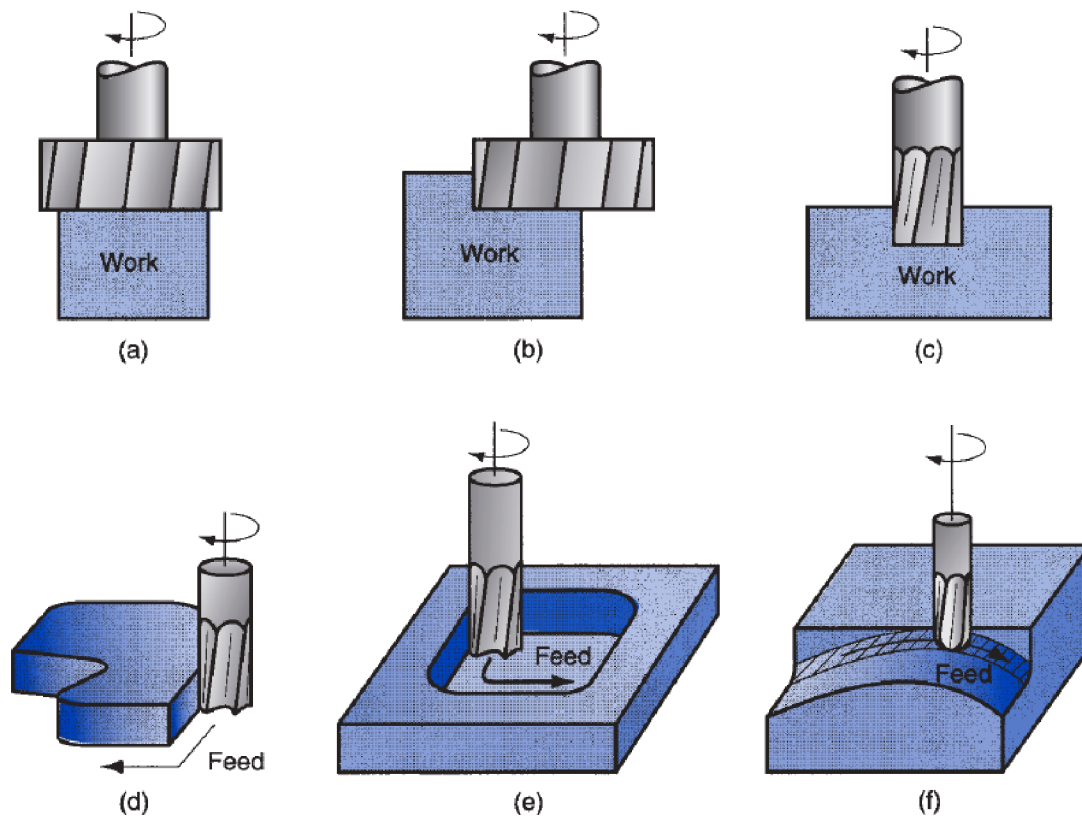


Figure 1.12 (a) conventional face milling, (b)partial face milling, (c) end milling, (d) profile milling, (e) pocket milling, (f) surface contouring [10]

To achieve the desired results when milling rotational surfaces, machinists must carefully control several variables. These include the speed of the spindle, the feed rate of the cutting tool, the depth of cut, and the coolant used to lubricate and cool the cutting tool. Proper selection and adjustment of these variables can help ensure the creation of accurate and precise features on the rotational surface.

**Cutting conditions:**

Feed rate [11]:

$$V_f = f_n \cdot n = f_z \cdot z_c \cdot n \text{ [mm/min]} \quad (1.4)$$

where:

 $f_n = f$  - Feed per revolution [mm]

 $f_z$  - Feed per tooth [mm]

 $z_c$  - Number of inserts [-]

 $v_f$  - Table feed per minute [mm.min<sup>-1</sup>]

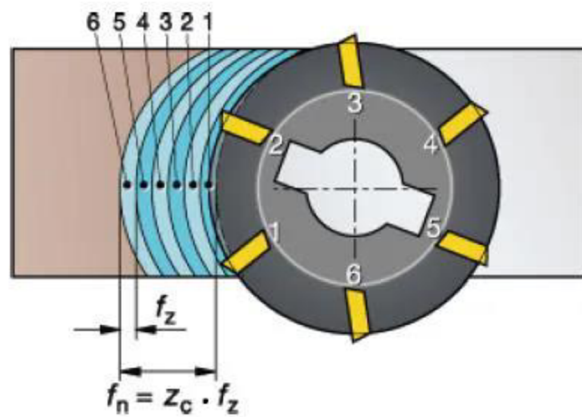
 $n$  - revolutions per minute [min<sup>-1</sup>]


Figure 1.13 Milling feeds [11]

Cutting speed [7]:

$$V_c = \frac{\pi \cdot D_1 \cdot n}{1000} \text{ [m.min}^{-1}\text{]} \quad (1.5)$$

where:

 $v_c$  - cutting speed

 $D_1$  - Diameter of the cutter [mm]

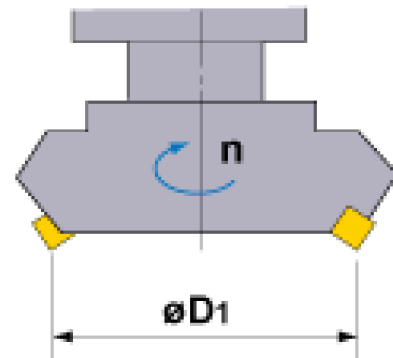
 $n$  - Revolutions per minute [min<sup>-1</sup>]


Figure 1.14 Diameter of the cutter [7]

Depth of Cut:

In milling, the depth of cut is two-dimensional:

 The Radial depth of cut ( $A_e$ ) is the length that the tool engages a workpiece perpendicular to its axis direction.

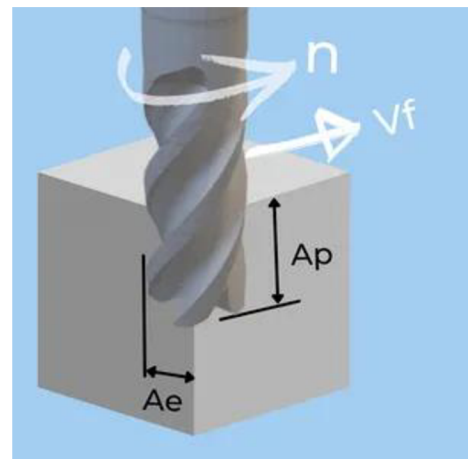
 The Axial depth of cut ( $A_p$ ) is the length in its axis direction. They are both measured perpendicular to the table feed direction. [12]


Figure 1.15 Depth of Cut in Milling [12]

Tools:

Milling Cutters are available in a wide variety of shapes and range of sizes as shown below. In the following image we can see some of the horizontal milling machine tools and the vertical milling machine tools:



Figure 1.16 Milling cutters [13]



### 1.1.3 Drilling:

Drilling is a machining operation that involves creating a hole in a workpiece using a rotating cutting tool. The cutting tool, known as a drill bit, is rotated at high speed, and fed into the workpiece to remove material and create the desired hole. Drilling is widely used across various industries for a range of applications, like creating simple holes for fasteners.

One of the primary advantages of drilling is its ability to create holes quickly and accurately. It is also a versatile process that can be used with a variety of materials and drill bit sizes.

Typical drilling operations [14]:

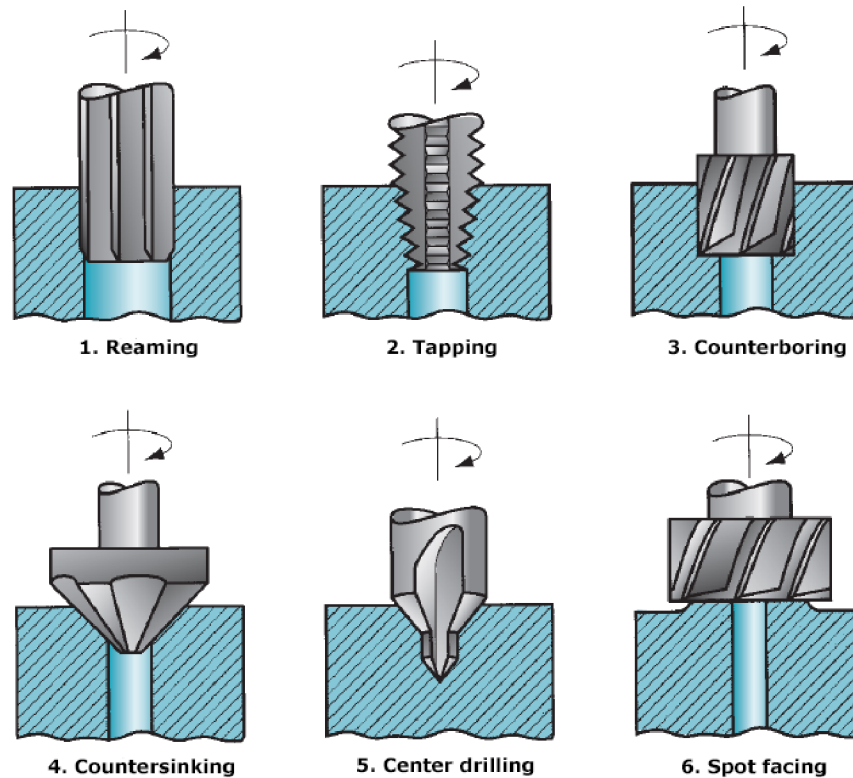


Figure 1.17 Tools and operations [14]

1. Reaming: A finishing operation that uses a multi-fluted cutting tool called a reamer to improve the dimensional accuracy and surface finish of a previously drilled hole.
2. Tapping: Tapping operation is performed by a tap and is used to provide internal threads on a pre-drilled hole allowing for the insertion of threaded fasteners such as screws and bolts.
3. Counterboring: Counterboring operation provides a stepped hole, in which a larger diameter follows a smaller diameter partially into the hole. A counterbored hole is usually used to seat bolt heads into a hole, so the heads do not protrude above the surface.
4. Countersinking: A process that creates a conical-shaped hole at the top of an existing hole to accommodate countersunk fasteners.
5. Centering: also called center drilling, this operation drills a starting hole to establish its location for later drilling accurately. Center drills, which are short and rigid, are used for this operation to provide accurate positioning and prevent deflection.
6. Spot facing operation is used to provide a flat machined surface on the workpiece in a localized area.

Feed of the main spindle [15]:

$$V_f = f_r \cdot n \quad [\text{mm} \cdot \text{min}^{-1}] \quad (1.6)$$

where:

$f_r = f$  - Feed per Revolution [mm]

$n$  - Spindle Speed in rotations per minute [ $\text{min}^{-1}$ ]

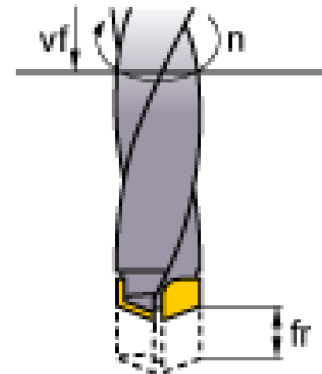


Figure 1.18 Feed in drilling [15]

Cutting speed:

$$v_c = \frac{\pi \cdot D \cdot n}{1000} \quad [\text{m} \cdot \text{min}^{-1}] \quad (1.7)$$

where:

$v_c$ - Cutting speed [ $\text{m} \cdot \text{min}^{-1}$ ]

$D$ - Diameter of the drill bit [mm]

$n$ - Revolutions per minute [ $\text{min}^{-1}$ ]

### Advantages of drilling:

**Versatility:** Drilling can be performed on various materials, such as metals, plastics, and composites, and can create holes of different sizes and depths.

**Speed:** Drilling is typically faster than other hole-making processes, such as milling or boring, making it suitable for high-volume production.

**Cost-effectiveness:** Drilling operations are generally less expensive than other machining processes, especially when using standard drill bits and machines.

**Simplicity:** The drilling process is relatively simple, with a wide range of machines and tooling available, making it accessible to a broad range of users and industries.



### 1.1.4 Grinding:

The grinding operations are very important for rotating parts since they are one of the most important factors in determining the precision of the created part. And so most rotating parts go into the grinding operation to achieve the required dimension toleration and surface roughness.

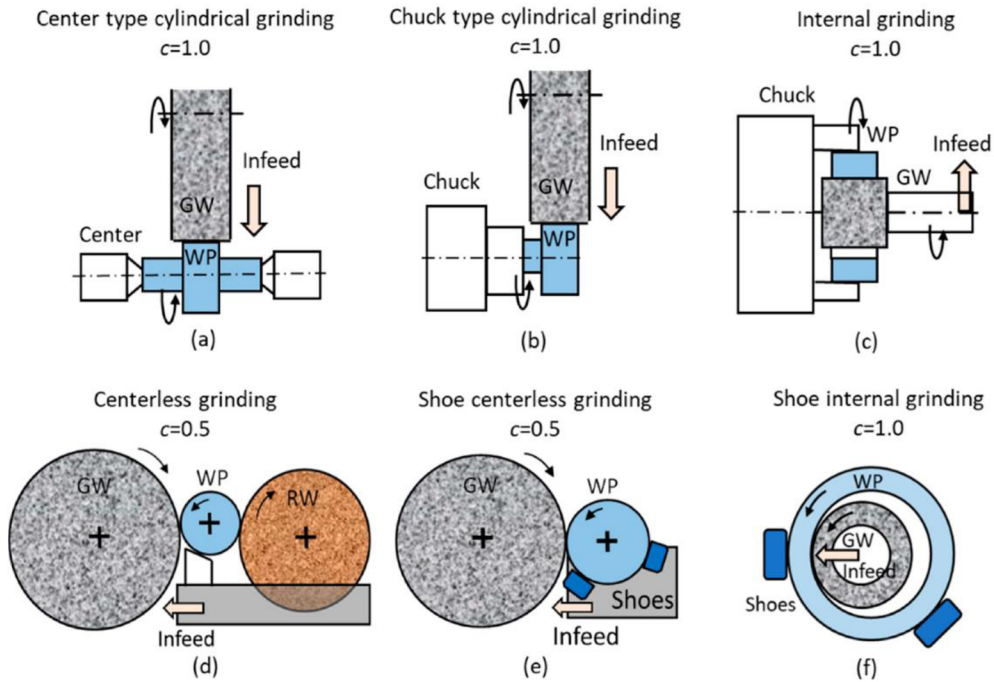


Figure 1.19 Grinding of a Rotational Surfaces

- (a) Center type cylindrical grinding; (b) Chuck type cylindrical grinding; (c) Internal grinding; (d) Centerless grinding; (e) Shoe centerless grinding; (f) Shoe internal grinding.[47]

## 1.2 Machine Tools for Rotating parts

In this chapter we will have a look at the different types of machine tools that provide Turning, Milling, Drilling and grinding operations. Then we will compare the conventional machines with the CNC to understand the difference between them.

### 1.2.1 Lathes

Lathes are the machines used for the turning process, the lathe machine is one of the oldest machine tools in existence. Lathe machines are an essential tool in the manufacturing industry. Lathe machines have been in use for centuries, and over time, they have evolved into several different types to meet the needs of various industries and applications. Lathe machines are used in a wide range of applications some of common applications are turning, threading, boring and drilling.



Figure 1.20 C6163b Universal Lathe / Conventional Lathe [16]

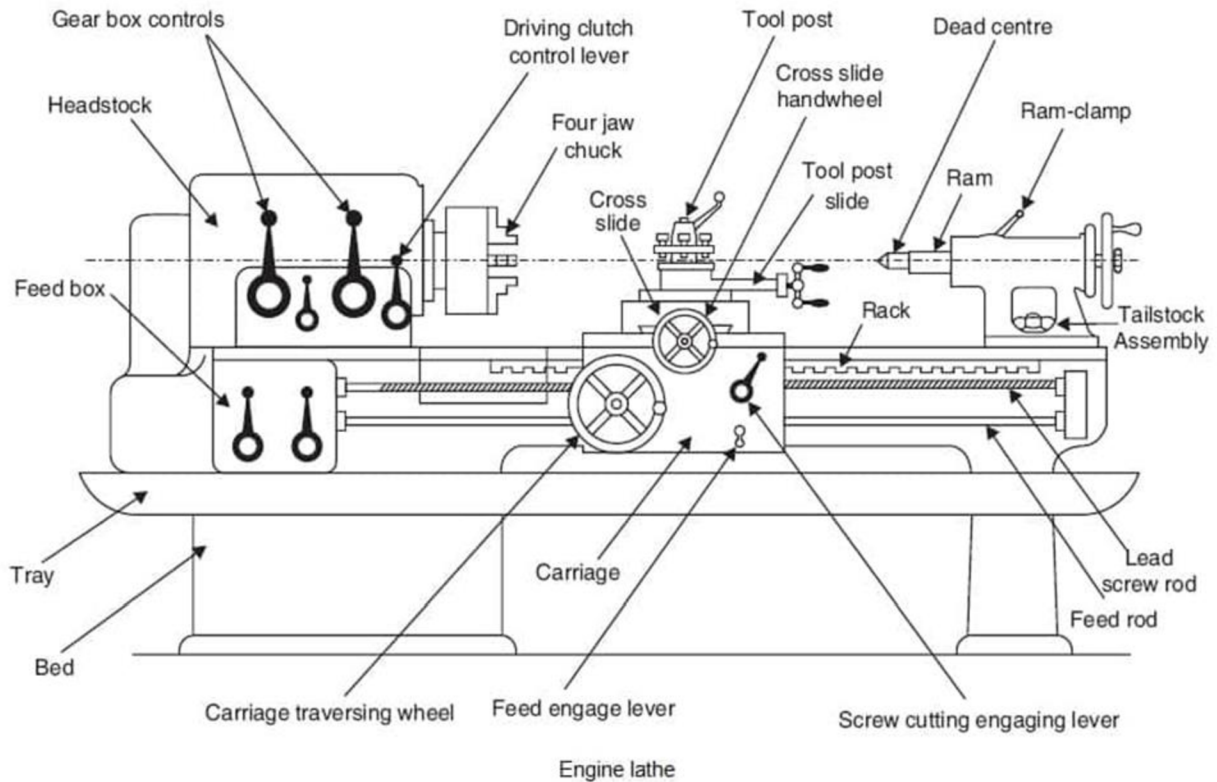
**Main lathe machine parts [17]:**

Figure 1.21 lathe machine parts [17]

1. **Bed:** The bed is the foundation of the lathe machine. It provides support for the other components and ensures that they are aligned correctly. The bed is typically made of cast iron or steel and is precision-machined to ensure flatness and accuracy.
2. **Headstock:** The headstock is located at the left end of the lathe and contains the spindle. The spindle is a rotating shaft connected to a chuck that holds the workpiece and is driven by a motor. The headstock also contains the gearing system that allows the spindle speed to be adjusted.
3. **Tailstock:** The tailstock is located at the right end of the lathe and is used to support the other end of the workpiece. It contains a quill that can be adjusted to hold the workpiece securely.
4. **Carriage:** The carriage is located between the headstock and the tailstock and moves along the bed. It contains the cutting tool and can be moved manually or automatically to provide stability and accuracy to the movement of the cutting tool.
5. **Tool turrets:** these are a part of CNC machines. It is a rotating mechanism that holds multiple tools, allowing for quick tool changes during the machining process. They are essential for automating machining processes, enabling the machine to perform a wide range of operations without manual intervention.

**Types:**

Depending on the industrial history as well as characteristics of the special workshop applications, the metal cutting lathes can be divided into several types: engine lathes (center lathes), speed lathes, turret lathes (capstan lathes), tool room lathes, bench lathes, automatic lathes, horizontal lathes, vertical lathes, and CNC lathes. [18]



**Turret Lathe Machine**



**Speed Lathe Machine**



**Engine Lathe Machine**



**CNC Lathe Machine**



**Tool Room Lathe Machine**



**Bench Lathe Machine**

Figure 1.22 Types of lathes [19]

## 1.2.2 Milling Machines

Milling machines are among the most important tools in modern manufacturing. These machines use a rotating cutting tool to remove material from a workpiece, creating a precise, finished shape. Milling machines can be used to create a wide range of shapes, including flat surfaces, slots, and contours, making them ideal for a variety of applications.



Figure 1.23 Vertical mill X50028 [20]



Figure 1.24 Horizontal Universal Milling Machine [21]



**Parts of milling machines:**

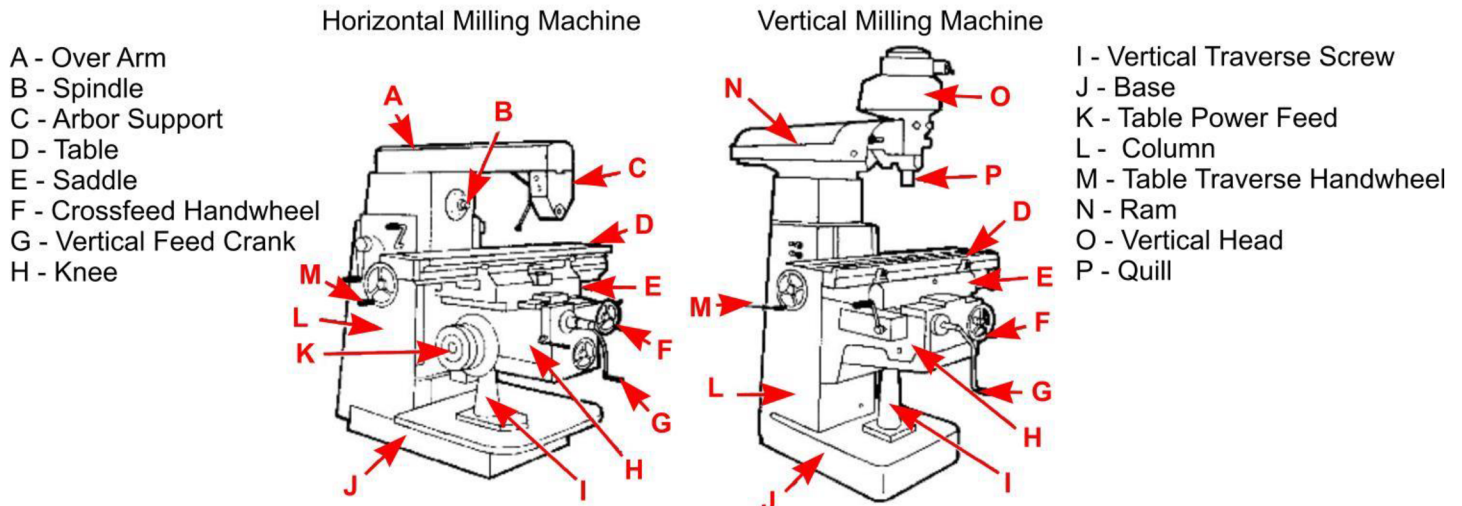


Figure 1.25 Parts of milling machines [22]

**Types of Milling Machines:**

There are several types of milling machines, each with their own unique features and advantages. Some of the most common types of milling machines include:

1. Vertical Milling Machine: This type of milling machine has a vertically oriented spindle that extends from the top of the machine. The workpiece is mounted on a table that can be moved in multiple directions, allowing for precise control over the cutting process.
2. Horizontal Milling Machine: This type of milling machine is horizontally oriented. The workpiece is mounted on a table that can be moved in multiple directions, allowing for control over the cutting process.

### 1.2.3 Drilling Presses

Drilling is a fundamental machining operation in metal manufacturing that involves creating holes in workpieces using rotary cutting tools. Drilling machines play a crucial role in the metalworking industry, offering precision, efficiency, and versatility in hole-making processes.

#### Parts of a drilling press:

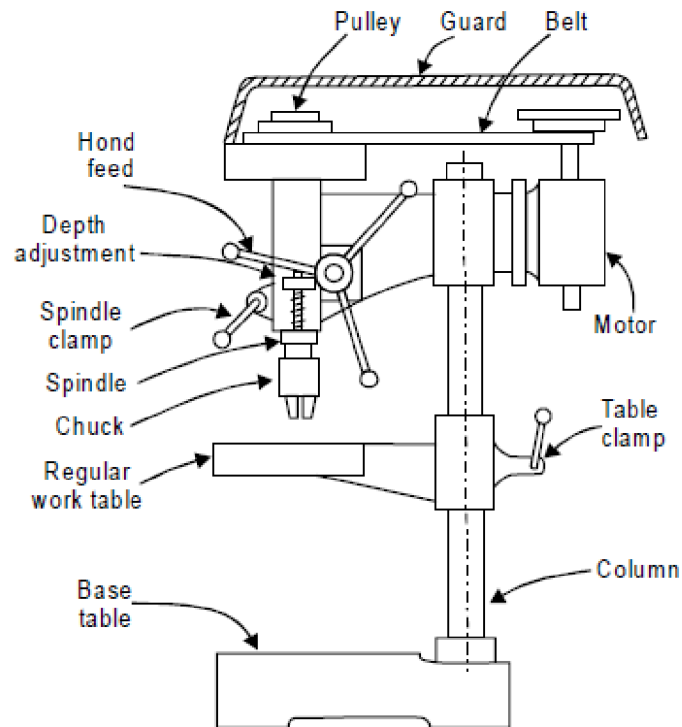


Figure 1.26 Parts of a drilling press [23]

There are various types of drilling machines commonly used in metal manufacturing the following are the most common:

- **Bench Drill Press:** The Benchtop Drill Press is a simple drilling machine that can be mounted on a workbench, this consists of a vertical pillar mounted on the base and a table and drill head (with belt pulley drive).
- **Floor Drill Press (Pillar Drilling Press):** similar to Benchtop drilling machine, however, bigger in size, higher in capacity (bigger size drill), and with power-feed. This will produce more accurate holes with a better finish and higher tool life than the benchtop machine. The pillar drilling machine is built for relatively heavier work and with power feeds [24].
- **Automatic drill press:** In an automatic drill press, the drilling operation is automated, reducing the need for manual intervention. An automatic drill press is perfect for a workshop with a lot of repetitive tasks. Automatic drill presses are helpful because they don't require too much human observation and attention.[25]
- **Radial drill:** is a machine tool that features an extended arm or beam along which a drill head can be moved to conveniently drill holes in large work pieces. A radial drill press allows the operator to advance the drill head along the machine's extended arm, rotate the arm in an arc, or tilt the drill head to drill at an angle [26]

- CNC Drill: CNC (Computer Numerical Control) drilling machines utilize computerized controls and automation to perform precise drilling operations with high accuracy and repeatability. These machines are equipped with multiple axes of movement, allowing for the drilling of complex hole patterns, angles, and depths. CNC drilling machines are widely used in industries that require high precision, such as aerospace. The drill bit movement is in X, Y, and Z axes. And can be programmed and fed into the CNC machine system for drilling of the holes at the desired location on the workpiece. The tool change can be manual or there can be a tool magazine and automated tool changing. [27]



Figure 1.27 Bench drill press [28]



Figure 1.28 JDP-20EVST-460 Industrial Floor Model Drill Press [29]



Figure 1.29 BAILEIGH INDUSTRIAL Radial Floor Drill Press [30]



Figure 1.30 ProArc Drill+1020 CNC drilling machine [31]



## 1.2.4 Grinding Machines

Grinding machines come in many different varieties as shown in the image below:

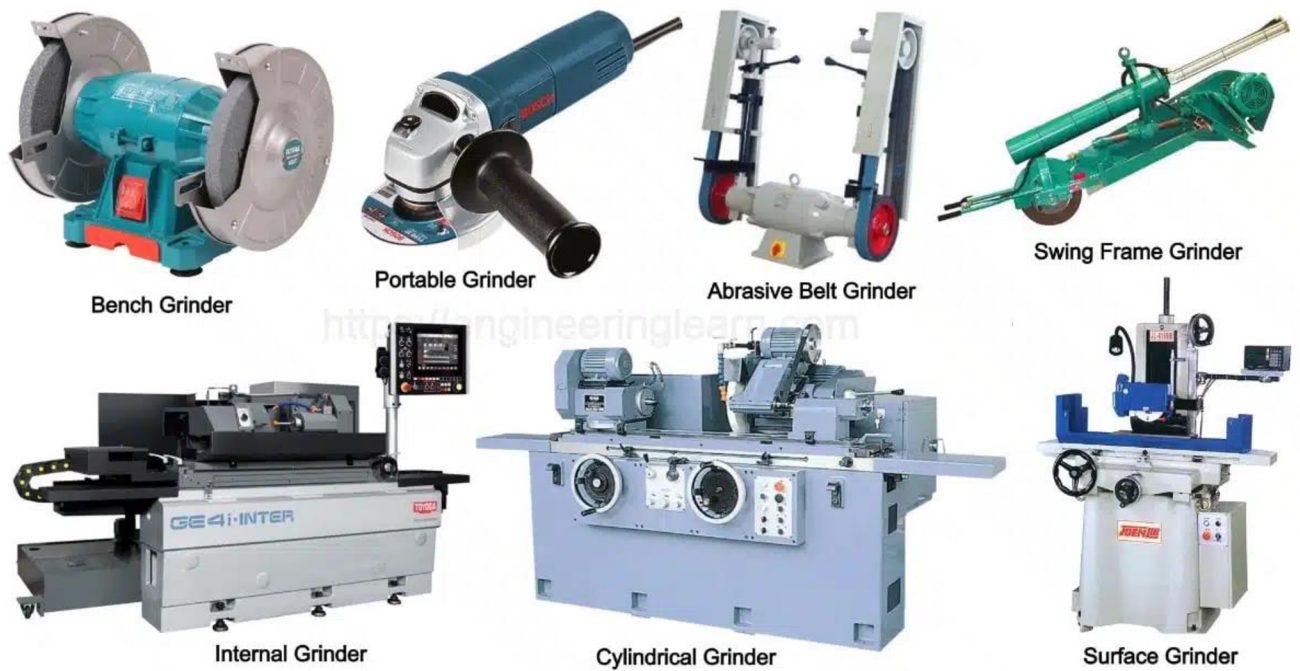


Figure 1.31 Types of Grinding Machines [48]

Most important grinders for rotating parts are the precision grinders some of which are the:

- Cylindrical Grinders
- Internal Grinders

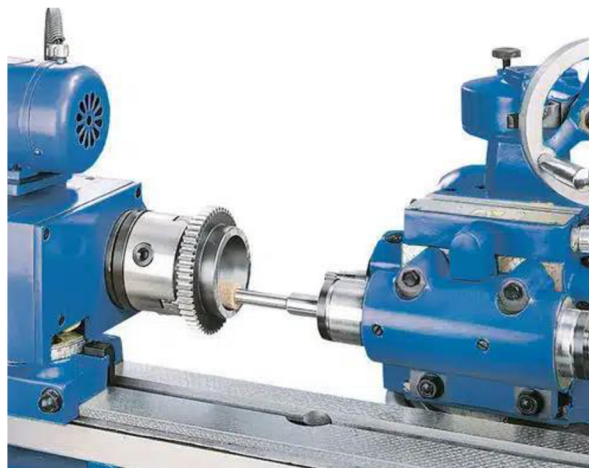


Figure 1.32 Internal Grinder [48]

### 1.3 Conventional VS CNC Machines

Here are some general notes about the difference between CNC and conventional machines:

#### Computer Numerical Control (CNC) machines:

CNC machines use computer software to control the machining process, allowing for high precision and repeatability. They are commonly used for complex parts and high-volume production.

CNC machines are made of similar components as those made for manual or conventional machines. For example, CNC lathes still need casting bed, headstock, gear box, spindle, and chuck. However, there are more components on CNC machines, such as the CNC control system. For example, the operator's panel for Computer Numeric Control, which the operator can interact with to provide input data (usually using G-code), such as the part zero position, tooling parameters, and programming instructions to define the machining process steps for the CNC machine. [32]

#### Conventional machines:

also referred to as manual machines, are controlled and operated by a machinist. This category includes lathes, milling machines, and drilling machines, among others. The operator directly manipulates the machine's controls.



Figure 1.33VF-3SS HAAS CNC Vertical Machining Center (Vertical CNC Mill)[33]

**Advantages of Conventional Machines:**

Conventional machines have several benefits, including [34] [35] [36][37][38]:

- lower initial costs, making them more accessible for smaller businesses or hobbyists.
- Their simplicity can make them easier to understand and operate, especially for those with limited experience.
- they can be more suitable for the making of prototypes, or small production runs, where there is no time to program a CNC machine, or the financial resources might be low.
- Shorter Setup Time: Conventional machines can have shorter setup times, especially for simple operation. Adjusting the machine and tooling can be quicker compared to programming and setting up a CNC machine.
- Easier to Repair: Repairs on conventional machines can be easier and less costly. With CNC machines, a failure in the control system or software can be complicated and expensive to fix.
- Feedback: conventional machines offer direct feedback of the cutting process, this can be beneficial for certain materials or for testing and learning.
- Backup method: even workshops that have CNC capabilities often chose manual machining for small-scale, one-time orders to save the time required to write a CNC program or when the CNC machine is in use by other machinists.

**Advantages of CNC Machines:**

CNC machines offer superior properties in machining including:

- Precision and Consistency reducing the potential for human error.
- Repeatability: the ability to carry out multiple operation procedures from one piece to another piece very quickly so that it would save lots of setting up time, which would be necessary on a manual machine.[32]
- High Productivity: CNC machines can also operate continuously, increasing productivity for high-volume production.
- Production of complex parts with high accuracy, which would be challenging or impossible with conventional machines.
- Less labor is required to operate CNC machinery Since CNC machining uses automation. Where a single skilled operator could potentially run several machining centers.
- Lower Costs in general: CNC machines have high speeds, are more efficient, precise and require fewer labor hours. Saving money or making more money is one of the popular benefits of CNC machining.
- Better Safety: operators are shielded and at a distance from the sharp tools and cutting process.

**Disadvantages of Conventional Machines:**

The primary disadvantage of conventional machines is their reliance on operator skill, which can lead to inconsistencies in part quality. They are also typically slower and less efficient than CNC machines, making them less suitable for high-volume production.

**Disadvantages of CNC Machines:**

CNC machines have higher initial costs and require skilled operators and programmers, which can be a barrier for smaller businesses.

The choice between conventional and CNC machines depends on several factors, including budget, part complexity (type of business products), production volume, and operator skill level. Conventional machines may be more appropriate for small businesses, low production volumes, or where operator feedback during machining is beneficial. On the other hand, CNC machines are typically the better choice especially for high-volume production and complex parts requiring high precision.

## 1.4 Cost

### 1.4.1 Cost Factors

The cost of producing a machined part can vary depending on many factors. By carefully considering these factors, machinists can optimize their machining processes to minimize costs and maximize efficiency. here are the most important factors to consider [39][40]:

- **Machine Time:** The amount of time a machine is used to produce a part is a major factor in the overall cost of machining. The longer a machine is running, the more it will cost to produce the part.
- **Labor:** The cost of labor is another important factor in machining costs. Skilled machinists with experience and expertise take payments, which will increase the overall cost of machining.
- **Tooling:** The cost of tooling, including cutting tools, drills, and other consumables, is another significant factor in machining costs. Higher-quality tools can be more expensive but can result in faster machining times and lower overall costs.
- **Materials:** The cost of the raw material being machined is one of the most significant factors in the cost of machining.
- **Machine Maintenance:** Regular maintenance and repair of machining equipment is essential to keep it running smoothly and efficiently.
- **Part Complexity:** The complexity of the part being machined is another important cost factor. Parts with intricate designs and tight tolerances may require more time and effort to produce, resulting in higher machining costs.
- **Quantity:** The quantity of parts being produced can also affect the overall cost of machining. Higher quantities may result in economies of scale, reducing the cost per part.
- **Surface Finish Requirements:** The surface finish requirements of the part being machined have a big effect on the cost of machining. Parts with high surface finish requirements may require additional machining operations or more time and effort to produce, resulting in higher costs.
- **Tolerance Requirements:** The tolerance requirements of the part being machined can also affect the cost of machining. Parts with tight tolerances may require more time and effort to produce, resulting in higher costs.

Looking at these cost factors it is very clear to see that time is almost connected to most of these factors, so we will focus on machining time further in this paper to assess the cost.

### 1.4.2 Machining time

In general, to calculate cutting time, we can simply divide how much material needs to be removed by the material removal rate per minute, and the result will be the time needed for cutting the workpiece.

To simplify the calculation of cutting time, we can do it per pass, where we calculate number of passes needed to machine a feature, and the time needed for each pass. (This time does not include preparation for cutting like placing the workpiece in the chuck and replacing of tools)

#### Cutting time for one passing:

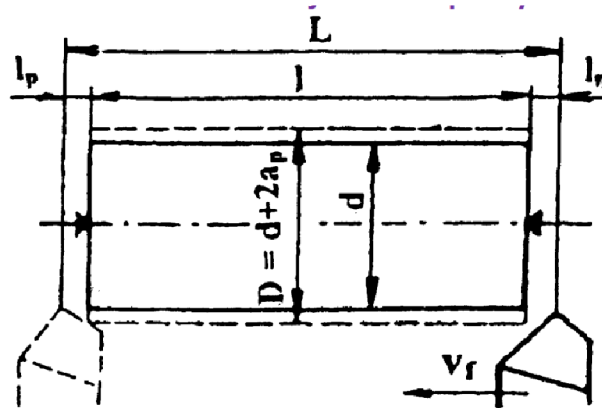


Figure 1.34 Cutting time for longitudinal turning [25]

$$t_{\text{cut}} = \frac{L}{v_f} = \frac{L}{f \cdot n} \quad [\text{min}] \quad (1.8)$$

$L$  - work piece length [mm]

$v_f$  - cutting length per minute [mm.min<sup>-1</sup>]

#### Cutting time for multiple passes:

$$t_{\text{cut}} = \frac{L}{f_r} \cdot i = \frac{L}{f \cdot n} \cdot i \quad [\text{min}] \quad (1.9)$$

$$n = \frac{1000 \cdot V_c}{\pi \cdot D} \quad [\text{min}^{-1}] \quad (1.10)$$

$$i = \frac{\frac{D-d}{2}}{ap} \quad (1.11)$$

$f_r$  - feed per minute [mm.min<sup>-1</sup>]

$i$  - number of passes (strokes) (this number depends on the depth of cut  $ap$  and amount of material to be removed)

$L$  - length of each pass [mm]

$f$  - feed rate per revolution [mm.min<sup>-1</sup>]

$n$  - rotational speed [min<sup>-1</sup>]

$V_c$  - Cutting speed [m.min<sup>-1</sup>]



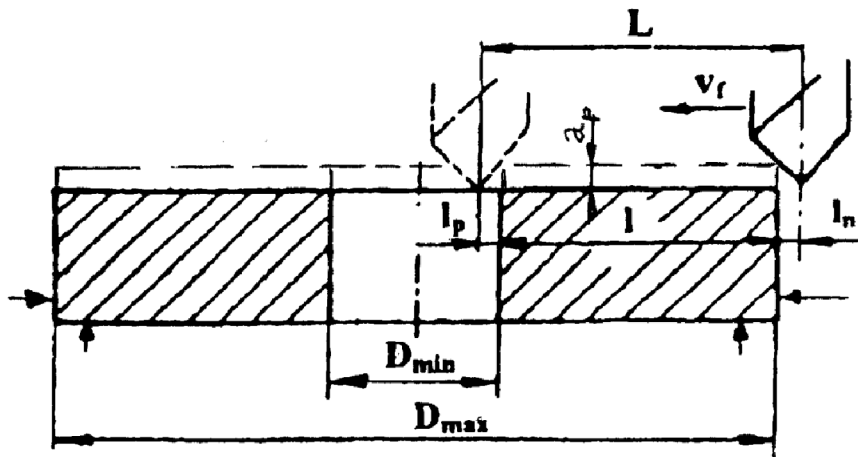


Figure 1.35 Cutting time for facing [25]

Cutting time for facing (turning):

$$t_{Asn} = \frac{L}{v_f} = \frac{l + l_n + l_p}{n \cdot f} = \frac{(D_{\max} + 2l_n) - (D_{\min} - 2l_p)}{2 \cdot n \cdot f} \quad [\text{min}] \quad (1.12)$$

$t_{Asn} = t_{\text{cut}}$  – cutting time [min]

$D_{\max}$  – maximum diameter of the machined surface [mm]

$D_{\min}$  – the minimum diameter of the machined surface [mm]

$a_p$  – Depth of cut [mm]

$l$  – length of machined surface [mm]

$l_n$  – entering length [mm]

$l_p$  – run length [mm]

$L$  – tool path in the direction of feed rate [mm]

$v_f$  – table feed rate [ $\text{mm} \cdot \text{min}^{-1}$ ]

Total machine time for one piece:

$t_{\text{cut}}$  = time needed to cut material (drilling + milling)

$t_{\text{prep}}$  = preparing time for each piece (aligning, clamping....)

$t_{\text{set-up}}$  = set-up time before starting the production, this time only needed for the first piece produced (collecting tools, checking machine, setting machine zeros, programming....)

The cutting time is the same for CNC and manual machine tools (if same tools, feeds, speeds...). Meanwhile machining time is more than just cutting time, since there is time needed to prepare for the cutting

### 1.4.3 Production Size

It is common knowledge that the bigger the size of production the lower the cost to produce for each piece, and to understand this we need to look into costs not related to production size like the following:

#### Setup cost

Setup costs cover the costs of preparation for the machining. Like the time it takes an operator to load and calibrate tooling, install fixtures and work-holding and establish machine/part zeroes and offsets. Setup costs account for a large amount of a part's price and will be most impacted by order quantity [41].

#### Programming for CNC machines

In order to machine a part, a programmer must first generate code to tell the CNC which operations to perform. This can be done by hand or with the help of CAD/CAM software. Depending on the complexity of the part, the programming process can take minutes or hours. This time is factored into preparation time.

Sometimes the production size can be very critical to the cost on the following chart we can see cost per part. Where the cost per unit for a production volume of 1000 is approximately 88% less than cost of a one-piece production.

Cost per unit vs. Number of units

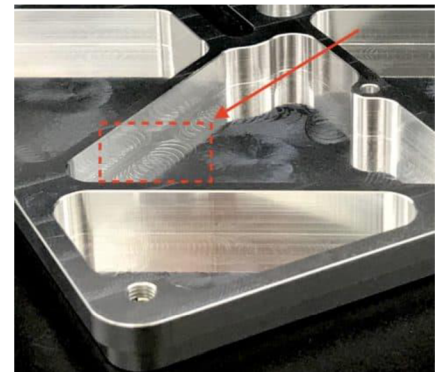
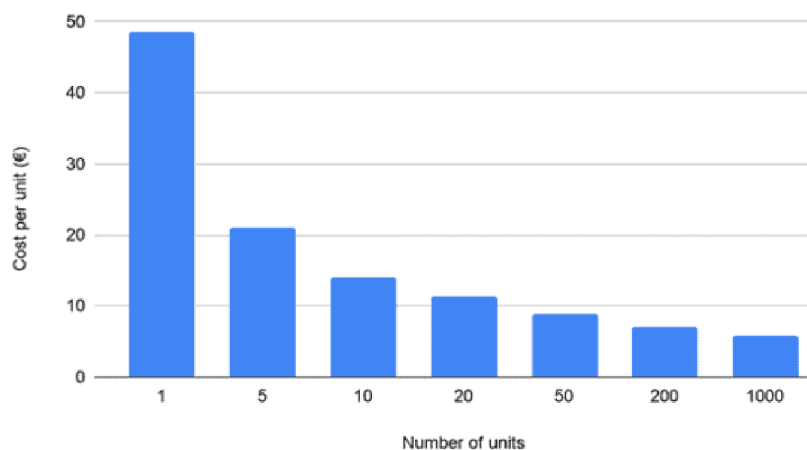


Figure 1.36 Cost dependence on order size for the part next to the chart made from aluminum [41]



#### 1.4.4 Cost of Tooling

Another factor for cost is tooling, sometimes the machining time can be much smaller by pushing cutting tools to cut more material (increasing cutting speeds and feeds), this causes tools to wear faster making the cost higher in terms of tooling but less in terms of machining time. So machinists carefully measure the priority of each production to machine time or tooling costs.

Tooling cost per piece can be calculated by the following formula:

$$\text{Tooling cost per piece} = \frac{t_{cut}}{t_L} \cdot K \text{ [\$]} \quad (1.13)$$

Where:

$T_{cut}$  – cutting time [min]

$T_L$  – total tool life [min]

$K$  – price of the tool [\\$]

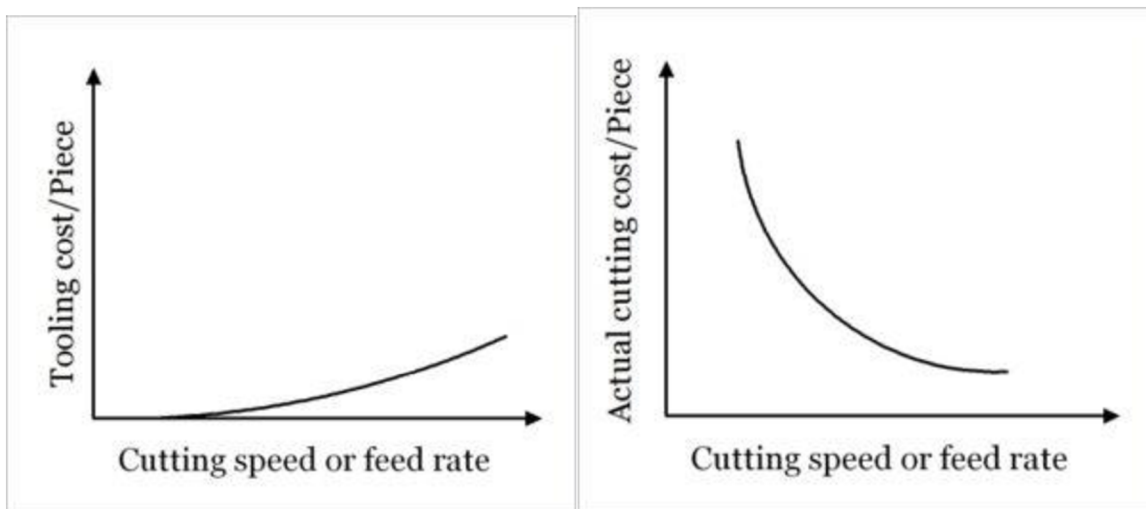


Figure 1.37 Tooling cost – cost of the cutting tool [49]

## 2 CHOSEN PROFILE (SHAFT)

For the purpose of this thesis there is a need to understand the difference between different machining technologies on a specific profile shape of rotating parts. The chosen profile was a shaft which shows different features requiring varying machining operations.

In this chapter we will have a look on the machining process of shafts, in terms of conventional and CNC, then there will be a cost investigation to determine the method for different production volumes.

### 2.1 Profile Specifications:

As we can see in the 3D model this shaft has many rotational surfaces on different diameters, as well as a hole and feather keyway.

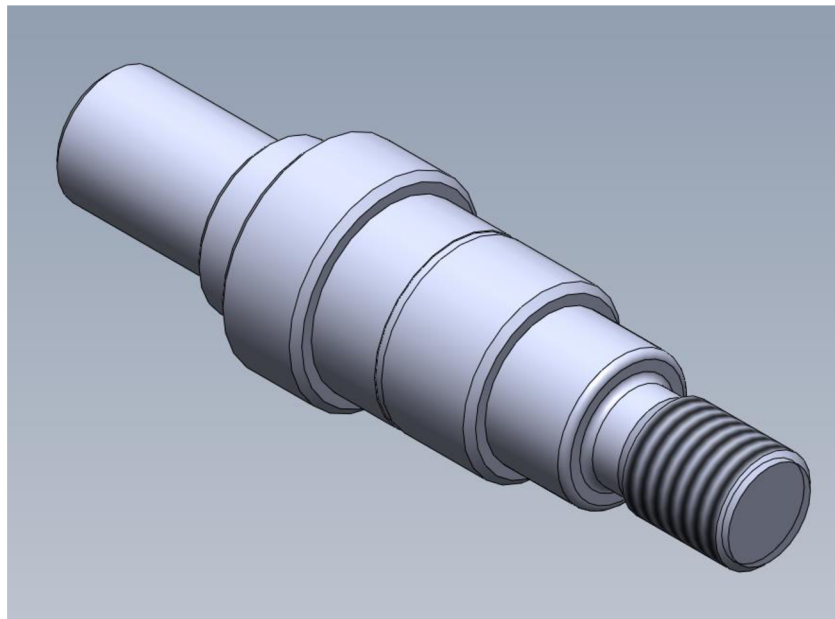


Figure 2.1 Isometric view for the Shaft

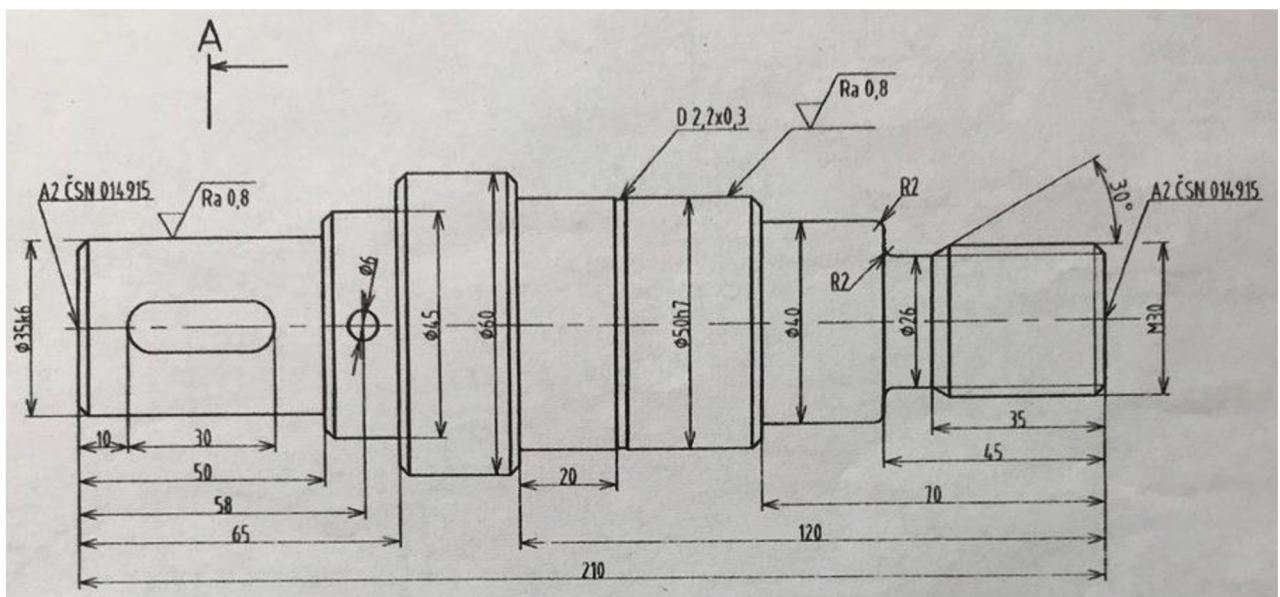


Figure 2.2 Drawing View for Dimensions

## 2.2 Machining Process Using Conventional or CNC Machines

The following process is the manufacturing of the shaft using classic machine tools, this kind of work is fully manual and will give clear understanding of the machining processes of rotational surfaces and rotating parts machining.

### 2.2.1 Cutting cylinder bar (Preparation of Workpiece):

In this step we prepare the work piece. For the purpose of creating a shaft usually it is cut from a cylindrical bar (sometimes from a casting). To perform this step, we can use a metal bandsaw.

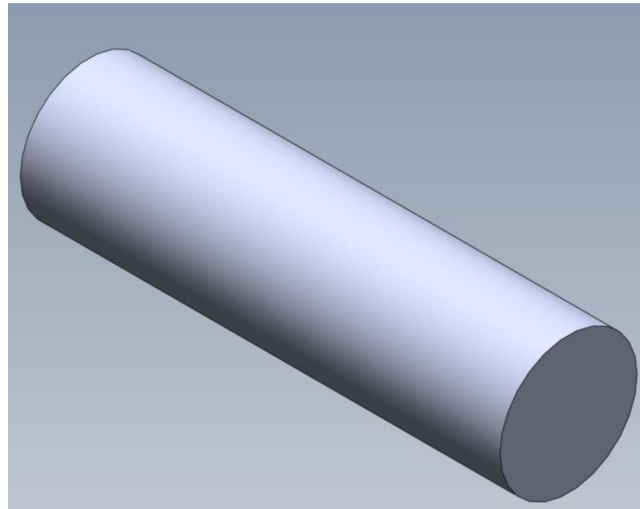


Figure 2.3 Metal Cutting Bandsaw [42] and Figure 2.4 Workpiece

#### Extra material for the diameter:

Since the biggest diameter  $\text{Ø}60$  requires no toleration (non-functional surface). Also, the next biggest diameter  $\text{Ø}50\text{H}7$  there is 10mm extra material for machining, we can start the workpiece from that diameter with no machining.

#### Extra material from length:

To estimate a safe extra material on the sides of the workpiece we can use the following equation:

$$\begin{aligned} D_{\text{max}} &= 60 \text{ [mm]} && \text{(max. diameter)} \\ L_{\text{extra}} &= 0,05 \cdot D_{\text{max}} + 2 && \text{(extra material)} \\ L_{\text{extra}} &= 0,05 \cdot 60 + 2 = 5 \text{ mm} \end{aligned} \quad (2.1)$$

So, we cut 215mm in length from a 60mm diameter bar material 11 500 [referenced in the drawing]

After this step a center hole can be drilled into the workpiece to allow for tailstock to support the workpiece from shaking and vibrating during the machining process. But due to the small length of the workpiece (215mm length and 60mm diameter) there is no need to attach the tailstock.

## 2.2.2 Turning

Note: it is necessary that during and after each of these turning operations to measure and make sure the cutting is within the toleration of the dimensions required.

- Clamping in the chuck
- Facing the first face
- Roughing  $\varnothing 35$  (with concern to extra material for finishing)



Figure 2.4

- Roughing  $\varnothing 45$  (with concern to extra material for finishing)

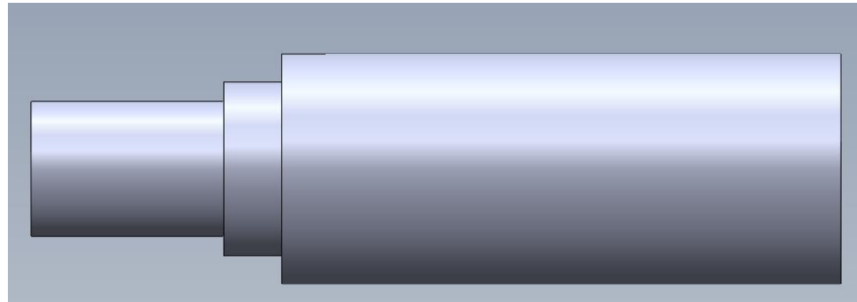


Figure 2.5

- Finishing of diameter  $\varnothing 35_{k6} \rightarrow 35^{+0,018}_{+0,002}$  (with concern to extra material for polishing)
- Finishing of diameter  $\varnothing 45$
- Chamfering  $2 \times 45^\circ$  (3x)

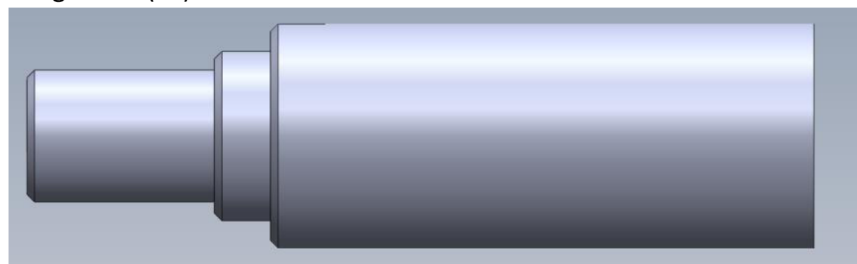


Figure 2.6

- Turning workpiece and clamping from other side.
- Facing the second face
- Roughing  $\varnothing 30$  (with concern to extra material for finishing)

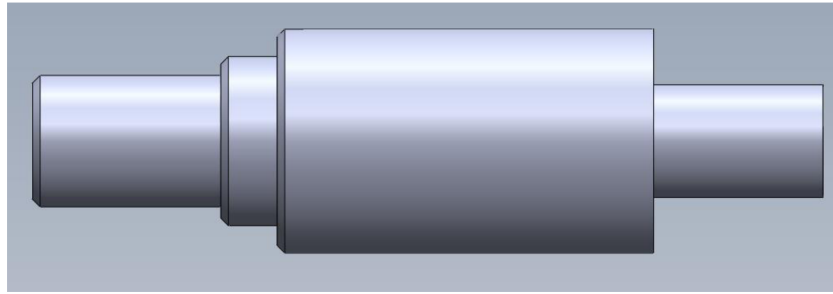


Figure 2.7

- Roughing  $\varnothing 26$

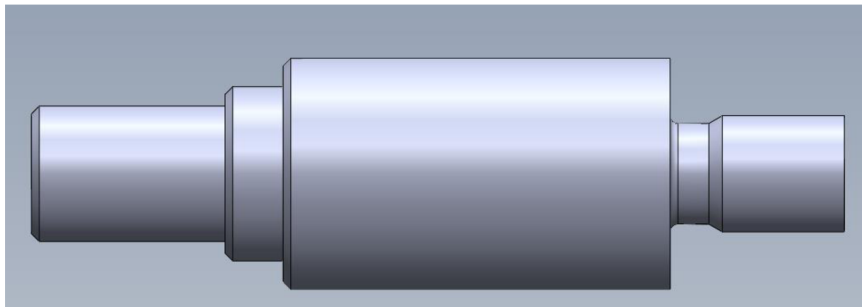


Figure 2.8

- Roughing  $\varnothing 40$  (with concern to extra material for finishing)

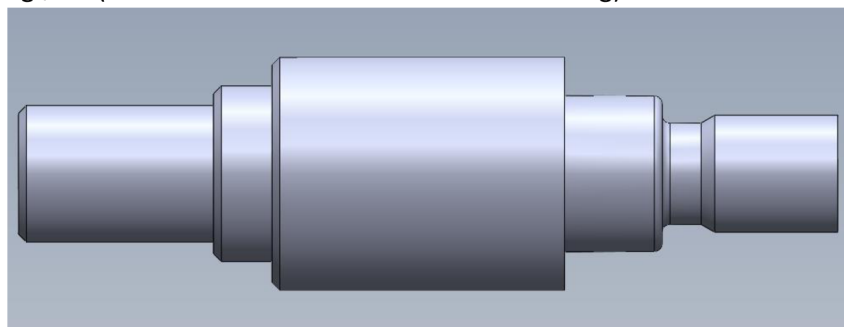


Figure 2.9

- Roughing  $\varnothing 50h7$  (with concern to extra material for finishing)

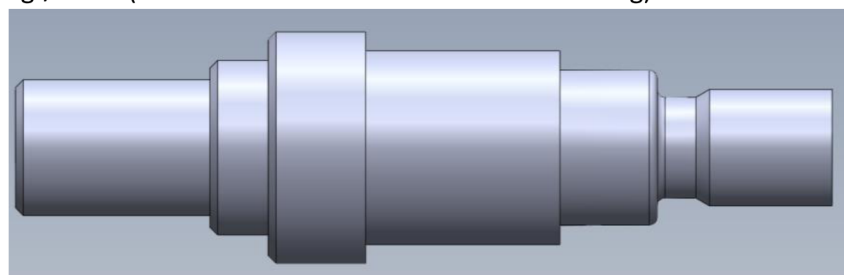


Figure 2.10

- Finishing  $\varnothing 30$
- Cutting  $30^\circ$  undercut neck
- Finishing  $\varnothing 26$
- Cutting R2 inner fillet
- Cutting R2 outer fillet

- Finishing  $\varnothing 40$
- Finishing of  $\varnothing 50 \rightarrow \varnothing 50^{0}_{-0.025}$  (with concern to extra material for polishing)
- Chamfering  $2 \times 45^\circ$  (3x)

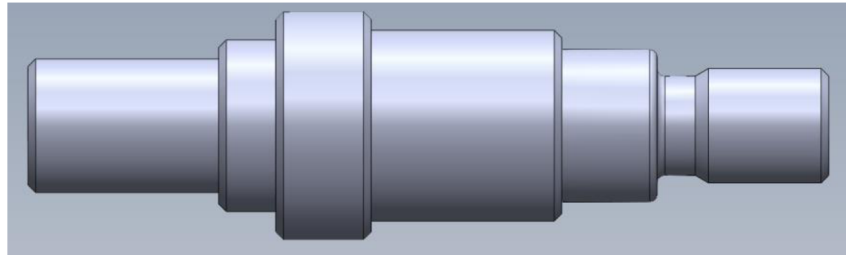


Figure 2.11

- Grooving  $2,2 \times 0,3$

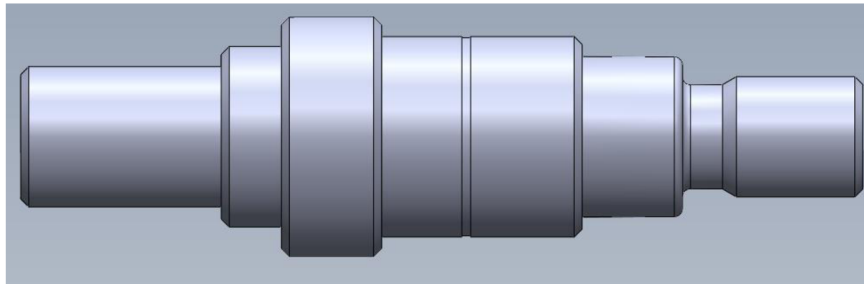


Figure 2.12

- Threading M30

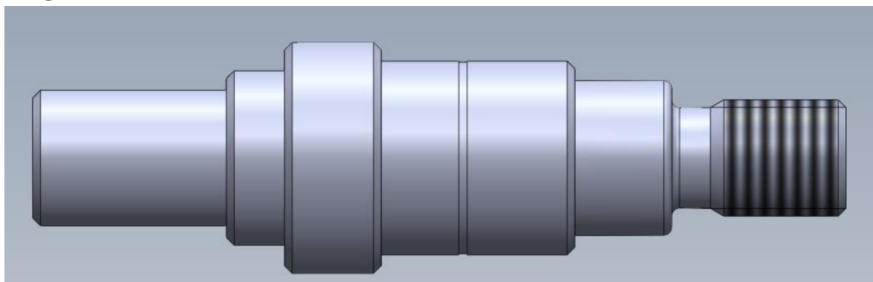


Figure 2.13

- Removing the shaft from the chuck

### 2.2.3 Milling

Note: it is necessary that during and after each of these turning operations to measure and make sure the cutting is within the toleration of the dimensions required.

- Clamping in the chuck
- Milling of slot 10x30 (max depth of  $4.7^{0}_{-0.2}$ ) (end mill smaller than slot width)
- Center drilling to determine position of  $\varnothing 6$  hole.
- Drilling  $\varnothing 6$  hole
- Reaming the  $\varnothing 6$  hole
- Removing the shaft from the chuck
- Deburring slot and hole

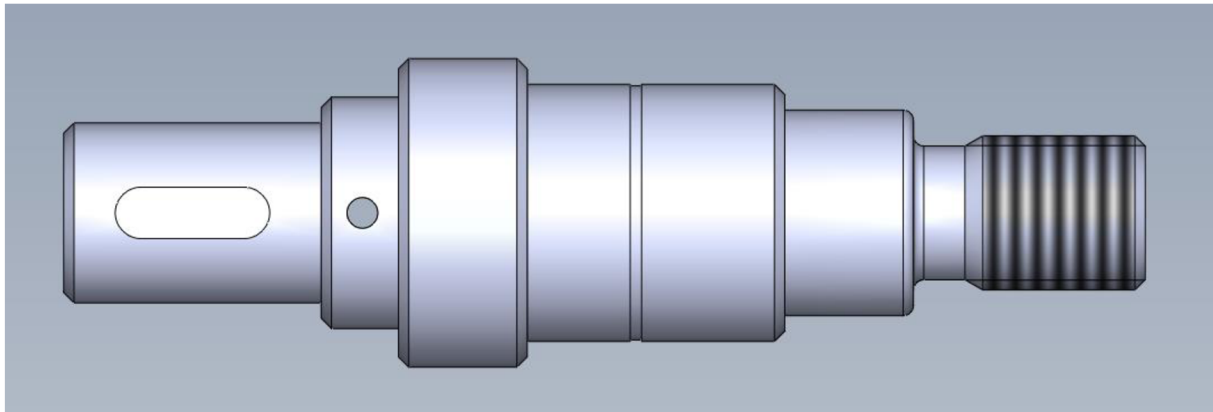


Figure 2.14

### 2.2.4 Polishing

Polishing of  $\varnothing 35h6$  and  $50h7$  to the required surface roughness and tolerances.

For this operation we can use: Cylindrical Grinding machine



Figure 2.15 Cylindrical Grinding Machine [43]

## Machining Using CNC Machine

Here we will only use CNC lathe machine and other machines (cutting/milling/polishing) will be manual (conventional machines) for convenience.

## Turning:

Note: measurements are taken after the operations are done. (also it is possible to stop the CNC machine to make measurements)

- Clamping in the chuck (**manual**)
- Programing the G-code and M-code(or by CAD/CAM software), and setting workpiece zeros(**manual**)
- Facing the first face
- Roughing  $\varnothing 35$  and  $\varnothing 45$  (with concern to extra material for finishing)
- Finishing of diameter  $\varnothing 45$  and  $\varnothing 35k6 \rightarrow 35^{+0,018}_{-0,002}$  (with concern to extra material for polishing)
- Chamfering  $2 \times 45^\circ$  (3x)
- Turning workpiece and clamping from other side.(**manual**)
- Facing the second face
- Roughing  $\varnothing 30$ ,  $\varnothing 26$ ,  $\varnothing 40$ ,  $\varnothing 50h7$  (with concern to extra material for finishing)
- Finishing  $\varnothing 30$ ,  $\varnothing 26$  (including  $30^\circ$  neck),  $\varnothing 40$  and  $\varnothing 50 \rightarrow \varnothing 50^0_{-0,025}$ (with concern to extra material for polishing)
- Cutting R2 inner fillet
- Cutting R2 outer fillet
- Chamfering  $2 \times 45^\circ$  (3x)
- Grooving 2,2x0,3
- Threading M30
- Removing the shaft from the chuck (**manual**)



## 2.3 Machining time:

### Turning cutting time:

To calculate the cutting time, we need to count the number of strokes and time needed for each stroke. The number of strokes depends on the depth of cut. In the following image we can see the areas of machining and each area has its own operations and cutting time as we can see in the table following.

Total Cutting time:

$$t_{\text{cut}} = \frac{L}{V_f} \cdot i = \frac{L}{f \cdot n} \cdot i$$

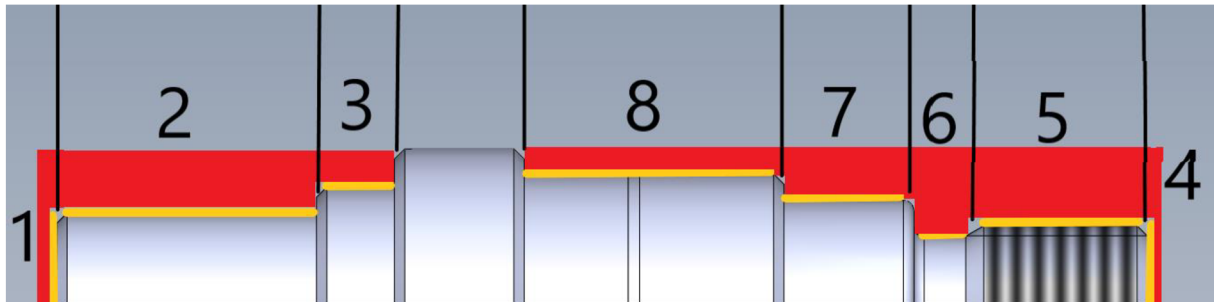


Figure 2.16 Machining areas, Red-Roughing Orange-finishing

Assuming High Speed Steel cutting tool the cutting speed of 80[m/min] can be suitable for steel machining, and feed rate of 0.2mm for roughing, 0.1mm for finishing [44].

Tab. 1 Cutting Times for Turning Of The Shaft Profile:

Area	Operation	$V_c$ [m.min <sup>-1</sup> ]	N [min <sup>-1</sup> ]	$D_{\max}$ [mm]	$D_{\min}$ [mm]	f [mm/rev]	$V_f$ [mm/min]	$a_p$ [mm]	i [-]	L [mm]	$t_{\text{cut}}$ [min]
1	face roughing	-	800	60	0	0,2		1	2	30	0,50
	face finishing	-	800	60	0	0,1		0,2	1	30	0,49
2	roughing	80	424	60	35	0,2	85	3	5	50	2,95
	finishing	80	728	35	35	0,1	73	0,2	1	50	0,69
3	roughing	80	424	60	45	0,2	85	3	3	15	0,53
	finishing	80	566	45	45	0,1	57	0,2	1	15	0,27
4	Face roughing	-	800	60	0	0,2		1	3	30	0,75
	face finishing	-	800	60	0	0,1		0,2	1	30	0,50
5	roughing	80	424	60	30	0,2	85	3	5	45	2,65
	finishing	80	849	30	30	0,1	85	0,2	1	45	0,53
	<b>Threading</b>	30	318	30	29,5	0,2	64	0,1	5	35	2,75
6	roughing	80	849	30	26	0,2	170	1	2	10	0,12
	finishing	80	979	26	26	0,1	98	0,2	1	10	0,10
7	roughing	80	424	60	40	0,2	85	3	4	25	1,18
	finishing	80	637	40	40	0,1	64	0,2	1	25	0,39
8	roughing	80	424	60	50	0,2	85	3	2	50	1,18
	finishing	80	509	50	50	0,1	51	0,2	1	50	0,98
$\sum t_{as}$											16,55

$D_{\max}$  Main diameter before machining

$D_{\min}$  Diameter after machining

**Machining Times for Manual Lathe:**

$t_{\text{cut}} = 16 + (16 \cdot 20\%) = 19,2$  [min] (turning + extra 20% of cutting time)  
 $t_{\text{prep}} = 10$  [min] (aligning, clamping, cleaning...)  
 $t_{\text{set-up}} = 10$  [min] (collecting tools, checking machine health, setting machine zeros...)

Total turning time for one piece =  $19,2 + 10 + 10 = 39,2$  [min]

**Machining Times for CNC Lathe:**

$t_{\text{cut}} = 16 + (16 \cdot 20\%) = 19,2$  [min] (turning + extra 20% of cutting time)  
 $t_{\text{prep}} = 7$  [min] (aligning, clamping, cleaning...)  
 $t_{\text{set-up}} = 30$  [min] (programming of G-code, checking coolant ...)

Total turning time for one piece =  $19,2 + 7 + 30 = 56,2$  [min]

**Milling Machining Times [45][46]:**

$t_{\text{cut}} = 1 + 2 = 3$  [min] (drilling + milling)  
 $t_{\text{prep}} = 4$  [min] (aligning, clamping, cleaning...)  
 $t_{\text{set-up}} = 8$  [min] (collecting tools and tooling, checking machine health, setting machine zeros...)

Total milling time for one piece =  $3 + 4 + 8 = 15$  [min]

**Machining Times for Grinding:**

$t_{\text{cut}} = 5$  [min] (Polishing)  
 $t_{\text{prep}} = 2$  [min] (aligning, clamping, cleaning...)  
 $t_{\text{set-up}} = 5$  [min] (programming of G-code, checking coolant ...)

Total grinding time for one piece =  $5 + 2 + 2 = 12$  [min]

**Total Shaft machining time for one piece using all manual machines:**

$t_{\text{tot}} = 39,2 + 15 + 12 = 66,2$  [min]

**Total Shaft machining time for one piece using CNC lathe and the rest manual:**

$t_{\text{tot}} = 56,2 + 15 + 12 = 83,2$  [min]

Tab. 2 Distribution of Machining time over technologies:

technology	Percentage of total time
Turning	59% - 67%
Polishing	14% - 18%
Milling	15% - 18%
Drilling	3% - 5%

## 2.4 SIZE OF PRODUCTION AND COST

For cost comparison we are only going to compare machining times in both situations, CNC or manual machine tools. Since time is the most significant factor that can be manipulated in the process of machining.

### Production Size Effect on Machining Time:

In the chart below we can see the effect of the production size on the machining time per piece. This effect is due to set-up times needed before starting the machining process.



Figure 2.17 Graph for relation between Production size and machining time per piece

We can clearly see the positive side of CNC machines, so they are better at achieving lower machining time for bigger sizes of production, and better in terms of precision. On the other hand, where small size production is planned it is better to use manual machines if the precision is not highly valued.

Another factor for cost is tooling, sometimes the machining time can be much smaller by pushing cutting tools to cut more material (increasing cutting speeds and feeds), this causes tools to wear faster making the cost higher in terms of tooling but less in terms of machining time. So machinists carefully measure the priority of each production to machine time or tooling costs.

### 3 CHOSEN PROFILE (DISC)

The second profile is a disc (flange) showing different features requiring varying machining operations. But also, a little different focus on machining on different machines other than shafts. In this chapter we will have a look at the machining process of a disc, in terms of conventional and CNC.

#### 3.1 Profile Specifications:

As we can see in the 3D model this disk has many rotational surfa

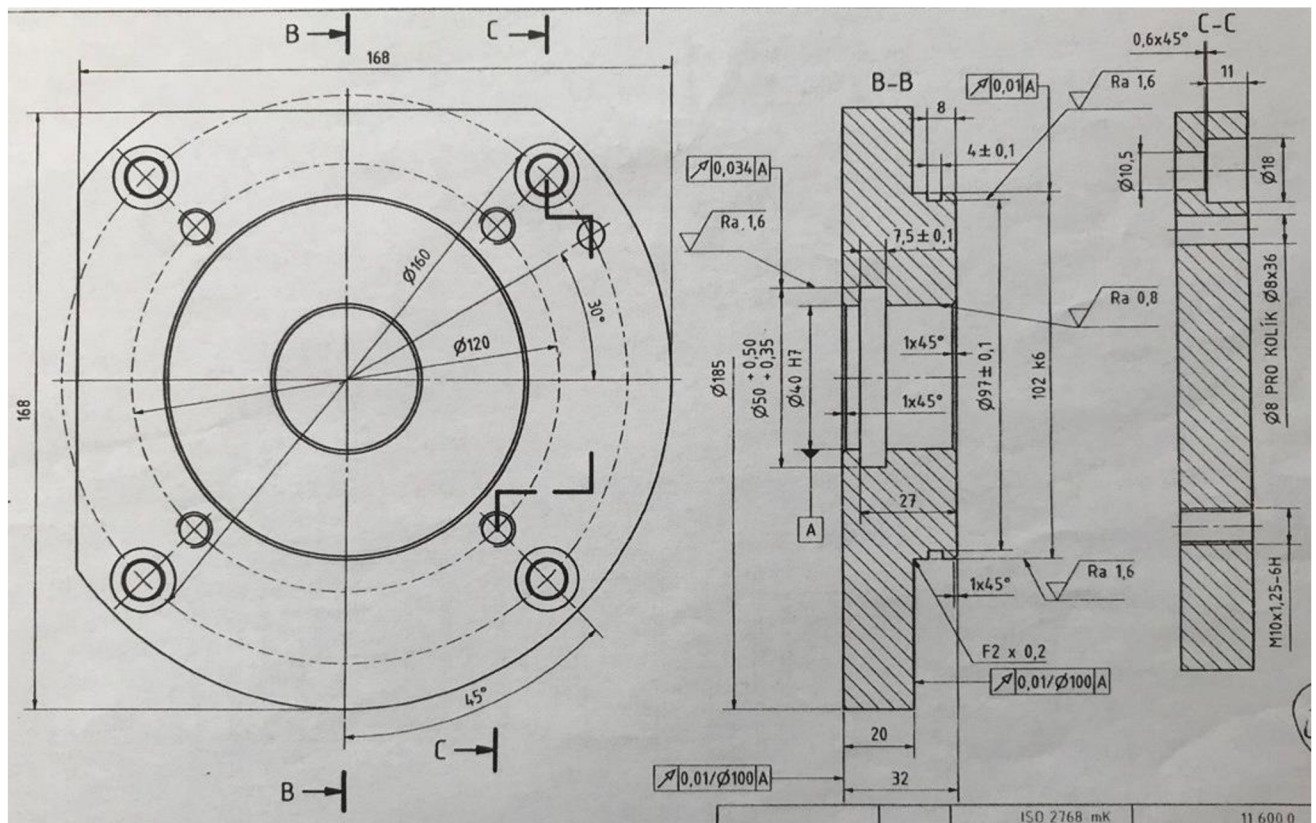


Figure 3.1 Drawing Views for disc dimensions

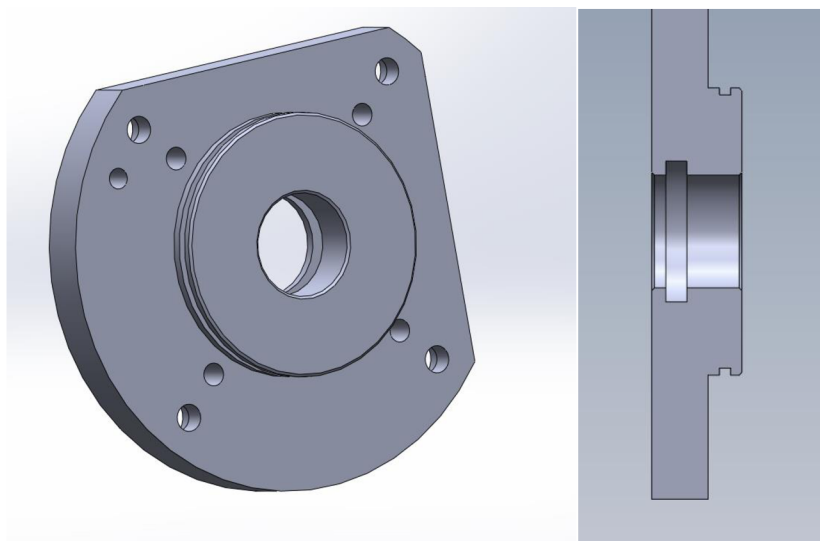


Figure 3.2 3D model to simplify the Disc shape

## 3.2 Machining Process Using Conventional or CNC Machines

### 3.2.1 Cutting cylinder bar (Preparation of Workpiece):

In this step we prepare the work piece. For the purpose of creating a Disc usually it is cut from a cylindrical bar (sometimes from a casting). To perform this step, we can use parting tools on a lathe or a metal bandsaw.



Figure 3.3 Metal Cutting Bandsaw [42]

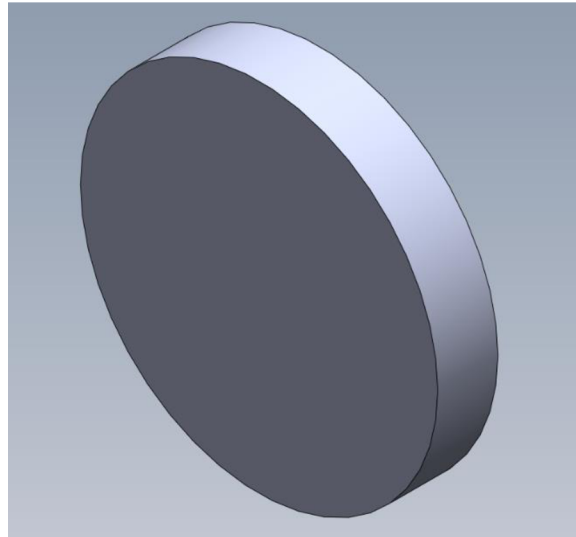


Figure 3.4 Workpiece

#### **Extra material for the diameter:**

No extra material is needed on the outer diameter since there is no machining required the outer diameter is  $\varnothing 190$

#### **Extra material from length:**

As mentioned in the drawing the workpiece is  $\varnothing 190 - 35$ , while the width of finished part is 32mm, so we need to have 3mm extra material for facing operations.

(However, it is recommended to have 11.5mm based on general estimation equation 2.1)

### 3.2.2 Turning:

- Clamping in the chuck
- Facing the first face
- Turning workpiece and clamping from other side
- Facing the second face
- Roughing  $\varnothing 102k6$  (with concern to extra material for finishing)



Figure 3.5

- Finishing of diameter  $\varnothing 102k6 \rightarrow \varnothing 102^{+0,025}_{+0,003}$  (with concern to extra material for polishing)
- Chamfering  $1 \times 45^\circ$



Figure 3.6

- Grooving

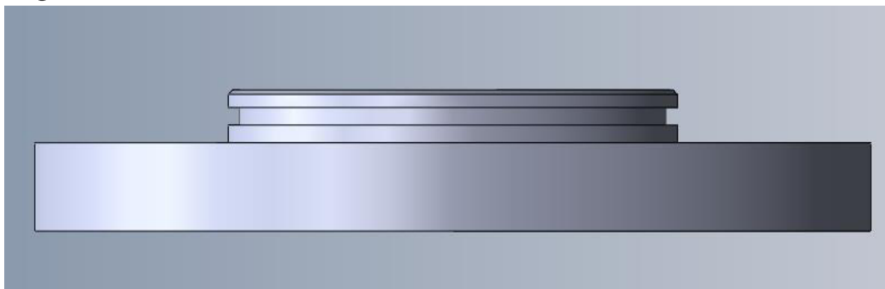


Figure 3.7

- Drilling  $\varnothing 16$

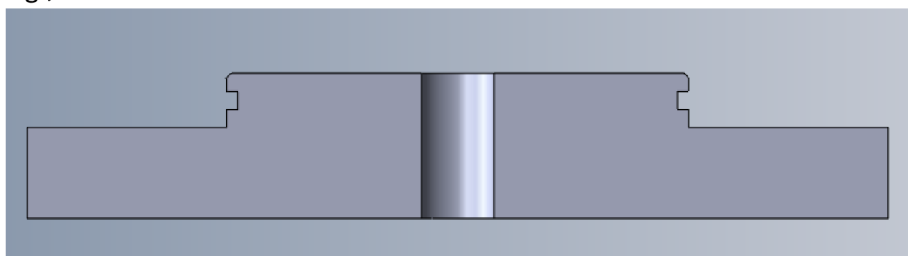


Figure 3.8

- roughing  $\varnothing 40H7 \rightarrow \varnothing 40^{+0,025}_{+0}$  (Ra 0.8) (with concern to extra material for finishing)

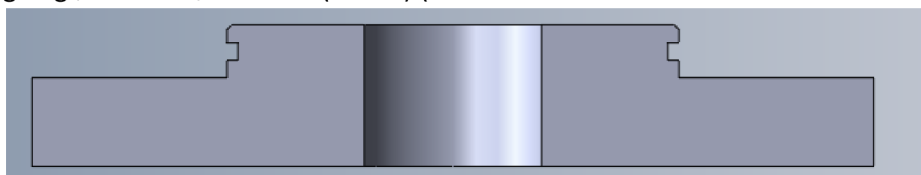


Figure 3.9

- finishing  $\varnothing 40H7 \rightarrow \varnothing 40^{+0,025}_{+0}$  (Ra 0.8) (with concern to extra material for polishing)

- Internal roughing of groove  $\varnothing 50^{+0,5}_{+0,35}$

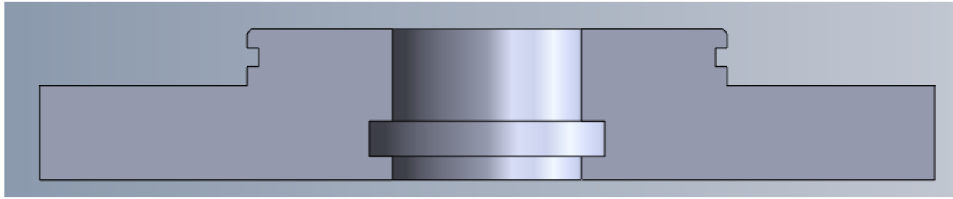


Figure 3.10

- Internal finishing of groove  $\varnothing 50^{+0,5}_{+0,35}$
- Chamfering  $1 \times 45^\circ$  (2x)

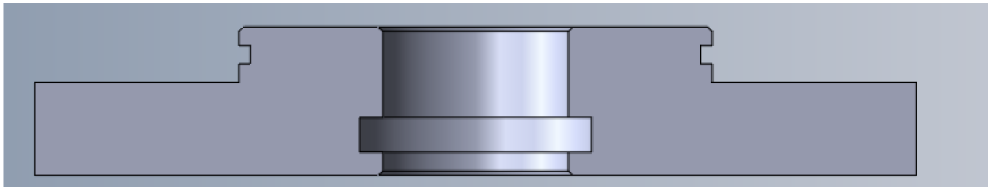


Figure 3.11

- Removing the disc from the chuck

### 3.2.3 Milling/Drilling:

We can also use a drill press for this operation.

- Clamping in the chuck
- Center Drilling all holes (9x)

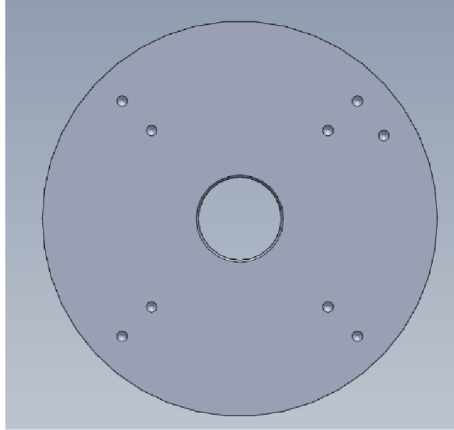


Figure 3.12

- Drilling holes  $\varnothing 10,5$  (4x)

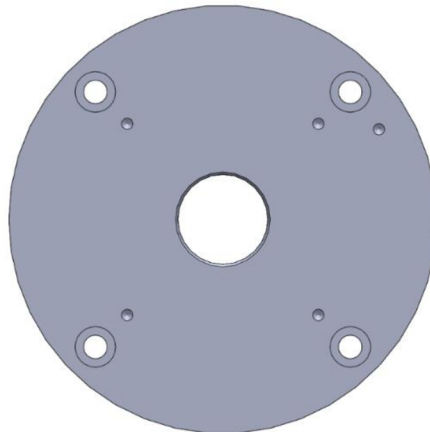


Figure 3.13

- Reaming holes  $\varnothing 10,5$  (4x)
- Drilling holes M10x1.,25-6H(4x)
- Counter boring holes  $\varnothing 18$  (4x)

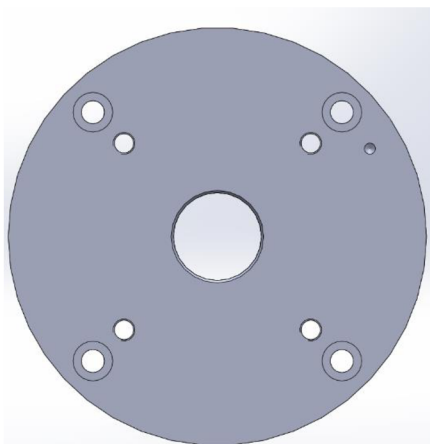


Figure 3.14



- Reaming holes  $\varnothing 18$  (4x)
- Drilling hole  $\varnothing 8$

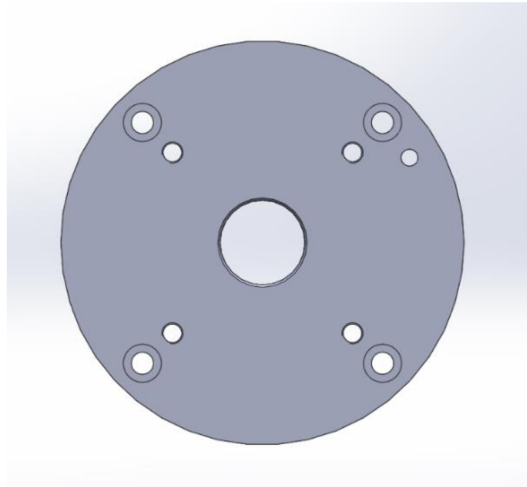


Figure 3.15

- Tapping holes M10x1.,25-6H(4x)
- Reaming hole  $\varnothing 8$
- End milling the straight sides of the final product.

This operation can also be done on a bandsaw, but if it is a CNC milling machine it would be better to just mill it as automatic following operation.

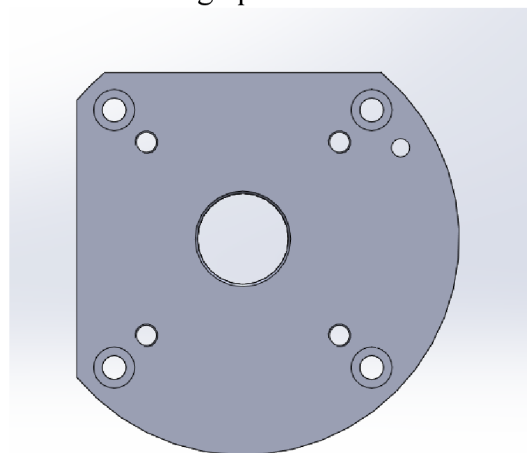


Figure 3.16

- Removing the disc from the vice
- Hand Deburring all edges.

### 3.2.4 Polishing:

Polishing of straight edges on the side, inner  $\varnothing 40h7$  (Ra0.8),  $\varnothing 102k6 \rightarrow \varnothing 102^{+0,025}_{+0,003}$ , to the required surface roughness and tolerances.

Machining Using CNC Machine

This disc can be machined using a manual Lathe, Mill, and grinding machines. Other possibility is to use CNC Lathe or CNC Mill or both of them. The cutting operations will not be different, but preparations for each operation can be totally different. For example, using a CAD/CAM system to generate the cutting program or programing it directly to the CNC machines.

### 3.3 Machining time:

#### Turning cutting time:

To calculate the cutting time, we need to count the number of strokes and time needed for each stroke. The number of strokes depends on the depth of cut. In the following image we can see the areas of machining and each area has its own operations and cutting time as we can see in the table following.

Total Cutting time:

$$t_{\text{cut}} = \frac{L}{V_f} \cdot i = \frac{L}{f \cdot n} \cdot i$$

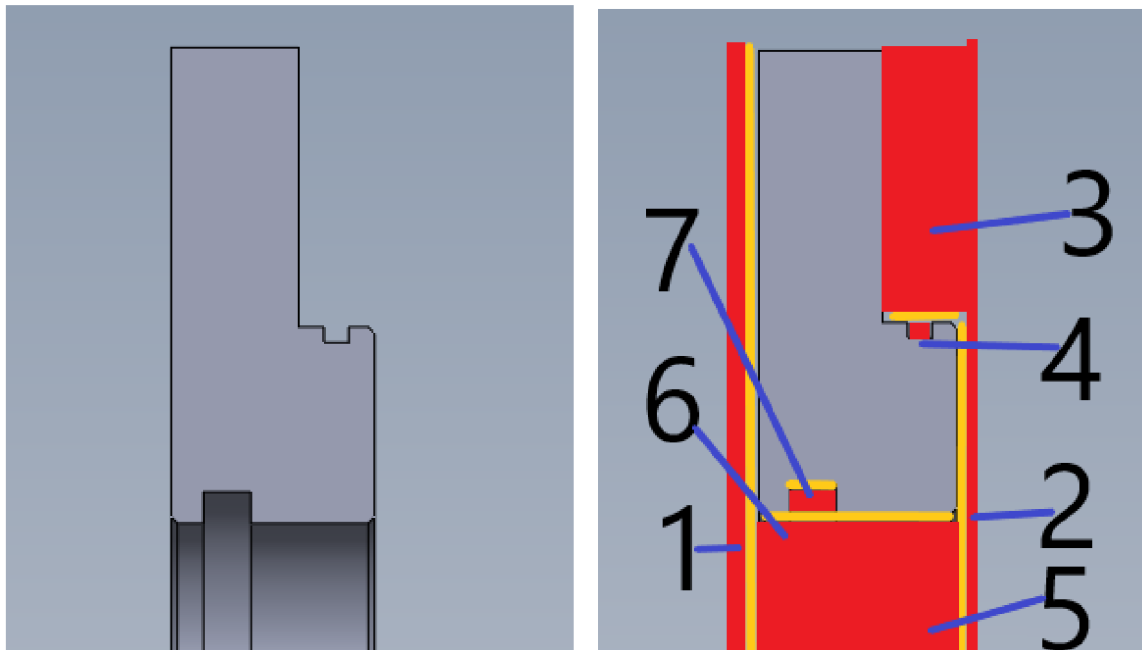


Figure 3.17

Tab. 3 Cutting Times for Turning of The Disc Profile:

Area	Operation	$V_c$ [m.min <sup>-1</sup> ]	N [min <sup>-1</sup> ]	$D_{\text{max}}$ [mm]	$D_{\text{min}}$ [mm]	f [mm]	$V_f$ [mm.min <sup>-1</sup> ]	$a_p$ [mm]	i [-]	L [mm]	$t_{\text{cut}}$ [min]
1	face roughing	-	800	60	0	0,2	-	1	2	-	0,50
1	face finishing	-	800	60	0	0,1	-	0,2	1	-	0,50
2	face roughing	-	800	60	0	0,2	-	1	1	-	0,25
2	face finishing	-	800	60	0	0,1	-	0,2	1	-	0,50
3	roughing	80	134	190	102	0,2	27	3	15	12	6,72
3	finishing	80	250	102	102	0,1	25	0,2	1	12	0,48
4	grooving	80	250	102	97	0,1	25	0,5	5	8	1,60
5	drilling	-	500	16	0	0,1	50	-	1	32	0,64
6	inner roughing	80	637	40	16	0,2	127	3	4	32	1,01
6	inner finishing	80	637	40	40	0,1	64	0,2	1	32	0,50
7	grooving	80	509	50	40	0,1	51	1	5	7,5	0,74
$\Sigma$	$t_{\text{cut}}$										13,43

**Machining Times for Manual Lathe:**

$t_{cut} = 13 + (16.20\%) = 15,6$  [min] (turning + extra 20% of cutting time)  
 $t_{prep} = 10$  [min] (aligning, clamping, cleaning....)  
 $t_{set-up} = 10$  [min] (collecting tools, checking machine health, setting machine zeros...)

Total Turing time for one piece =  $15,6+10+10 = 35,6$  [min]

**Machining Times For CNC Lathe:**

$t_{cut} = 13 + (16.20\%) = 15,6$  [min] (turning + extra 20% of cutting time)  
 $t_{prep} = 7$  [min] (aligning, clamping, cleaning....)  
 $t_{set-up} = 30$  [min] (programing of G-code, checking coolant ....)

Total Turing time for one piece =  $15,6+7+30 = 52,6$  [min]

**Milling/drilling cutting time:**

To calculate cutting time of drilling we can use timetables from standards which show time for all operations needed, and time for each stroke depending on number of holes and required operations the standard used can be found at [45][46]

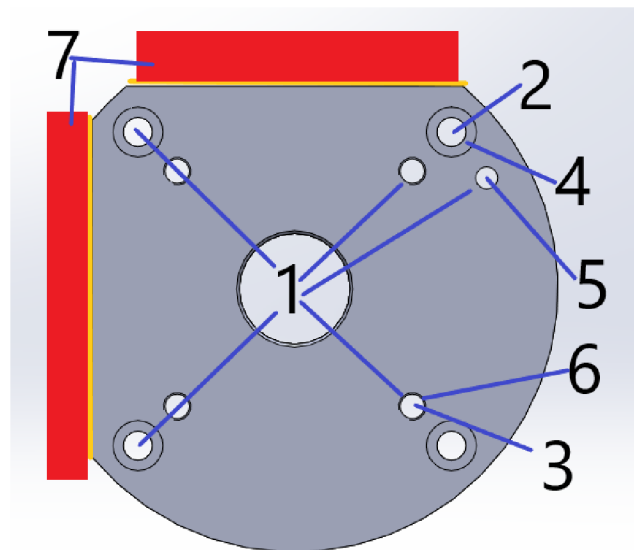


Figure 3.18

Tab. 4 Cutting Times for Milling of Disc Profile:

area	type of cutting	$t_{cut}$ [min]
1	Center drilling	0.2
2	drilling 10,5	1
3	drilling 10	1
4	counterboring 18	2
5	drilling 8	0.5
6	tapping M10	2
7	Milling	3
$\sum t_{as}$		9.7

**Machining Times for Manual Milling Machine:[45][46]**

$t_{\text{cut}} = 9,7$  [min] (drilling + milling)  
 $t_{\text{prep}} = 8$  [min] (aligning, clamping, cleaning...)  
 $t_{\text{set-up}} = 8$  [min] (collecting tools, checking machine health, setting machine zeros...)

Total milling time for one piece =  $9,7+8+8 = 25,7$  [min]

**Machining Times for CNC Milling Machine:[45][46]**

$t_{\text{cut}} = 9,7$  [min] (drilling + milling)  
 $t_{\text{prep}} = 4$  [min] (aligning, clamping, cleaning...)  
 $t_{\text{set-up}} = 20$  [min] (collecting tools and tooling, checking machine health, setting machine zeros...)

Total milling time for one piece =  $9,7+4+20 = 33,7$  [min]

**Machining Times for Grinding:**

$t_{\text{cut}} = 10$  [min] (Polishing)  
 $t_{\text{prep}} = 2$  [min] (aligning, clamping, cleaning...)  
 $t_{\text{set-up}} = 8$  [min] (programming of G-code, checking coolant ....)

Total grinding time for one piece =  $10+2+8 = 20$  [min]

**Total Disc machining time for one piece using CNC lathe and CNC Mill:**

$t_{\text{tot}} = 52,6+33,7+20 = 106,3$  [min]

**Total Disc machining time for one piece using CNC lathe and manual Mill:**

$t_{\text{tot}} = 52,6+25,7+20 = 98,3$  [min]

**Total Disc machining time for one piece using manual lathe and CNC Mill:**

$t_{\text{tot}} = 35,6+33,7+20 = 89,3$  [min]

**Total Disc machining time for one piece using manual lathe and manual Mill:**

$t_{\text{tot}} = 35,6+25,7+20 = 81,3$  [min]

Distribution of Machining time over technologies:

Technology	Percentage of total time
Turning	40% - 53%
Polishing	19% - 25%
Milling	10% - 14%
Drilling	15% - 22%

### 3.4 SIZE OF PRODUCTION AND COST

For cost comparison we are only going to compare machining times in both situations, CNC or manual machine tools. Since time is the most significant factor that can be manipulated in the process of machining.

#### Production Size Effect on Machining Time:

In the chart below we can see the effect of the production size on the machining time per piece. This effect is due to set-up times needed before starting the machining process.

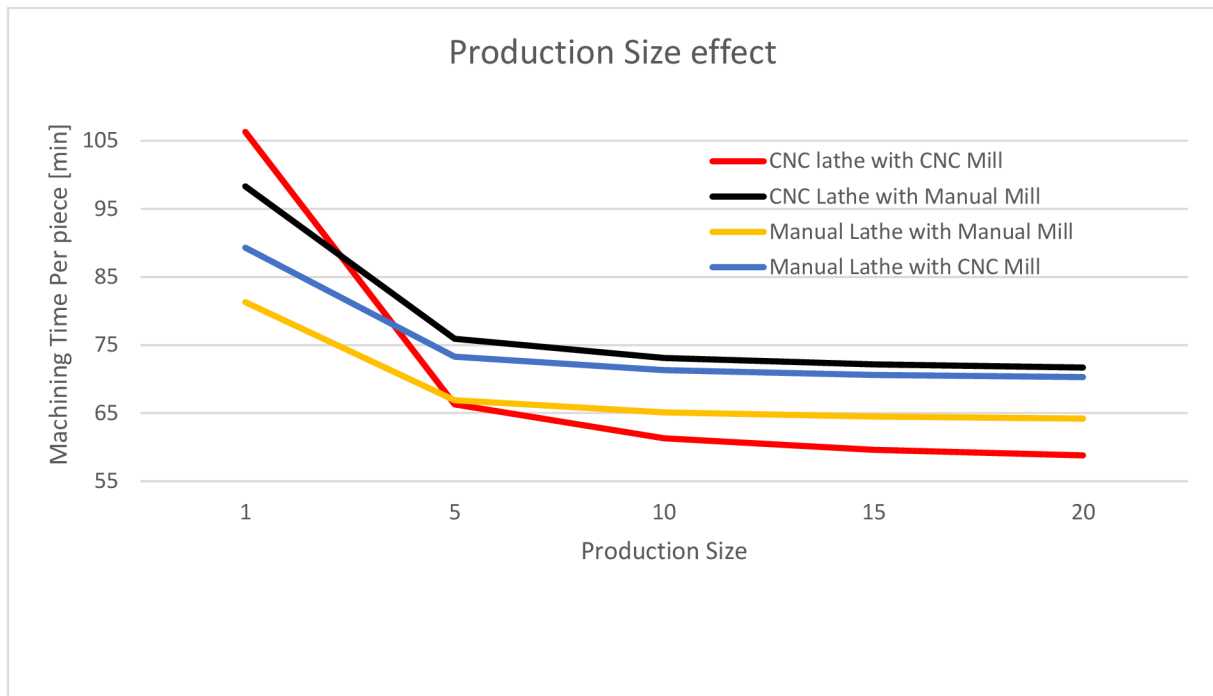


Figure 3.19 Graph for relation between Production size and machining time per piece

We can clearly see the positive side of CNC machines, so they are better at achieving lower machining time for bigger sizes of production, and better in terms of precision. On the other hand, where small size production is planned it is better to use manual machines if the precision is not highly valued.

Another factor for cost is tooling, sometimes the machining time can be much smaller by pushing cutting tools to cut more material (increasing cutting speeds and feeds), this causes tools to wear faster making the cost higher in terms of tooling but less in terms of machining time. So machinists carefully measure the priority of each production to machine time or tooling costs.

## SUMMARY

Some of the results of this thesis can be summarized as following:

- Manufacturing of rotating parts is mainly done by turning, milling, drilling, and grinding.
- As a result of calculations of machining times it is clear that the use of CNC machines is superior for high-volume production.
- CNC machines are superior in terms of precision and repeatability.
- For cost-effective production: - CNC for higher volume production and - manual machine tools for piece production.
- From the percentage of work done by lathes we can say that the most important technology for rotating parts is turning since usually the functional surfaces and machining time is on turning. So, for a workshop specialized in machining rotating parts investing in CNC lathe would be the priority depending on the type of production they have.
- Based on the required shape of the rotating part, the machine tools are chosen, and cost effectiveness and precision requirements decide the usage of CNC or manual. And in many cases manual machine tool can be favored.
- For the mentioned shaft profile, I would recommend manual machine tools for production size up to 8 pieces. More than that I would recommend CNC machines.
- For the mentioned disc profile, I would recommend manual machine tools for production size up to 5 pieces. More than that I would recommend CNC machines.

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## LIST OF SYMBOLS

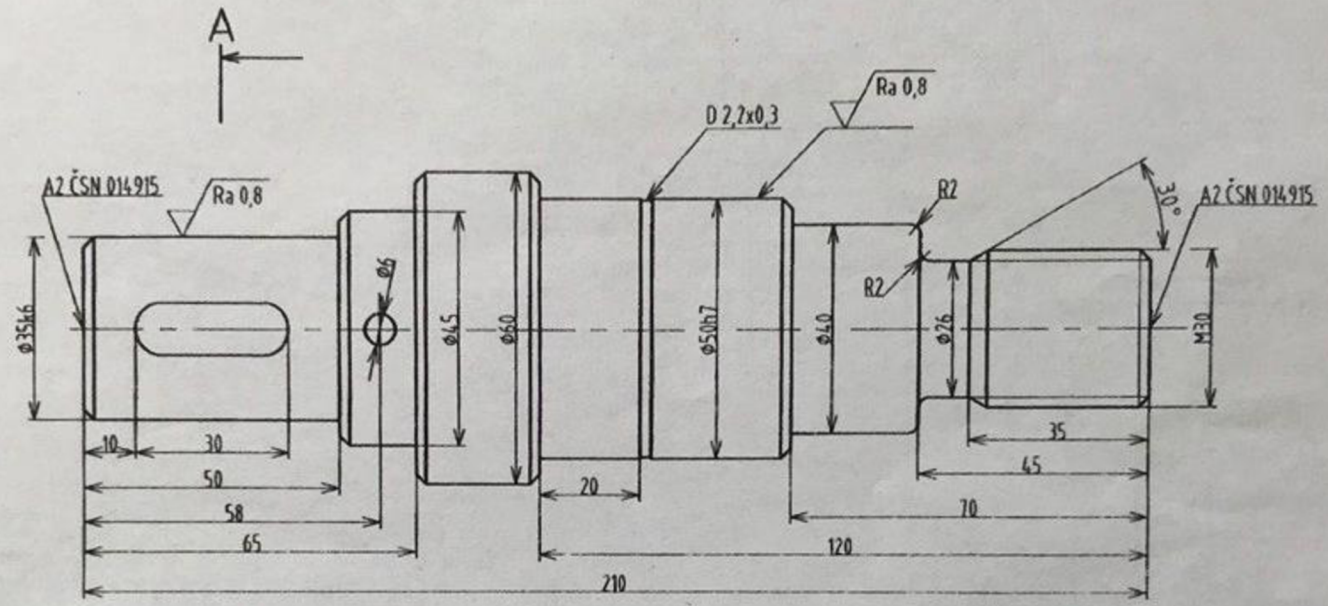
Symbol	Meaning	Unit
f	Feed per revolution	[mm]
$V_f$	Table feed per minute	[mm.min <sup>-1</sup> ]
n	Spindle speed	[min <sup>-1</sup> ]
$V_c$	Cutting speed	[m.min <sup>-1</sup> ]
D	Diameter	[mm]
$a_p$	Depth of cut	[mm]
$R_e$	Nose radius of the cutting insert	[mm]
H	Theoretical surface roughness	[ $\mu$ m]
$f_z$	Feed per tooth	[mm]
z	Number of cutting inserts	[-]
$t_{cut}$	Time needed to cut material	[min]
$t_{prep}$	preparing time	[min]
$t_{set-up}$	set-up time before starting the production	[min]
$t_{tot}$	Total time	[min]
$D_{max}$	Maximum diameter	[mm]
$D_{min}$	Minimum diameter	[mm]
$L_{extra}$	Extra material from the length side	[mm]
Ø	Diameter sign	[-]
i	Number of passes	[-]
%	Percentage	[-]

## ATTACHMENTS

- Attachment 1      Shaft Drawing  
Attachment 1      Disc Cover Drawing

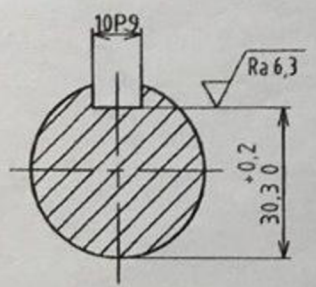


115



A

A-A



122

145

HRANY SRAZIT 2x45°

Struktura povrchu: Ra 3,2 (✓)	Hrany -0,3 +0,3	Měřítko 1:1	Přesnost ISO2768-mH
			Tolerování ISO8015
			Promítání
Materiál 11 500	Položka 660-215 ČSN 42 5551	Hmotnost 0,8 kg	CHRÁNĚNO PODLE ISO 16016
 USTAV KONSTRUOVÁNÍ	Druh dokumentu VÝKRES SOUČÁSTI	Název HŘÍDEL	
	Kreslil KOSÍŘ TOMÁŠ	Číslo dokumentu HRD_01	
	Schválil		
	Datum vydání 8.2.2011		

VYTVORENO VE VYUKOVEM PRODUKTU SPOLECNOSTI AUTODESK

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