

# MANUFACTURING

Instructions for Laboratory



Lodz University of Technology  
Handbooks and Scripts

**LODZ 2022**

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ISBN 978-83-66741-39-3

DOI: 10.34658/9788366741393

**Lodz University of Technology Press**

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Lodz University of Technology Handbooks and Scripts, No .2383

First edition

## Preface

Making things has been an essential activity of human civilizations since before recorded history. Today, the term manufacturing is used for this activity. For technological and economic reasons, manufacturing is important to the welfare of the all developed and developing nations. Technology can be defined as the application of science to provide society and its members with those things that are needed or desired. Technology affects our daily lives, directly and indirectly, in many ways. Manufacturing is the critical factor that makes technology possible.

The word **manufacture** is derived from two Latin words, **manus** (hand) and **factus** (make); the combination means made by hand. The English word manufacture is several centuries old, and “made by hand” accurately described the manual methods used when the word was first coined.

Manufacturing – Instructions for laboratory, is designed for a first course or two-course sequence in manufacturing at the beachelor’s level in mechanical, industrial, and manufacturing engineering curricula. Given its coverage of engineering materials, it is also suitable for materials science and engineering courses that emphasize materials processing. Finally, it may be appropriate for technology programs related to the preceding engineering disciplines. Most of the script’s content is concerned with manufacturing processes (about 65% of the text), but it also provides significant coverage of engineering materials and production systems. Materials, processes, and systems are the basic building blocks of modern manufacturing and the three broad subject areas covered in the script.

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# Laboratory 1

## *Survey of machine tools for selected cutting processes*

Laboratory leader: Ph.D. Andrzej Zora

**Objective:** To acquaint students with the construction of selected types of machine tools for cutting processes, their kinematics, equipment, types of tools used and technological abilities.

### **I. Introduction**

When starting the analysis of a given machine or group of machines number of questions should be answered:

1. What was the purpose of building this machine (what tasks is it supposed to perform)?
2. How it can be achieved through the use of this machine?
3. What are the main components of the analyzed machine?
4. What additional equipment can be used in this machine? How it increases its abilities?
5. Which types of the analyzed machine can be used for specific applications?

During the laboratory, in accordance with the presented diagram, three basic types of conventional machine tools for cutting processes will be analyzed. Their structure will be discussed and examples of applications for machining for lathes, milling machines and drilling machines will be presented.

### **II. Lathes**

#### **1. Types of surfaces that can be shaped on a lathe**

The basic machining operations for which lathes are used are the shaping of circular-symmetric surfaces. They can be both internal and external. Examples of such surfaces are:

- outer cylindrical surface;
- outer conical surface;
- spherical outer surface;
- groove on the outer surface;
- thread;
- chamfer;
- machining undercut;
- center hole;
- inner cylindrical surface;
- inner conical surface;
- groove in the inner surface;
- tap.

Another, very important type of surfaces that can be shaped on a lathe are planes. This can be, for example, the end face of the workpiece or the surface of the flange perpendicular to the axis of the workpiece.

Special, dedicated terms are used to describe the shaping of some types of surfaces:

- end face surface (plane) - facing;
- groove on the outer surface - grooving;
- cutting off part of the material - parting.

Various terms are used to describe the shaping of external and internal surfaces:

- external surfaces - turning;
- internal surfaces - boring.

On a lathe surfaces can be shaped not only by cutting treatment. Chipless treatment can also be used. In this way, for example, can be made:

- knurl - knurling;
- thread - thread forming.

## **2. Elements of the lathes structure**

In order to obtain the above-mentioned types of surfaces, certain elements of the lathe structure are necessary, enabling the realization of the kinematic scheme characteristic for it. The main components of the lathe construction are presented in Figure 1.1:

1. bed;
2. left leg (with engine inside);
3. headstock;
4. tailstock;
5. cross slide;
6. carriage;
7. feed rod;
8. lead screw;
9. tool post;
10. guideways;
11. spindle;
12. jaw chuck;
13. center.

## **3. Ways of fixing the workpiece**

The workpiece can be fixed and clamped in the machining space via fixtures mounted on the spindle tip and (sometimes) in the tailstock. They can be:

- jaw chuck (self-centering three-jaw chuck, four-jaw chuck, ... );
- jaw chuck – long workpiece supported by the dead center mounted in a tailstock;
- two centers – the rotational movement is transmitted to the workpiece via dog;
- special turning chuck.

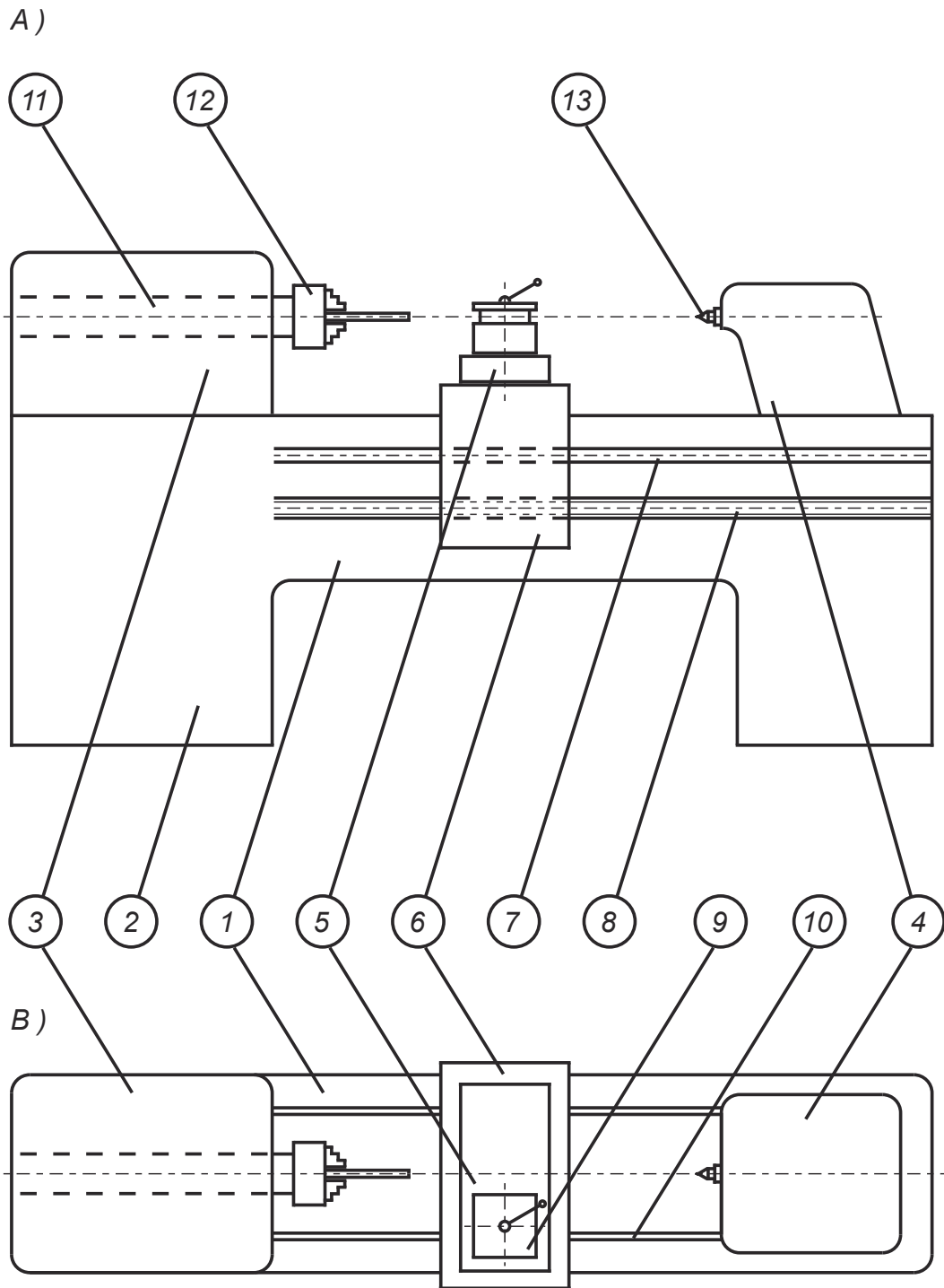


Figure 1.1. Basic lathe structure with the main components marked:  
 A) Side view of a lathe, B) top view of a lathe

Another feature of the lathe that should be taken into account in terms of objects that can be machined is the construction of the spindle : it is not a full shaft, but a pipe. This means that at the lathe long workpieces (shafts, bars) which are located in the middle of the spindle and fixed and clamped by the jaw chuck can be machined. In mass production this enables workpieces to be shaped directly from a rolled bar, without necessity of dividing the material into shorter sections.

#### **4. The kinematics of the machining processes on a lathe**

The kinematics of the machining processes on a lathe is significantly different from that used on other machine tools:

- main cutting movement (rotary) is performed by the workpiece;
- feed movement (usually linear) is performed by the tool;
- depth of cut is determined by the tool position in the direction perpendicular to the machining direction.

Most often the axis around which the objects rotates is horizontal.

The most frequently used element of the lathe structure that takes part in the transmission of drive and change of its character from rotary to linear is the feed rod. When it is necessary to precisely link the rotary movement of the spindle with the linear movement of the tool (e.g. in thread turning), then a lead screw is used.

#### **5. Tools**

A variety of tools can be used when machining on the lathe. For machining external surfaces (for turning) turning cutters of various shapes are used. Boring bars are used for machining internal surfaces (for boring). Both types of tools are most often mounted in a tool post which is placed on a cross slide. Typically four tools can be mounted at the same time in a tool post. If it is necessary to use more tools in one technological operation they can be mounted in the rear slide.

In addition to tools typical for turning operations on a lathe many other tools can be used, e.g. those typical for drilling operations:

- drill bits;
- reamers;
- taps;
- thread dies.

Most often they are mounted in the tailstock quill.

When drilling a hole on a lathe the tool (drill bit) is not supported near the machining point. This may result in an off-center hole being made. In order to avoid this it is necessary to create a leading surface in advance. A center drill (short, stiff tool) is used for this purpose. This ensures that the hole is coaxial with the axis of rotation of the workpiece. A surface made with a center drill (center hole) is also used to support long workpieces (shafts) during machining in order to make them more rigid during further treatment on a lathe and during subsequent machining operations on other machine tools (e.g. grinders).

#### **6. Examples of special kinds of equipment and special types of lathes**

In order to obtain the possibility of a faster tools change during the operation other than the typical method of tools mounting was developed. They are placed in the turret head which is located in front of the spindle. The replacement of successively working tools is achieved by rotating the turret head. This solution is commonly used in CNC lathes. Changing the tools



location from the tool post to the turret head is so important to the design and operation of the lathe that they are called turret lathes.

Depending on the characteristics of the machining process that is carried out on the lathe and depending on the characteristics of the workpiece specialized types of lathes are used. An example is a carousel lathe.

If a workpiece of large size and weight is to be machined on a lathe it would be very difficult to lift it above the bed and mount it in the chuck. It is much easier to place it on a flat, horizontal table surface, as is the case with a carousel lathe. During machining on this machine tool the workpiece rotates with the table around the vertical axis.

In mass production lathes with several spindles are used. Several bars located at the centers of the spindles are treated simultaneously by a set of tools, which allows to achieve high machining process efficiency. The operation of the lathe components is controlled by cams. This type of lathes is referred to as multi-spindle automatic lathes. It is a construction solution that is often the basis for introducing CNC control.

### **III. Drilling machines**

#### **1. Types of surfaces that can be shaped on a drilling machines**

The basic machining operations for which drilling machines are used are the shaping of internal circular-symmetric surfaces. Examples of such surfaces are:

- holes in workshop tolerances (drilled);
- tolerated holes (drilled and reamed);
- conical surfaces;
- chamfers;
- cylindrical deepenings;
- bored surfaces;
- taps.

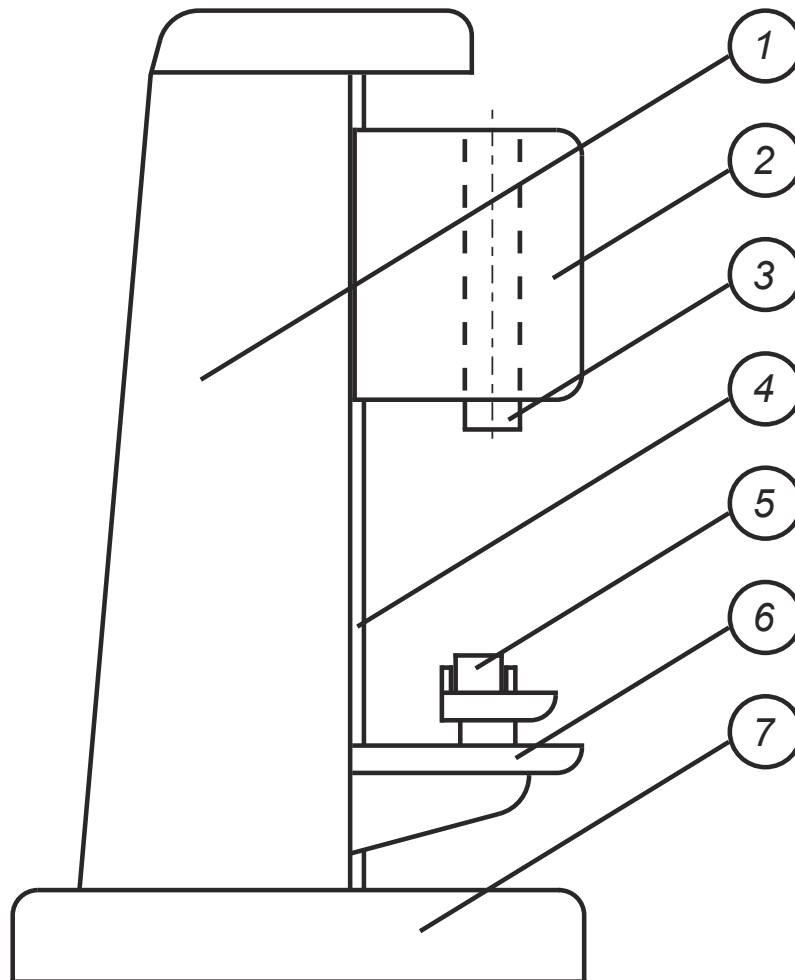
Another, very important type of surfaces that can be shaped on a drilling machines are planes.

This can be, for example, the top surface the workpiece perpendicular to the axis of the drilling machine.

#### **2. Elements of the drilling machines structure**

In order to obtain the above-mentioned types of surfaces, certain elements of the drilling machine structure are necessary, enabling the realization of the kinematic scheme characteristic for it. The main components of the drilling machine construction are presented in Figure 1.2:

1. column;
2. headstock;
3. spindle;
4. guideways;
5. drilling jig (vice, chuck) with a workpiece;
6. table;
7. base.



*Figure 1.2. Basic drilling machine structure with the main components marked*

### **3. Ways of fixing the workpiece**

The workpiece can be fixed and clamped in the machining space directly on a drilling machine table or via fixtures mounted on the table. The most typical are various types of vices.

For the round objects chucks typical for lathe machining can be used three-jaw self-centering chuck.

For workpieces of complex shapes are used special drilling jigs. If more than one hole is planned we use indexing drilling jigs.

#### **4. The kinematics of the machining processes on a drilling machine**

The kinematics of the machining processes on a drilling machine is related to the tool. It performs the following movements:

- main cutting movement (rotary);
- feed movement (linear).

The workpiece remains stationary during machining.

#### **5. Tools**

The most commonly used drilling tools are tools for holes machining:

- drill bits;
- reamers;
- countersinks;
- counterbores;
- center drills;
- taps.

The center drill is used in order to define precisely the axis of the hole which is going to be machined.

Tools with cylindrical shank are mounted in universal drilling chuck. Tools with tapered shank (Morse taper) are mounted directly into spindle quill.

#### **6. Examples of special kinds of equipment and special types of a drilling machines**

In order to obtain the possibility of a faster tools change during the operation they are placed in the turret head which is located in the front part of the headstock. Another solution is to use drill chuck that allows to change the tools without stopping rotation.

If a workpiece of large size and weight is to be machined the radial drilling machine is going to be applied. It allows the hole to be drilled in a big distance from the drilling machine column.

When more than one hole is drilled, especially in mass production, multi-spindle drilling machines are used.

### **IV. Milling machines**

#### **1. Types of surfaces than can be shaped on a milling machine**

Among machine tools milling machines are characterized by the greatest versatility and enable machining of the most diverse types of surfaces. It is due to the wide variety of tools that can be used. Both internal and external surfaces can be created. However, on the milling machine, the most commonly manufactured surfaces are planes.

## 2. Elements of the milling machines structure

The main components of the milling machine construction are presented in Figure 1.3:

1. column;
2. spindle;
3. overarm;
4. guideways;
5. table;
6. knee;
7. base;
8. chuck (vice) with a workpiece.

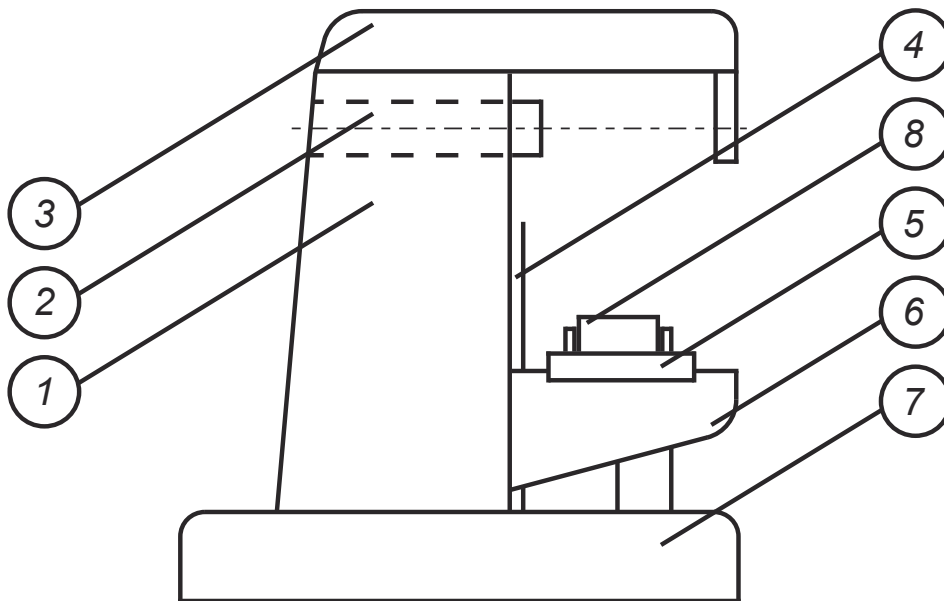


Figure 1.3. Basic horizontal milling machine structure with the main components marked

## 3. Ways of fixing the workpiece

The workpiece can be fixed and clamped in the machining space directly on a milling machine table or via fixtures mounted on the table. The most typical are various types of vices.

For the round objects chucks typical for lathe machining can be used three-jaw self-centering chuck.

For workpieces of complex shapes are used special milling chucks.

## 4. The kinematics of the machining processes on a milling machine

During machining processes on a milling machine only the main cutting movement (rotary) is related to the tool. It doesn't change its position while machining.

The feed movement is related to the workpiece. When the object is placed on the table the movement is linear which is reflected in shaped surfaces. If it is necessary to obtain a round surface the object itself or together with a chuck should be placed on a rotary table.

## 5. Tools

A big variety of cutters can be applied for milling process. Tools vary depending on whether the horizontal or vertical milling machine is used.

During work on the horizontal milling machine the tools are mounted on the milling arbor. It allows to apply more than one tool at the time. As a result more than one surface can be machined which increases efficiency of the process.

On the vertical milling machine, tools are mounted directly in the spindle.

## V. Selection of cutting parameters

For each of the types of machining described above the choice of machining parameters is crucial. These parameters are selected depending on:

- workpiece material;
- tool material;
- tool type;
- type of the surface to be shaped;
- type of machining (roughing or finishing).

These parameters are usually selected based on the tool manufacturer's specifications in the catalogue.

Additionally should be taken into account:

- shape of the workpiece (its stiffness);
- expected machining accuracy.

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# LABORATORY 1 REPORT

## *Survey of machine tools for selected cutting processes*

Laboratory leader: Ph.D. Andrzej Zora

Date: .....

Grade: .....

Group: .....

**Task 1:** Based on the information presented during the laboratory, previous knowledge and self-collected materials:

- Draw a sketch of the lathe marking of the most important structural elements.
- On the next sketch present the types of movements that can be performed by the most important structural elements of the lathe.
- In the drawing present the types of surfaces that can be shaped on a lathe. Mark what structural elements of the lathe are involved in this process and how they move.
- In the drawings present different ways of fixing and clamping the workpiece on a lathe.
- In the drawing present the most important tools used on the lathe, indicate the places where they are mounted.
- In the drawing present special kinds of equipment used on a lathe. For what purpose it is used?
- List known special types of lathes. In what processes are they used?

**Task 2:** Perform the tasks presented above for milling and drilling machines.

**Conclusions:**

.....

.....

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## Laboratory 2

### *Survey of machine tools for grinding processes*

Laboratory leader: Ph.D. Andrzej Zora

**Objective:** To acquaint students with the construction of basic types of machine tools for grinding processes, their kinematics, equipment, types of grinding wheels used and technological abilities.

#### **I. Introduction**

When starting the analysis of grinders treated as a separate group of machine tools, it is necessary to answer the question what is the purpose of their use. After all, all variety of shapes of the workpieces can be obtained using other machine tools. The main reason for using grinding machines is to achieve higher accuracy of details.

#### **II. The importance of the grinding process**

Growing quality requirements for the currently manufactured elements of machines result in an increasing share of grinding process as a finishing treatment. The grinding as the last operation of the technological processes determines the final state of the manufactured items. This is especially true in reference to the properties of their surface layer. That is why the grinding operation has crucial importance for the whole efficiency of production process.

The grinding process is used not only to improve the quality of manufactured details. Some items, due to the characteristics of the material they are made of (e.g. hardness or brittleness), cannot be machined with conventional cutting tools at all. It is necessary to apply abrasive processing.

#### **III. Characteristics of the grinding process**

##### **1. Tools**

The nature of the tools used in the grinding process is completely different from those used in other cutting processes. They are made of a composite material. Grinding wheels consist of:

- abrasive grain;
- bond.

Among the grinding wheels can be distinguished:

- conventional grinding wheel;
- ultra-hard grinding wheel.

The most commonly used conventional abrasives are:

- aluminum oxide;
- silicon carbide.

The binders in conventional grinding wheels are:

- ceramic binders;
- resins;
- rubber.

Among the ultra-hard abrasives can be distinguished:

- natural diamond;
- synthetic diamond;
- cubic boron nitride.

In the construction of these grinding wheels a metal bond is used.

The shapes of the bonded abrasive tools depend on the type of machining and the process kinematics used on a given type of grinding machine. The most often disc grinding wheels (straight type) are used.

The active cutting surface of the grinding wheel is the peripheral surface of the disc. Other common grinding wheel shapes are among others:

- cup grinding wheels;
- dish grinding wheels;
- saucer grinding wheels;
- mounted point.

For special machining tasks profile grinding wheels are used.

All bonded abrasive tools are characterized by special features that result from their construction (abrasive grains embedded in the bond), which in turn determines the way the grinding wheels work. These features are:

- large number of abrasive grains statistically distributed on the grinding wheel surface;
- low protrusion of abrasive grains above the bond surface;
- negative rake angle;
- blunting abrasive grains – the formation of flat surfaces rubbing against the workpiece;
- crushing of abrasive grains during the grinding process.

## **2. Shaping the machining properties of grinding wheels**

Tools used in all types of machining lose their cutting properties with the course of cutting process. Conventional cutting tools are sharpened by grinding to restore these properties.

In order to restore their cutting properties grinding wheels are subjected to a conditioning process (dressing process). It consists in removing the outer layer of the grinding wheel (bond) together with the abrasive grains in it that have lost their cutting properties. As a result of this process new abrasive grains with sharp cutting edges are exposed.



The conditioning process is also used to restore the shape of the profile grinding wheels. This is necessary because the profile grinding wheels wear out unevenly during grinding. Since the profile of the grinding wheel is mapped to the shape of the workpiece the conditioning process is crucial to obtain the desired shape accuracy.

The tools that are used in the conditioning process are dressers. Due to the high hardness of the grinding wheels the material used for dressers is diamond. The most commonly used types of dressers are:

- single point dressers;
- roller dressers.

Note that during the sharpening process of conventional tools the goal is to restore their original properties (blade geometry). In the case of grinding wheels the applied conditioning process parameters may shape the desired characteristics of the abrasive tool.

Another feature that distinguishes the grinding wheels conditioning process from the sharpening of conventional cutting tools is the place where they are performed. Conventional cutting tools are sharpened outside the machine tool (in the case of modern tools the sharpening process does not occur at all). During the conditioning process the grinding wheel is still attached to the grinding machine.

### **3. Preparing the grinding wheel for work**

The high rotational speed at which the grinding wheels work requires proper preparation for work to ensure the safe course of the grinding process:

- the grinding wheel (the material it is made of) must be checked for strength to prevent it from breaking under the load of centrifugal force and cutting forces. This can be achieved by measuring the natural frequency of vibrations of the grinding wheel;
- the outer cylindrical surface of the grinding wheel must be shaped (dressed) so as to obtain high concentricity with the axis of grinding wheel (spindle) rotation;
- the arrangement of the grinding wheel and the holder by which it is mounted on the spindle end must be carefully balanced. Otherwise the displacement of the center of gravity of the holder and grinding wheel in relation to the axis of rotation may cause vibrations during the grinding process, which causes structure errors on the machined surface.

### **4. Grinding process parameters**

The characteristics of abrasive tools determine special parameters of the grinding process:

- high cutting speed (peripheral speed of grinding wheel) – many times higher than in other types of cutting processes;
- high – in comparison to other machining processes – speed of the workpiece feed (reciprocating speed of the table);
- small depth of allowance removed in one pass;
- total machining allowance removed in multiple cutting passes;
- final surface conditions achieved through sparking-off passes.

For grinding process the choice of machining parameters is crucial. These parameters are selected depending on:

- workpiece material (hardness);
- tool (grinding wheel) material – abrasive material, grinding grains size;
- bond applied;
- tool type (shape);
- tool characteristic (grinding wheel structure, grinding wheel hardness);
- type of the surface to be shaped;
- type of machining (roughing or finishing).

These parameters are usually selected based on the tool manufacturer's specifications in the catalogue.

Additionally should be taken into account:

- shape of the workpiece (its stiffness);
- expected machining accuracy.

Examples of typical parameters used during surface grinding are presented below:

1. Cutting speed for conventional grinding is in the range from 25 m/s to 30 m/s. It demands the achievement of high rotational speed. Depending on the diameter of the tool (grinding wheel) it is from 1 500 RPM to even 100 000 RPM. Cutting speeds for grinding at elevated speeds are 45 m/s, and for high speed grinding from 90 m/s to 100 m/s.
2. Typical reciprocating speed of the table is 10 m/min.
3. Total machining allowance in the range from 0.2 mm to 0.3 mm.
4. Allowance removed in one pass depends on the type of process (roughing or finishing) and it is in the range from 0.01 mm to 0.05 mm.

## **5. The most characteristic feature of the grinding process**

The construction of abrasive tools and typical parameters of the grinding process cause that large amounts of thermal energy are emitted during cutting. This can result in an excessive increase in temperature in the cutting zone, and consequently overheating of the machined material and a reduction in the performance of the workpiece. To avoid this it is necessary to apply intensive cooling during machining.

## **6. Properties of the workpiece determined during the grinding process**

The influence of the grinding process is mostly related to the surface layer of the workpiece. The following features of workpieces are modified:

- dimensional accuracy of the workpiece – thanks to the small height of the layer removed in one grinding pass;
- high shape accuracy (e.g. flatness, cylindricity) of the ground surface;
- low roughness of the ground surface;
- no waviness of the ground surface.

## **7. Kinematics of the grinding process**

In most cases the kinematics of the grinding process are identical to the earlier stages of the manufacturing process, shaping the same types of surfaces e.g.:

- when grinding the planes with the peripheral surface of a disc grinding wheel kinematics corresponds to surface milling with a cylindrical milling cutter on a horizontal milling machine;
- when grinding surfaces with a cup grinding wheel kinematics corresponds to surface milling with a milling head on a vertical milling machine.

The greatest differences in the kinematics of the process occur when grinding rotating surfaces.

When grinding the outer cylindrical surfaces the main cutting speed is generated by the grinding wheel rotating at high speed. At the same time for the workpiece to be ground around it must rotate. In order to achieve the desired dimension the grinding wheel is moved radially towards the workpiece.

If the length of the cylindrical surface is greater than the width of the grinding wheel its movement along the axis of the workpiece is also necessary. This process is called longitudinal grinding.

If the length of the cylindrical surface is smaller than the width of the grinding wheel longitudinal movement is not needed. This process is called plunge grinding.

For grinding the internal cylindrical surfaces mounted points are used. Since they must fit entirely inside the machined hole hence the need to use abrasive tools with small diameters. As a result it is necessary to use higher rotational speed of the tool in comparison to external surfaces grinding. The spindle on which the mounted point is attached is placed in front of the spindle on which the workpiece is mounted.

## **IV. Grinding machines**

### **1. Construction principles**

The construction of grinding machines must enable the achievement of two basic goals of the grinding process:

- shaping the ground surface with the desired geometry;
- obtaining the desired parameters of the stereometry of the workpiece surface layer.

In most cases to accomplish the first task the construction system of the grinder corresponds to that used in conventional cutting machine tools that shape the same type of surface (plane grinding).

When grinding rotary surfaces (external and internal) two headstocks, two spindles and two drives are used separately for the workpiece and for the grinding wheel.

In order to achieve the desired surface conditions after grinding the following solutions are used:

- the high rigidity of the grinder (grinding wheel support stiffness – headstock, bearing) significantly exceeds the strength requirements – in order to obtain the desired dimensional accuracy;
- precise bearing of the grinding wheel spindle and the workpiece spindle;
- in order to eliminate a potential source of vibrations the drive is transferred from the engine to the grinding wheel spindle by means of a belt transmission;
- in many cases the construction of grinders resigns from the use of gears and the grinding wheel can rotate at only one specified rotational speed.

## 2. Element of the horizontal spindle surface grinding machines structure

The main components of the horizontal spindle surface grinding machine construction are presented in Figure 2.1:

1. base;
2. column;
3. headstock;
4. spindle;
5. table (usually electromagnetic);
6. workpiece;
7. tool (grinding wheel);
8. guideways.

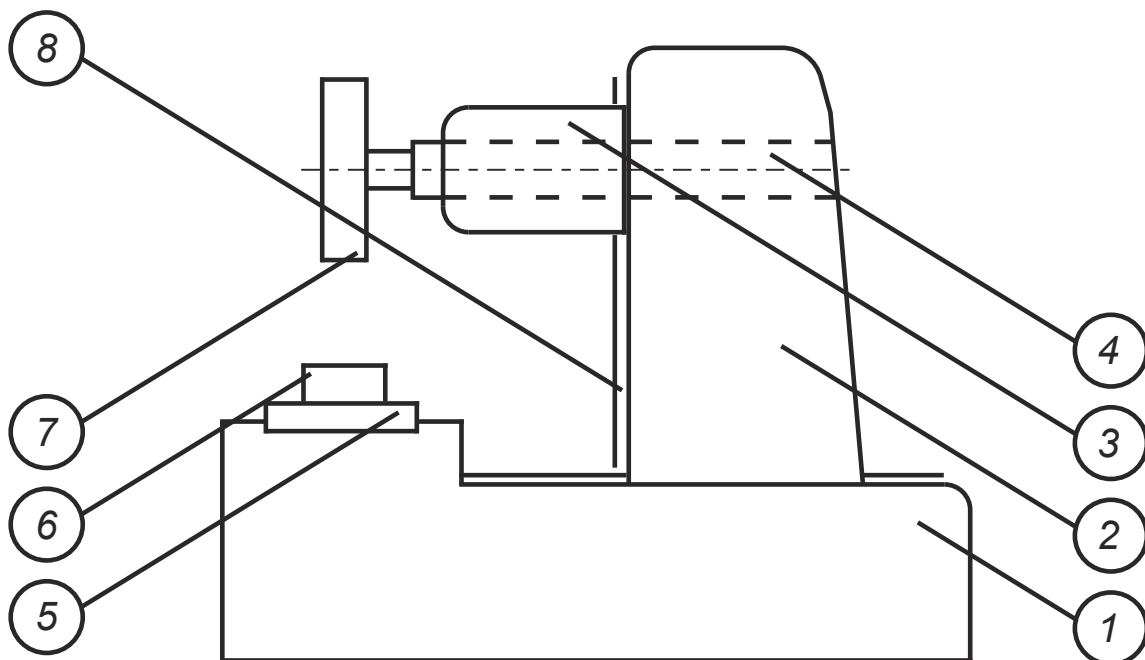


Figure 2.1. Basic structure of the horizontal spindle surface grinding machine with the main components marked

### **3. Special types of equipment typical for grinders**

The characteristics of the grinding process, the abrasive tools used and desired processing results require the use of special equipment for grinding machines.

The small depth of cut used during grinding process results in a low level of cutting forces (in comparison to other machining operations). At the same time in order to obtain the desired machining accuracy it is necessary to accurately and reproducibly fix and clamp the workpiece. For these reasons electromagnetic chucks are often used in grinding operations. In this way objects made of ferromagnetic materials can be attached.

Because of large amounts of thermal energy emitted during grinding an efficient cooling system is required.

Due to the necessity of periodic conditioning of the grinding wheel (in order to maintain their cutting properties) devices are installed on the grinders to enable this process to be carried out. This is particularly the case in high-efficiency grinding operations where continuous dressing with roller dressers is used.

In order to ensure the possibility of checking and correcting the balance of the grinding wheel special heads are sometimes mounted on the grinders for dynamic balancing of the grinding wheel.

Since the primary goal of the grinding process is to achieve high dimensional and shape accuracy the devices for active control are often used to check the dimensions achieved during the operation.

### **4. Special types of grinding processes and special types of grinding machines**

One type of special grinding process is high speed grinding. During such a process the grinding wheel operates at a speed several and sometimes several dozen times higher than during conventional grinding. Carrying out this process requires increased stiffness of the grinder and even more precise preparation (balancing) of the grinding wheel and bearing its spindle. Due to their durability only ultra-hard metal-bonded grinding wheels are used for high speed grinding.

Another special grinding process is creep feed grinding. This process is characterized by a low feed speed of the workpiece and a large (in comparison to other types of grinding) depth of cut – all the allowance is removed in one pass. These cutting parameters result in larger arc length of contact between the grinding wheel and the workpiece when compared with reciprocating grinding. In order to counteract the excessive release of thermal energy in this area it is necessary to apply continuous dressing of the grinding wheel (with the use of roller dressers) and very intensive cooling.

Sometimes the grinding process must be carried out on items with non-standard dimensions, e.g. very long. Such workpieces cannot be mounted on typical grinders – they do not fit between the headstock and the tailstock. For such tasks centerless grinders are used. The workpiece

(shaft) is placed between the regulating wheel and disc grinding wheel. Under the shaft there is a support blade. Centerless grinding is also used for machining short items in order to increase the efficiency of the process by eliminating the clamping and unclamping the workpiece on the machine tool.

## V. Literature

- [1] **S. Y. Liang** *Analysis of machining and machine tools*, Springer, London, UK, 2016.
- [2] **R. H. Todd, D. K. Allen, L. Alting** *Manufacturing Processes Reference Guide*, Industrial Press Inc., New York, USA, 1994.
- [3] **R. Kibbe** *Grinding Machine Operations*, John Wiley and Sons Inc., New York, USA, 1985.

# LABORATORY 2 REPORT

## *Survey of machine tools for grinding processes*

Laboratory leader: Ph.D. Andrzej Zora

Date: .....

Grade: .....

Group: .....

**Task 1:** Based on the information presented during the laboratory, previous knowledge and self-collected materials:

- Draw a sketch of the grinding machine for shafts marking of the most important structural elements.
- On the next sketch present the types of movements that can be performed by the most important structural elements of the grinding machine for shafts (while grinding long and short surfaces).
- Perform the tasks presented above for plane grinding and hole grinding.
- What types of grinding processes were presented during the laboratory?
- In the drawing present the types of surfaces that can be shaped by grinding. Mark what structural elements are involved in this process and how they move.
- What is the most commonly used parameter describing the surface stereometry after treatment? What values of this parameter are characteristic for the surface after grinding?

**Task 2:** Based on the information presented during the laboratory, previous knowledge and self-collected materials:

- In the drawing present the most typical shapes of grinding wheels.
- What types of abrasive tools (shape, abrasive grain, bond) were presented during the laboratory?

**Task 3:** Based on the information presented during the laboratory, previous knowledge and self-collected materials:

- In the drawing present special kinds of equipment used on a grinding machines. For what purpose it is used?
- In the drawing present special types of grinders. Mark their kinematics. In what processes are they used?

**Conclusions:**

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# Laboratory 3

## *Technological abilities of CNC machine tools*

Laboratory leader: Ph.D. Andrzej Zora

**Objective:** To acquaint students with the construction of basic types of CNC machine tools for cutting processes, their kinematics, equipment, types of tools used and technological abilities.

### **I. Introduction**

When starting the analysis of a specific machine or subgroup of machines (CNC machine tools) distinguished by a set of characteristic features in relation to the base group (conventional machine tools), number of questions should be answered:

1. What was the purpose of modifying the machines from the basic group?
2. What new tasks is to be performed by the modified machine (subgroup of machines) or how the tasks hitherto performed by base machines will be performed in a different way?
3. How it can be achieved through the use of those machines?
4. What are the new, better effects of using the modified subgroup of machines compared to those achieved so far?
5. What are the main components of the analyzed machines that distinguish them from the base group?
6. What additional equipment can be used in these machines ? How it increases their abilities?
7. Which types of the analyzed machines can be used for specific applications?

During the laboratory, in accordance with the presented diagram, exemplary CNC machine tools for cutting processes will be analyzed. The structure will be discussed and examples of applications for machining will be presented.

### **II. Conventional machine tools**

Since CNC machine tools are a subgroup of the entire class of machine tools (all of them are used to shape workpieces), the analysis of the purposefulness of their creation and usage should begin with an analysis of the features characterizing the work of typical machine tools. Particular attention should be paid to features that may adversely affect the quality of the products obtained and reduce the efficiency of the production process. Taking these aspects into account, the main features of conventional machine tools are:

- One type of conventional machine tools is most often used to shape only one type of surface (lathe for rotating objects, milling machine for rectilinear surfaces, drilling machine for basic types of holes, boring machines for complex holes), which significantly limits the versatility of their usage. Consequently, in order to obtain a workpiece whose shape consists of various types of surfaces, it is necessary to use a number of conventional machine tools. This, in turn, causes the necessity of repeatedly fixing and clamping workpieces in the machining spaces of subsequent machine tools, and then their unclamping. Repeatedly determining the position of the workpiece to be machined negatively affects the accuracy of the mutual position of the shaped surfaces.



The usage of many machining stations also involves the need to transport items between these stations, which is another factor that reduces the efficiency of the production process.

- Tool change on conventional machine tools is very often complicated and time-consuming and requires the subsequent positioning of the tool in relation to the workpiece. Different dimensions and different characteristic of the tools sometimes cause difficulties and sometimes even make it impossible to use them on the same conventional machine tool.
- Treatment of surface with a complex or unusual shape requires the usage of a special tool, special machining equipment, and in the case of serial production, even a special machine tool (profile machine tool). Very often these solutions can only be used for that specific workpiece. After its machining they are useless.
- Conventional machine tools are controlled by a operator (human). This means that their work parameters (e.g. speed of setting movements) must be adjusted to the psycho-physical abilities of the worker. Very often this means their reduction which results in a further decrease reduction in the process efficiency. In addition process features such as repeatability, quality or failure-free operation of the machine tool are exposed to the influence of typically human factors such as fatigue, lack of concentration, inattention or mistakes.

### **III. CNC machine tools – main features**

When the features of conventional machine tools that may adversely affect the course of the machining process are known, it is possible to analyze how individual aspects are solved in CNC machine tools.

#### **1. Concentration of machining operations**

By machining a workpiece on a CNC machine tool it is possible to apply many different machining technologies (e.g. milling, drilling, boring, tapping) which allows for machining a number of surfaces of one object with different shapes in one machining operation. This allows to avoid the need to move the workpiece between successive machining stations, which significantly increases the efficiency of the production process. Sometimes all surfaces that require it can be machined in only one machining operation. This situation is called complete machining.

Treatment of many surfaces on one station means carrying out subsequent machining after the object is fixed and clamped only once. This not only reduces the duration of the operation, but above all allows to obtain a very high quality of the manufactured items, in particular the mutual position of the shaped surfaces.

The use of many different machining technologies on one station makes it difficult to clearly define its type. For this reason the term machining center is very often used.

#### **2. Tool change**

The use of various technologies and the treatment of surfaces of various shapes requires the use of different tools (differing in type, shape and size) and the possibility of their quick replacement. In CNC machine tools all tools regardless of their own characteristics are

embedded in the identical adapters and placed in the tool magazine. This enables their quick, automatic replacement which also increases productivity. Because in the magazine can very often be placed several dozen different universal tools they can be used to treat most of typical surface shapes. In CNC machine tools special tools are used much less frequently than in conventional machine tools.

### 3. Kinematics of CNC machine tools

The shape of the surfaces treated on CNC machine tools depends not only on the shape of the tools used, but also on the mutual displacement and change of the position of the tools in relation to the workpiece. The shape of complex surfaces is very often approximated (with the desired accuracy) by successive paths of universal tools. These movements are controlled by the CNC machine control program.

Figures 3.1, 3.2 and 3.3 show examples of kinematic systems used in CNC machine tools.

The coordinates of tool path can be modified depending on the change in its geometric features, e.g. blunting, rounding edges or sharpening. Changes in the geometric parameters of the tool are entered in a special section “tool compensation” and automatically included in the kinematics of its movement.

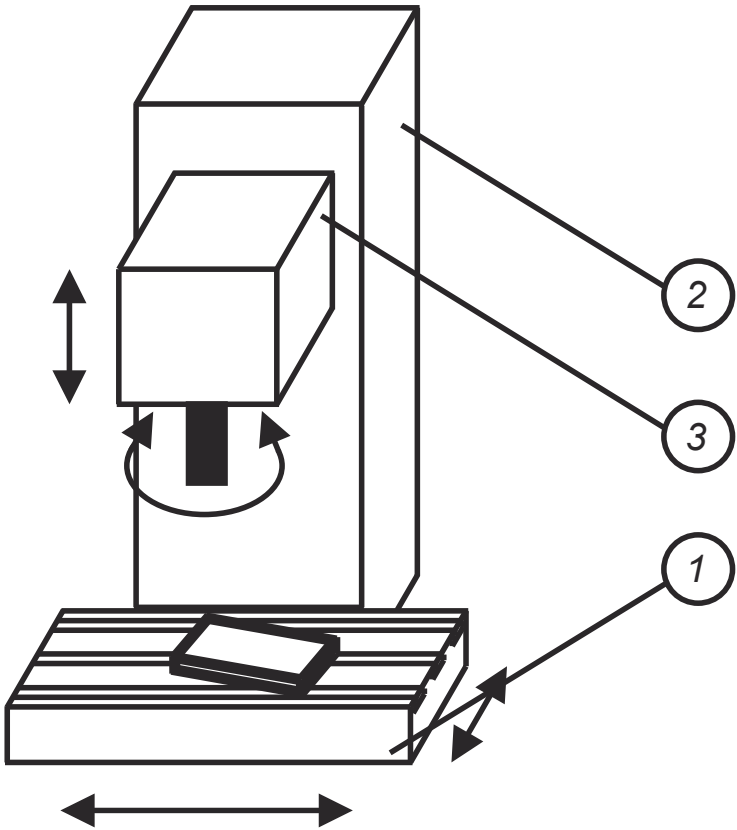


Figure 3.1. CNC machine tool with 3 axes numerically controlled.  
Table (1) moves along X axis and Y axis. Headstock (3) moves along column (2): Z axis. Tool rotates.

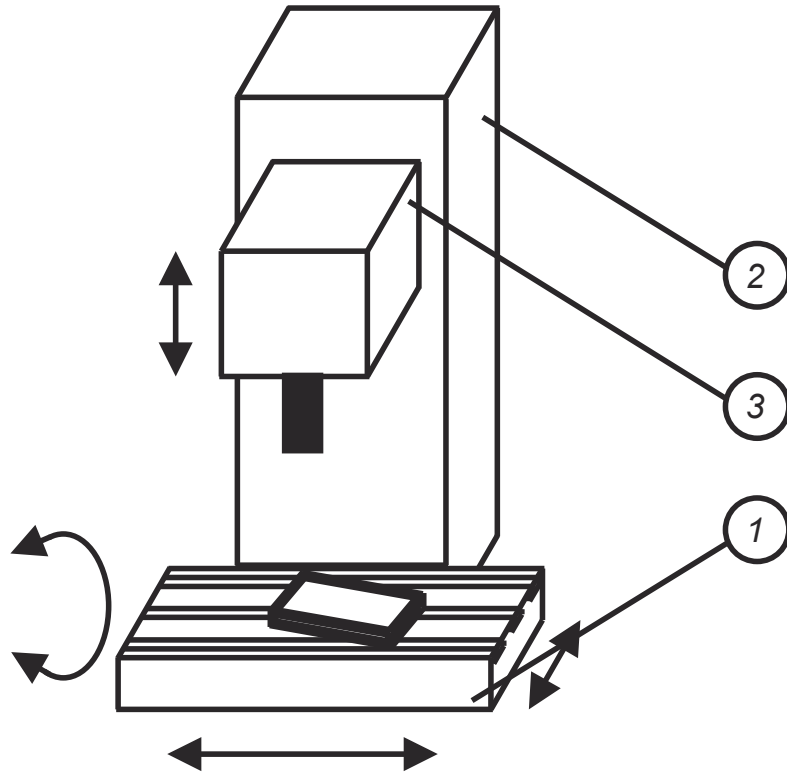


Figure 3.2. CNC machine tool with 4 axes numerically controlled. Table (1) moves along X axis and Y axis. It can also rotate: A axis. Headstock (3) moves along column (2): Z axis. Tool rotates.

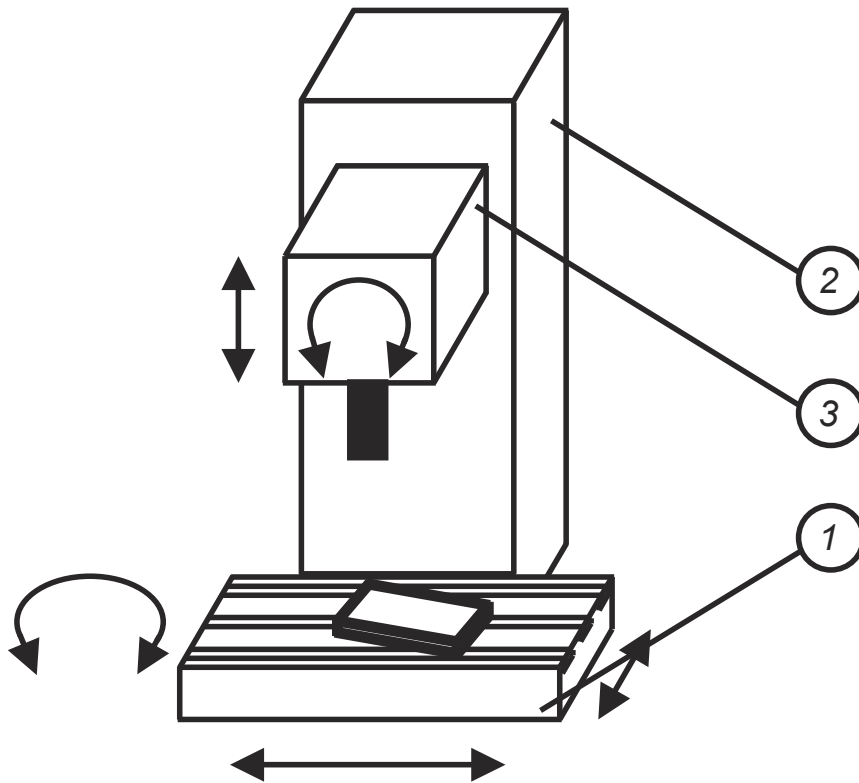


Figure 3.3. CNC machine tool with 5 axes numerically controlled. Table (1) moves along X axis and Y axis. It can also rotate: C axis. Headstock (3) moves along column (2): Z axis and rotates: B axis. Tool rotates.

Even obtaining the basic geometric shapes of surfaces such as a straight line (defined at an angle in relation to the main axes of the machine tool coordinate system) or a circle requires the use of special elements of the control system, which are:

- linear interpolator;
- circular interpolator.

#### **4. Numerically controlled machine tools**

Limiting the impact and sometimes even complete elimination of the influence of the human factor on the course of the machining process is carried out on CNC machine tools through the use of computer control. This allows to avoid limitations related to the psycho-physical abilities of the worker (e.g. use higher speeds of tools settings movements, faster tools changes or simultaneous operation of several machine tool components) and reduce the possibility of errors in the process.

The control program is stored in the memory of the CNC machine tool in an electronic form. This enables a quick modification of the selected program and adapting it to the changed requirements. Also the entire currently executed program can be quickly replaced by another one in the machine's operational memory and used to produce a workpiece of a completely different shape.

The control program can be entered directly from the CNC machine tool control panel or developed on an external computer using CAM software. In the second case it is usually necessary to use the post-processor in order to adapt the control code to a specific CNC machine tool.

#### **IV. CNC machine tools – distinctive design features and additional equipment**

In order to achieve the accuracy of displacements defined in the control program in the CNC machine tools during the machining process the following solutions are applied:

- individual, independent feed drives for each controlled axis;
- individual electronic position or displacement measuring systems for each controlled axis;
- ball-screw gears to convert rotary to linear motion;
- rolling or other low friction guide ways.

Other elements of equipment that extend the capabilities of the CNC machine tools, and thus increase their efficiency are:

- devices for on-line measuring of the workpiece dimensions;
- devices for on-line process monitoring;
- devices (roller dressers) for shaping the cutting properties of the abrasive tool (grinding wheel) – on CNC grinding machines;
- manipulators and feeders enabling automatic exchange of workpieces;
- mechanical chip removal systems.

#### **V. CNC machine tools – main characteristic functional features and advantages**

The applied design solutions, especially regarding tools (tools magazine with the possibility of their automatic replacement), computer control and optional additional equipment, make CNC

machine tools characterized by two basic functional features, key to their use in production processes:

- flexibility;
- versatility.

This allows the use of CNC machine tools not only in mass or series production, but also in small-batch or even piece production.

Regarding the workpieces the following features of CNC machine tools should be emphasized:

- repeatability of manufactured items which results in their full interchangeability;
- high quality, especially in terms of dimensional and shape accuracy;
- high productivity.

## **VI. Literature**

- [1] **S. Y. Liang** *Analysis of machining and machine tools*, Springer, London, UK, 2016.
- [2] **R. H. Todd, D. K. Allen, L. Alting** *Manufacturing Processes Reference Guide*, Industrial Press Inc., New York, USA, 1994.
- [3] **R. Quesada** *Computer Numerical Control. Machining and Turning Centers*, Pearson Printice Hall, Columbus, USA, 2005.

# LABORATORY 3 REPORT

## *Technological abilities of CNC machine tools*

Laboratory leader: Ph.D. Andrzej Zora

Date: .....

Grade: .....

Group: .....

**Task 1:** Based on the information presented during the laboratory, previous knowledge and self-collected materials:

- Draw a sketch of the selected CNC machine tool marking of the most important structural elements.
- On the next sketches present the types of movements that can be performed by the most important structural elements of the CNC machine tools – illustrate the various kinematic systems used on CNC machine tools.
- What types of CNC machine tools were presented during the laboratory ?

**Task 2:** Based on the information presented during the laboratory, previous knowledge and self-collected materials:

- In the drawing present the shape of tool adapters used on CNC machine tools.
- In the drawing present the types of tool magazines used on CNC machine tools. What types of magazines were presented during the laboratory ?

**Task 3:** Based on the information presented during the laboratory, previous knowledge and self-collected materials:

- In the drawing present special kinds of equipment used on the CNC machine tools. For what purpose it is used?
- List known special types of the CNC machine tools. In what processes are they used?

**Conclusions:**

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## Laboratory 4

### *Example of EdgeCAM software application in part programming for a milling machine and lathe*

Laboratory leader: Ph.D. Katarzyna Koter

**Objective:** The aim of the laboratory is to get familiar with the Edgcam software which is used to prepare and simulate CNC-programs on the examples of milling and turning machines.

#### I. Introduction

The purpose of the laboratory is getting to know EdgeCAM – CAM system for NC part programming. Computer-aided manufacturing (CAM) software are used in manufacturing of workpieces to control machine tools. EdgeCAM provides functionality for programming milling machines, lathes and wire electrical discharge machines. Among others, EdgeCAM allows creating toolpaths for manufacturing operations, development component cycle times and simulating the machine motion in order to avoid collisions.

During laboratories, students will learn how to use EdgeCAM for milling and turning processes, including preparation, manufacturing and simulation of machining. The instruction is divided in two parts – MT3 which explains the use of EdgeCAM on the milling example and MT4 which shows programming of the lathes.

#### II. General overview

The Homework license allows students to run educational software with majority of features, besides generating NC code. To switch to Homework Mode, you have to find the Windows Notification Area (right bottom corner of the screen) right-click the CLS icon and click Homework Mode on the menu (Figure 4.1).

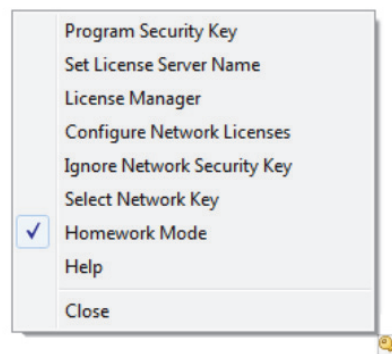


Figure 4.1. Menu in the Windows Notification Area

After turning on EdgeCAM, the Program Launcher runs, where can be chosen the type of the part which user want to prepare manufacturing process for. After choosing Milling, Turning and Wire part (Figure 4.2), you will be transferred to the appropriate working environment.



Figure 4.2. Working environments

After opening working environment, the main menu is visible on the top of the screen. Ribbons (Figure 4.3) represents the following options:

- **File:** loading, inserting, saving etc.;
- **Setup:** Stock, Machine and Drawing;
- **Features;**
- **Machining:** Manufacturing operations;
- **NC Code.**

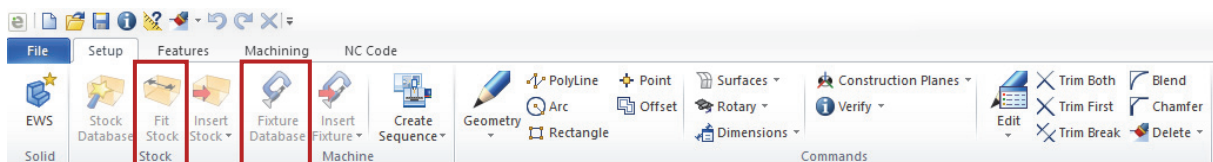


Figure 4.3. Main Menu

In the left corner of the screen, there are visible icons responsible for Component, Stock, Machine and Tool display (Figure 4.4).



Figure 4.4. Display icons



In order to Insert the component to working Environment, you have to click File/Insert and choose the file with the model (Figure 4.5). Workpiece model can be loaded from any CAD system, including: Autodesk Inventor, Solid Edge, SolidWorks, Pro/ENGINEER, Pro/DESKTOP Unigraphics and independent formats: IGES, DXF, VDA, Parasolid, STEP ACIS.

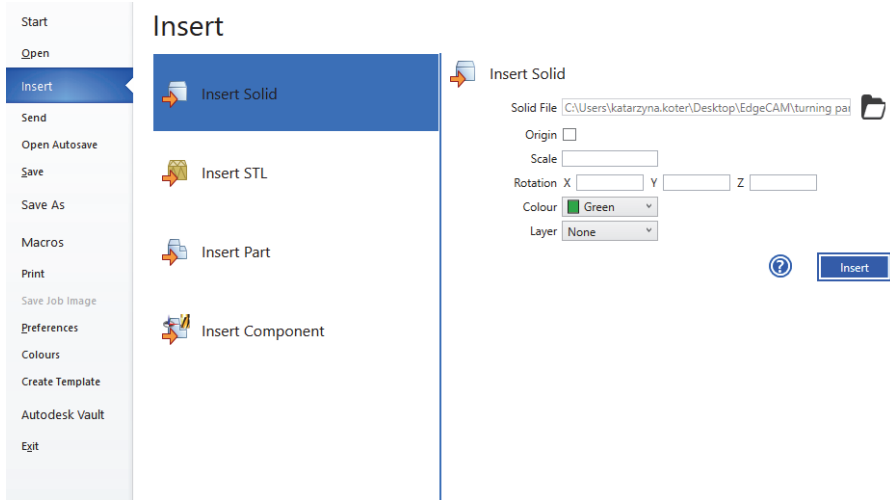


Figure 4.5. Insert window

### III. Milling example

After opening the milling environment and loading the model, the component is visible in the center of the screen (Figure 4.6). Coordination system in the left bottom corner shows the workpiece orientation in the coordinate system. The beginning of the coordination system is visible on the component, according to its position in the CAD model. Adjustment of its position is possible from Component setup window, Datum and position section (Figure 4.7).

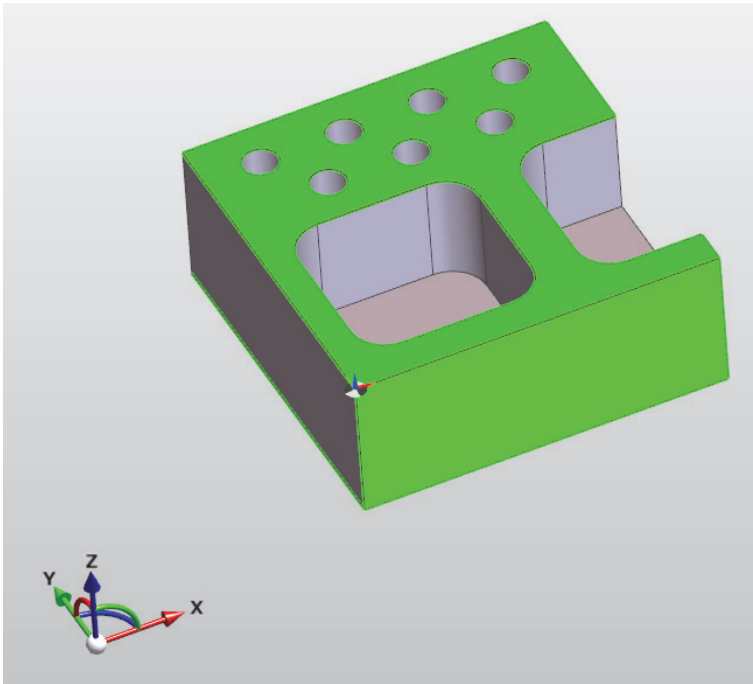


Figure 4.6. Coordination system of loaded component

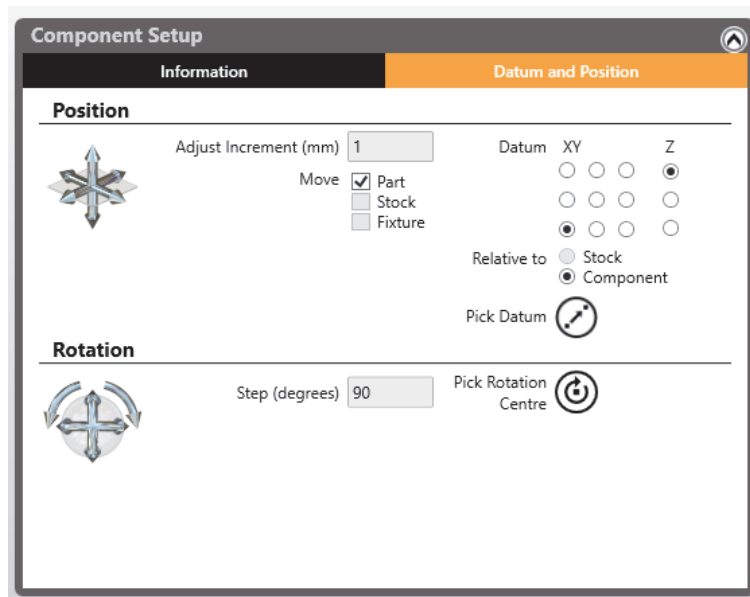


Figure 4.7. Datum and position section

## 1. Stock

Stock is necessary to show how the initial billet of material is being machined. It is also used in the roughing cycles as boundaries, which limits area of material removed. Fit stock option (Figure 4.3) allows to adjust the size of the stock based on the shape of the loaded component by adding Offsets on the sides (Figure 4.8). Shape of the stock is predefined as box or cylinder.

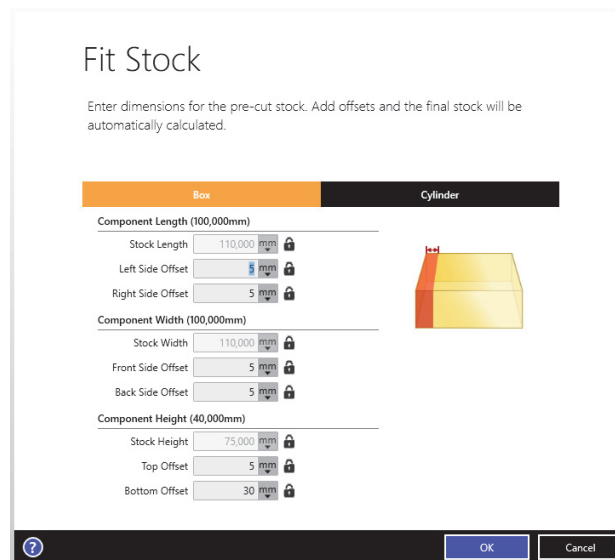


Figure 4.8. Fit stock option

## 2. Fixtures

Fixtures represent how the work piece will be clamped. It helps to plan manufacturing process and avoid collisions. From the Fixture Database (Figure 4.3) you can choose required type and size of fixture and define stock position (Figure 4.9).

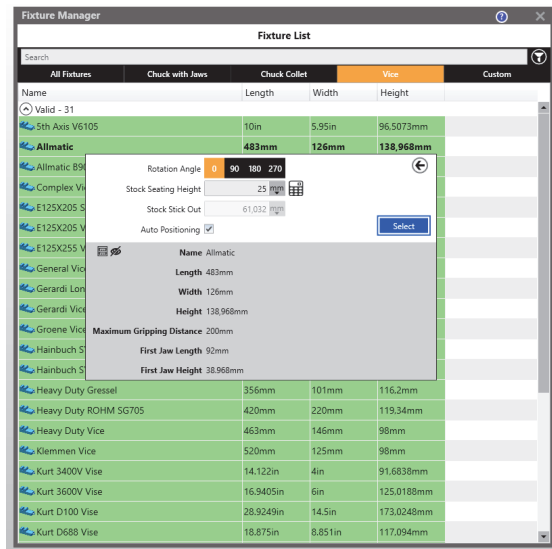


Figure 4.9. Fixture List

Stock mounted in the fixture is shown in Figure 4.10.

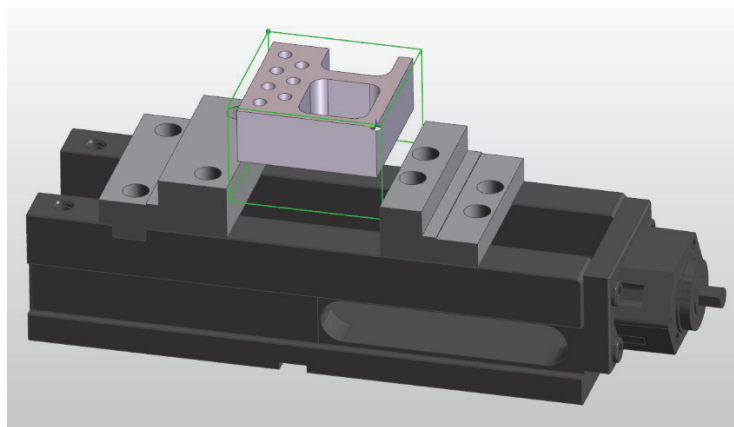


Figure 4.10. Stock mounted in the fixture

### 3. Features

Features represent the geometry, based on which machining cycles will be created. Types of the milling features: bosses, pockets, holes etc. are determined based on geometry properties. They can be defined based on the geometry of the component or be created by the user. To search for features on the component, use Feature Finder option (Figure 4.11).

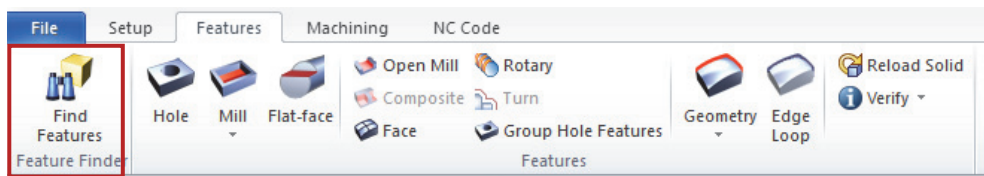


Figure 4.11. Features option

In the milling environment, Feature finder allows to choose what kind of milling options will be adapted to the component (Figure 4.12). User can also define advanced options of the feature, including minimum or maximum size of holes and adjust color representation.

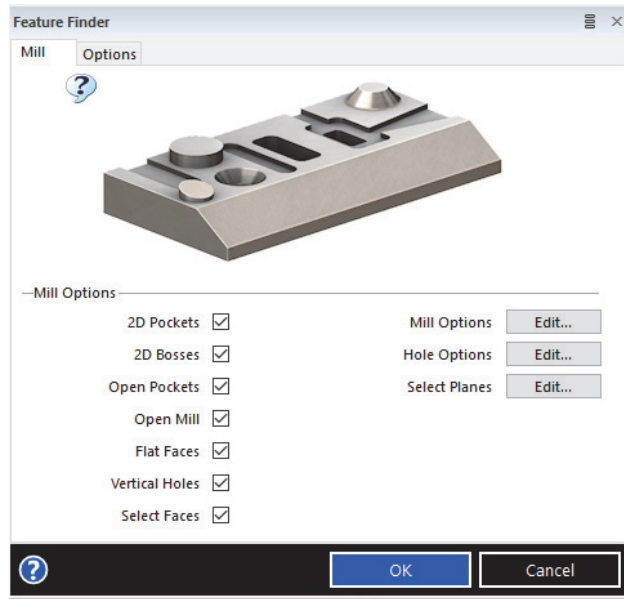


Figure 4.12. Feature finder

Defined features will be visible on the Feature browser on the left side of the screen. Also, they will be represented on the component with different color to each feature. Notice, that group of the hole of the same size will be defined as one feature (Figure 4.13).

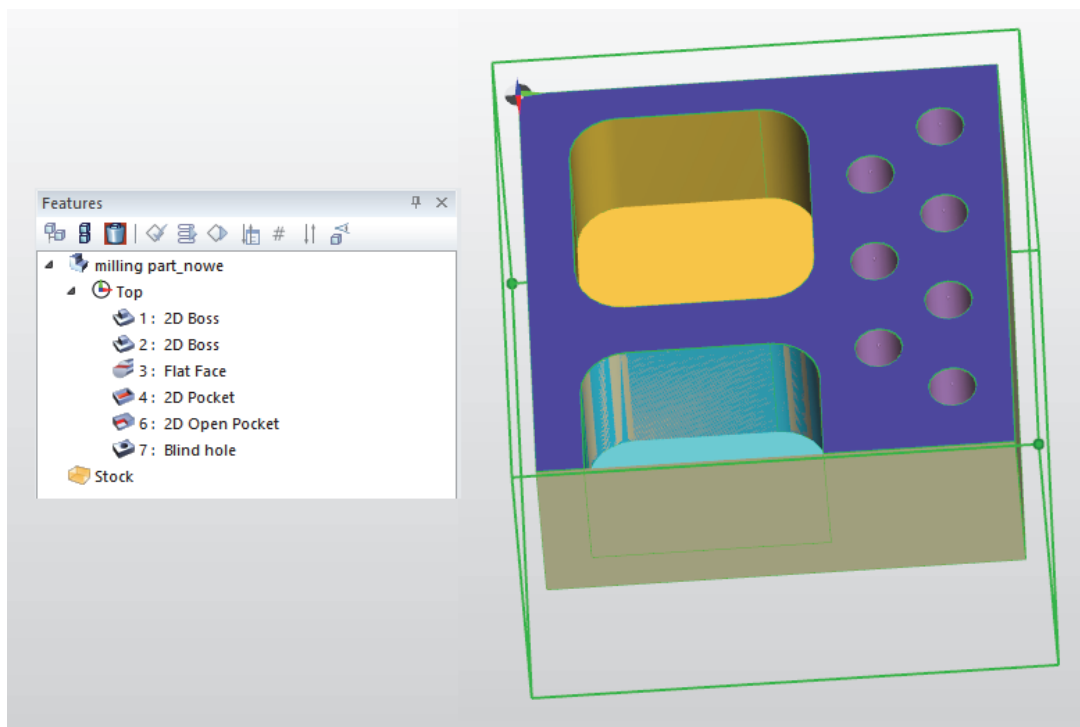


Figure 4.13. Feature browser and feature representation on the component

#### 4. Creating milling sequence

After preparation process, which included adapting stock, fixture and features, user have to create milling sequence. Click on the screen with the right button of the mouse, and from the

menu choose Manufacture option (Figure 4.14). Then, in Create Milling Sequence window define sequence name.

A Code generator will represent type of the milling machine used in the process. Chosen postprocessor will affect the manufacturing process, defining possible operations based on the machine capabilities like number of working axis and adjust toolpaths to size of the machine working space. Different postprocessors are used to each milling machine type. It allows for accurate simulation of the process to observe and prevent collisions.

Component and machine setup options allows to define the initial CPL (construction plane). CPL defines a local co-ordinate system at any orientation to the World axes.

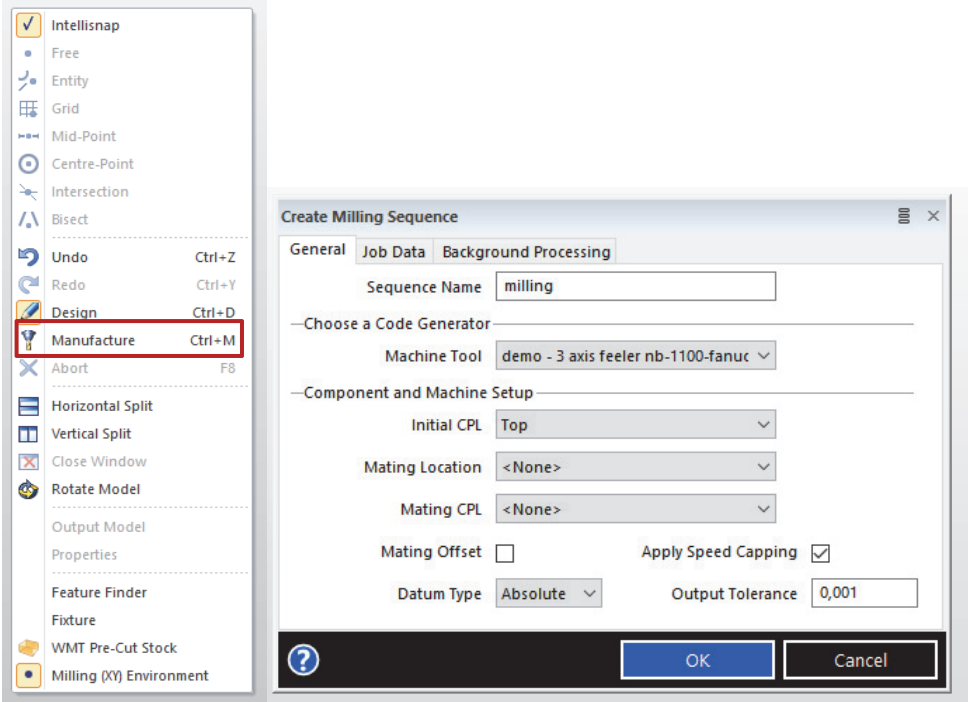


Figure 4.14. Creating milling sequence

When milling sequence is created, the mill operation can be defined. In the machining menu (Figure 4.15) user can choose:

- **Automatic Manufacturing**, which allows to plan and apply strategies based on created features.
- **Mill operations**, responsible for different types of operations.
- **Other milling cycles**, used for selecting and moving the tool and advanced milling operations.

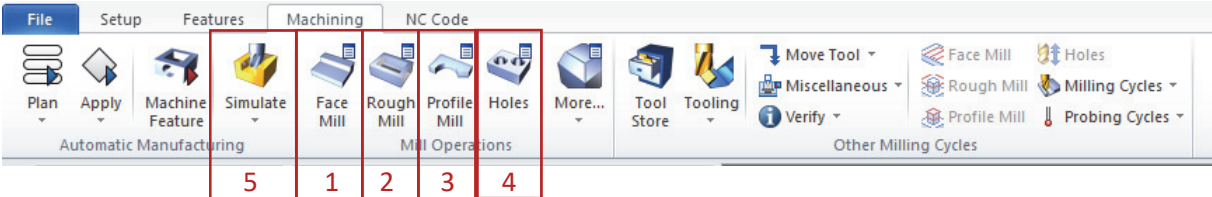


Figure 4.15. Mill operations menu

## 5. Face mill operation

Face mill operation (Figure 4.15 no. 1) generates a toolpath with a series of straight parallel cuts in horizontal planes and is used to create flat face on the component. To define the range of cut, you have to select closed profiles (Figure 4.16), based on the upper frame of the stock.

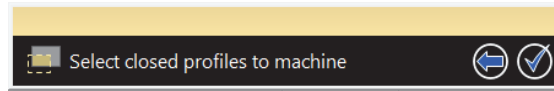


Figure 4.16. Select closed profiles command

In the Face Mill Operation Menu (Figure 4.17), define machining parameters.

### GENERAL

#### Mill type:

- **Climb** – the movement direction of the cutter is consistent with the direction of rotation.
- **Conventional** – the movement direction of the cutter is opposite to the direction of rotation.
- **Optimized** – the direction of movement is alternately Climb and Conventional.

**Angle** – the lacing angle in degrees.

**% Stepover** – the maximum spacing between passes as a percentage of the tool Small Diameter.

**Lead Length/Radius** – adds a linear/arc lead move onto and off the part.

**Stock Offset** – the distance that the toolpath boundary is offset outside or inside (negative values) your selected boundary.

### DEPTH

**Clearance** – the Z-value at or above which the tool may move at the rapid rate with no danger of colliding with the workpiece.

**Level** – the Z-value below which cutting is liable to start.

**Depth** – this is added to the Level value to produce the level at which cutting is to stop.

**Cut increment** – material value in the Z axis of cutting in one tool pass.

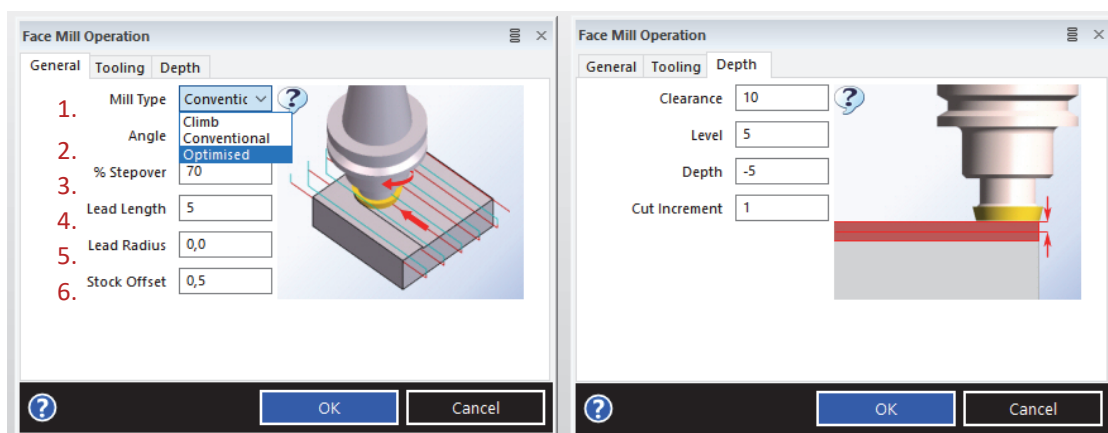


Figure 4.17. Face Mill Operation Menu

Choose the tool from the Tool Store and define tooling parameters (Figure 4.18).

## TOOLING

**Feedrate** – the rate of movement in the workplane.

**Plunge Feed** – specifies the rate of movement in the direction of the tool axis.

**Speed** – the tool spindle speed.

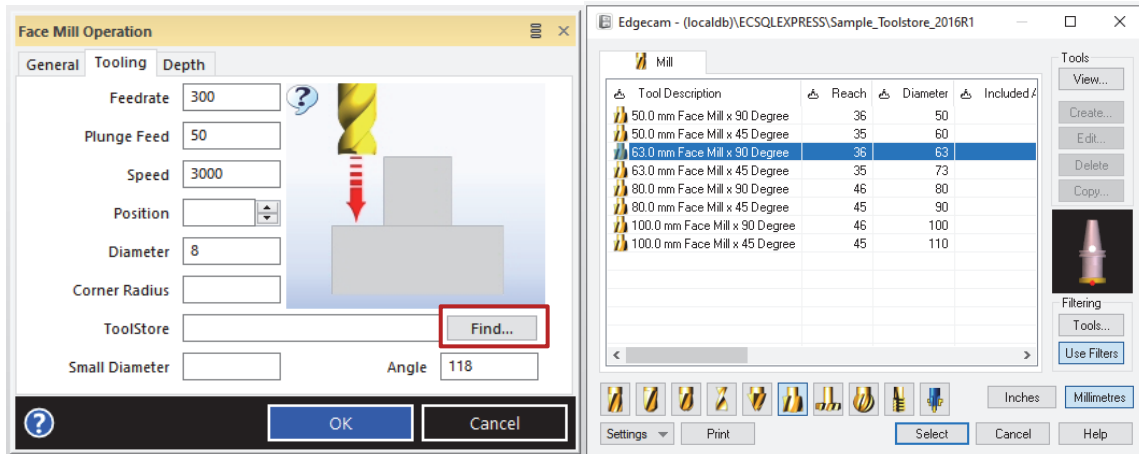


Figure 4.18. Tooling parameters menu

Toolpaths created in the Face Mill Operation and chosen tool are shown in Figure 4.19. Straight lines represent feed movement, dotted lines represent rapid movements of the tool.

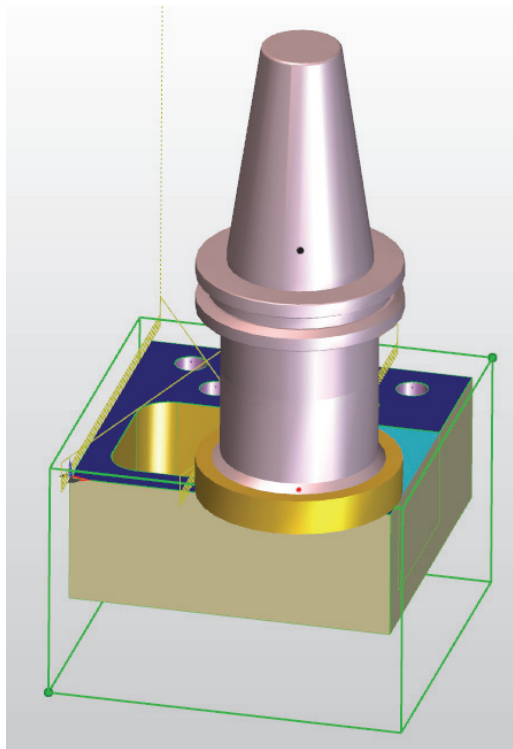


Figure 4.19. Results of the Face mill Operation

## 6. Rough mill operation

Rough mill operation (Figure 4.15 no. 2) is used to remove stock material from the component. Choose the feature **2D Boss** to define geometry of the component which will be result of the operation. Define General and Depth parameters (Figure 4.20) Notice, that in Rough Mill Operation, Depth Parameter (a) is equal to 0, as in this case the depth is counted from the lowest feature level.

Choose the Digitize Stock option to define boundaries of the machining. After defining and approving all of Operation parameters, choose the upper frame of the stock (Figure 4.21) to set the boundaries.

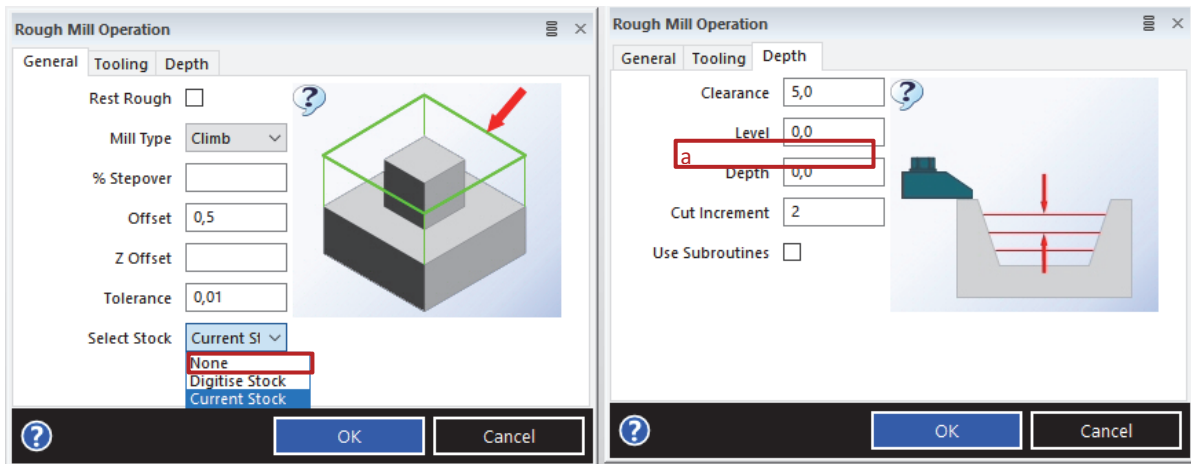


Figure 4.20. Rough Mill Operation Menu

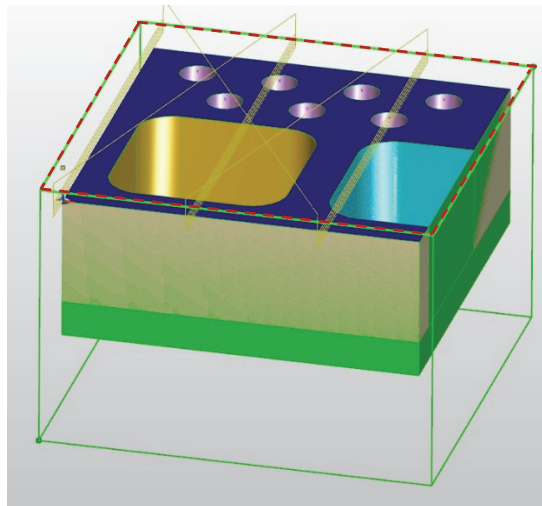


Figure 4.21. Boundries defined based on the stock



Define tool parameters and choose the tool from the Tool Store (Figure 4.22).

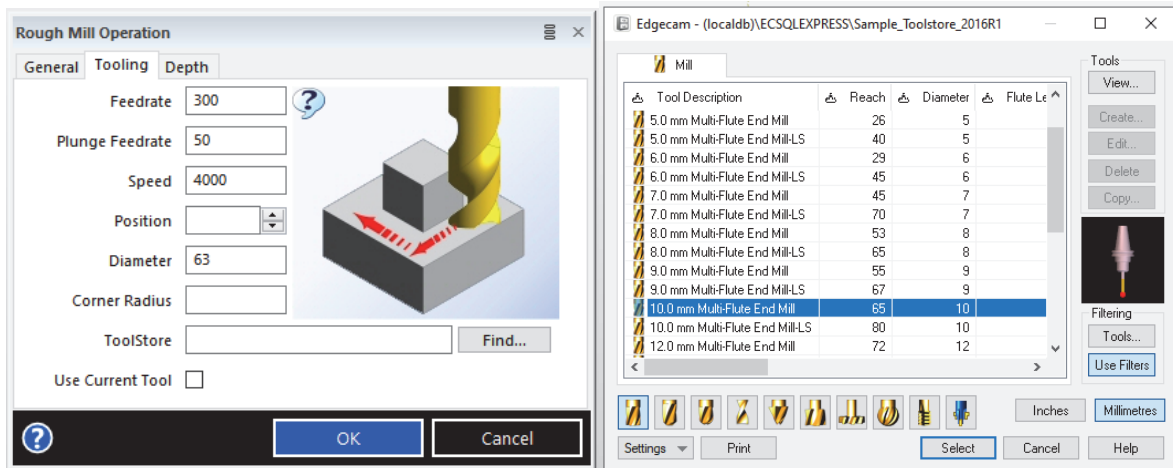


Figure 4.22. Tooling parameters menu

Result of the Rough Mill Operation is shown in Figure 4.23.

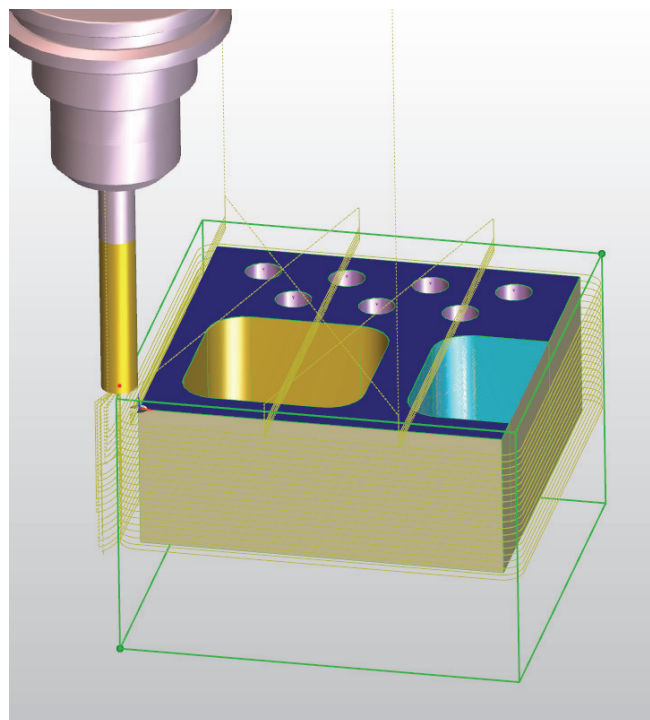


Figure 4.23. Rough Mill Operation Results

## 7. Profile Mill Operation

Profile Mill Operation (Figure 4.15 no. 3) creates finishing pass around the profile of the component or the feature. Choose the feature **2D Boss** to define geometry of the component which will be result of the operation. Define General Parameters and choose Compensation (Figure 4.24).

## COMPENSATION

**None** – the output toolpath is created for the center of the tool.

**Centre Line** – the output toolpath is created for the center of the tool with use of Codes G40/41/42.

**Geometry** – the output toolpath is created for the edge of the tool with use of Codes G40/41/42.

Define Tooling parameters and choose a tool from the Tool Store (Figure 4.25).

Result of the Profile Mill Operation is shown in Figure 4.26. Toolpath of this operation is designated by purple lines. Yellow toolpaths represent previous operations – Face and Rough Mill.

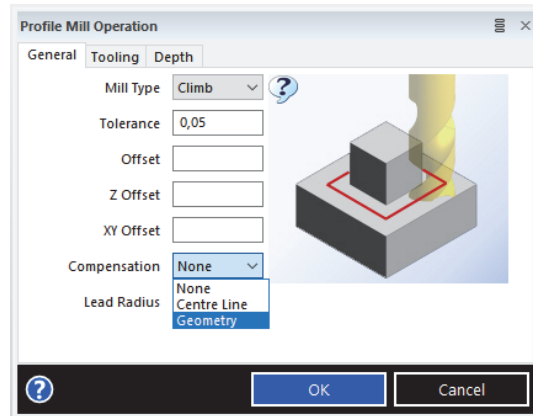


Figure 4.24. Profile Mill Operation General parameters

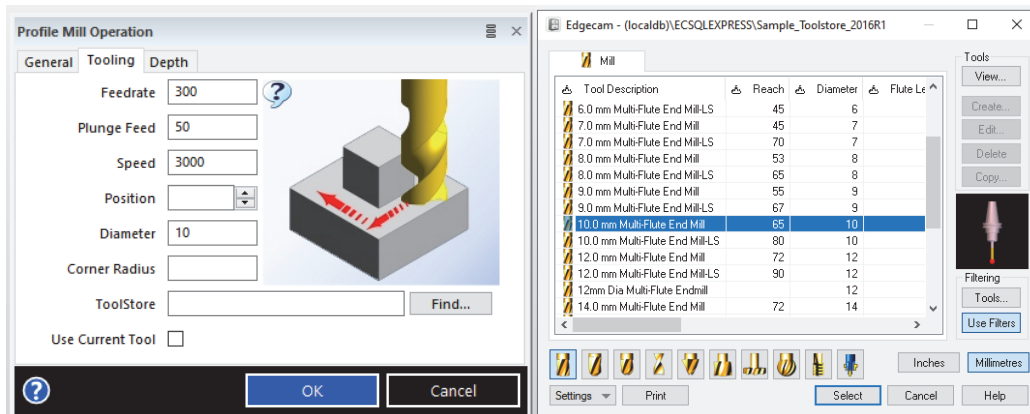


Figure 4.25. Profile Mill Operation Tooling Parameters

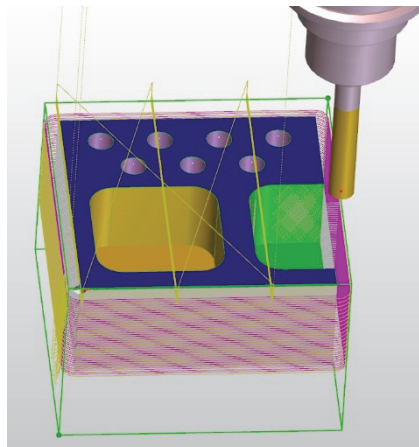


Figure 4.26. Results of the Profile Mill Operation

## 8. Holes

Holes operation (Figure 4.15 no. 4) is used for different hole creation methods, including drilling, reaming and boring. Choose the feature **Blind hole** to select points of the holes (Figure 4.27).

Holes Operation menu (Figure 4.28) is divided in five sections:

- General;
- Centre/Spot;
- Preparation;
- Roughing;
- Finishing.

In the General Option window (Figure 4.28) designate **Clearance** and define if it is associated with the Feature or the Model, choose **Termination** and **Optimise Path**, to determine the order in which the holes are machined.



Figure 4.27. Selecting points command

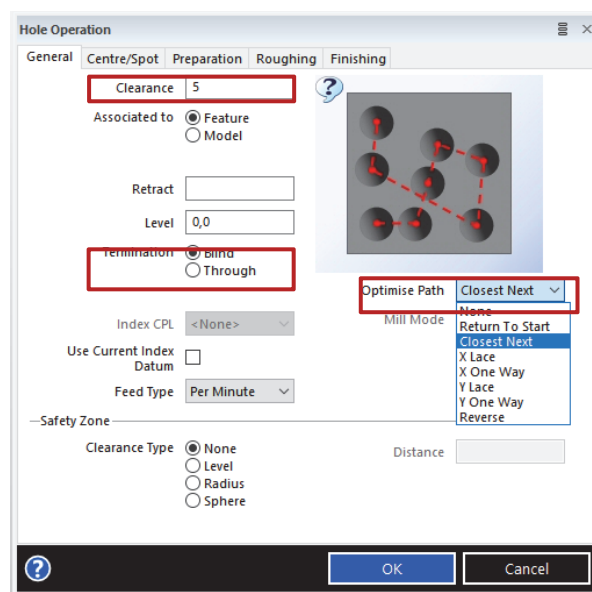


Figure 4.28. Hole Operation – general options

### OPTIMISE PATH

**None** – the holes are machined in the order in which they were selected.

**Return to Start** – the holes are machined in the order that produces the shortest path, based on a need to return to the start point at the end of the cycle.

**Closest Next** – the next nearest hole is next machined.

**X Lace** – the holes are drilled in rows, working in alternate left/right directions.

**X One Way** – the holes are drilled in rows, working in one direction.

**Y Lace** – the holes are drilled in columns, working in alternate up/down directions.

**Y One Way** – the holes are drilled in columns, working in one direction.

Use Centre/Spot Menu (Figure 4.29) to create a small divot to correctly locate the center of a drill when initiating a plunge. Choose a tool from a Tool Store.

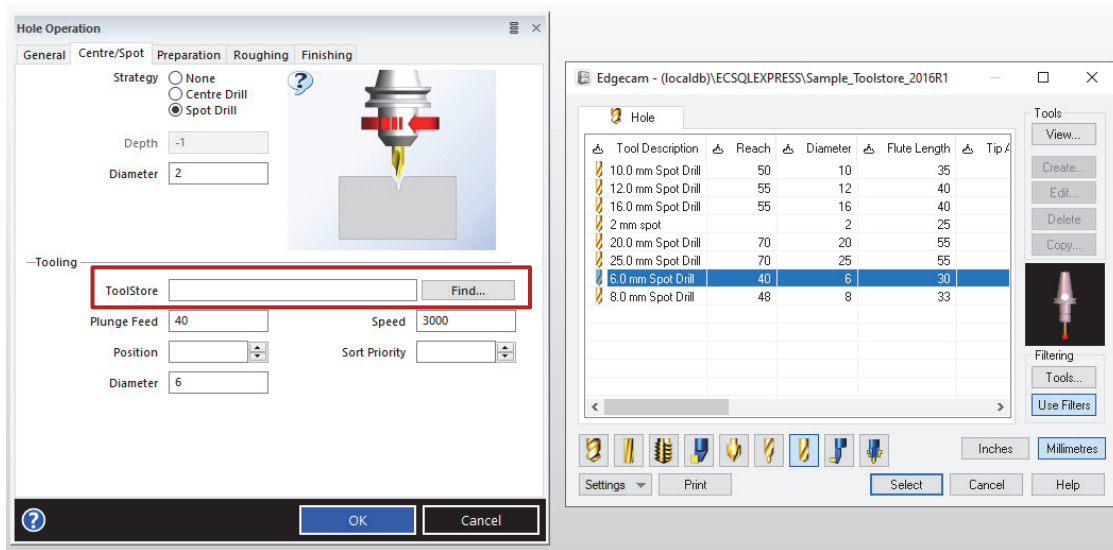


Figure 4.29. Hole Operation - Centre/Spot Menu

Use Roughing Menu (Figure 4.30) to define drill parameters, apply strategy and choose the tool.

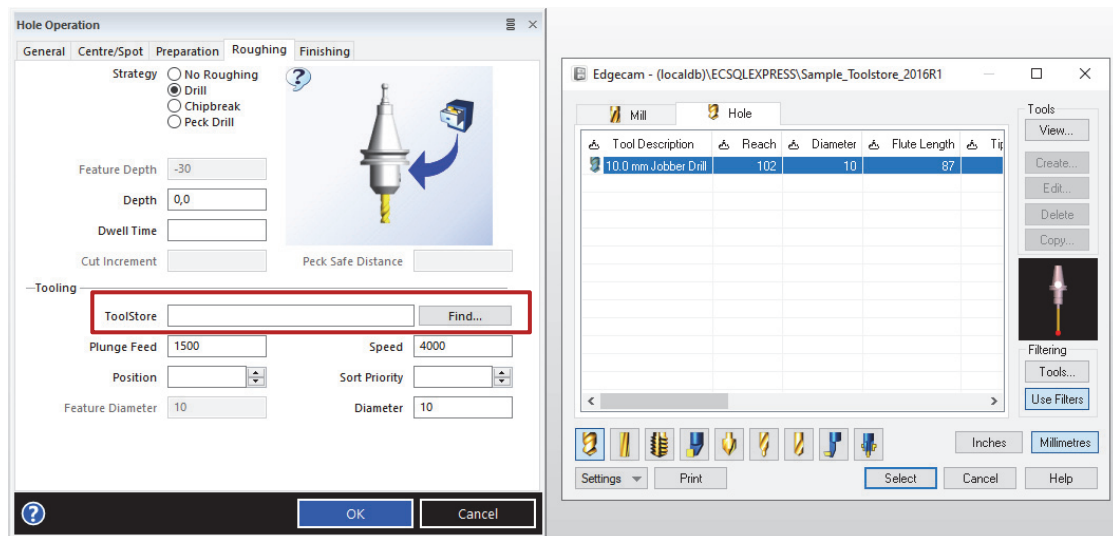


Figure 4.30. Hole Operation - Roughing Menu

## ROUGHING STRATEGIES

### No roughing

**Drill** – the tool advances in a series of 'Cut Increments', moving back to the Retract height between each advance.

**Chip break** – the tool retracts by the 'Peck Safe Distance' after each advance.

**Peck drill** – breaks down the cut into a number of smaller advances with intermediate retracts.

Result of the Holes operation is shown in Figure 4.31.

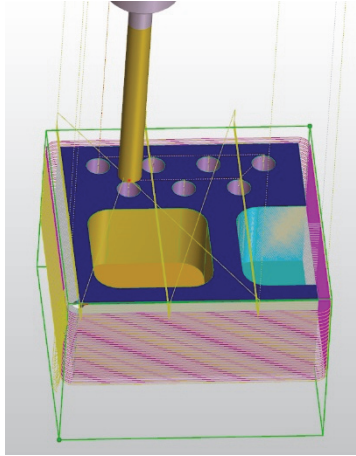


Figure 4.31. Result of the Holes operation

Use the Rough Mill Operation (Figure 4.15 no. 2) to prepare machining of the pockets (features **2D pocket**, **2D Open Pocket**). For the **2D Open Pocket**, set the boundaries as upper frame of the stock as in Figure 4.21. Result of the pocket machining is shown in Figure 4.32.

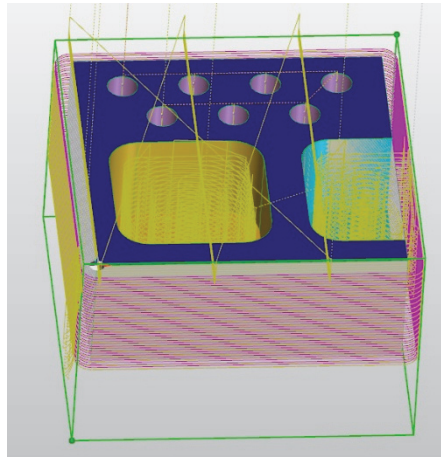


Figure 4.32. Result of the pockets machining

To open advanced Roughing menu and define strategy of pocket machining double click on the 6.1 Roughing in the Sequence Browser (Figure 4.33). In General Roughing Options Menu (Figure 4.34) apply strategy of pocket machining (Figure 4.35).

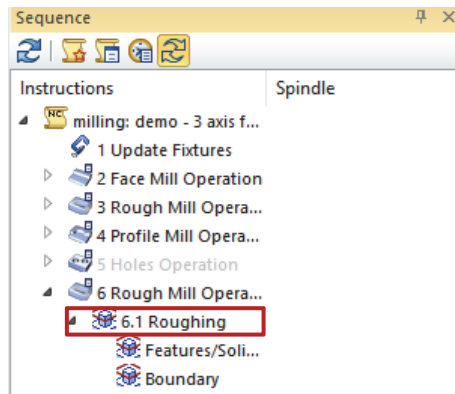


Figure 4.33. Sequence Browser

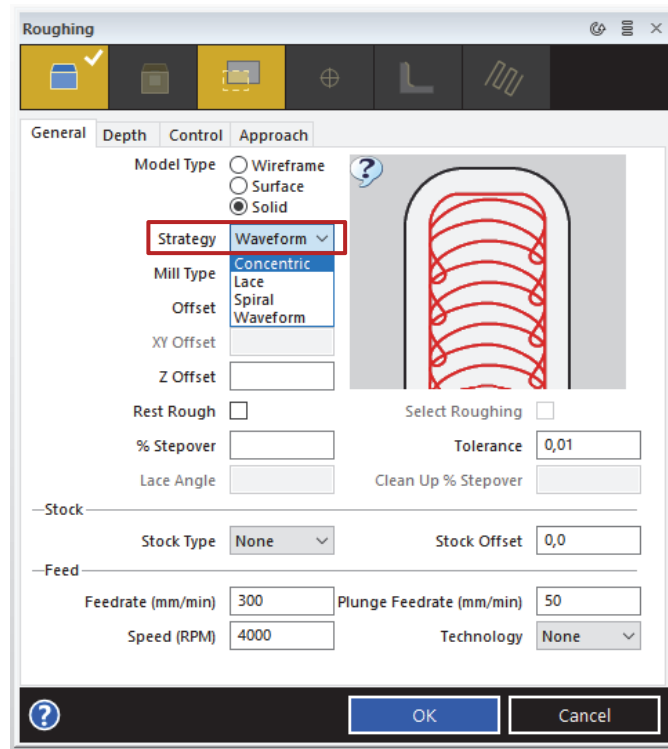


Figure 4.34. General Options Roughing Menu

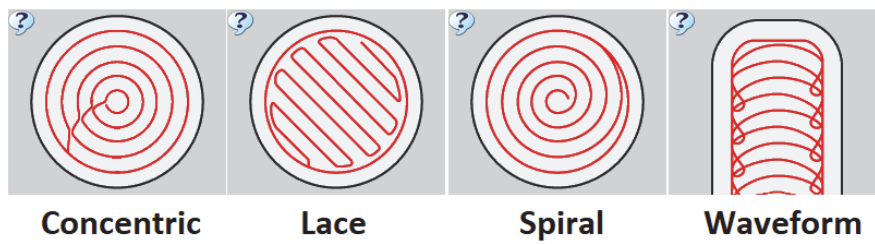


Figure 4.35. Roughing Pockets Strategies

Result of applying pocket strategies is shown in Figure 4.36.

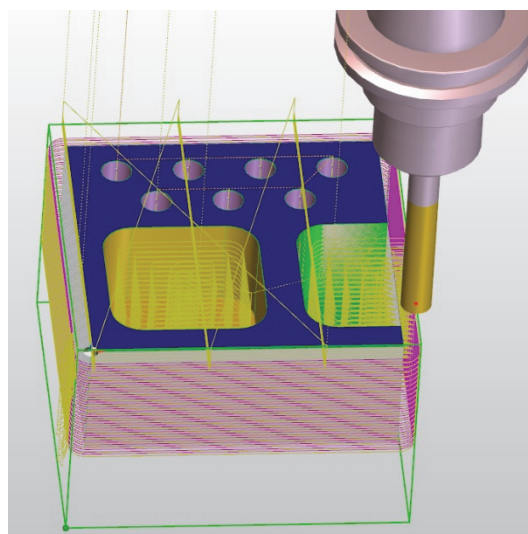


Figure 4.36. Results of applying pocket strategies

Operation details of the pocket (Figure 4.37) shows, the difference of cycle time and number of code elements before and after applying a roughing pocket strategy.

*1/10 Toolpath : 674 : 10.0 mm Multi-Flute End Mill 26*** : Roughing CPL : 'Top' Cycle Time: 24 minutes 26 seconds Elements : 3270 Dependency CLEAR	*1/5 Toolpath : 674 : 10.0 mm Multi-Flute End Mill 26: Roughing CPL : 'Top' Cycle Time: 17 minutes 56 seconds Elements : 643 Dependency CLEAR
---	---

Figure 4.37. Pocket Operation details (before and after)

## 9. Simulation

To run the simulator and verify the sequence use Simulation button in Machining Menu (Figure 4.15 no. 5).

Simulation window is shown in Figure 4.38.

Use the Main toolbar (A) to control the simulation.

Use the Display toolbar (B) to control the simulation display and collision control options.

Use the Sequence browser (C) to investigate the sequence start the simulation at any point in the instruction list.

To view a comparison between the stock and the component use View comparison (D).

Results of the simulation are shown in Figure 4.39. Results of comparison between the stock and the component are shown in Figure 4.40.

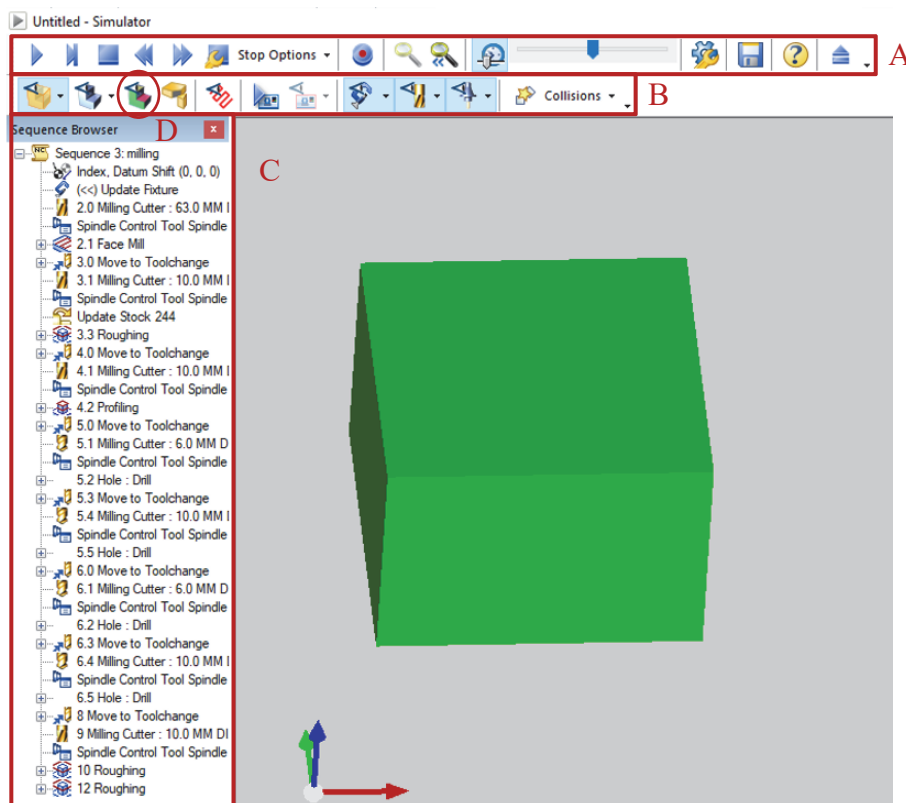
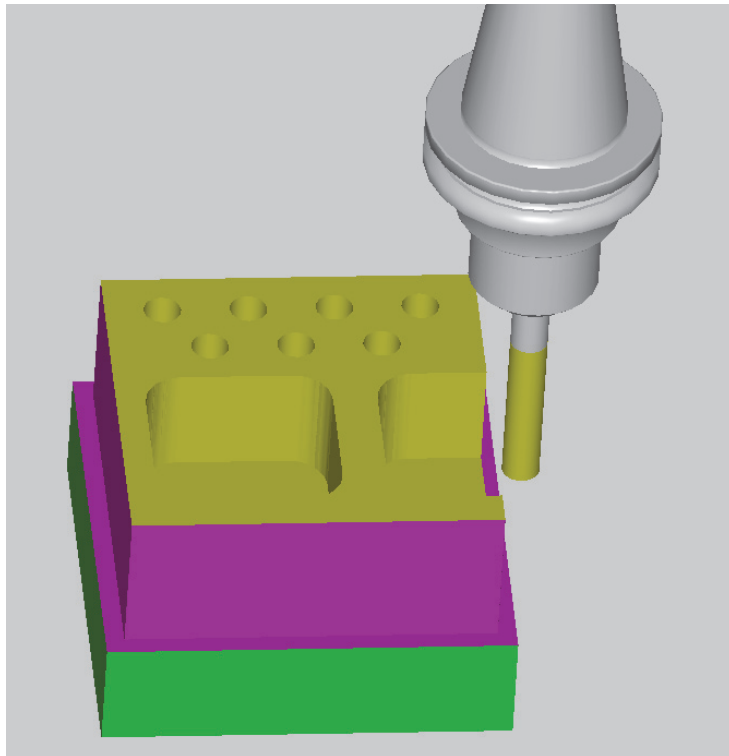
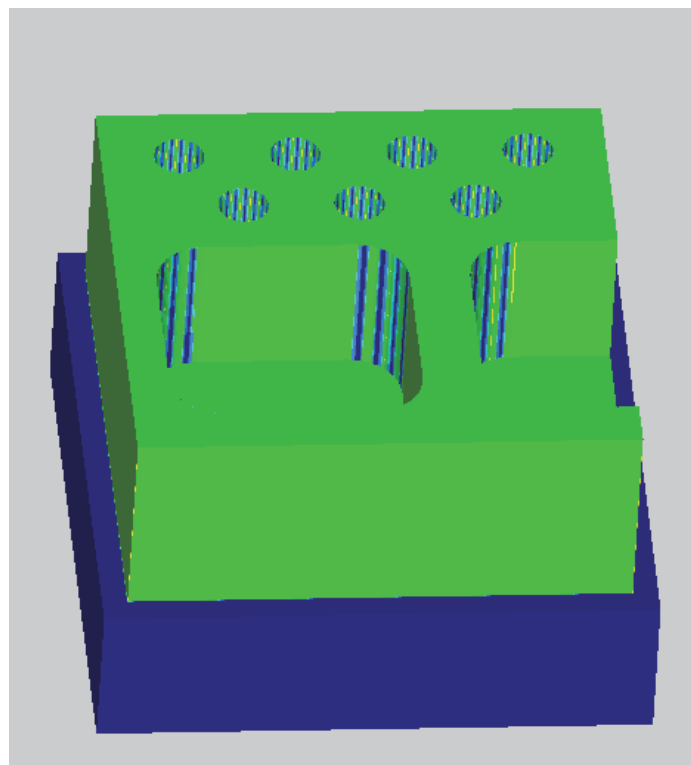


Figure 4.38. Simulation Interface



*Figure 4.39. Simulation results*



*Figure 4.40. Results of comparison between the stock and the component*

#### **IV. Turning example**

After opening the turning environment and loading the model, the component is visible in the center of the screen (Figure 4.41). Coordination system in the left bottom corner shows



the direction and sense of the axis of the coordinate system. The beginning of the coordination system is visible on the component, according to its position in the CAD model. Adjustment of its position is possible from Component setup window, Datum and position section (Figure 4.42).

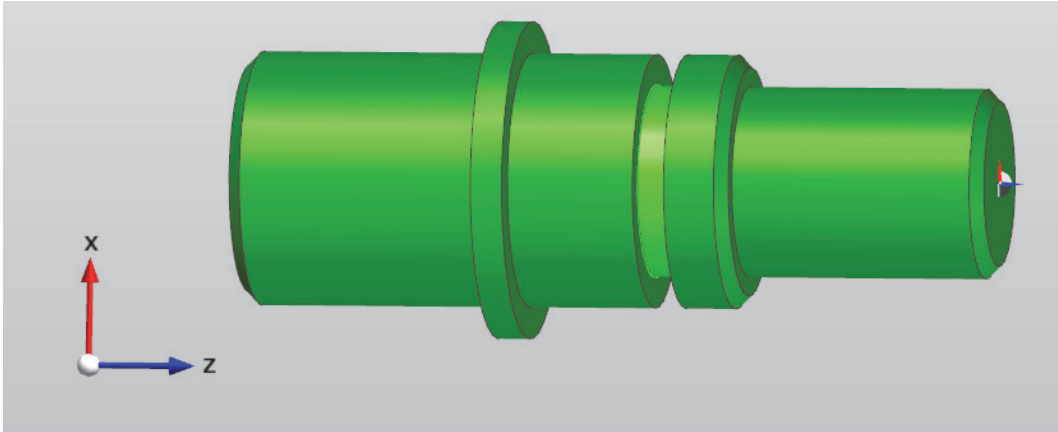


Figure 4.41. Coordination system of loaded component

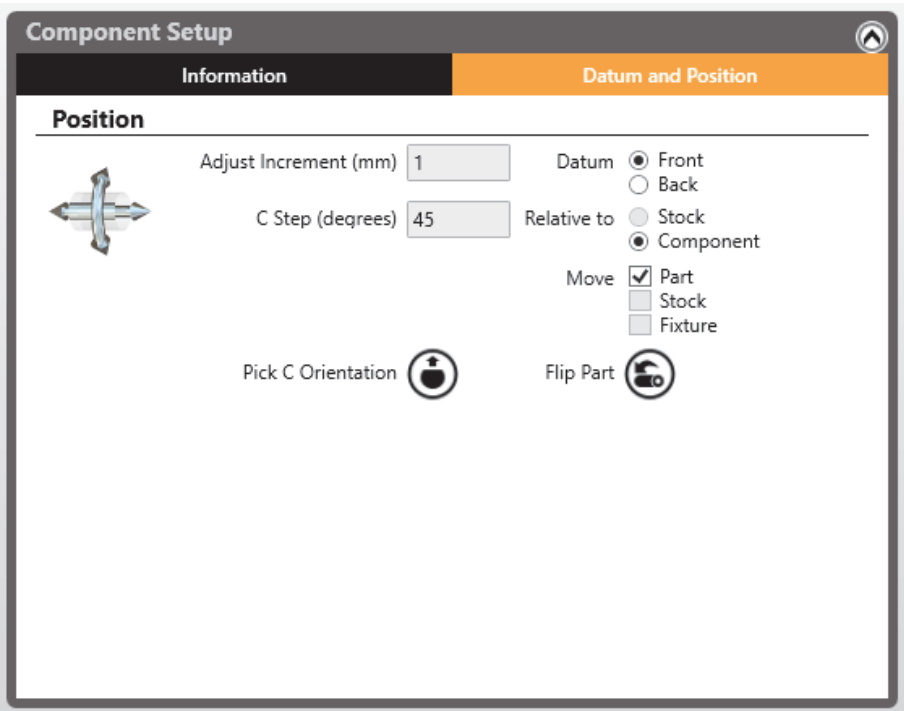


Figure 4.42. Datum and position section

**1. Stock**

Stock is necessary to show how the initial billet of material is being machined. It is also used in the roughing cycles as boundaries, which limits area of material removed. Fit stock option (Figure 4.3) allows to adjust the size of the stock based on the shape of the loaded component by adding Offsets on the sides (Figure 4.43). Shape of the stock is predefined as cylinder.

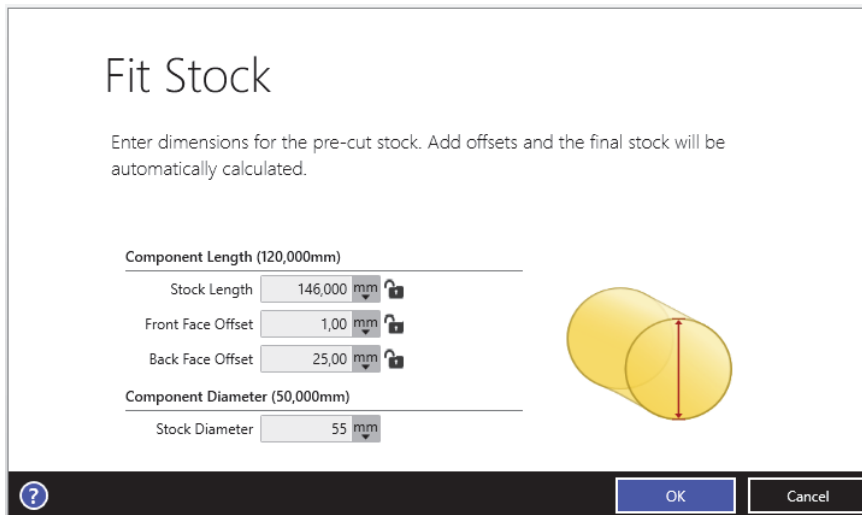


Figure 4.43. Fit stock option

## 2. Fixtures

Fixtures represent how the work piece will be clamped. It helps to plan manufacturing process and avoid collisions. From the Fixture Database (Figure 4.3) you can choose required type and size of jaws and define stock position (Figure 4.44).

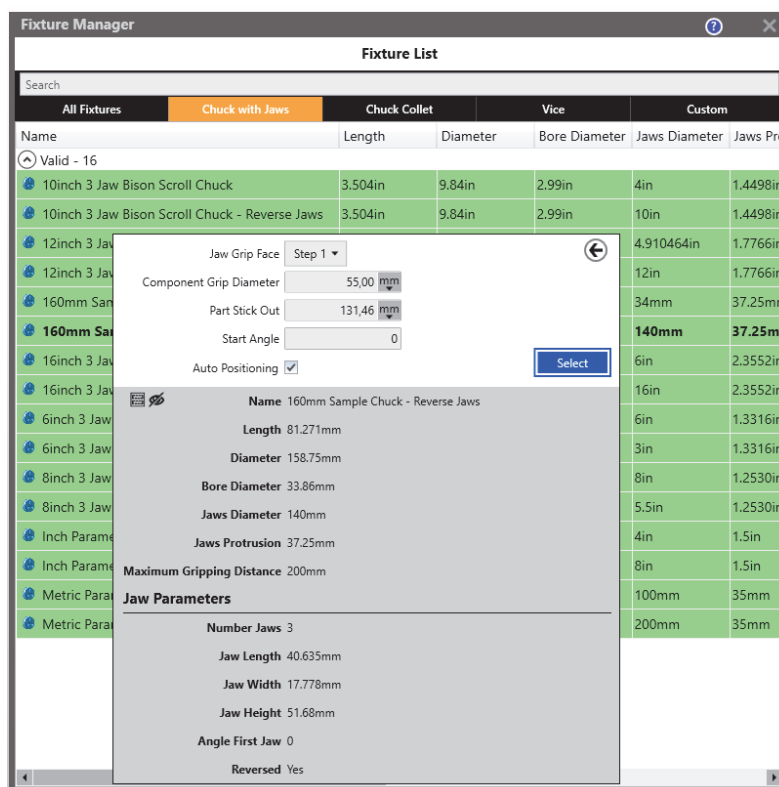


Figure 4.44. Fixture List

Stock mounted in the fixture is shown in Figure 4.45.

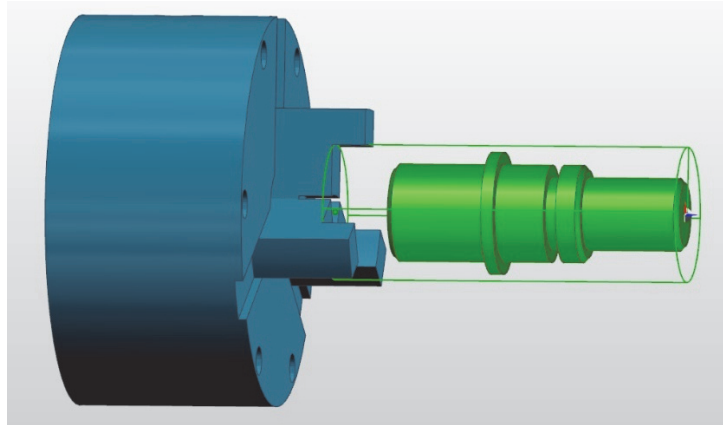


Figure 4.45. Stock mounted in the jaws

### 3. Features

Features represents the geometry, based on which machining cycles will be created. Types of the turning features: turn faces, front/back profiles, grooves etc. are determined based on geometry properties. They can be defined based on the geometry of the component or be created by the user. To search for features on the component, use Feature Finder option (Figure 4.11). In the turning environment, Feature finder allows to choose what kind of turning options will be adapted to the component (Figure 4.46). User can also define milling features and advanced options of the feature, including minimum or maximum diameters, positions of turning profiles and adjust color representation. Defined features will be visible on the Feature browser on the left side of the screen. Also, they will be represented on the component with colors assigned to each feature (Figure 4.47).

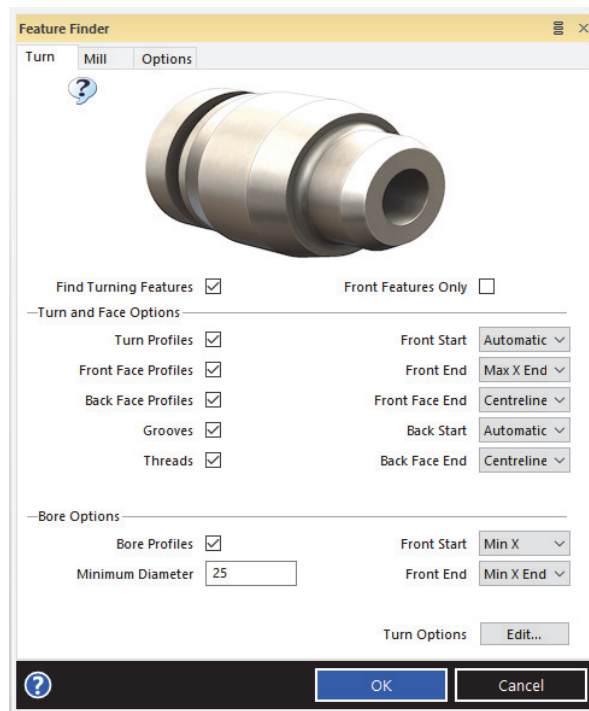


Figure 4.46. Feature finder

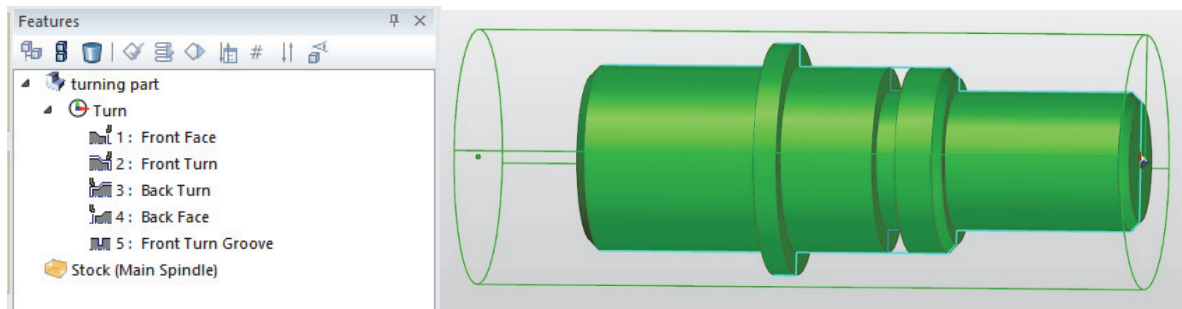


Figure 4.47. Feature browser and feature representation on the component

#### 4. Creating turning sequence

After preparation process, which included adapting stock, fixture and features, user have to create turning sequence. Click on the screen with the right button of the mouse, and from the menu choose Manufacture option (Figure 4.48). Then, in Create Turning Sequence window define sequence name.

A Code generator will represent type of the turning machine (lathe) used in the process. Chosen postprocessor will affect the manufacturing process, defining possible operations based on the machine capabilities like number of working axis and adjust toolpaths to size of the machine working space. Different postprocessor are used to each milling machine type. It allows for accurate simulation of the process in order to observe and prevent collisions.

Component and machine setup options allows to define the initial CPL (construction plane). CPL defines a local co-ordinate system at any orientation to the World axes.

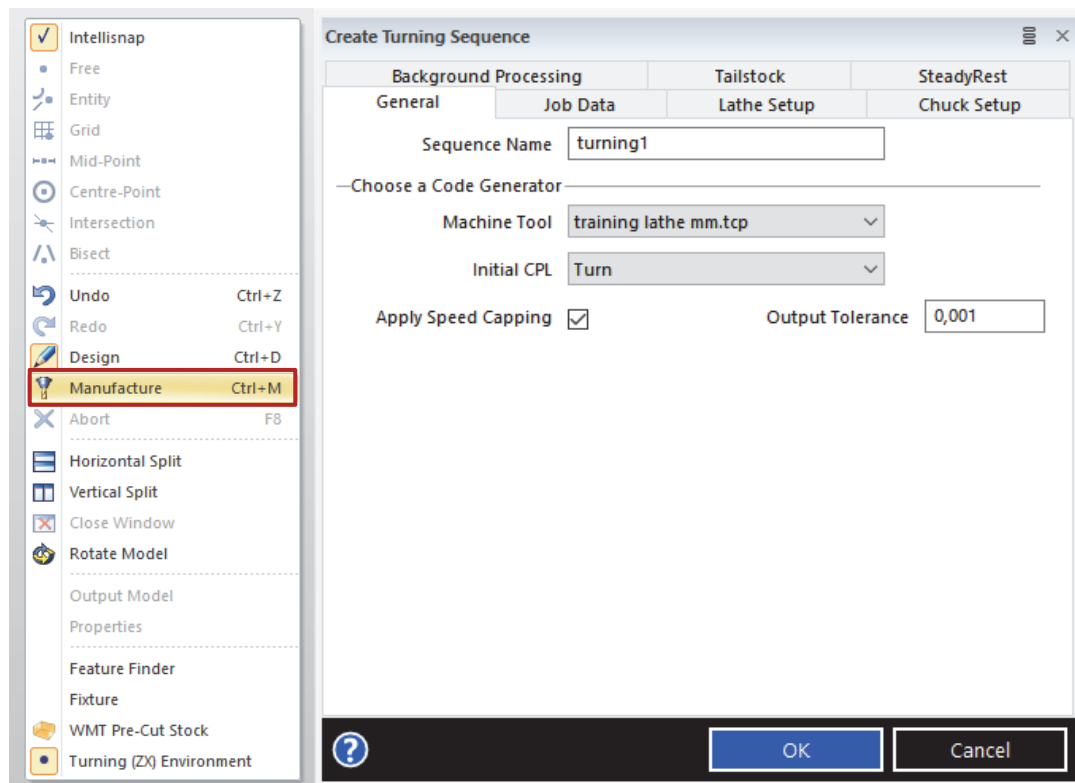


Figure 4.48. Creating milling sequence

When turning sequence is created, the mill operation can be defined. In the machining menu (Figure 4.49) user can choose:

- **Automatic Manufacturing**, which allows to plan and apply strategies based on created features.
- **Turning operations**, responsible for different types of turning operations.
- **Mill Operations**, responsible for different types of turning operations.
- **Other Machining cycles**, used for selecting and moving the tool and advanced turning and milling operations.

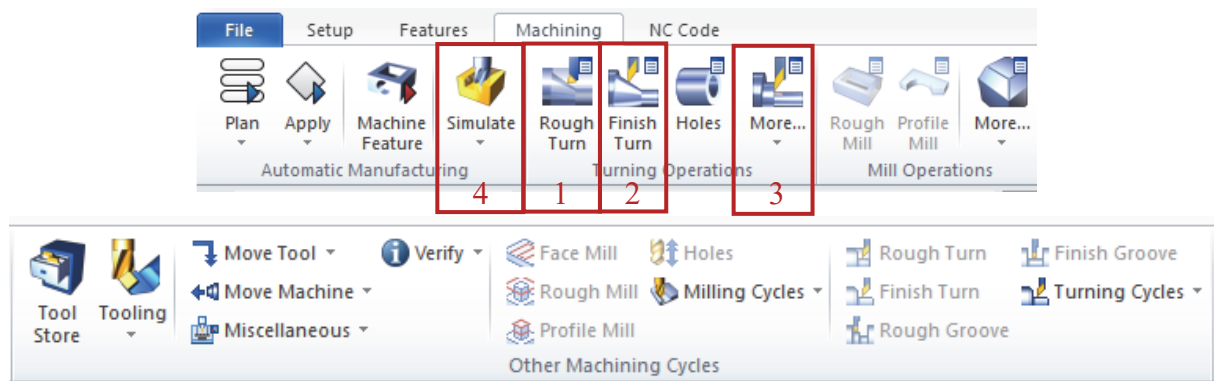


Figure 4.49. Turning operations menu

Other turning operations, like Straight turn, Grooves etc. are hidden under a **More** icon (Figure 4.49 no. 3). They are shown in Figure 4.50.

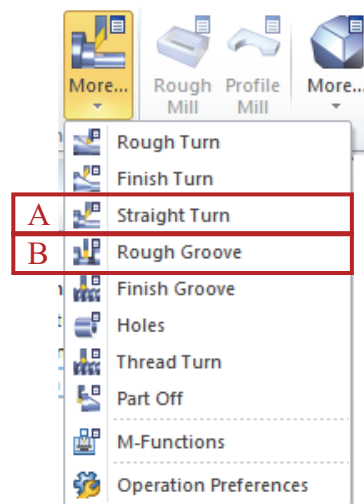


Figure 4.50. More turning Options

## 5. Straight Turn Operation

The Straight Turning (Figure 4.50, A) operation can be used to make the initial facing cut on the profile, so that future roughing passes can be taken over a smoother surface. Select a cycle start position at the edge of the stock (Figure 4.51). Then, select a destination point, at the surface of the component, below the beginning of the coordination system (Figure 4.52).

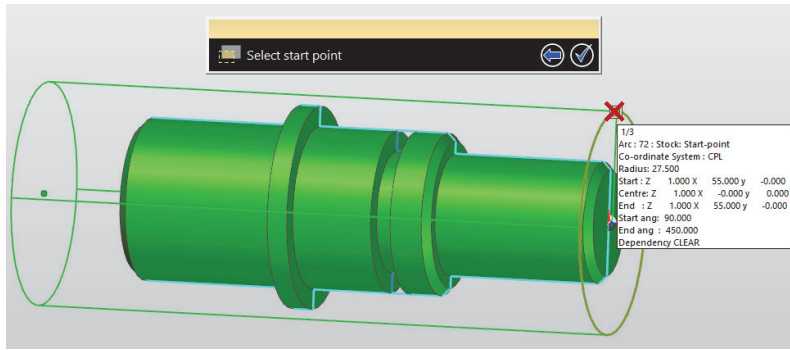


Figure 4.51. Straight Turn Operation - start point

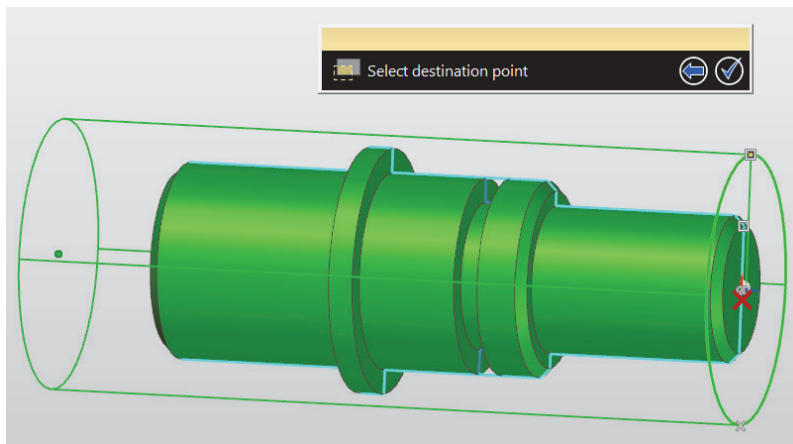


Figure 4.52. Straight Turn Operation – destination point

In the Straight Turn/Face Operation Menu (Figure 4.53), define General machining parameters.

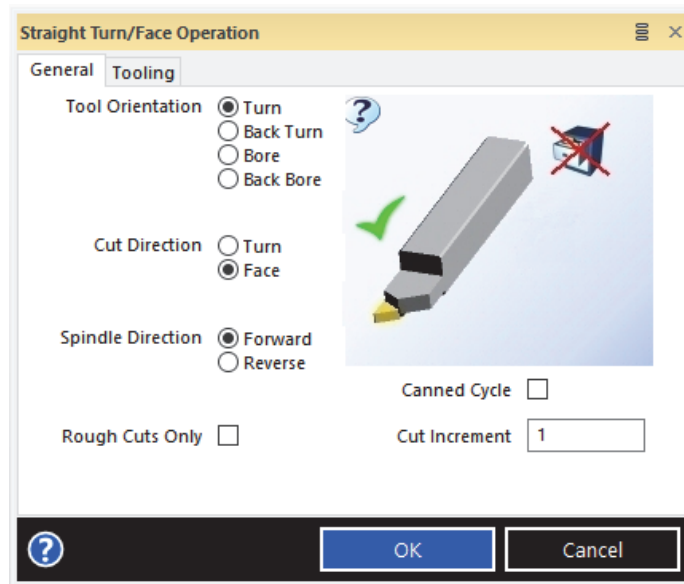


Figure 4.53. Straight Turn/Face Operation – General Parameters Menu

## GENERAL

**Tool orientation** – how the tool is loaded for the operation.

**Cut direction:**

- **Turn** – parallel to the work piece's rotational axis.
- **Face** – perpendicular to the work piece's rotational axis.

**Spindle direction** – specifies the spindle direction as Forward or Reverse.

**Cut increment** – specifies the distance between cuts in the units used for the part.

Choose the tool from the Tool Store and define tooling parameters (Figure 4.54).

## TOOLING

**Feedrate** – rate of advance of the tool along each cutting pass.

**Speed** – spindle speed of the turning centre in revolutions per minute.

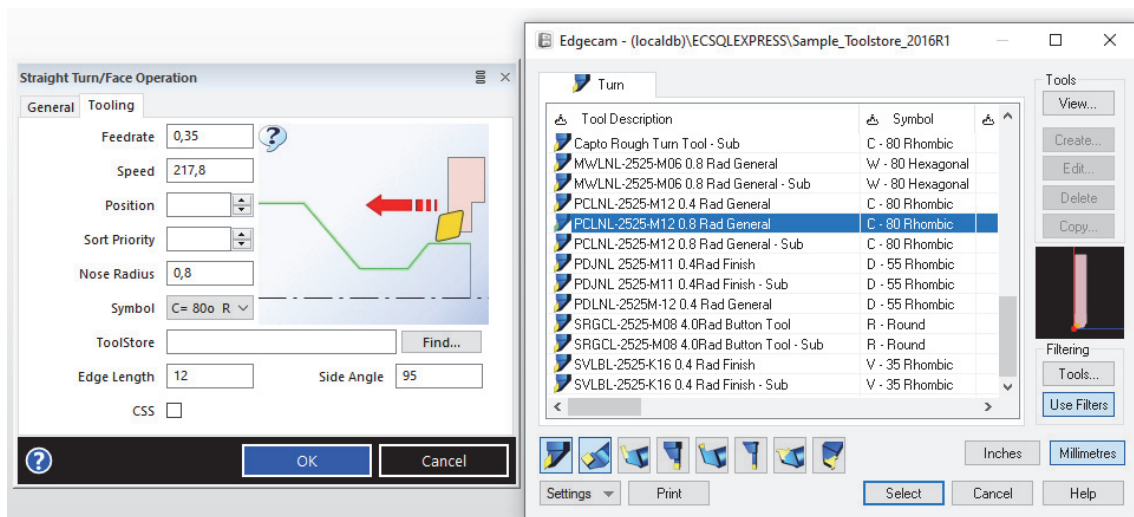


Figure 4.54. Straight Turn/Face Operation – Tooling Parameters Menu

Results of the Straight Turn/Face Operation – created toolpaths and chosen tool are shown in Figure 55. Straight lines represent feed movement, dotted lines represent rapid movements of the tool.

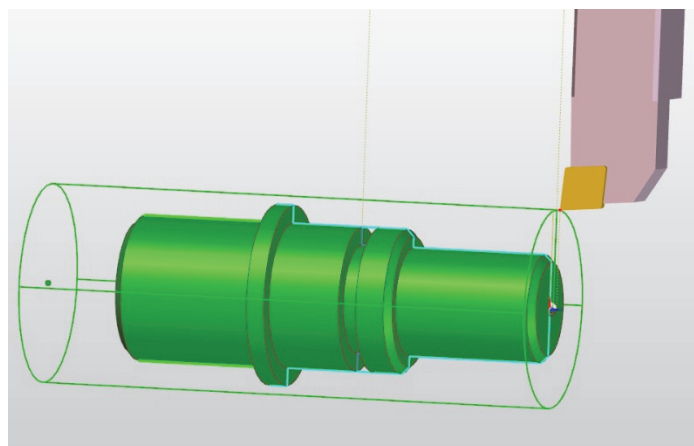


Figure 4.55. Results of the Straight Turn/Face Operation

## 6. Rough turn

The Rough Turning operation (Figure 4.49 no. 1) is used for successive stock removal cuts down to a profile. Select Front Turn feature (Figure 4.56) as a turn profile.

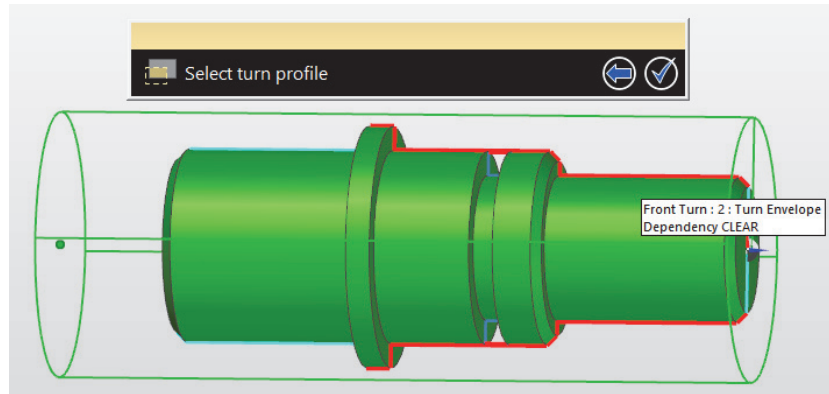


Figure 4.56. Selecting Front Turn profile

Define start point for selected profile according to the cut direction. Arrow representing start point (Figure 4.57) should be located on the outside of the component.

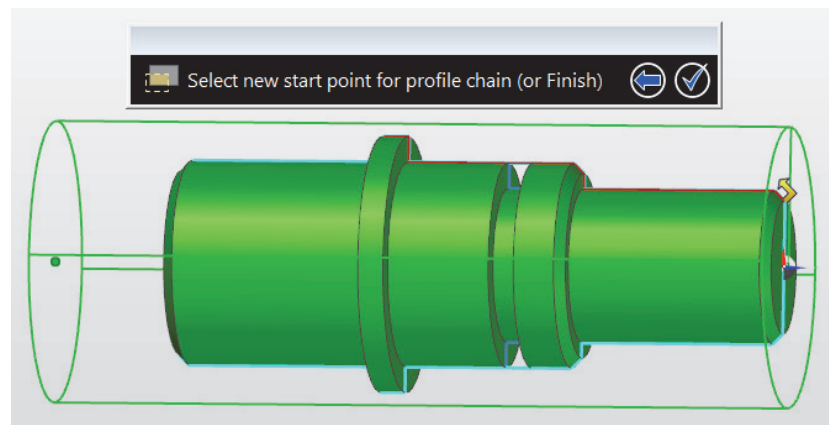


Figure 4.57. Defining position of the starting point

Define the position of the end point at the end of the front turn feature (Figure 4.58).

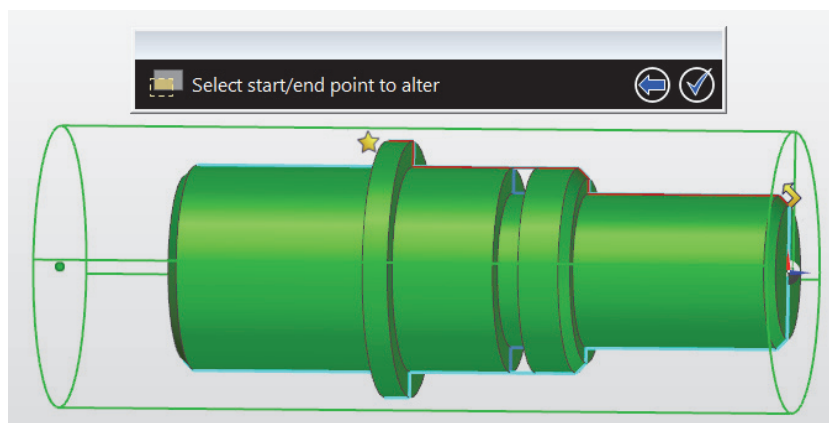


Figure 4.58. Defining position of the end point



Define the Cycle start position (Figure 4.59) to limit machining to stock range.

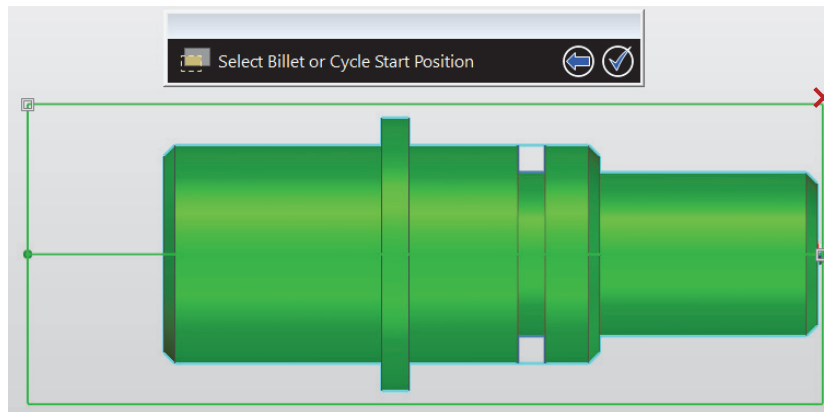


Figure 4.59. Defining Cycle Start Position

In the Rough Turn Operation Menu (Figure 4.60), define General machining parameters.

## GENERAL

**Cut Increment** – specifies the distance between cuts in the units used for the part.

**Z Offset** – specifies an offset in Z to apply to the profile boundary.

**X Offset** – specifies an offset in X to apply to the profile boundary.

### Compensation:

- **None** – cancels all compensation.
- **Controller Offset** – radius compensation based on G Code, left of right (G41/G42), output toolpath coincides with the part outline.
- **Pathcomp** – the radius compensation, the toolpath is for the gauge point of the tool.

**Profile Extension** – extend toolpath out to stock boundary along **start** and **end** cut vectors.

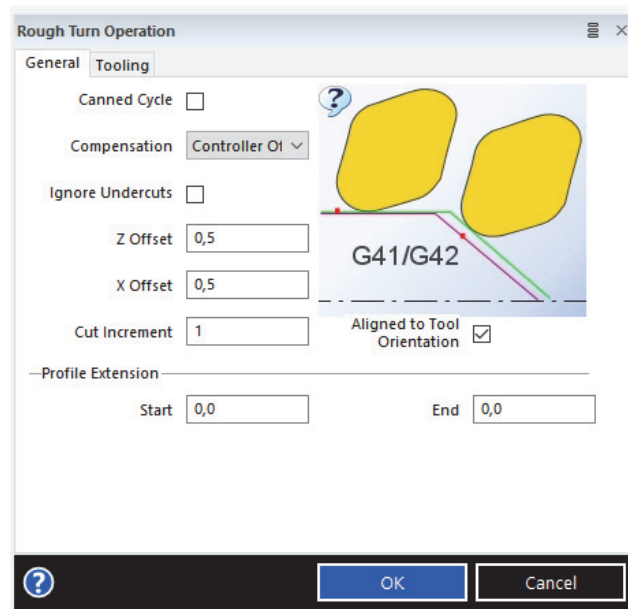


Figure 4.60. Rough Turn Operation Menu

Choose the tool from the Tool Store and define tooling parameters (Figure 4.61).

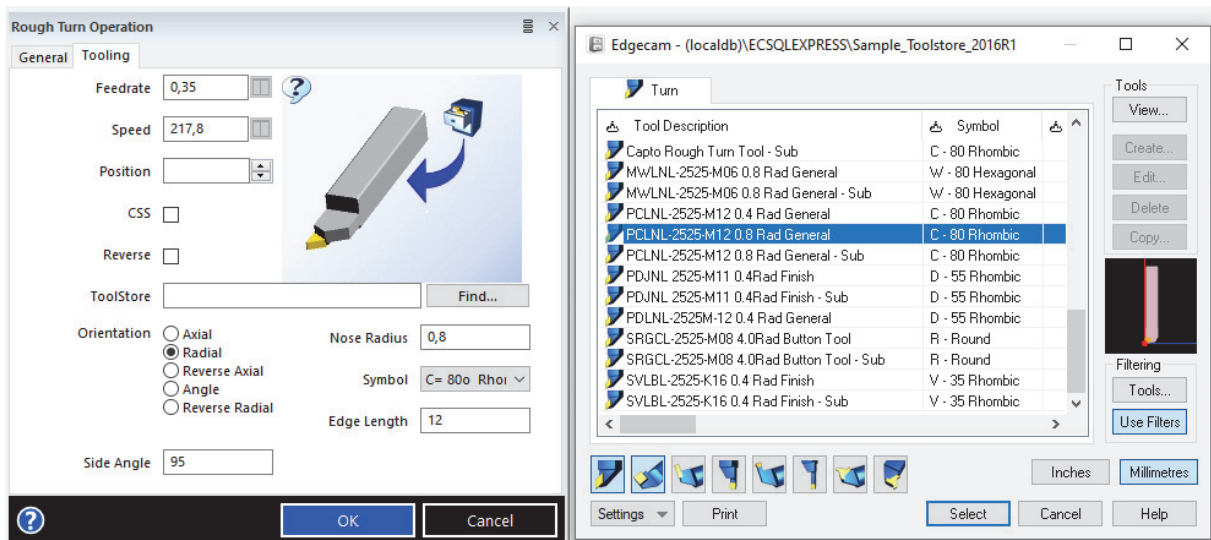


Figure 4.61. Rough Turn Operation – Tooling Parameters Menu

Results of the Rough Turn Operation – created toolpaths and chosen tool are shown in Figure 4.62.

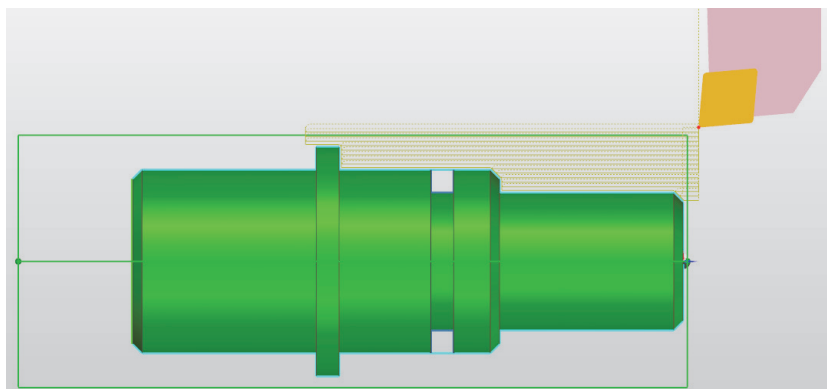


Figure 4.62. Results of the Rough Turn Operation

## 7. Finish turn

The Finish Turning operation (Figure 4.49 no. 2) is used to pass the tool once along the profile. Select Front Turn feature (Figure 4.63) as a turn profile.

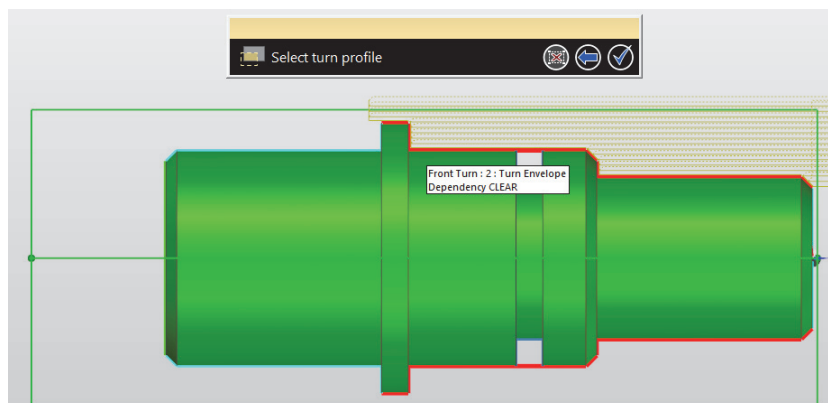


Figure 4.63. Selecting Front Turn profile

Define start point for selected profile according to the cut direction. Arrow representing start point should be located on the outside of the component. Star representing end point should be located at the end of the front turn feature (Figure 4.64).

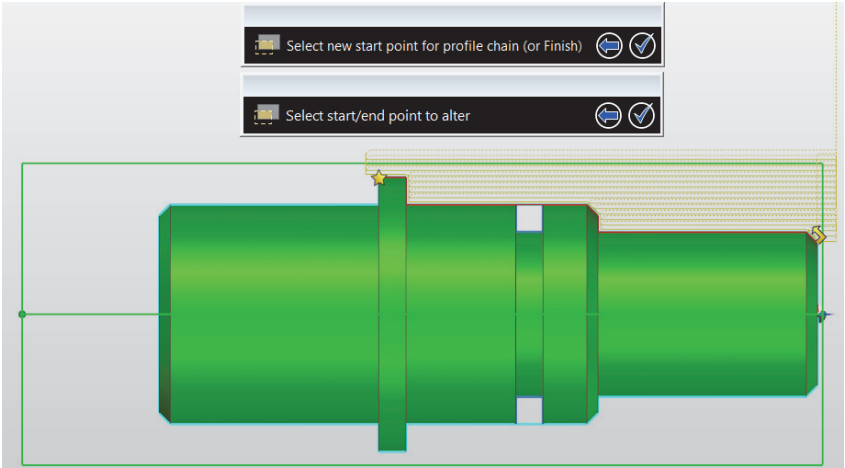


Figure 4.64. Defining position of the starting/end point

Choose the tool from the Tool Store and define tooling parameters (Figure 4.65).

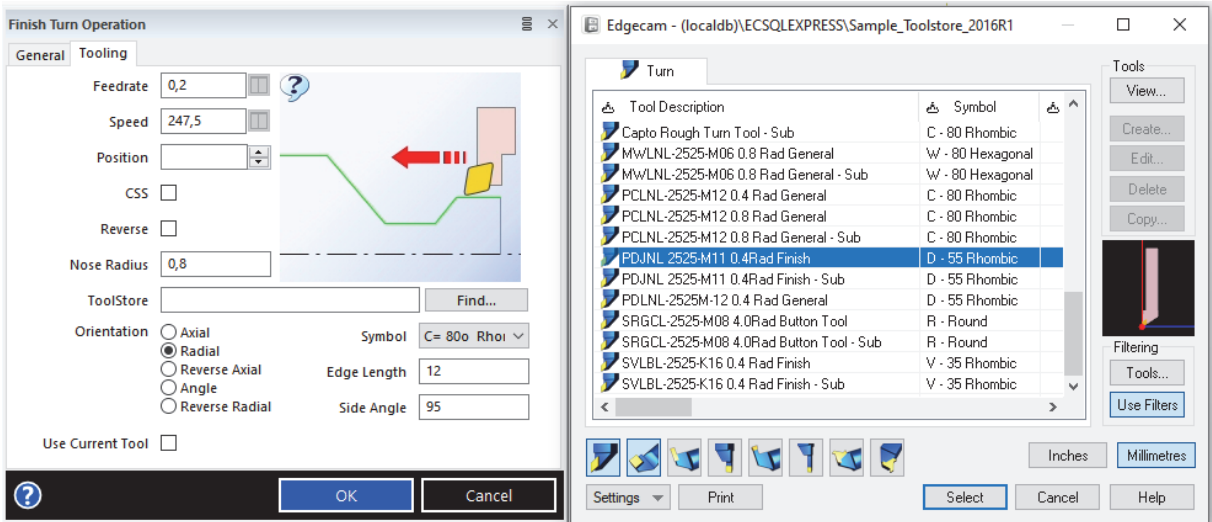


Figure 4.65. Finish Turn Operation – Tooling Parameters Menu

Results of the Rough Turn Operation are shown in Figure 4.66.

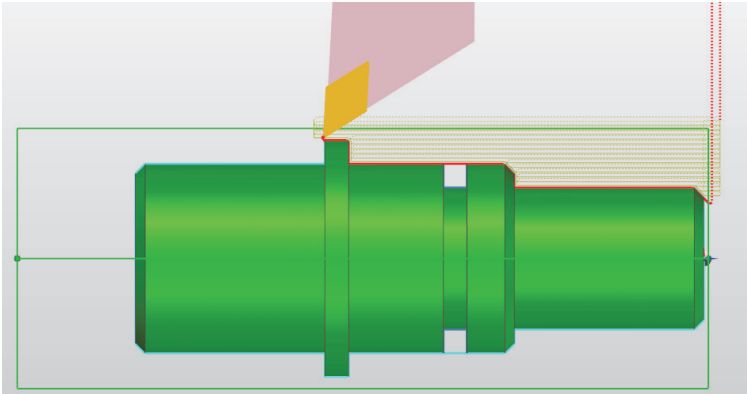


Figure 4.66. Results of the Rough Turn Operation

## 8. Rough grooves

The Rough Grooving (Figure 4.50, B) operation is typically used to remove the bulk of material from a groove profile. Select Front Turn Groove (Figure 4.47) as a turn profile. Then set the cycle start position (Figure 4.67).

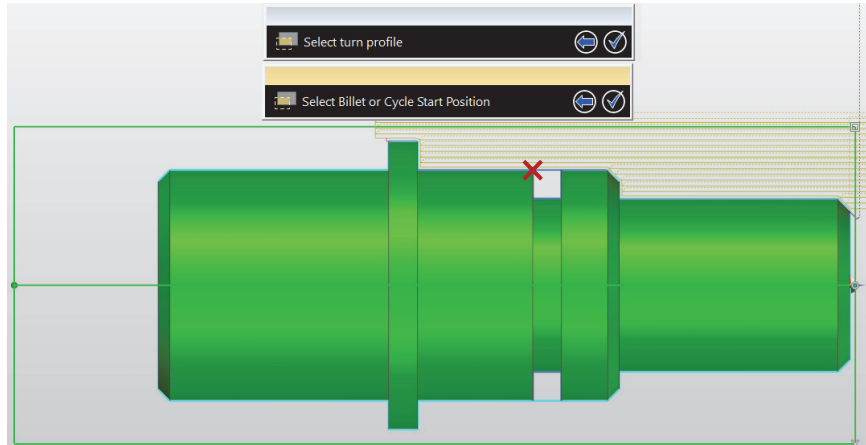


Figure 4.67. Cycle start position of the Groove

In the Rough Groove Operation Menu (Figure 4.68), define General machining parameters.

### GENERAL

**Cycle type** - the strategy for cutting the groove.

- **Sequential** – the tool starts at one groove edge and moves to the other edge, always in the same direction.
- **Centre Sequential** – the tool starts at the middle and moves towards one groove edge. Once this is reached the tool moves back to the middle and cuts to the other edge.
- **Centre Alternate** – the tool starts in the middle, then makes alternate cuts to the left and right of the middle until the groove edges are reached.
- **Sequential Castellation** – the tool starts at one groove edge and moves to the other edge, producing full width cuts. It then goes back and removes the 'rings' left behind by the first cutting pass.

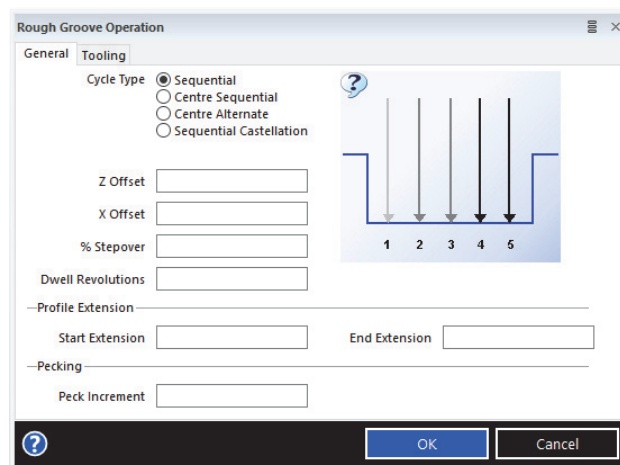


Figure 4.68. Rough Groove Operation Menu

Choose the tool from the Tool Store and define tooling parameters (Figure 4.69).

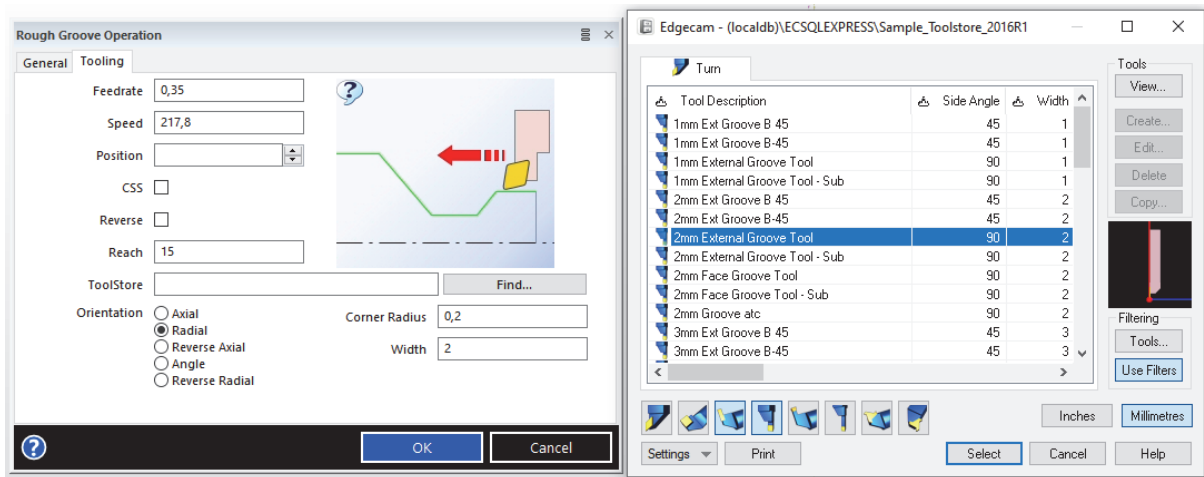


Figure 4.69. Rough Groove Operation – Tooling Parameters Menu

Results of the Rough Groove Operation are shown in Figure 4.70.

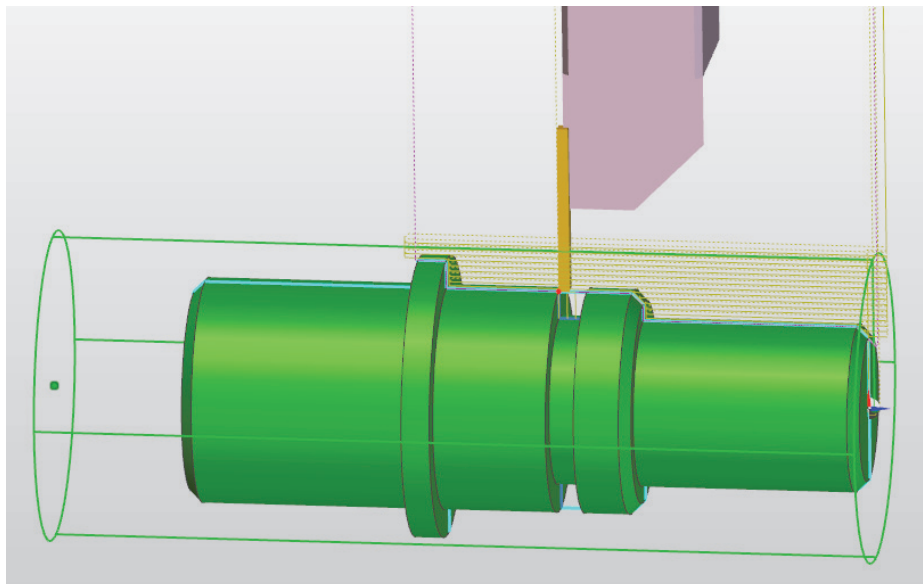


Figure 4.70. Results of the Rough Turn Operation

## 9. Additional turning sequence

To create second turning sequence for a back part of the component, click on the **New Sequence** icon in the Sequence Browser (Figure 4.71, A). In Create Turning Sequence window define sequence name.

Choose a Machine Tool and define the initial CPL (Figure 4.71, B). Initial CPL should be located accordingly to the component position during machining (**Back Inv Turn**).

Select Spindle Main Position (Figure 4.72) at the left side of the component.

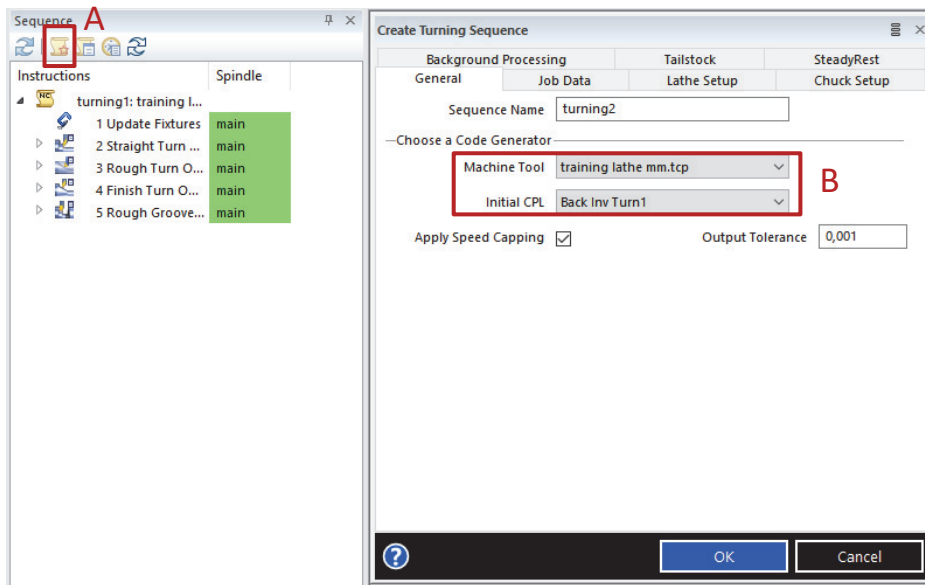


Figure 4.71. Create Turning Sequence Menu

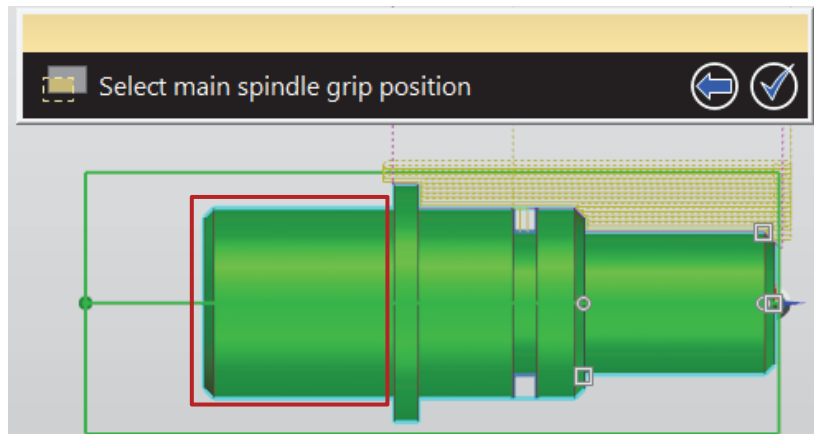


Figure 4.72. Spindle grip position

Create Straight Turning for the Back Face Select a cycle start position at the edge of the stock. Then, select a destination point, at the surface of the component, below the beginning of the coordination system (Figure 4.73).

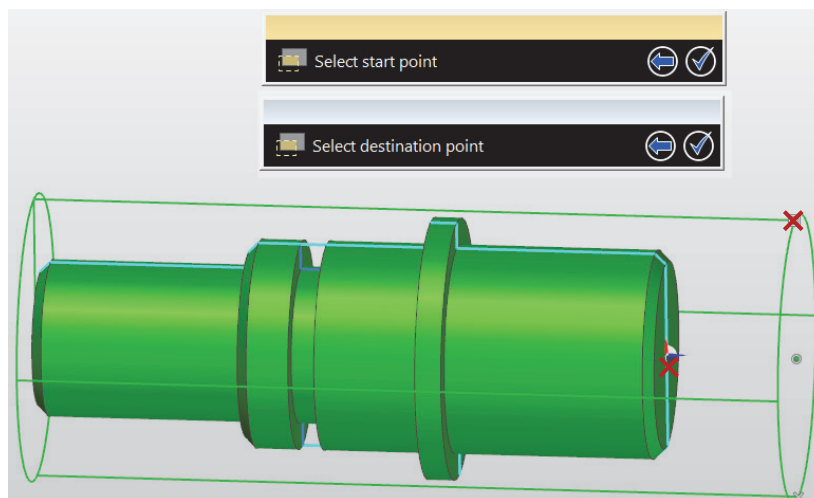


Figure 4.73. Straight Turn Operation – start/destination point

Create Rough Turn Operation. Select Back Turn feature (Figure 4.74) as a turn profile.

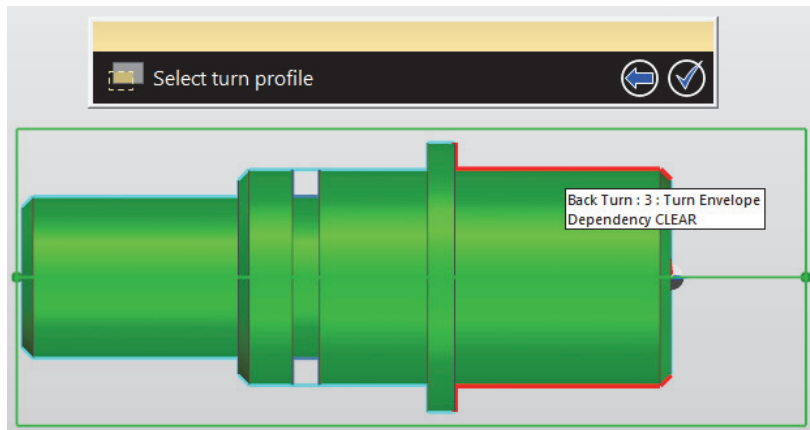


Figure 4.74. Selecting Back Turn profile

Define start point for selected profile according to the cut direction. Arrow representing start point should be located on the outside of the component. Star representing end point should be located at the end of the front turn feature. Define the Cycle start position to limit machining to stock range (Figure 4.75).

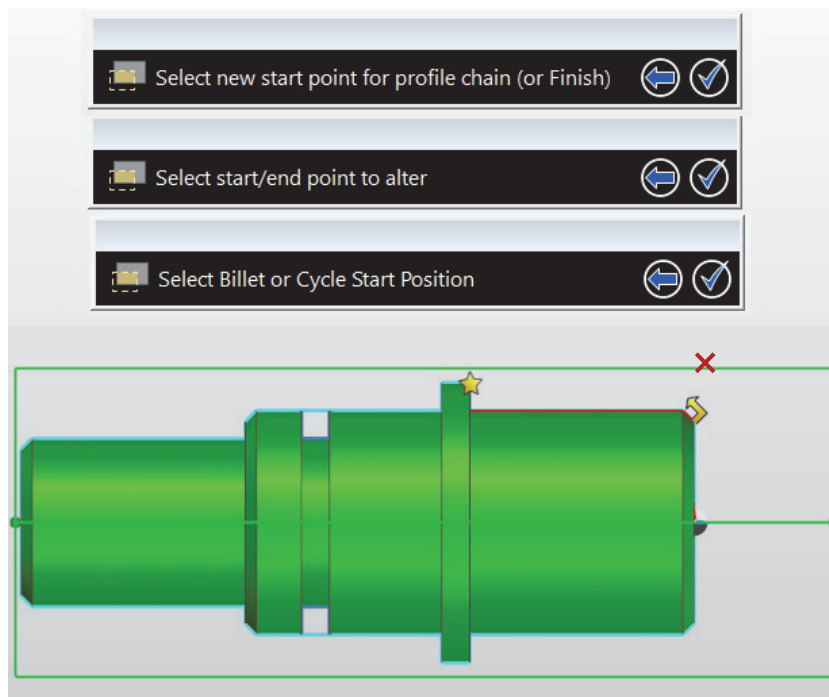


Figure 4.75. Defining start/end point, selecting Cycle Start Position

Results of the Rough Turn Operation are shown in Figure 4.76.

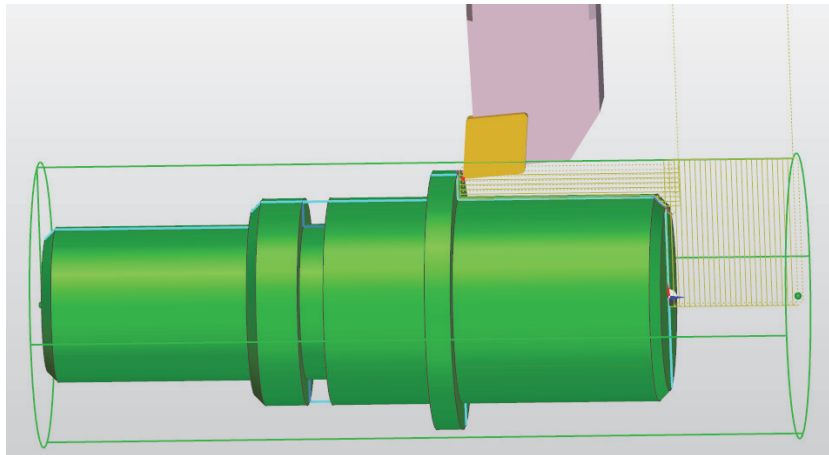


Figure 4.76. Results of the Rough Turn Operation

## 10. Simulating Multiple Sequences

To run the simulator and verify the sequence use Simulation button in Machining Menu (Figure 4.49 no. 4). If more than one sequence is available for simulation, Select Sequences Menu will show up (Figure 4.77). To simulate more than one sequence, select the sequences from a list of available sequences. You can define the order of the simulation by changing the positions of the selected sequences in the selected sequence list.

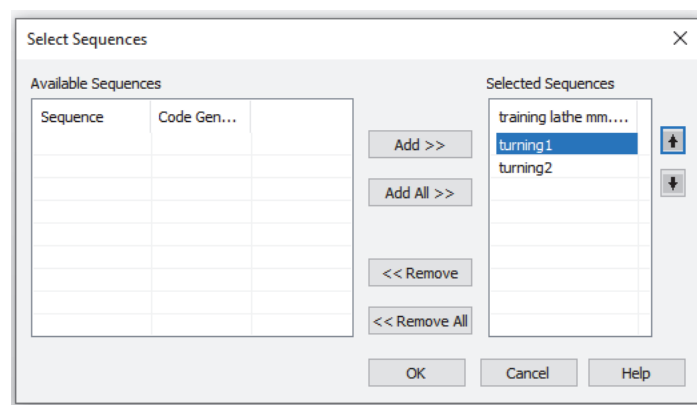


Figure 4.77. Select Sequence Menu

Simulation window is shown in Figure 4.78.

Use the Main toolbar (A) to control the simulation.

Use the Display toolbar (B) to control the simulation display and collision control options.

Use the Sequence browser (C) to investigate the sequence start the simulation at any point in the instruction list.

To view a comparison between the stock and the component use View comparison (D).

Results of the simulation are shown in Figure 4.79. Results of comparison between the stock and the component are shown in Figure 4.80.



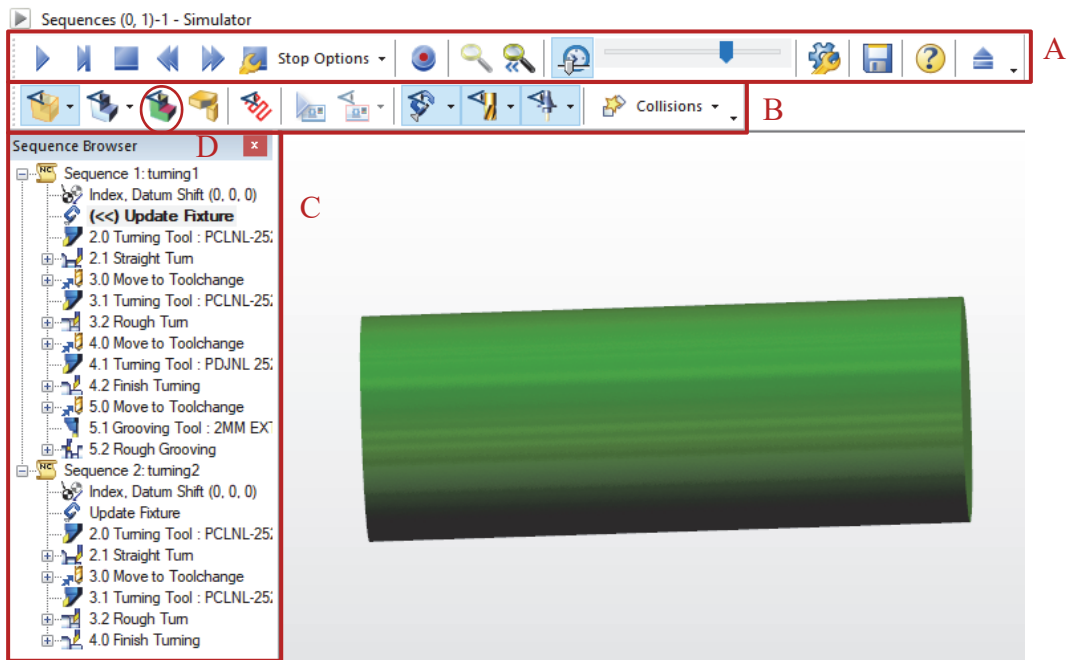


Figure 4.78. Simulation Interface

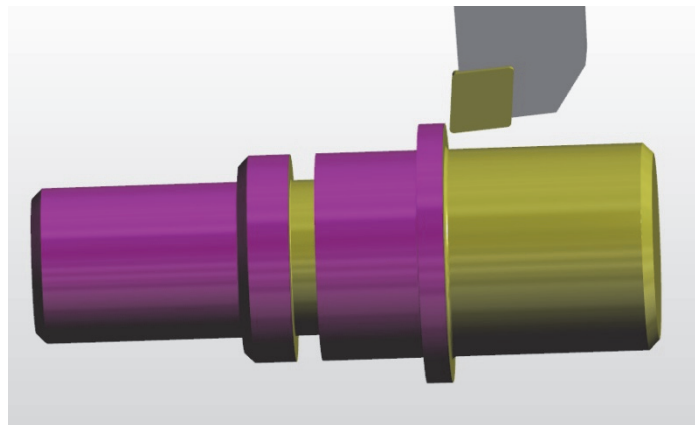


Figure 4.79. Simulation results

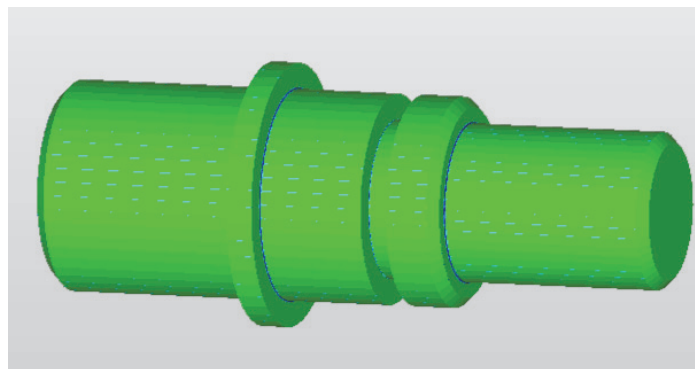


Figure 4.80. Results of comparison between the stock and the component

## V. Literature

- [1] **K. Augustyn** *EdgeCAM Komputerowe wspomaganie wytwarzania*, Helion, Gliwice 2004.
- [2] [www.edgecam.com](http://www.edgecam.com), Access 20.04.2020.

## LABORATORY 4A REPORT

### *Example of EdgeCAM software application in part programming for a milling machine*

Laboratory leader: Ph.D. Katarzyna Koter

Date: .....

Grade: .....

Group: .....

**Task 1:** Create milling sequence for the assigned component.

#### **Conclusions:**

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## LABORATORY 4B REPORT

### *Example of EdgeCAM software application in part programming for a turning machine*

Laboratory leader: Ph.D. Katarzyna Koter

Date: .....

Grade: .....

Group: .....

**Task 1:** Create turning sequence for the assigned component.

#### **Conclusions:**

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# Laboratory 5

## *Programming of CNC Milling Machine*

Laboratory leader: Ph.D. Katarzyna Koter

**Objective:** The aim of the laboratory is to get familiar with programming of CNC Machines based on milling example.

### **I. Introduction**

Computer Numerical Control (CNC) machining is a manufacturing process where regulation functions of the machine are controlled by microcomputer to remove layers of material from a stock piece and produces a designed part. A CNC machine is a programmable machine capable of autonomously performing the operations of CNC machining.

The term NC (CNC) machine control program is understood as an ordered set of program tasks in the form of lines called program blocks. A modern program block is an address block with a variable length, limited by the line length. A block consists of a series of instructions. The instruction is an address (capital Latin letter) and a numeric value. Most addresses can appear only once in one block, although a few, such as G and M, can appear multiple times. Addresses can be divided into several groups, depending on what functions they control:

- **Geometric functions** – represent addresses X, Y, Z, A, B, C, D, E, I, J, K, ...  
The numbers after these letters indicate the position or displacement of the controlled element (tool or workpiece).
- **Preparatory functions** – G address, they specify many activities such as the type of programming, interpolation, movement, etc.
- **Technological functions** – address T (tool number), F (feed speed), S (rotational speed or cutting speed).
- **Auxiliary functions** – address M, responsible, for example, for the coolant or the direction of rotation.
- **Functions of activation (calling) of the correction** – addresses G, H, L.
- **Functions of calling machining cycles** – address G, subroutines - addresses P, Q.
- **Additional** – address O (offset), address N (block number), R (parameter or base area).

Specification of selected G and M functions is shown in Table 5.1.

Table 5.1. Specification of selected G and M functions

G00	Rapid Motion Positioning
G01	Linear Interpolation Motion
G02	Circular Interpolation Motion
G04	Exact Stop
G35	Automatic Tool Diameter Measurement
G36	Automatic Work Offset Measurement
G37	Automatic Tool Offset Measurement
G40	Cutter Comp Cancel
G41	2D Cutter Compensation Left
G42	2D Cutter Compensation Right
G43	Tool Length Compensation
G51	Scaling (Group 11)
G52	Set Work Coordinate System
G53	Non-Modal Machine Coordinate Selection
G54-59	Select Work Coordinate System
G60	Uni-Directional Positioning
G76	Fine Boring Canned Cycle
G77	Back Bore Canned Cycle
G80	Canned Cycle Cancel
G81	Drill Canned Cycle
G82	Spot Drill Canned Cycle
G83	Normal Peck Drilling Canned Cycle
G84	Tapping Canned Cycle (Group 09)
G90	Absolute Position Commands
G91	Incremental Position Commands
G92	Set Work Coordinate Systems Shift Value
G93	Inverse Time Feed Mode
G94	Feed Per Minute Mode
G95	Feed per Revolution
G98	Canned Cycle Initial Point Return
G99	Canned Cycle R Plane Return
M0	Stop
M1	Sleep
M3	Spindle On, Clockwise (CNC specific)
M4	Spindle On, Counter-Clockwise (CNC specific)
M5	Spindle Off (CNC specific)
M7	Mist Coolant On (CNC specific)
M8	Flood Coolant On (CNC specific)
M9	Coolant Off (CNC specific)
M30	Program End and Reset

## II. Interpolation Motions

The numerical data controlling the numerical machine tool can be divided into two groups:

- information about the tool path in the coordinate system, adapted according to the machine tool guide system;

- technological tasks such as the type of treatment (turning, drilling, threading), cutting parameters (rotation, feed), tool number, coolant, etc.

Depending on the type of the programmed function, the control system will control the movement according to linear or circular interpolation. Linear interpolation refers to the linear displacement of the axis (one, two or three axes at a time). Circular interpolation concerns the simultaneous movement of 2 axial carriages (interpolation in a plane).

## 1. G01 Linear Interpolation Motion

The tool travels in a straight line to the target position at the specified feedrate while machining the workpiece. The control system activates the linear interpolation function to calculate the travel of the tool.

Linear interpolation produces motion:

- in a specific direction along a straight line;
- from the origin point to the programmed destination point with absolute programming **G90** or incremental programming **G91**;
- with a specified feed rate **F**;
- with programmed spindle speed **S**.

For the example shown in Figure 5.1, NC Code was created. Movements with linear interpolation run parallel to the coordinate axis or at any angle.

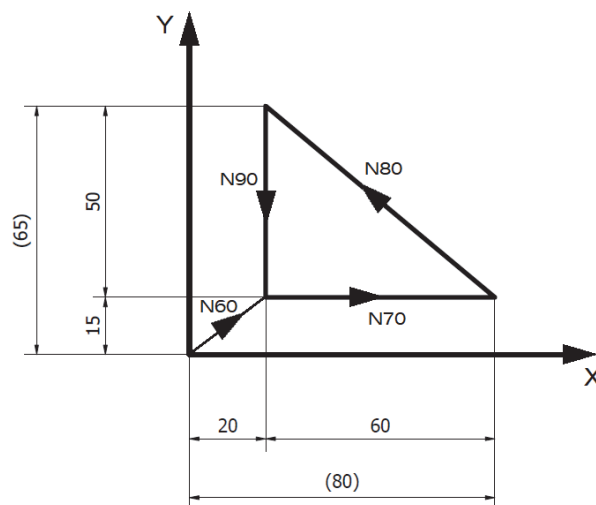


Figure 5.1. Linear interpolation example

Codes were created with Absolute and Incremental Positioning (Table 5.2).

**Absolute Positioning G90** – all workpiece piece dimensions and movements of the machine are read from the working datum position.

**Incremental Positioning G91** – workpiece piece dimensions and movements of the machine are read from current position.

Table 5.2. Linear Interpolation code example

Absolute positioning		Incremental positioning	
N00	G90;	N00	G91;
N10	T9 M06;	N10	T9 M06;
N20	G54;	N20	G54;
N30	G43 H09;	N30	G43 H09;
N40	F200. S6000 M03;	N40	F200. S6000 M03;
N50	M08;	N50	M08;
N60	G00 X20. Y15.;	N60	G00 X20. Y15.;
N70	G01 X80.;	N70	G01 X60.;
N80	G01 X20 Y65.;	N80	G01 X-60. Y50.;
N90	G01 Y15.;	N90	G01 Y-50.;
N100	M30;	N100	M30;

## 2. G02/ G03 Circular Interpolation Motion

When machining a workpiece, the tool travels between two points on the circumference of a circle. As a result of using the G02 or G03 functions, the control system calculates the traversing distance according to circular interpolation.

Circular interpolation forces the tool to move:

- **clockwise** arc when **G02** is programmed;
- **counterclockwise** when **G03** is programmed;
- in relation to the designed center;
- from start point to programmed end point.

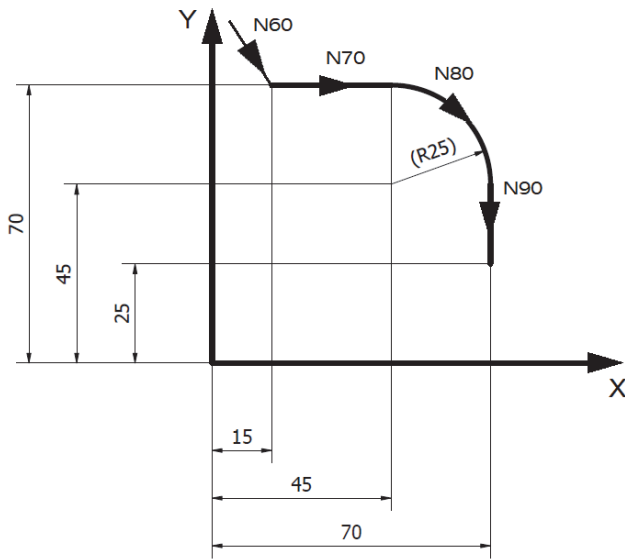
The X, Y, Z axes are assigned to the coordinates of the arc center with the symbols **I, J, K**. The distance is calculated from the origin of the coordinate system:

- to the arc center in the case of absolute programming;
- from the starting point of the arc to the arc center in the case of incremental programming.

Another method of defining circular interpolation is using the **R** address, which value defines the distance from the starting point to the center of the circle.

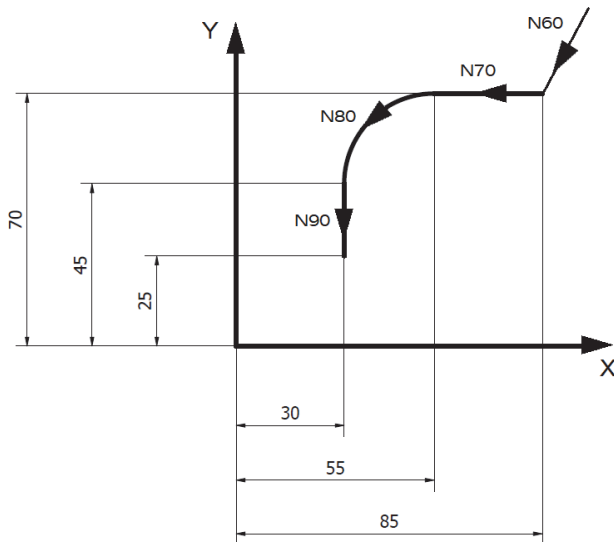
Figure 5.2 and shows a clockwise circular interpolation example.

Figure 5.3 shows a counterclockwise circular interpolation example.



N00	G90;
N10	T9 M06;
N20	G54;
N30	G43 H09;
N40	F200. S6000 M03;
N50	M08;
N60	G00 X15. Y70.;
N70	G01 X45.;
N80	G02 X70. Y45. R25.;
N90	G01 Y25.;
N100	M30;

Figure 5.2. Clockwise circular interpolation example



N00	G90;
N10	T9 M06;
N20	G54;
N30	G43 H09;
N40	F200. S6000 M03;
N50	M08;
N60	G00 X85. Y70.;
N70	G01 X55.;
N80	G03 X30. Y45. I55. J45.;
N90	G01 Y25.;
N100	M30;

Figure 5.3. Counterclockwise circular interpolation example

### 3. Programming example

Figure 5.4 shows programming example. NC code for the example is presented in Table 5.3.



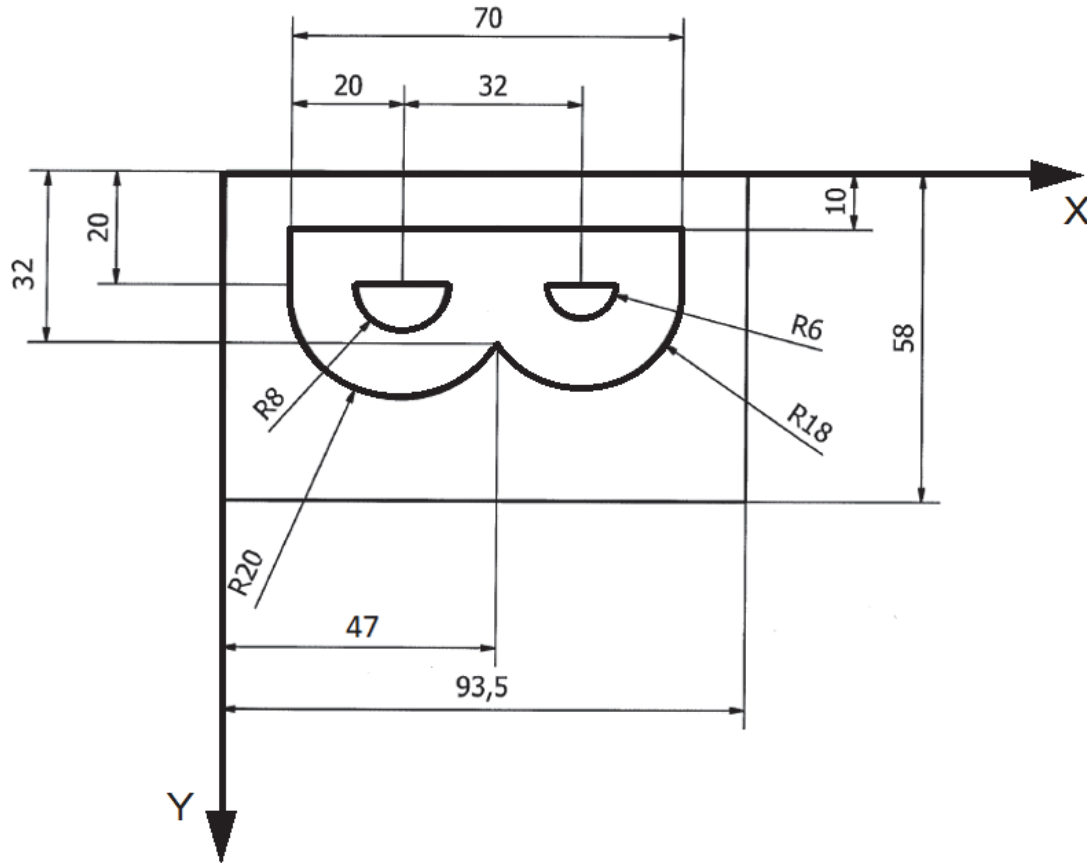


Figure 5.4. Programing example

Table 5.3. Example NC code

No.	NC code	Comment
N00	G90	Absolute Position
N10	T9 M06	Tool number, Toolchange
N20	G54	Work Coordinate System
N30	G43 H09	Tool Length Compensation of tool T9
N40	F200. S6000 M03	Feed [mm/min], Spin [m/min], Spindle On
N50	M08	Flood Coolant On
N60	G00 X10. Y-10. Z2.	Rapid Motion Positioning
N70	G01 Z-0.2;	Linear Interpolation Motion
N80	G01 X80.;	
N90	G01 Y-20.;	
N100	G02 X47. Y-32. R18.;	CW Circular Interpolation Motion
N110	G02 X10. Y-20. R20.;	
N120	G01 Y-10.;	
N130	G00 Z2.;	
N140	G00 X22. Y-20.;	
N150	G01 Z-0.2;	
N160	G01 X38.;	
N170	G02 X22. Y-20. R8.;	
N180	G00 Z2.;	
N190	G00 X56. Y-20.;	

N200	Z-0.2;	
N210	G03 X68. Y-20 R6.;	CCW Circular Interpolation Motion
N220	G01 X56.;	
N230	G00 Z30.;	
N240	M30;	Program End and Reset

### III. CNC Machine

In this laboratory, HASS 3-axis CNC Milling Machine, shown in the Figure 5.5 is used. The scheme of this machine tool is shown in Figure 5.6.



*Figure 5.5. HASS 3-axis CNC Milling Machine*

For programming, the control pendant with control display and keyboard is used.

The control display is organized into panes that vary depending on the current control mode, and on what display keys are used. Basic display layout is shown in Figure 5.7.

The keyboard (Figure 5.8) is divided into eight sections:

- A. **Function Keys** – different functions depending upon operation mode, tool functions.
- B. **Jog Keys** – free motion functions.
- C. **Override Keys** – used to override the speed of (rapid axes motion, programmed feeds and spindle speeds).
- D. **Display Keys** – access to the machine displays, operational information and help pages.
- E. **Cursor Keys** – to move to various screens and fields in the control, to edit CNC programs.
- F. **Alpha Keys** – the letters of the alphabet along with some special characters.
- G. **Mode Keys** – change the operational state of the CNC machine tool.
- H. **Number Keys** – to enter numbers and a special characters into the control.

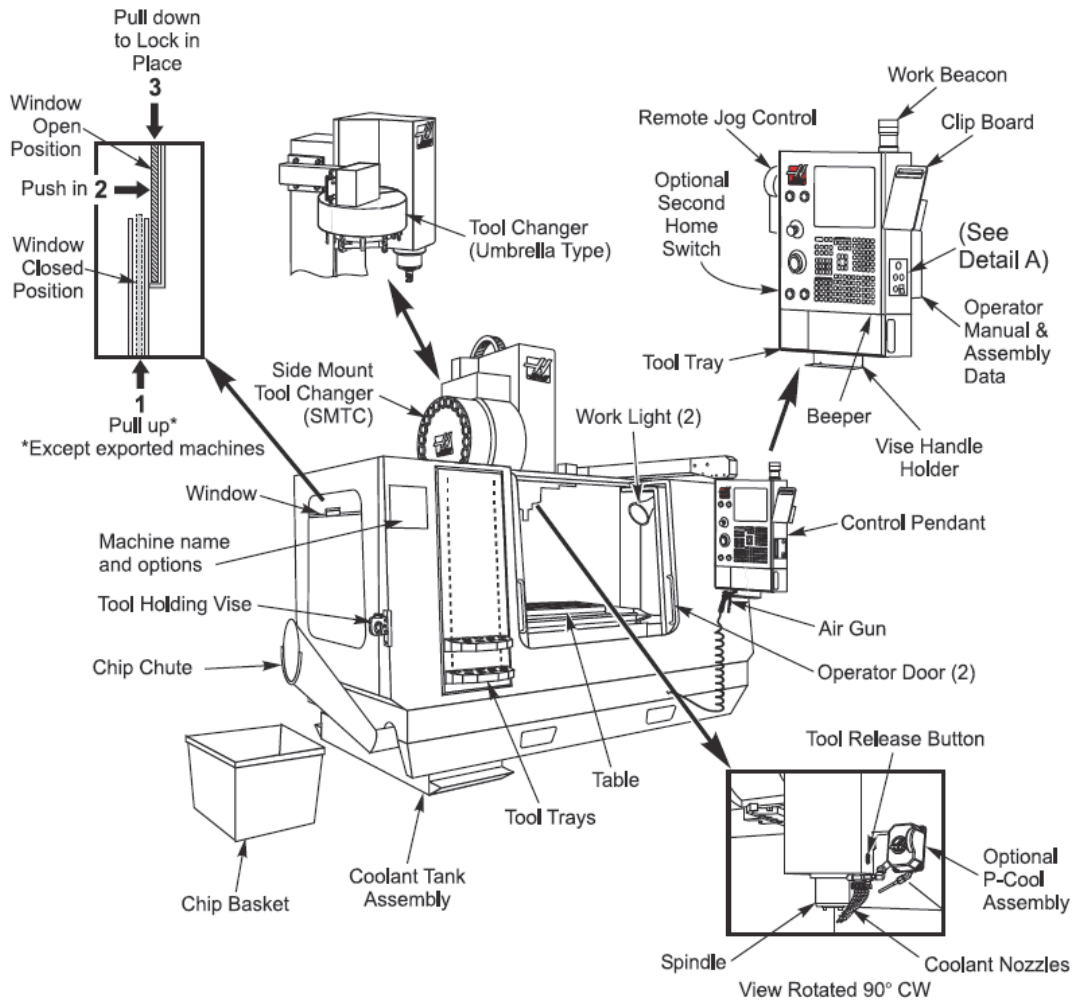


Figure 5.6. Scheme of CNC Milling Machine [1]

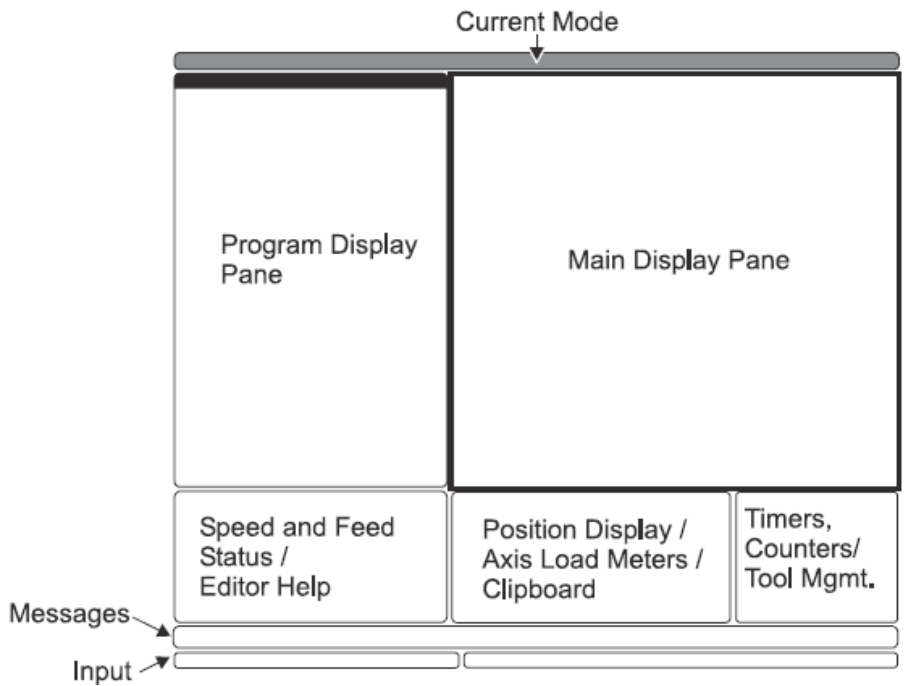


Figure 5.7. Basic display layout [1]



Figure 5.8. The pendant keyboard [1]

#### IV. Literature

- [1] HASS 9 -8000 Mill Operator's Manual, June 2008.

# LABORATORY 5 REPORT

## *Programming of CNC Milling Machine*

Laboratory leader: Ph.D. Katarzyna Koter

Date: .....

Grade: .....

Group: .....

**Task 1:** Get to know with the construction and basic technical parameters of the CNC Milling Machine.

**Task 2:** Prepare the NC code for the milling operation, based on the drawing provided by the teacher.

**Task 3:** Observe the machining process and examine results.

### **Conclusions:**

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# Laboratory 6

## *Pneumatic drives and control*

Laboratory leader: Ph.D. Błażej Witkowski

**Objective:** To learn about the pneumatic elements used in the construction of systems and pneumatic control.

### I. Introduction

Nowadays compressed air devices and installations are found in many industries branches. Pneumatic devices exist as elements of machines or are independent mechanisms. The use of compressed air to drive and control devices is associated with the introduction of automation of production processes

The main advantages of using pneumatics are:

- air surrounds us everywhere and is for free;
- compressed air is easy to store and transport over long distances;
- the outflowing air is ecological (it does not pollute environment). It is non-flammable and does not explode;
- compressed air allows us to achieve high speeds and accelerations;
- velocity and force can be set sleeplessly (velocity – the change of flow rate; force - pressure regulation). Additional disposal installation is unnecessary;
- pneumatic devices can work reliably in a wide temperature range and in a variety of environments;
- the devices can be loaded up to stop (they are not sensitive on overloading).

The main disadvantages of using pneumatics are: the need for accurate pre-treatment and the compressibility of the air.

The properties of gases are described by the general gas state equation in the form (6.1):

$$p_1V_1/T_1 = p_2V_2/T_2 = \dots = const \quad (6.1)$$

This equation is the theoretical basis for calculations and pneumatic device selection, where:

$p_1, p_2$  – fluid pressure [MPa];

$V_1, V_2$  – fluid volume [m<sup>3</sup>];

$T_1, T_2$  – fluid temperature [°C].

As standard, the pneumatic system consists of two circuits as shown in the Figure 6.1:

- generation, preparation and distribution of compressed air (Figure 6.1 (1)-(10));
- air collection and use (Figure 6.1 (11)-(16)).

Compressed air is transported by a pipeline to the individual collection points. To avoid pressure losses in long pipelines, their diameter must be sufficiently large. The pipeline has a constant slope (1 - 2%) to drain the condensate at the lowest point. Pipelines are built as circular (closed loop) and linear.

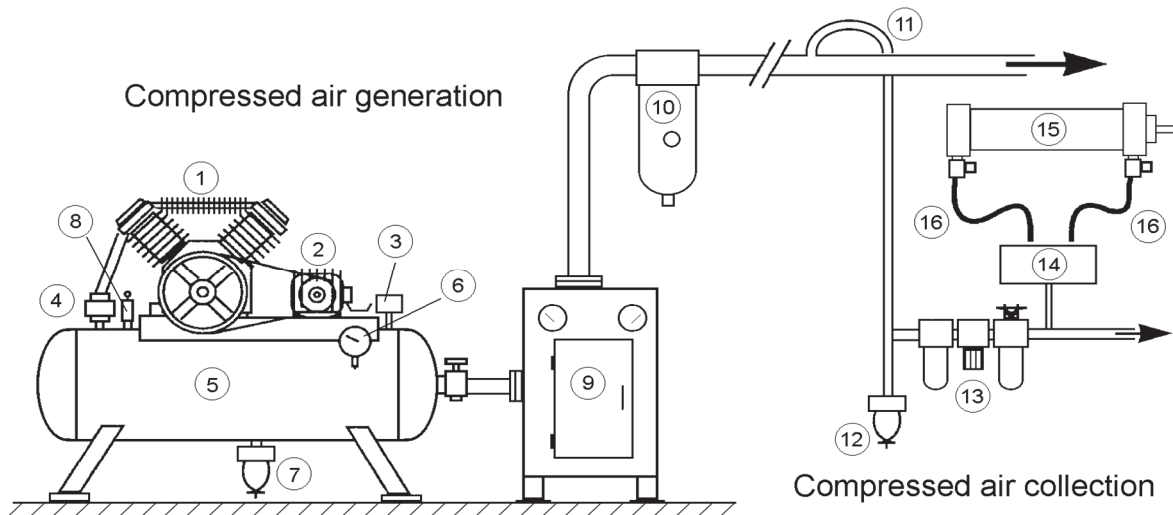


Figure 6.1. Scheme of pneumatic system [1]: 1 Compressor, 2. Electric motor, 3. Pressure transmitter, 4. Check valve, 5. Air tank, 6. Manometer, 7. Drain, 8. Compressor safety valve, 9. Air dryer, 10. Main line filter, 11. Branch from the main pipeline, 12. Drain, 13. Modular F.R.L. (Air Filter, Regulator, Lubricator), 14. Directional control valve, 15. Pneumatic actuator, 16. Throttle valve

## II. Generation of compressed air and distribution

Compressed air is produced by compressors that convert the mechanical energy of an electric motor into compressed air energy. Compressors can be divided according to the principle of operation into:

- positive-displacement (Figure 6.2): with a linear drive (piston type, membrane type), with a rotary drive (vane type, screw type, Roots),
- dynamic displacement (turbine, Figure 6.3): axial and radial compressors.

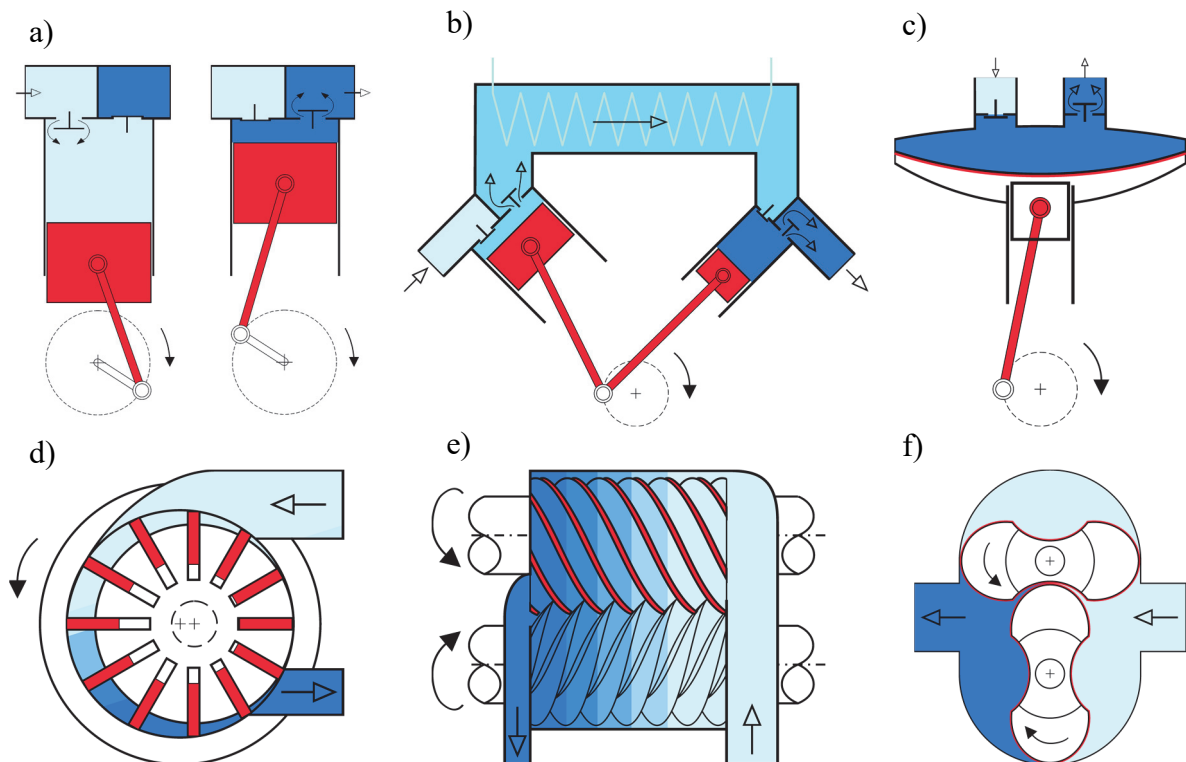


Figure 6.2. Positive-displacement compressors with a linear drive [1]: (a)-(b) Piston type, (c) Membrane type, (d) Vane type, (e) Screw type, (f) Roots

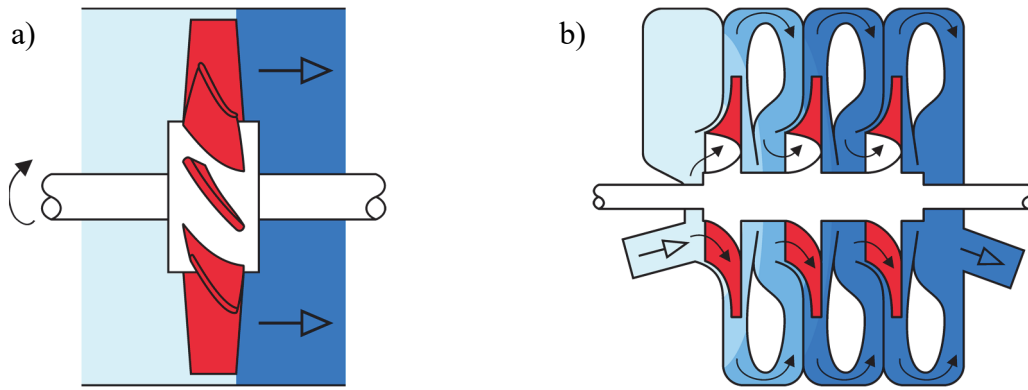


Figure 6.3. Dynamic displacement compressors [1]: (a) axial and (b) radial compressors

Depending on the required working pressure and capacity, the appropriate type and type of compressor is selected. In practice, the most used are reciprocating compressors, which can be single-stage or multi-stage. Compressor capacity is a function of the compressed air consumer's capacity.

In industrial plants, compressor stations are usually used and compressed air is distributed through a pipeline system around the plant.

The elements that guarantee correct compressor operation include:

- pressure relay – controls compressor operation by tank's pressure control;
- non-return valve – closes the air outflow from the tank to the compressor;
- safety valve – protects the system against exceeding the maximum set pressure value;
- tank – stores air to compensate for pressure fluctuations and enables the precipitation and removal of condensate.

As a result of compression, the air heats up and after cooling down in the pipeline water condenses in the form of condensate. To reduce the amount of condensate downstream of the compressor, coolers are installed to separate up to 70% of the moisture contained in the compressed air and dryers that bind the water in a chemical reaction.

Behind the tank, in the main supply line to the network, a filter is installed that ensures a large flow of compressed air, whose task is to remove larger mechanical impurities, oil from the compressor and condensed water. If a higher operating pressure is required in the network or its part, then pressure amplifiers are used to increase it 2 or 4 times.

### III. Fluid Conditioning unit

Initial drying and filtering does not guarantee the correct functioning of the pneumatic elements. Therefore, it is necessary to thoroughly clean and dry the compressed air as close to the receiving device as possible, adjust its pressure and lubricate it.

Currently, the standard solution is modular sets consisting of a: air filter, pressure regulator and lubricator (Figure 6.4).





Figure 6.4. Fluid conditioning unit: (a) real [4], (b) full symbol, (c) simplified symbol

## 1. Filters

Filters task is to remove mechanical impurities from the compressed air and water condensed during treatment. The characteristic value for filters is the nominal filtering accuracy of mechanical impurities - the smallest diameter of spherical particles (in mm) retained by the filter in an amount equal to 90-95% of the total amount in the medium before filtering. Standard filter catches solid particles larger than 5  $\mu\text{m}$  and fine filter catches particles larger than 0.3  $\mu\text{m}$ . Filter with schematic symbols are shown in Figure 6.5.

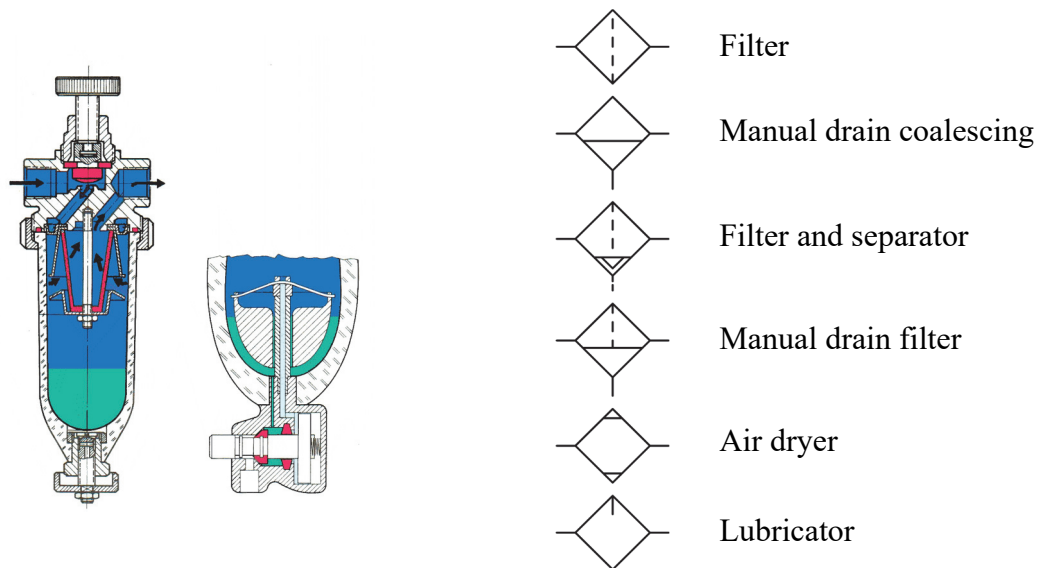


Figure 6.5. Filter and its schema symbols [1]

## 2. Lubricators

Lubricators are used to saturate compressed air with oil. They operate on the principle of vacuum created. They can be ordinary and selective. The characteristic quantity for the lubricator is the nominal volumetric flow rate through the lubricator ( $Q_{\text{min}}$ ) - the smallest relative to normal conditions in the volume of the medium flowing per unit time through the lubricator at which the drop begins in the lubricator when the pressure at the outlet thereof is equal to the nominal.

## IV. Energy control units

Elements belonging to this group are called valves. They are used to control: the direction of the air flow, the air pressure, the amount of air flow and shut off the air flow.

### 1. The directional valves

Directional valves allow you to control the direction of air flow in the pneumatic lines. For the actuator to work properly, its chambers must be supplied with compressed air. For example, when moving to the right position, apply compressed air to the left ventricle and let it flow out of the right ventricle. When moving to the left position, air must flow in the opposite direction through the same lines.

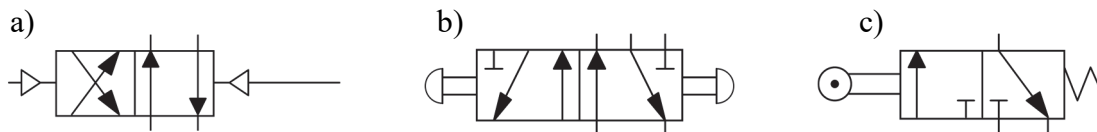


Figure 6.6. Directional valve schema symbols: (a) four way / two position valve (4/2) pneumatic control, (b) five way / two position valve (5/2) mechanical control, (c) three way / two position valve (3/2) mechanical control with return spring

Basic parameters of directional valves are:

- number of input and output channels and the number of possible operating positions (e.g. 5/2 valve - five-way / two-position valve Figure 6.6);
- control method (mechanically, pneumatically, electromagnetically);
- size and maximum air flow.

### 2. The pressure regulator valve

A pressure reducing valve called a regulator is used to reduce the inlet pressure to a set value. Too much airflow pressure opens the vent and excess air is released into the atmosphere, as it is shown in the Figure 6.7. In order to set the desired pressure, a screw is screwed in or out, which causes the tension of the valve spring.

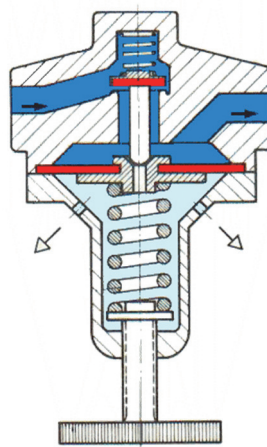


Figure 6.7. Pressure regulator valve [1]

### 3. The flow control valve

The flow control valve are called throttle valves. The flow is regulated by changing the cross-section of the channel through which the air stream flows. They are most often used to regulate the velocity of pneumatic actuators. They are generally combined with a check valve (non-return throttle valve, Figure 6.8).

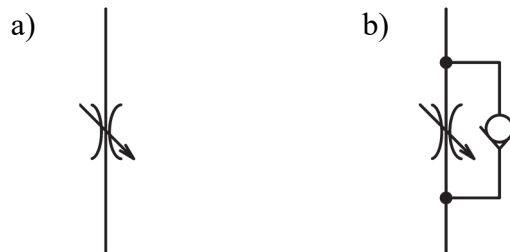


Figure 6.8. a) The throttle valve, b) non-return throttle valve

## V. Actuators

There are many varieties of pneumatic actuators. Generally, they can be divided into piston rod, rodless and rotary cylinders.

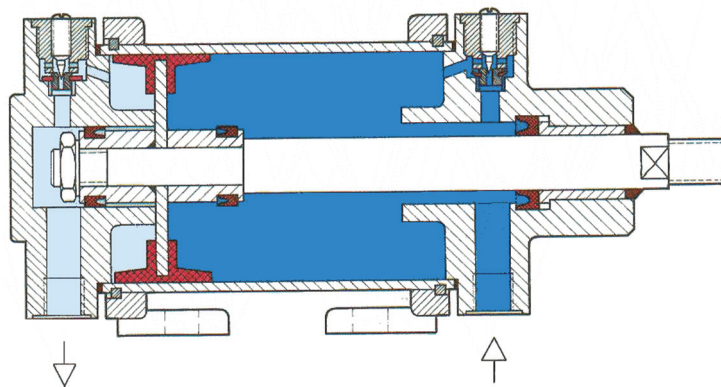


Figure 6.9. Actuator double-acting, with a single piston rod, with adjustable air cushioning [1]

### 1. The actuators with piston rod

Piston rod cylinders are classified into single-acting, double-acting; with a single piston rod and a double piston rod (Figure 6.9).

In single-acting cylinders, the force of the compressed air on the surface of the piston acts in one direction only. They are used for fixing, feeding and pushing out various types of elements. They show lower air consumption.

The force in the return stroke is smaller because the area of the piston is smaller due to the piston rod. In cylinders with double piston rods, the forces are equal.

For large-size cylinders, adjustable air cushioning is used at the end of travel.

## 2. The rodless actuators

Rodless cylinders are used in the construction of manipulators and feeders. They are built in variants: with magnetic coupling and mechanical coupling. The actuator carriage is mechanically connected to the piston through a slot in the profile of the actuator body. The slot is closed with an elastic sealing tape. The actuator has a system of cushioning and determining the position of the piston

## 3. The rotary actuators

They are used in the construction of manipulators for the implementation of rotary motion. They are built as piston-wing and piston-swinging.

## VI. Others pneumatic elements

For the operation control and proper functioning of compressed air driven systems, it is necessary to use many additional elements, selected examples of which are presented below:

- digital pressure gauge (Figure 6.10);
- silencer;
- connectors and wires.



Figure 6.10. Digital pressure gauge

## VII. Creating pneumatic diagrams

Creating pneumatic diagrams is based on the standard ISO 1219 – 1 and ISO 1219 – 2 [2, 3]. Each pneumatic element is shown in a simplified manner on schema. The position of individual elements may also differ from the real positions of the elements among themselves. Drawing a diagram should follow a few rules:

- Always draw the layout as it actually is. If, at the beginning of the cycle, the actuator has an extended piston rod, the actuator should be drawn on the diagram with the extended piston rod.
- Use only horizontal or vertical lines connecting pneumatic components.
- The vent symbols should be drawn right next to the valve, without unnecessary gaps.
- Only draw valve inputs and outputs for one function.
- Valve symbols can be rotated every 90 degrees.

Directional valves have several functions (min. 2). Usually, a connection or a vent is drawn at the bottom. Connections to other actuators are drawn at the top of the valve. The way of switching the valve between its functions is shown on the both sides of the valve. You can

imagine a separate frame to which the wires are connected and a slider with valve functions moving underneath it (Figure 6.11).

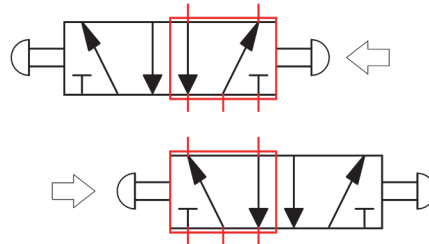


Figure 6.11. Different slider position in valve 5/2 with mechanical control

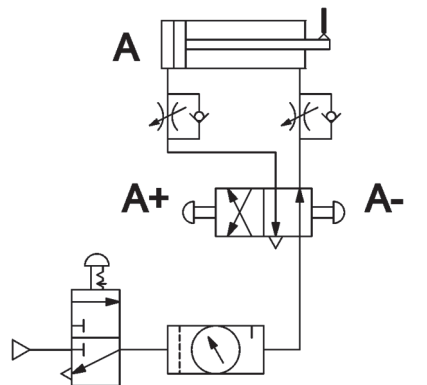


Figure 12. Example of schema

Drawing the diagram starts from the end of the airflow – from the actuators. Next, you need to draw a directional valve that allows us to move the actuator piston in different directions. At the end should be drawn exhaust and pressure supply. The example of simple schema is depicted in Figure 6.12.

## VIII. Literature

- [1] **M. Krępski, S. Sucharzewski** *Laboratory instruction*, <https://ioitbm.p.lodz.pl/labs/p/P-1-instrukcja.pdf>, Lodz 2011.
- [2] *ISO 1219 – 1:2012 Fluid power systems and components — Graphical symbols and circuit diagrams — Part 1: Graphical symbols for conventional use and data-processing applications.*
- [3] *ISO 1219 – 2:1995 Fluid power systems and components — Graphic symbols and circuit diagrams — Part 2: Circuit diagrams.*
- [4] <https://www.smc.eu/pl-pl>, Access: February 2021 (Internet sources).

# LABORATORY 6 REPORT

## *Pneumatic drives and control*

Laboratory leader: Ph.D. Błażej Witkowski

Date: .....

Grade: .....

Group: .....

**Task 1:** Draw a schematic of the system with a throttle check valve. Describe how this valve works.

**Scheme:**

**Conclusions:**

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**Task 2:** Design and build a simple pneumatic system, described by the lecturer.

**Scheme:**

**Conclusions:**

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# Laboratory 7

## *Vacuum technology*

Laboratory leader: Ph.D. Błażej Witkowski

**Objective:** The main aim of the exercise is to learn about the vacuum technology.

### I. Introduction

Negative pressure is a gaseous state with a pressure lower than atmospheric pressure. Negative pressure (vacuum) is determined by a minus sign before the value (e.g. -88 kPa). Mechanical vacuum pumps are used to generate a negative pressure. They function as opposed to compressors (Laboratory 6, Figure 6.1). Are driven by electric motors and the pump suction port is connected to the space in which the pressure is to be released. The extracted air is discharged into the atmosphere.

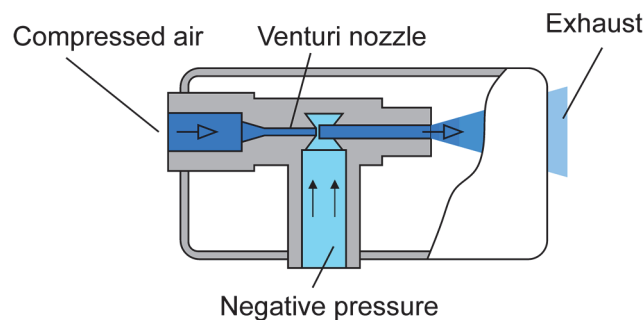


Figure 7.1. Ejector cross-section

Another way to create a vacuum is to use ejectors. They operate on the based on a Venturi tube. A stream of compressed air is passed through the nozzle, as it shown on the Figure 7.1. When the nozzle cross-section starts to decrease, the speed of the air stream increases. The flow rate must be constant, what is described by equation (7.1):

$$D_1 V_1 = D_2 V_2 = \dots = const, \quad (7.1)$$

where:

$D_1, D_2$  – pipe cross-section area [mm<sup>2</sup>];

$V_1, V_2$  – air velocity [m/s].

An increase in speed causes an increase in dynamic pressure. It follows from the Bernoulli equation (7.1) that the sum of the static and dynamic pressures must be constant:

$$\frac{\rho V^2}{2} + p = const, \quad (7.2)$$

where:

$\rho$  – air density [kg/m<sup>3</sup>];

$p$  – air static pressure [MPa];

$V$  – air velocity [m/s].



Based on the equation (7.2), one can obtain that an increase in dynamic pressure causes a decrease in static pressure. A perpendicular hole is made in the venturi tube after the main channel narrowing. This is where the decrease in static pressure will occur, which is used to create the vacuum.

Advantages of the ejector compared to a vacuum pump:

- no wear;
- any working position;
- no heating;
- energy savings (energy consumption only during activity);
- small dimensions and weight;
- the vacuum value can be adjusted by the supply pressure;
- the possibility of installing the suction cup directly on the ejector;
- can be used in potentially explosive atmospheres.

Ejectors can be single-stage or multi-stage (Figure 7.2).

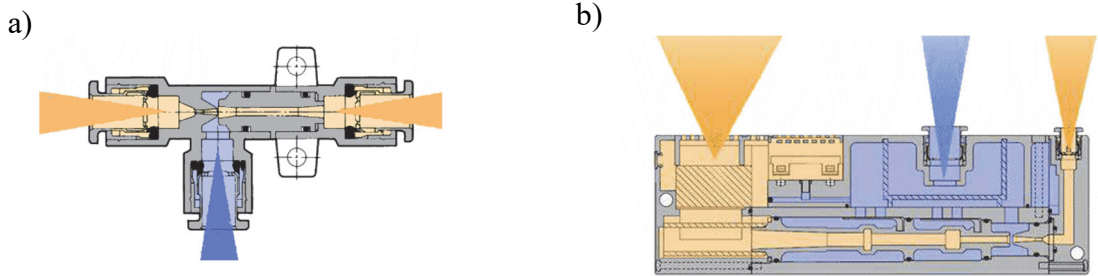


Figure 7.2. Multi-stage ejectors [1]: (a) one-stage ejector, (b) three-stage ejector

Multi-stage ejectors have several Venturi tubes placed in series. They increase the speed of operation and the volume of sucked air. The discharged air from the ejectors is released into the atmosphere through a silencer. The outlet cross-section must be sufficiently large to prevent the build-up of back pressure.

**II. Suction cup**

Vacuum systems are used to transport elements using suction cups that have different shapes (Table 7.2), dimensions and are made of different materials (Table 7.1). The lift force depends on the cross-section of vacuum pad and negative pressure related to atmospheric pressure (Figure 7.3).

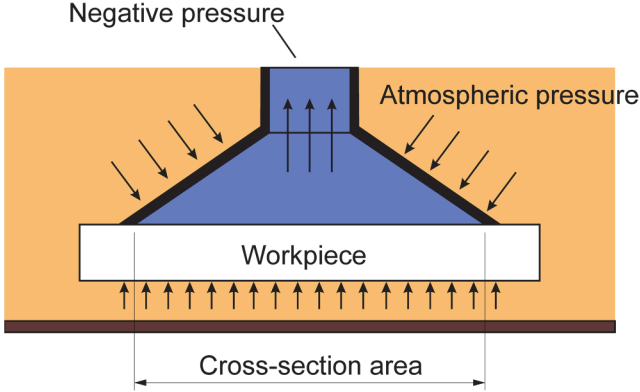











Figure 7.3. Simplify operation of the suction cup

Table 7.1. Materials use to suction cup [2]

Material	Purpose	Color
NBR	For general use, cardboard, veneers, metal surfaces	Black
Silicon	For semiconductors, injection molded parts, thin and resin bonded parts	White
Polyurethane	For cardboard, veneers, metal surfaces	Brown
Fluorine rubber	For chemical elements	Black with green mark
Conductive silicone	For semiconductors (resistance to static elements)	Black with white mark
Conductive NBR	For semiconductors (resistance to static elements)	Black with two white marks

Table 7.2. Shape of suction cup [2]

Pad name	Pad shape	Purpose
Flat		To be used when adsorption surface of workpiece is flat and not deformed.
Flat with rib		To be used when workpiece is likely to deform or in the case of releasing work certainly.
Deep		To be used when workpiece is curved shape.
Bellows		To be used when there is not enough space to install buffer or adsorption surface of workpiece is slanted.
Oval		To be used when workpiece has limited adsorption surface or long in length and work is required to locate precisely.
Ball joint		To be used when adsorption surface of workpiece is not horizontal.

Long stroke buffer		To be used when workpiece height is not even or cushioning toward workpiece is required.
Large		To be used when workpiece is heavy weight.
Conductive		As one of the countermeasures against the static electricity, rubber material with reduced resistance is used. For antistatic measures.

The suction cups can be fixed rigidly or in the holder with shock-absorption, which allows to compensate for large irregularities in the surface of the gripped detail.

### III. Literature

- [1] **Yunus A. Cengel, John M. Cimbala**, FLUID MECHANICS: FUNDAMENTALS AND APPLICATIONS, December 20, 2004, ISBN-10: 0-07-247236-7.
- [2] <https://www.smc.eu/en-gb/products/vacuum-pads-with-adapter-lateral-entry-with-one-touch-fitting~138607~nav#s>, Access: May 2022 (Internet sources).

# LABORATORY 7 REPORT

## *Vacuum technology*

Laboratory leader: Ph.D. Błażej Witkowski

Date: .....

Grade: .....

Group: .....

**Task 1:** Describe three programs of manipulator. Based on manipulator schema, describe positioning method for pneumatic actuators.

**Scheme:**

**Description:**

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**Task 2:** Describe the different types of suction cups - construction, purpose, material, which item to use for.

**Cross-section of suction cups:**

**Description:**

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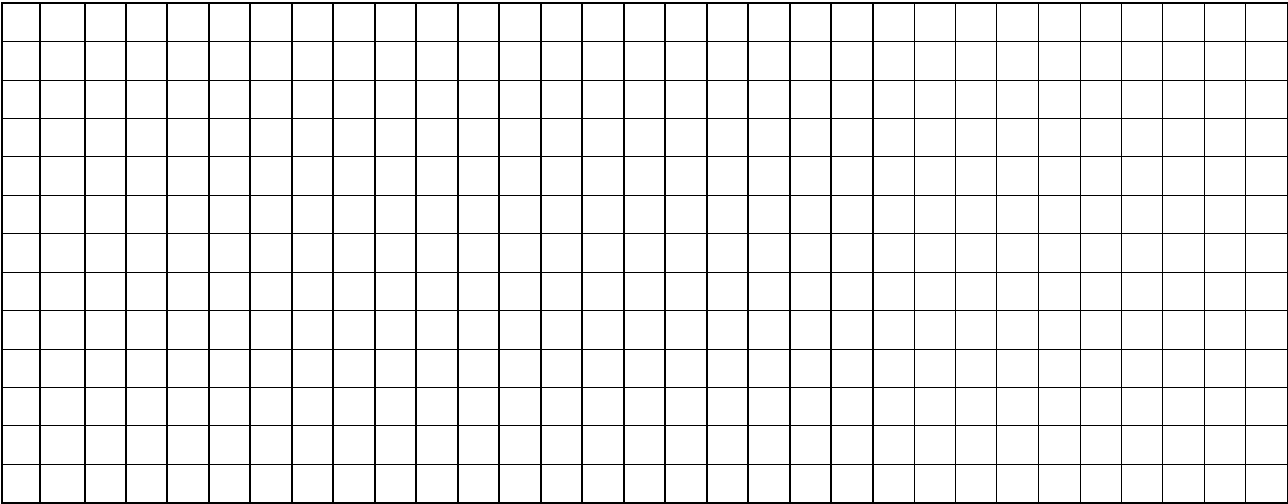
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**Task 3:** Perform the functional characteristics of the ejector in function of the generated vacuum on the supply pressure.

**Measurements:**

Supply Pressure [MPa]	0.00	0.02	0.04	0.06	0.08	0.10	0.12	0.14	0.16	0.18	0.20
Negative Pressure [kPa]											
Supply Pressure [MPa]	0.22	0.24	0.26	0.28	0.30	0.32	0.34	0.36	0.38	0.40	0.42
Negative Pressure [kPa]											
Supply Pressure [MPa]	0.44	0.46	0.48	0.50	0.52	0.54	0.56	0.58	0.60	0.62	0.64
Negative Pressure [kPa]											

**Plot:**



**Observations:**

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# Laboratory 8

## *Metrology*

Laboratory leader: Ph.D. Piotr Zgórnjak

**Objective:** During the laboratory classes, students learn about various measurement methods and the selected measuring equipment used in workshop measurements.

### I. Introduction

In precision measurements various methods of measurement are followed depending upon the accuracy required and the amount of permissible error. There are numerous ways in which a quantity can be measured. Any method of measurement should be defined in such a detail and followed by such a standard practice that there is little scope for uncertainty. The nature of the procedure in some of the most common measurements is described below. Actual measurements may employ one or more combinations of the following [5].

### II. Measuring methods

**Direct method of measurement.** In this method the value of a quantity is obtained directly by comparing the unknown with the standard. It involves, no mathematical calculations to arrive at the results, for example, measurement of length by a graduated scale. The method is not very accurate because it depends on human insensitiveness in making judgement.

**Indirect method of measurement.** In this method several parameters (to which the quantity to be measured is linked with) are measured directly and then the value is determined by mathematical relationship. For example, measurement of density by measuring mass and geometrical dimensions.

**Differential or comparison method of measurement.** This method involves measuring the difference between the given quantity and a known master of near about the same value. For example, determination of shaft with gauge block stock on a comparator (Microcator).

**Coincidence method of measurement.** In this differential method of measurement the very small difference between the given quantity and the reference is determined by the observation of the coincidence of scale marks. For example, measurement on vernier caliper.

**Null method of measurement.** In this method the quantity to be measured is compared with a known source and the difference between these two is made zero.

**Deflection method of measurement.** In this method, the value of the quantity is directly indicated by deflection\* of a pointer on a calibrated scale.

\* - sometimes some calculations is needed e.g. difference calculations, unit transformation etc.

## Contact and contactless methods of measurements.

- In **contact methods** of measurements, the measuring tip of the instrument actually touches the surface to be measured. In such cases, arrangements for constant contact pressure should be provided to prevent errors due to excess contact pressure.
- In **contactless method** of measurements, no contact is required. Such instruments include tool-maker's microscope and projection comparator, etc.

For every method of measurement a detailed definition of the equipment to be used, a sequential list of operations to be performed, the surrounding environmental conditions and descriptions of all factors influencing accuracy of measurement at the required level must be prepared and followed.

### III. The measuring equipment

#### 1. A Vernier Caliper

A construction of vernier caliper is presented in Figure 8.1.

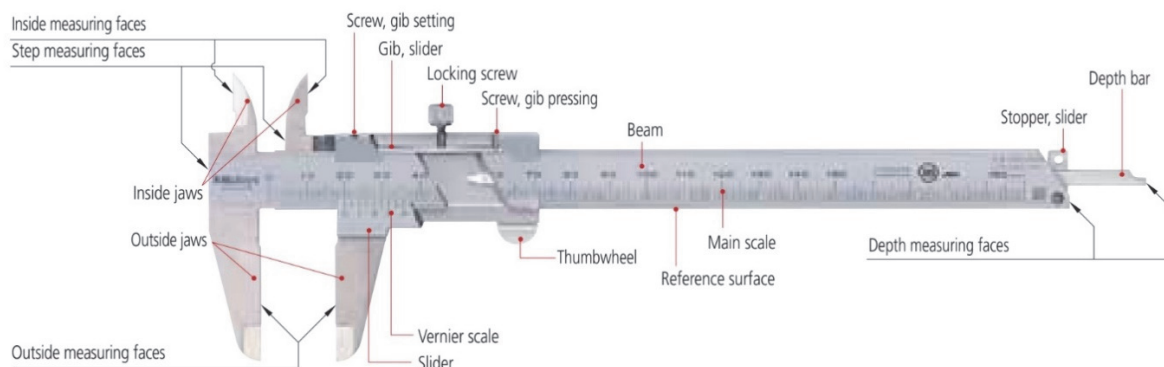
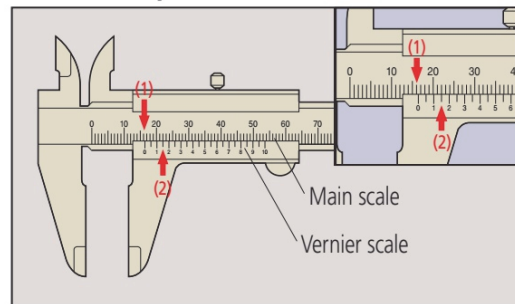


Figure 8.1. Construction of vernier caliper [4]

Vernier scale – this is a short auxiliary scale that enables accurate interpolation between the divisions of a longer scale without using mechanical magnification. The principle of operation is that each vernier scale division is slightly smaller than a main scale division, so that successive vernier graduations successively coincide with main scale graduations as one is moved relative to the other. Specifically,  $n$  divisions on a vernier scale are the same length as  $n-1$  divisions on the main scale it works with, and  $n$  defines the division (or interpolation) ratio. Although  $n$  may be any number, in practice it is typically 10, 20, 25, etc., so that the division is a useful decimal fraction. Calipers were made that gave an even finer resolution of 0.02 mm. These required a 49-division vernier scale dividing 50 main scale divisions. However, they were difficult to read and are now hard to find since digital calipers with an easily read display and resolution of 0.01 mm appeared. The example of reading with a resolution 0.05 mm is presented in Figure 8.2.



## Vernier Calipers



Graduation	0.05 mm
(1) Main scale	16 mm
(2) Vernier	0.15 mm
Reading	16.15 mm

Figure 8.2. Reading procedure [4]

Note: Above left, 0.15 mm (2) is read at the position where a main scale graduation line corresponds with a vernier graduation line.

## 2. Standard Analog Outside Micrometer

The construction of a Standard Analog Outside Micrometer is shown in Figure 8.3.

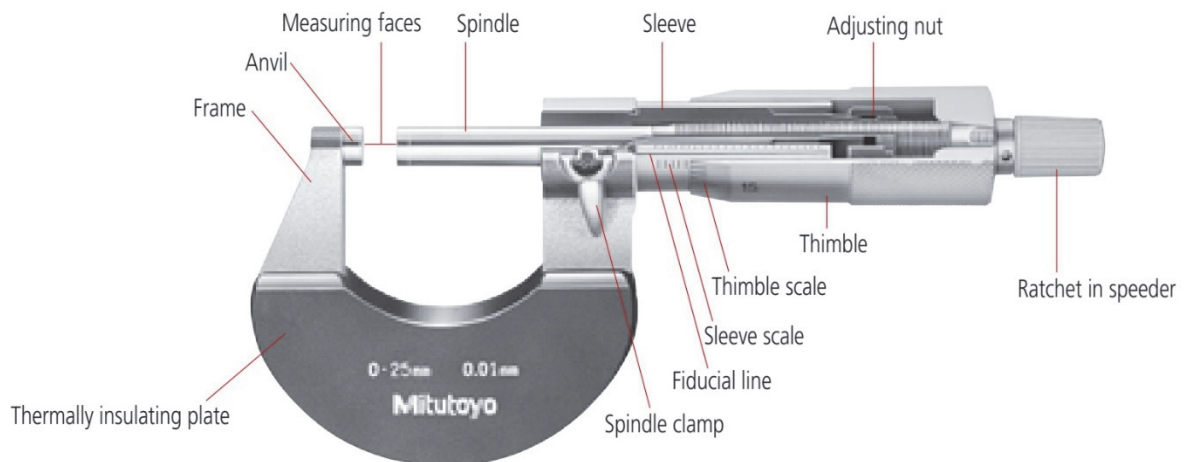
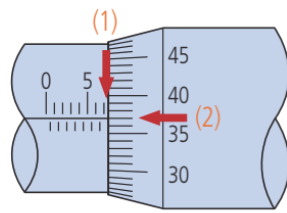


Figure 8.3. Standard Analog Outside Micrometer [4]

The principle of operation of micrometric instrument is described and presented in Figure 8.4.

### Micrometer with standard scale (graduation: 0.01 mm)



(1) Sleeve scale reading	7. mm
(2) Thimble scale reading	+ 0.37 mm
Micrometer reading	7.37 mm

Note: 0.37 mm (2) is read at the position where the sleeve fiducial line is aligned to the thimble graduations.

The thimble scale can be read directly to 0.01 mm, as shown above, but may also be estimated to 0.001 mm when the lines are nearly coincident because the line thickness is 1/5 of the spacing between them.

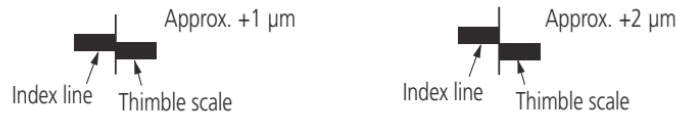


Figure 8.4. Standard Analog Outside Micrometer - reading principles [4]

### 3. A Digimatic Outside Micrometer

The electronic micrometer for external dimensions of production shown in Figure 8.5 from the Japanese company Mitutoyo has a reading resolution of 0.001 mm. Instrument error according to the manufacturer's data, it is  $\pm 0.001$  mm. To this must be added a counting error (also  $\pm 0.001$  mm). This micrometer can work both in absolute mode (ABS function) and comparator (ZERO function). Thanks to the value pre-setting function reference (ORIGIN function) for its calibration, you can use any standards lengths. It has the ability to output measurement data. One is powered silver oxide battery (SR-44), the normal lifetime of which is approx. 1 year. Has a built-in auto power off function (autosleep).

#### Digimatic Outside Micrometer

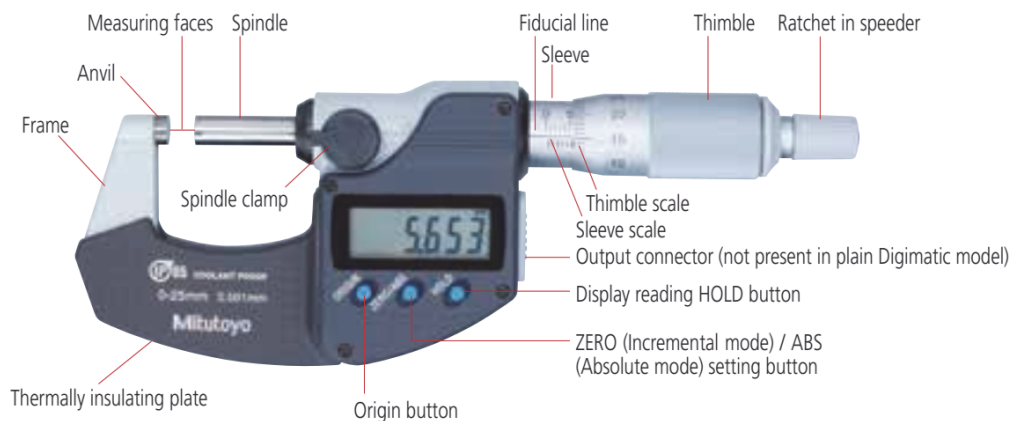


Figure 8.5. Digimatic outside micrometer - nomenclature [4]

This kind of equipment can be connected to digimatic mini-processor. It is possible to print measuring data and make statistics on the base of required tolerance limits. Also it is possible to connect output of mini-processor directly to the computer with appropriate software such as: Excel, Matlab, Statistica etc. The Figure 8.6 shows Mitutoyo digimatic mini-processor DP-1 VR.

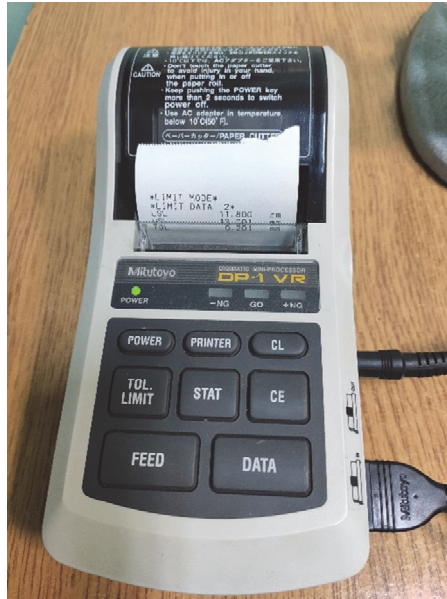


Figure 8.6. Mitutoyo digimatic mini-processor DP-1 VR

#### 4. The successive subtraction procedure for using gauge blocks

Gauge blocks are pieces of wear-resistant material of rectangular cross-section used as references for performing length measurements. They come in sets of blocks with a range of standard lengths. In use, the blocks are stacked to make up a desired length. The gauge block set is illustrated in Figure 8.7.

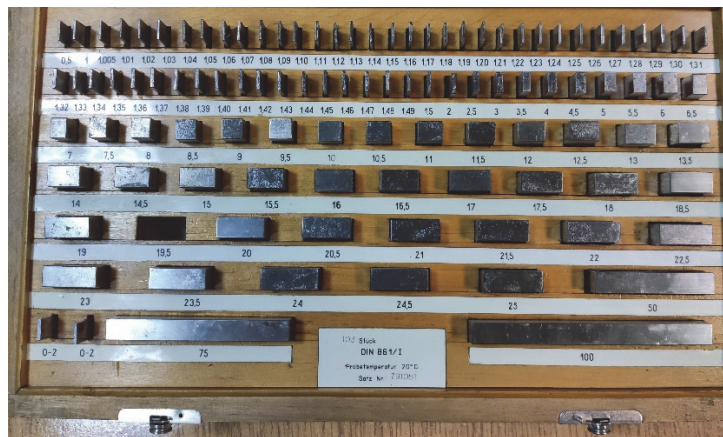


Figure 8.7. Gauge block set

Select gauge blocks to be combined to make up the size required for the stack. The successive subtraction procedure for using gage blocks is shown in Figure 8.8.

- (1) Take the following things into account when selecting gauge blocks.
  - a. Use the minimum number of blocks whenever possible.
  - b. Select thick gauge blocks whenever possible.
  - c. Select the size from the one that has the least significant digit required, and then work back through the more significant digits.
- (2) Clean the gauge blocks with an appropriate cleaning agent.

- (3) Check the measuring faces for burrs.
- (4) Apply a very small amount of oil to the measuring face and spread it evenly across the face. (Wipe the face until the oil film is almost removed.) Grease, spindle oil, vaseline, etc., are commonly used.
- (5) Gently overlay the faces of the gauge blocks to be wrung together. There are three methods to use (a, b and c as shown below) according to the size of blocks being wrung:

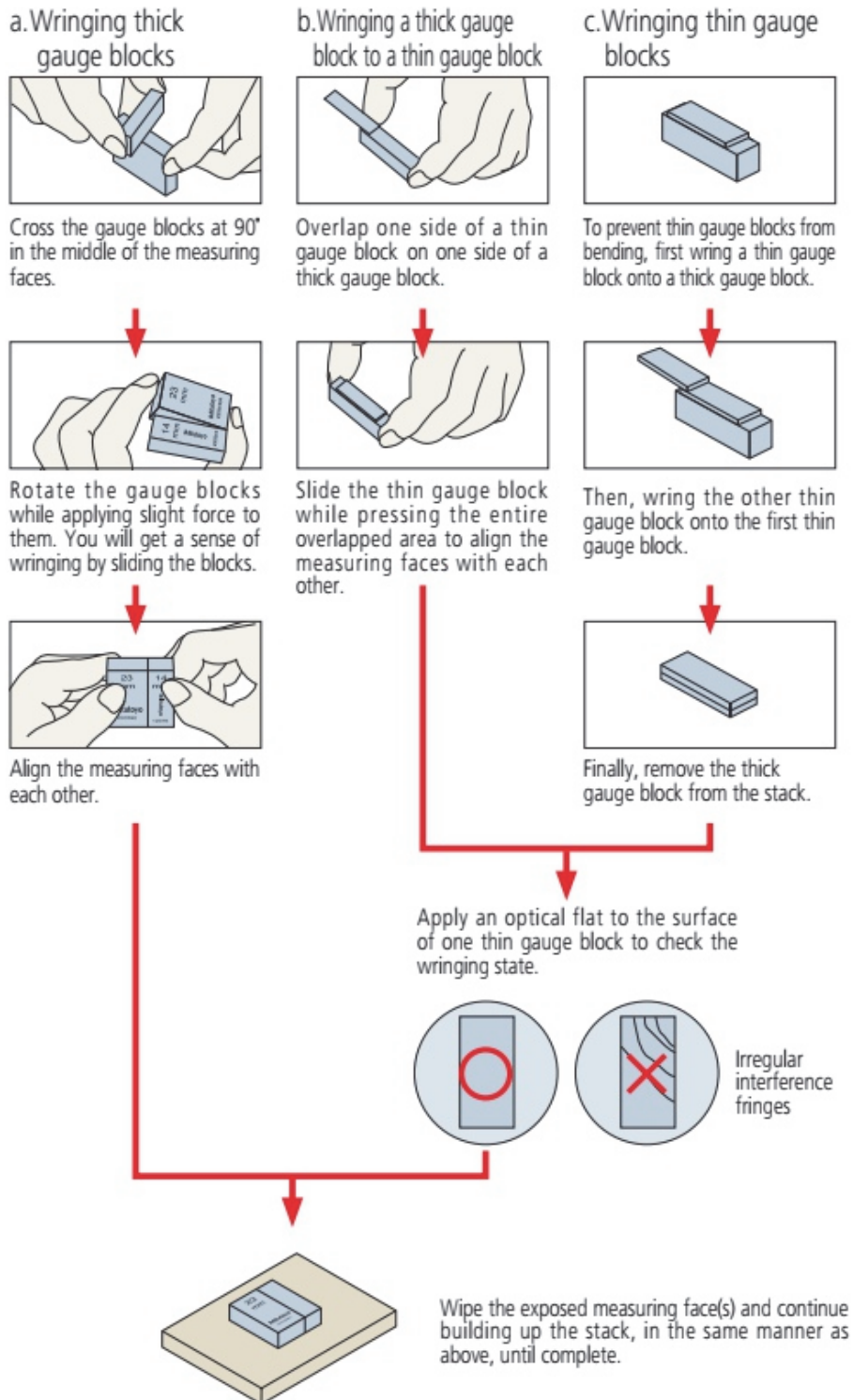


Figure 8.8. Successive Subtraction Procedure for using gage blocks [4]

## 5. A Dial Indicator

A dial indicator is composed of a graduated dial, spindle, pointer and a satisfactory means for supporting or clamping it firmly. Most indicators have a spindle travel equal to 10 revolutions of the hand. Between the test point and the hand is interposed an accurate multiplying mechanism that magnifies on the dial any movement of the point. This tool may be considered either a measuring device or a gage. As a measuring device it measures inaccuracies in alignment, eccentricity and deviations on surfaces supposed to be parallel. In gaging work it gives a direct reading of tolerance variations from the exact size.

The nomenclature of dial indicator is depicted in Figure 8.9a. A dial test indicator equipped with a permanent magnet base is shown in Figure 8.9b.

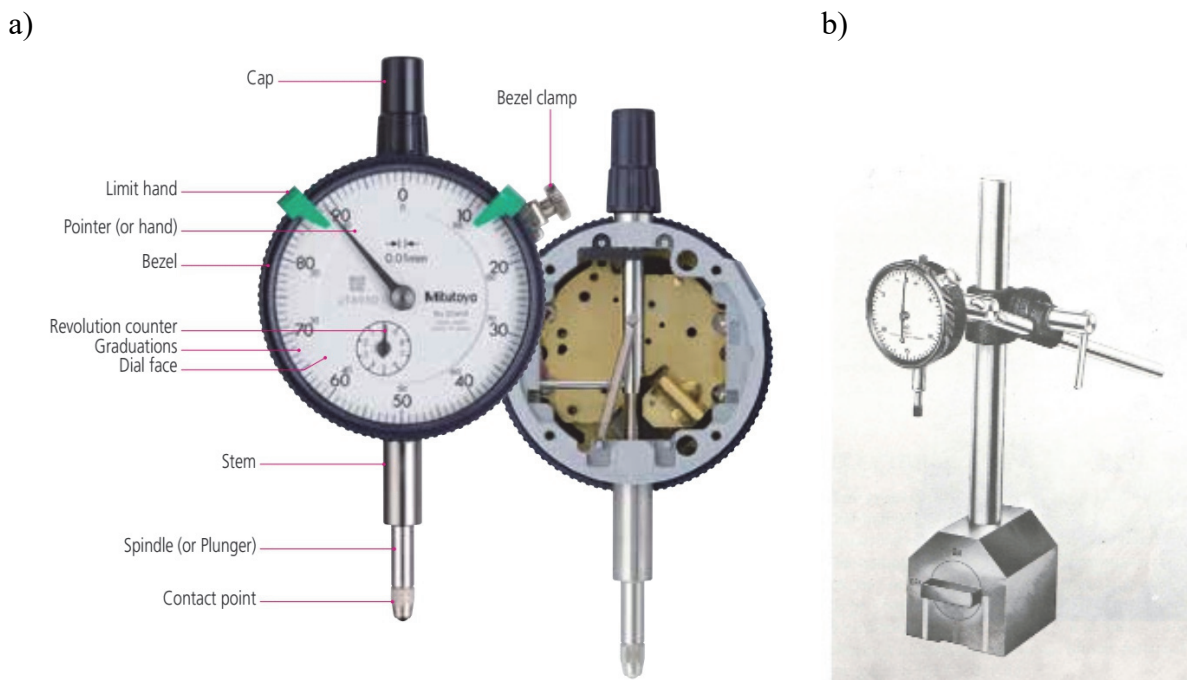


Figure 8.9. Dial indicator: a) nomenclature [4], b) dial indicating gauge with permanent magnet base [1]

This base operates in the same fashion as a permanent magnet chuck. With the handle in the base turned to the “on” position the indicator is held securely on the horizontal, vertical or overhead flat surface of any machine. Other methods of support are a suitable clamp or a heavy base as used on a surface gauge.

The examples of application of dial indicator is shown in Figure 8.10. In case of differential measuring method, in the first step rough measurement of the sample is needed. On the base of obtained result, successive subtraction procedure for using gauge blocks have to be employed. Also appropriate measuring pressure between contact point and the sample need to be adjusted.

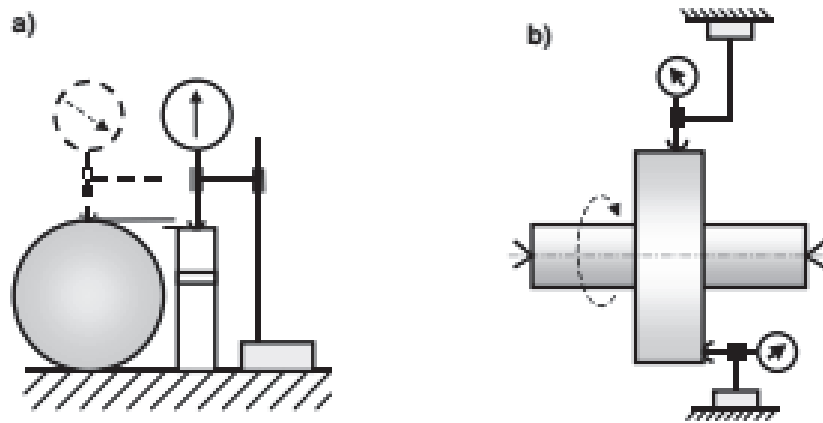


Figure 8.10. Typical application of dial indicators: a) differential method; b) measurement of shape and position deviations [6]

## 6. A Microcator

When we are using microcator, we need to use differential measuring method. It is connected with very narrow range of measurement. In our case it is equal to  $\pm 60 \mu\text{m}$ . The schematic view how to operate microcator is presented in Figure 8.11b.

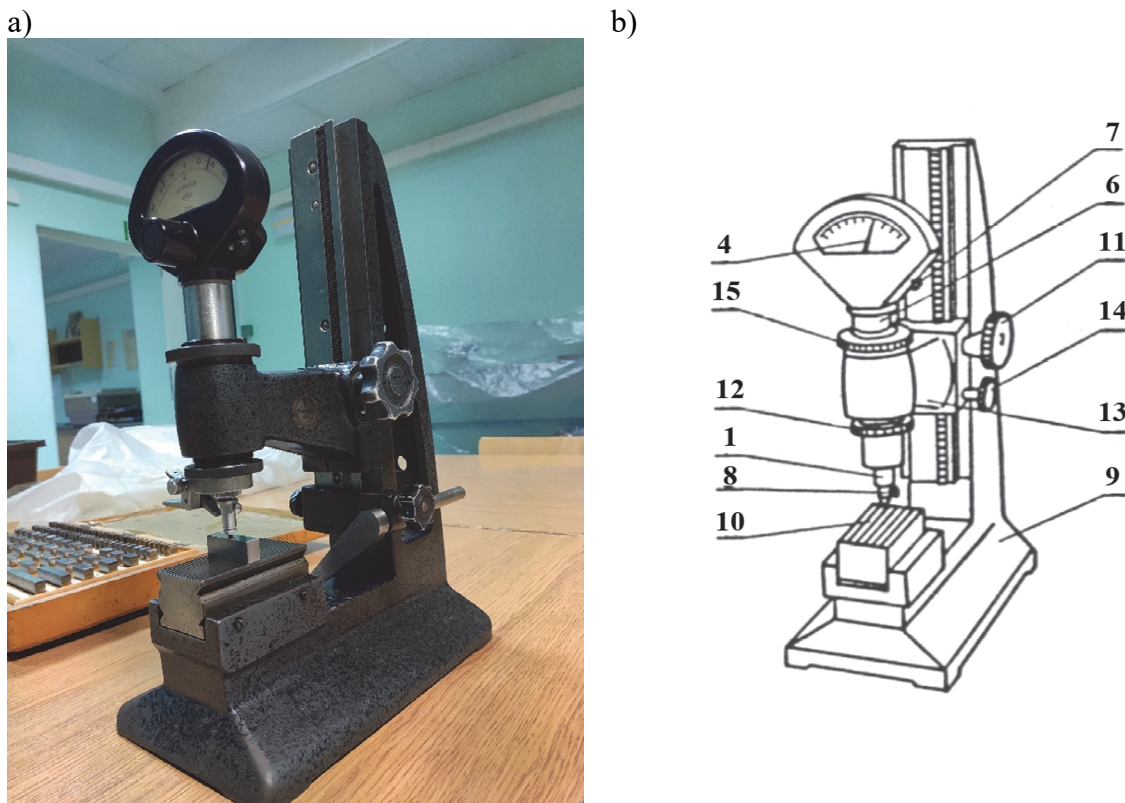


Figure 8.11. General views: a) real view, b) schematic view for operation procedure description [6]

The body of the microcator 6 mounted in the arm 13 is moving after base column 9 with knob 11. It is done this way sensor coarse setting. It is used to lock the arm on the column

screw 14. The exact setting of the sensor is made by moving the body the microcator relative to the arm at with knob 15. To lock the body of the microcator in the arm is used knob 12. If an undesirable shift occurs during locking pointers to divide it they can be eliminated with the scale rotation knob 7. To be determined the position of the measured objects the measuring table 10 is used. The measuring sample need to be located between measuring tip 1 and the table 10. Differences between gauge block stack and the dimension of a sample (Figure 8.11a) can be observe on the scale by pointer 4. Measuring pin 1 can be moved up by lever 8.

In Figure 8.12, spring sensor, known as microcator or metrotest, has a relatively high sensitivity and accuracy (limit errors reach  $\pm 1\%$  of the indication value), they work without friction and without differences in indications when changing the direction of the stylus travel. The sensor transducer uses the elastic properties of the helically twisted ribbon spring. The band spring 1 is twisted so that it has left-hand turns on one half of its length and right-handed on the other. Moving the measuring pin 3 upwards tilts the tip of the tension spring 6 and simultaneously extends the band spring 1. The stretched band spring 1 unscrews and deflects the pointer 2 attached to it.

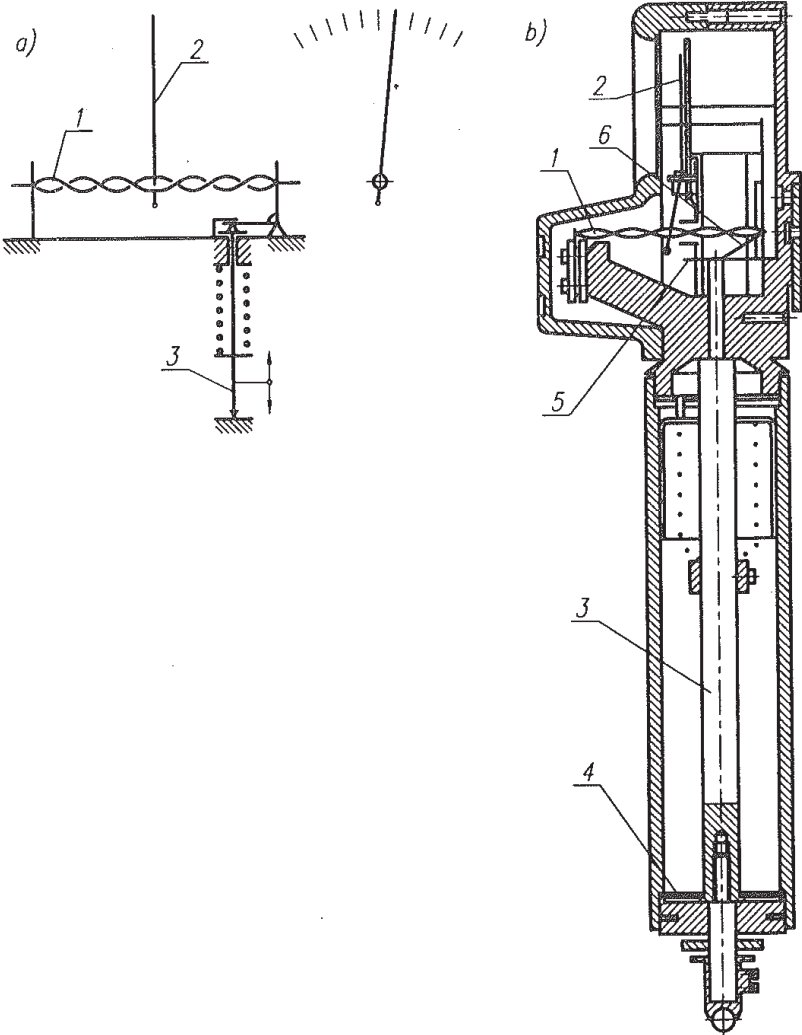


Figure 8.12. Spring sensor (microcator): a) principle of operation, b) structure: 1 - tape spring, 2 - pointer, 3 - pin, 4 - diaphragm, 5 - flat spring, 6 - tension spring [3]

## 7. The optical instruments

Because of their extreme accuracy and ability to measure parts without pressure of contact, numerous optical instruments have been devised for inspecting and measuring. A microscope for toolroom work is shown in Figure 8.13.



*Figure 8.13. Toolroom microscope MWD – laboratory equipment*

An object viewed is greatly enlarged, and the image is not reversed as in the ordinary microscope. To be measured a part is first clamped in proper position on the arms slide stage. The microscope is focused and the part to be measured brought under the crossline seen in the microscope. The micrometer screw is then turned until the other extremity is under the crossline, the dimension being obtained from the difference in the two readings. The micrometer screws operate in either direction and read to an accuracy of 0.01 mm, sometimes with electronic micrometer screws (0.001 mm).

The electronic version of tool work microscopes is commonly used for workshop measurements. The example of the microscope from Vision Engineering with Dynascope technology is depicted in Figure 8.14.





Figure 8.14. Electronic version of Tool work microscope QC300 from Vision Engineering

More information about this equipment can be found in user manual available on Institute of Machine Tools and Production Engineering website [6], instruction MWG-10.

#### IV. Literature

- [1] **B. H. Amstead (et. al)** *Manufacturing Processes, 8<sup>th</sup> edition John Wiley & Sons*, ISBN 0-471-842 36-2, United States of America and Canada (Book).
- [2] **J. Zawada** *Metrologia Wielkości Geometrycznych zagadnienia wybrane skrypt Politechnika Łódzka*, Łódź 2011 r., (Book).
- [3] **W. Jakubiec, J. Malinowski** *Metrologia Wielkości Geometrycznych, WNT Warszawa* 1993 r. ISBN 83-204-1688-4, (Book).
- [4] <https://www.mitutoyo.com/literature/>, Access: 16.06.2021 (Internet sources).
- [5] <https://what-when-how.com/metrology/classification-of-methods-of-measurements-metrology/>, Access: 22.04.2021 (Internet sources).
- [6] [https://ioitbm.p.lodz.pl/?page\\_id=291&lang=pl](https://ioitbm.p.lodz.pl/?page_id=291&lang=pl), Access: 16.06.2021 (Internet sources).

# LABORATORY 8 REPORT

## *Metrology*

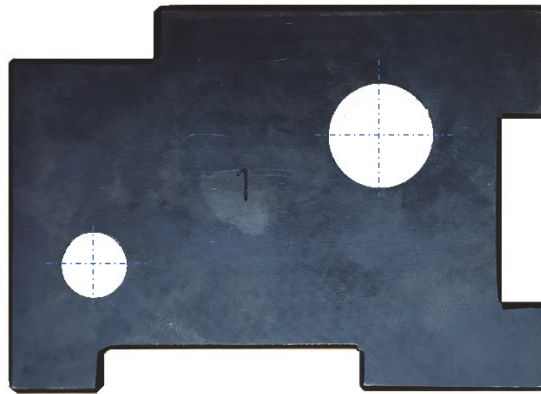
Laboratory leader: Ph.D. Piotr Zgórniak

Date: .....

Grade: .....

Group: .....

**Task 1:** Measurement of the sample by means of measuring equipment presented during laboratory classes. Create sketch of the sample with dimensions needed to determine all geometrical features of the workpiece presented in Figure 1 below. Complete the Table 1 and make a drawing with the necessary dimensions to manufacture the part. Make necessary calculations if needed.



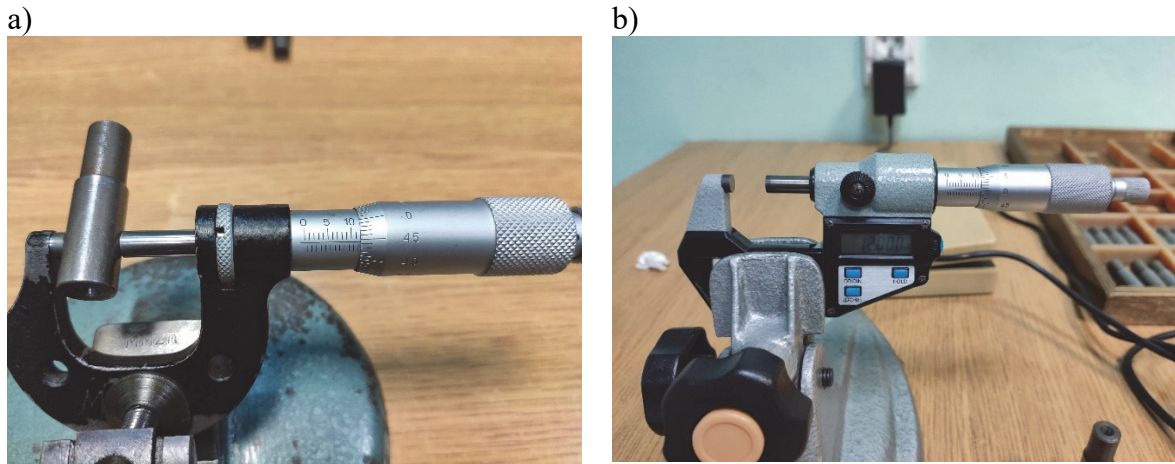
*Figure 1. Sample for measurements*

*Table 1. Measuring results*

Dimension	Value	Equipment		Dimension	Value	Equipment
A				L		
B				M		
C				N		
D				O		
E				P		
F				R		
G				S		
H				T		
I				U		
J				W		
K						

**Task 2:** Micrometer measurements

First you need to use conventional outside micrometer and measure all shafts given to you by a leader. Tabularize results. In the next step, measure all shafts by means of digimatic micrometer.



*Figure 2. Outside micrometers: a) analog outside micrometer, b) Mitutoyo digimatic micrometer*

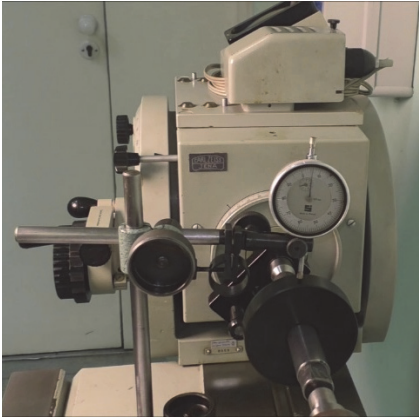
Use upper and lower limit provided to you by the leader of laboratory classes and print measured results with statistics. Attach the printout from the Mitutoyo digimatic mini-processor DP-1 VR to the report. Then you need to compare, in the graph, results obtained by employed equipment. Formulate conclusions and write observations.

*Table 2. Micrometer results*

<b>Shaft number</b>	<b>Analog outside micrometer [mm]</b>	<b>Digimatic outside micrometer [mm]</b>

**Task 3:** Use dial indicator and required equipment to measure radial and axial run-out values. Write results of measurements in appropriate table.

a)



b)

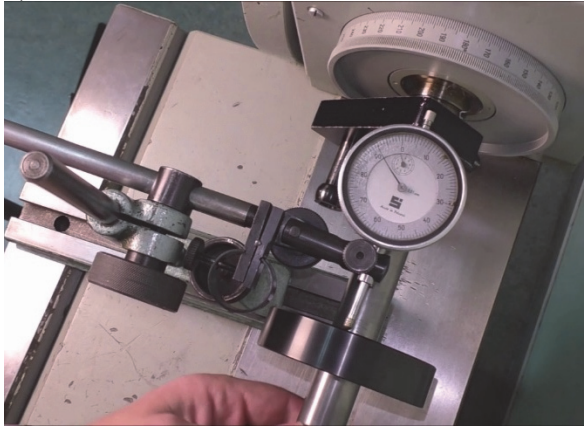


Figure 3. Run-out measurements: a) radial run-out, b) axial run-out

Table 3. Dial indicator results

	<b>Min.</b>	<b>Max.</b>	<b>Run-out</b>
<b>Radial (a)</b>			
<b>Axial (b)</b>			

**Task 4:** Use microcator for height shaft measurement. Use appropriate gauge blocks and calculate final results of measurements for all shafts given to you by leader of laboratory classes. Write results of measurements in appropriate table.

Table 4. Microcator results

<b>Shaft number</b>	<b>Vernier caliper reading [mm]</b>	<b>Gauge block stock dimension [mm]</b>	<b>Microcator reading [mm]</b>	<b>Final result [mm]</b>

**Task 5:** Use electronic QC300 Tool work microscope to determine the positions of center holes and its diameters in accordance to work coordinate system located in left bottom corner of the sample presented in Figure 4. Write results of measurements in appropriate table. Compare these results to the values obtained by using vernier caliper. Formulate conclusions and observations.

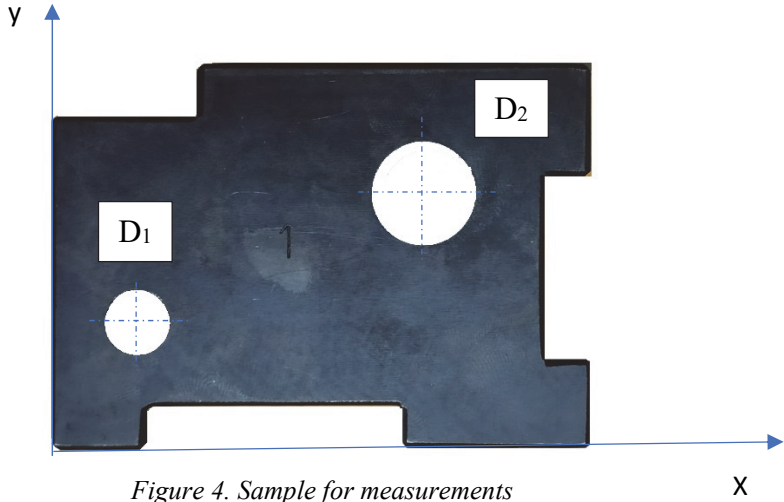


Figure 4. Sample for measurements

Table 5. Result of measurements

Symbol of dimension	Results
$X_1$	
$Y_1$	
$D_1$	
$X_2$	
$Y_2$	
$D_2$	

**Conclusions:**

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# Laboratory 9

## Chip formation process

Laboratory leader: Ph.D. Piotr Zgórniak

**Objective:** The aim of the exercise is the practical observation of the chip formation process and the examination of the influence of selected cutting parameters on the course of this process as well as the form and shape of the generated chips.

### I. Introduction

Machining is a manufacturing process in which a sharp cutting tool is used to cut away material to leave the desired part shape. The predominant cutting action in machining involves shear deformation of the work material to form a chip; as the chip is removed, a new surface is exposed. Machining is most frequently applied to shape metals. The process is illustrated in the diagram of Figure 9.1.

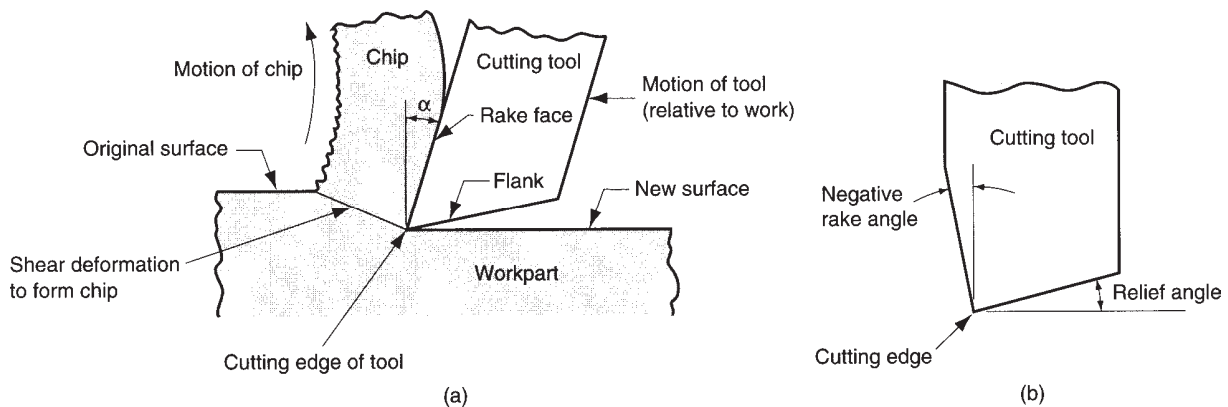


Figure 9.1. (a) A cross-sectional view of the machining process. (b) Tool with negative rake angle; compare with positive rake angle in (a) [3]

The geometry of most practical machining operations is somewhat complex. A simplified model of machining is available that neglects many of the geometric complexities, yet describes the mechanics of the process quite well. It is called the orthogonal cutting model, Figure 9.1. Although an actual machining process is three-dimensional, the orthogonal model has only two dimensions that play active roles in the analysis.

### II. The orthogonal cutting model

By definition, orthogonal cutting uses a wedge-shaped tool in which the cutting edge is perpendicular to the direction of cutting speed. As the tool is forced into the material, the chip is formed by shear deformation along a plane called the shear plane, which is oriented at an angle  $\phi$  with the surface of the work. Only at the sharp cutting edge of the tool does failure of the material occur, resulting in separation of the chip from the parent material. Along the shear

plane, where the bulk of the mechanical energy is consumed in machining, the material is plastically deformed.

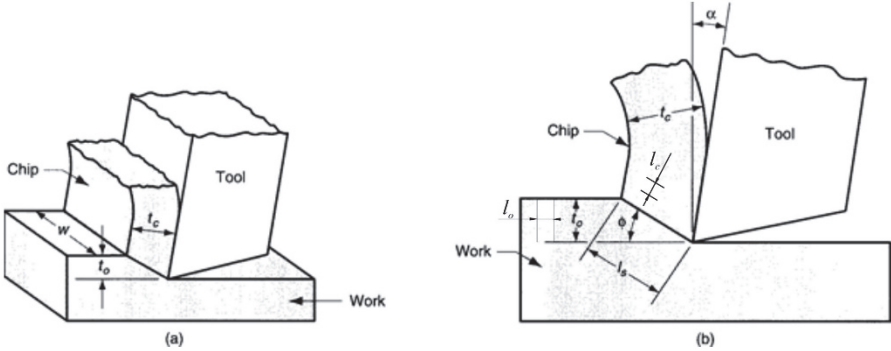


Figure 9.2. Orthogonal cutting: a) as a three-dimensional process, and (b) how it reduces to two dimensions in the side view [3]

The tool in orthogonal cutting has only two elements of geometry: rake angle and clearance angle. As indicated previously, the rake angle  $\alpha$  determines the direction that the chip flows as it is formed from the workpiece; and the clearance angle provides a small clearance between the tool flank and the newly generated work surface. During cutting, the cutting edge of the tool is positioned a certain distance below the original work surface. This corresponds to the thickness of the chip prior to chip formation,  $t_0$ . As the chip is formed along the shear plane, its thickness increases to  $t_c$ . The ratio of  $t_c$  to  $t_0$  is called the chip thickness ratio (or simply the chip ratio)  $r$ . Chip ratios can be determined by measuring length  $r_l$  (chip ratio concerning length) and by measuring depth of cut and chip thickness  $r_t$  (chip ratio concerning thickness).

Formula:

$$r_l = \frac{l_0}{l_c} \tag{9.1}$$

$$r_t = \frac{t_c}{t_0} \tag{9.2}$$

where:

- $t_0$  – depth of cut [mm];
- $t_c$  – thickness of the chip [mm];
- $l_0$  – length of cut [mm];
- $l_c$  – length of the chip [mm].

Since the chip thickness after cutting is always greater than the corresponding thickness before cutting, the chip ratio will always be greater than 1.0. In addition to  $t_0$ , the orthogonal cut has a width dimension  $w$ , as shown in Figure 9.2 (a), even though this dimension does not contribute much to the analysis in orthogonal cutting. The geometry of the orthogonal cutting model allows us to establish an important relationship between the chip thickness ratio, the rake angle, and the shear plane angle. Let  $l_s$  be the length of the shear plane. We can make the substitutions:  $t_0 = l_s \sin \phi$ , and  $t_c = l_s \cos(\phi - \alpha)$ .

The classification of chip types for completion of Task 1.4 concerning an influence of workpiece material on chip types is presented in Figure 9.3.

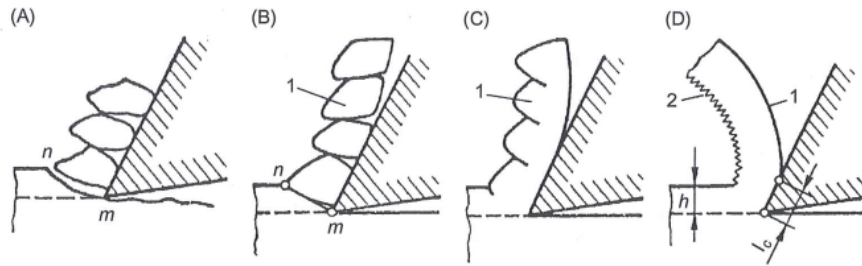


Figure 9.3. Classification of chip types: (A) discontinuous, (B) elemental, (C) segmented, (D) continuous [2]

Classification of chip forms according to ISO 3685-1977 (E) for completion of all tasks concerning turning operation is shown in Figure 9.4.

8. NEEDLE CHIPS						
7. ELEMENTAL CHIPS						
6. ARC CHIPS		6.1. Connected		6.2. Loose		
5. CONICAL HELICAL CHIPS		5.1. Long		5.2. Short		5.3. Snarled
4. WASHER-TYPE HELICAL CHIPS		4.1. Long		4.2. Short		4.3. Snarled
3. SPIRAL CHIPS		3.1. Flat		3.2. Conical		
2. TUBULAR CHIPS		2.1. Long		2.2. Short		2.3. Snarled
1. RIBBON CHIPS		1.1. Long		1.2. Short		1.3. Snarled

Figure 9.4. Classification of chip forms according to ISO 3685-1977 (E) [2]



### III. Description of the test stand

The stand for observation and recording of the chip formation process with the use of a multimedia board and a digital camera is presented in Figure 9.5.

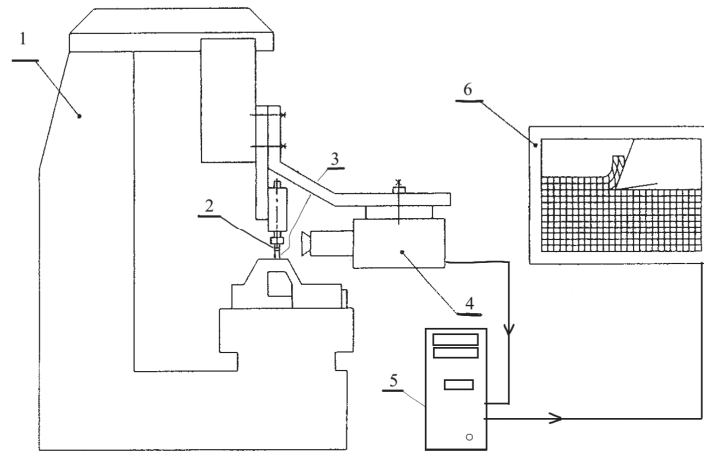


Figure 9.5. Diagram of chip formation experimental stand [1]

Cutting tests are carried out on a specially modified milling machine. Instead of a milling mandrel with a disk milling cutter, a holder with a planer cutting tool 2 is mounted. The cutting tool stands still with the machine tool body and a rectilinear movement is performed by the workpiece 3 fixed by the holder on the machine tool table. The view of the cutting zone is recorded by a digital camera 4, from which the signal is sent to the computer 5. Using the software supporting the multimedia board 6, it is possible to make the necessary measurements of linear dimensions and angles. On their basis, chip ratios and shear angles are determined. It is also possible to save video sequences and take photos.

### IV. The course of the laboratory exercise

In the first part of the laboratory classes, the influence of cutting parameters on the chip ratio coefficients and shear angle should be determined. For this purpose, appropriate graphs should be prepared and final conclusions drawn.

In the second part, for a given workpiece materials, by changing the cutting parameters and the rake angles, observe the shape and variety of the obtained chips and compare them with the table included in introduction.

### V. Literature

- [1] **B. Kruszyński (et. al)** *Laboratorium Obróbki Skrawaniem*, Wydawnictwo Politechniki Łódzkiej, Łódź, PL, 1999 (Script PŁ), ISBN 83-87198-74-9.
- [2] **W. Grzesik** *Advanced Machining Processes of Metallic Materials, Theory, Modelling, and Application*, Elsevier Second Edition (2017), (Book).
- [3] **Mikell P. Groover** *Fundamentals of Modern Manufacturing, Materials, Processes, and Systems, 5<sup>th</sup> Edition* Wiley (2013,2010,2008,2004), (Book), 978-1-118-231463 Printed in United States of America.

# LABORATORY 9 REPORT

## *Chip Formation Process*

Laboratory leader: Ph.D. Piotr Zgórniak

Date: .....

Grade: .....

Group: .....

### Part 1: Orthogonal cutting model

**Task 1.1:** : An influence of cutting velocity  $v_c$  [mm/min.] on chip ratios

*Table 1. Constant parameters*

<i>Rake angle <math>\alpha</math> [°]</i>	<i>Depth of cut <math>a_p</math> [mm]</i>	<i>Material</i>

*Table 2. Variable parameters*

<i>Cutting velocity</i>	<i>Chip ratio <math>r_l</math> (length)</i>		<i>Chip ratio <math>r_t</math> (thickness)</i>			<i>Shear angle <math>\Phi</math> [°]</i>	
$v_{c1} =$	$l_{o1}$		$r_{l1} =$	$t_{o1}$		$r_{t1} =$	$\Phi_1 =$
	$l_{c1}$			$t_{c1}$			
$v_{c2} =$	$l_{o2}$		$r_{l2} =$	$t_{o2}$		$r_{t2} =$	$\Phi_2 =$
	$l_{c2}$			$t_{c2}$			
$v_{c3} =$	$l_{o3}$		$r_{l3} =$	$t_{o3}$		$r_{t3} =$	$\Phi_3 =$
	$l_{c3}$			$t_{c3}$			

**Task 1.2:** An influence of depth of cut  $t_0$  [mm] on chip ratios

*Table 3. Constant parameters*

<i>Rake angle <math>\alpha</math> [°]</i>	<i><math>v_c</math> [mm/min.]</i>	<i>Material</i>

*Table 4. Variable parameters*

<i>Depth of cut <math>t_0</math></i>	<i>Chip ratio <math>r_l</math> (length)</i>		<i>Chip ratio <math>r_t</math> (thickness)</i>			<i>Shear angle <math>\Phi</math> [°]</i>	
$t_{o1} =$	$l_{o1}$		$r_{l1} =$	$t_{o1}$		$r_{t1} =$	$\Phi_1 =$
	$l_{c1}$			$t_{c1}$			
$t_{o2} =$	$l_{o2}$		$r_{l2} =$	$t_{o2}$		$r_{t2} =$	$\Phi_2 =$
	$l_{c2}$			$t_{c2}$			
$t_{o3} =$	$l_{o3}$		$r_{l3} =$	$t_{o3}$		$r_{t3} =$	$\Phi_3 =$
	$l_{c3}$			$t_{c3}$			

**Task 1.3:** An influence of rake angle  $\alpha$  [ $^{\circ}$ ] on chip ratios

Table 5. Constant parameters

$v_c$ [mm/min.]	Depth of cut $t_o$ [mm]	Material

Table 6. Variable parameters

Rake angle [ $^{\circ}$ ]	Chip ratio $r_l$ (length)		Chip ratio $r_t$ (thickness)		Shear angle $\Phi$ [ $^{\circ}$ ]
$\alpha_1 =$	$l_{01}$	$r_{l1} =$	$t_{01}$	$r_{t1} =$	$\Phi_1 =$
	$l_{c1}$		$t_{c1}$		
$\alpha_2 =$	$l_{02}$	$r_{l2} =$	$t_{02}$	$r_{t2} =$	$\Phi_2 =$
	$l_{c2}$		$t_{c2}$		
$\alpha_3 =$	$l_{03}$	$r_{l3} =$	$t_{03}$	$r_{t3} =$	$\Phi_3 =$
	$l_{c3}$		$t_{c3}$		

**Task 1.4:** An influence of workpiece material on chip types

Table 7. Constant parameters

Cutting velocity $v_c$ [mm/min.]	Depth of cut $t_o$ [mm]	Rake angle $\alpha$ [ $^{\circ}$ ]

Table 8. Variable parameters

Workpiece Material	Chip type
Aluminium	
Brass	
Cast iron	

**Conclusions:**

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## Part 2: Turning operation

**Task 2.1:** An influence of cutting velocity on chip forms after turning operation

Table 9. Constant parameters

Feed $f$ [mm/rev.]	Depth of cut $a_p$ [mm]	Workpiece material

Table 10. Variable parameters

Workpiece diameter $d$ [mm]	Rotational speed $n$ [rev./min.]	Cutting velocity $v_c$ [m/min.]	Type of the chip
$d_1$	$n_1$	$v_{c1}$	
$d_2$	$n_2$	$v_{c2}$	
$d_3$	$n_3$	$v_{c3}$	
$d_4$	$n_4$	$v_{c4}$	

**Task 2.2:** An influence of depth of cut  $a_p$  on chip forms after turning operation

Table 11. Constant parameters

Feed $f$ [mm/rev.]	Cutting velocity $v_c$ [m/min.]	Workpiece material	Workpiece diameter $d$ [mm]

Table 12. Variable parameters

Depth of cut $a_p$ [mm]	Type of the chip
$a_{p1}$	
$a_{p2}$	
$a_{p3}$	
$a_{p4}$	

**Task 2.3:** An influence of feed on chip forms after turning operation

Table 13. Constant parameters

Depth of cut $a_p$ [mm]	Cutting velocity $v_c$ [m/min.]	Workpiece material	Workpiece diameter $d$ [mm]	Rotational speed $n$ [rev./min.]

Table 14. Variable parameters

Feed [mm/rev.]	Type of the chip
$f_1$	
$f_2$	
$f_3$	
$f_4$	

**Conclusions:**

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# Laboratory 10

## *Cutting tool design and sharpening*

Laboratory leader: Ph.D. Piotr Zgórniak

**Objective:** To acquaint students with the geometries and sharpening procedures of cutting tools such as: single-point turning tool, twist drill, shell end mill cutter, form relieved mill cutter and hob cutter. The cutting tools are presented in Figure 10.1.



*Figure 10.1. Cutting tools presented during laboratory classes*

### **I. Introduction**

Cutting tools are designed with sharp edges to minimize rubbing contact between the tool and workpiece. Variations in the shape of the cutting tool influence tool life, surface finish of the workpiece, and the amount of force required to shear a chip from the parent metal. The various angles ground on a tool bit are called the *basic tool angles*, and compose what is often

termed the *tool geometry*. The schematic diagram in Figure 10.2 shows the basic tool angles of single-point turning tool.

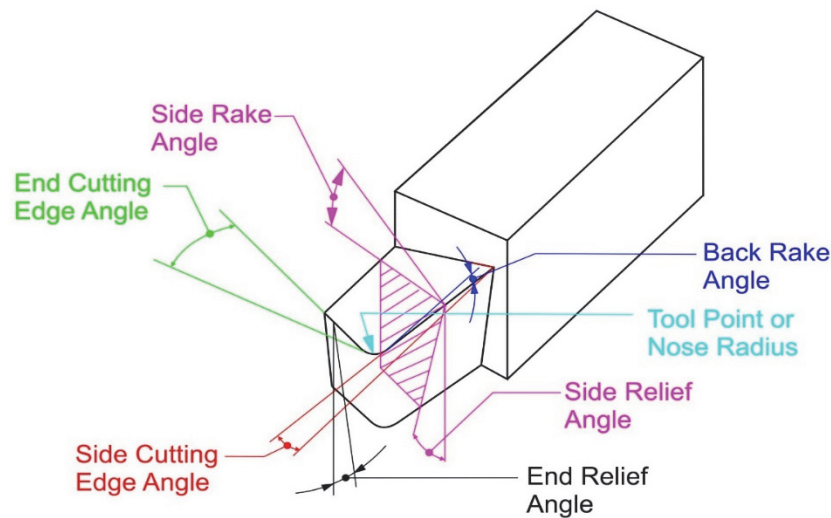


Figure 10.2. Terms applied to single-point turning tool [1]

The signature is a sequence of numbers listing the various angles, in degrees, and the size of the nose radius. This numerical method of identification has been standardized by the American Standards Association, and is illustrated in Figure 10.3, together with the elements that make up the tool signature.

**Back Rake Angle.** This is the angle between the face of the tool and a line that is parallel to the base of the toolholder. It is measured in a plane that is parallel to the side cutting edge and perpendicular to the base. Variations in the back rake angle affect the direction of chip flow. As this angle is increased while other conditions remain constant, tool life will increase slightly and the cutting force required will decrease. Because continual regrinding of this angle reduces the thickness of the tool with its resultant weakening, steep rake angles are usually obtained by alterations in the side rake rather than the back rake angle.

**Side Rake Angle.** This angle is defined as the angle between the tool face and a plane parallel to the tool base. It is measured in a plane perpendicular to both the base of the holder and the side cutting edge. Variations in this angle affect the direction of chip flow. As the angle is increased, reductions in cutting force, increased tool life, and improvement in surface finish usually result.

**End Relief Angle.** This is the angle between the end flank and a line perpendicular to the base of the tool. The purpose of this angle is to prevent rubbing between the workpiece and the end flank of the tool. An excessive relief angle reduces the strength of the tool, so the angle should not be larger than necessary.

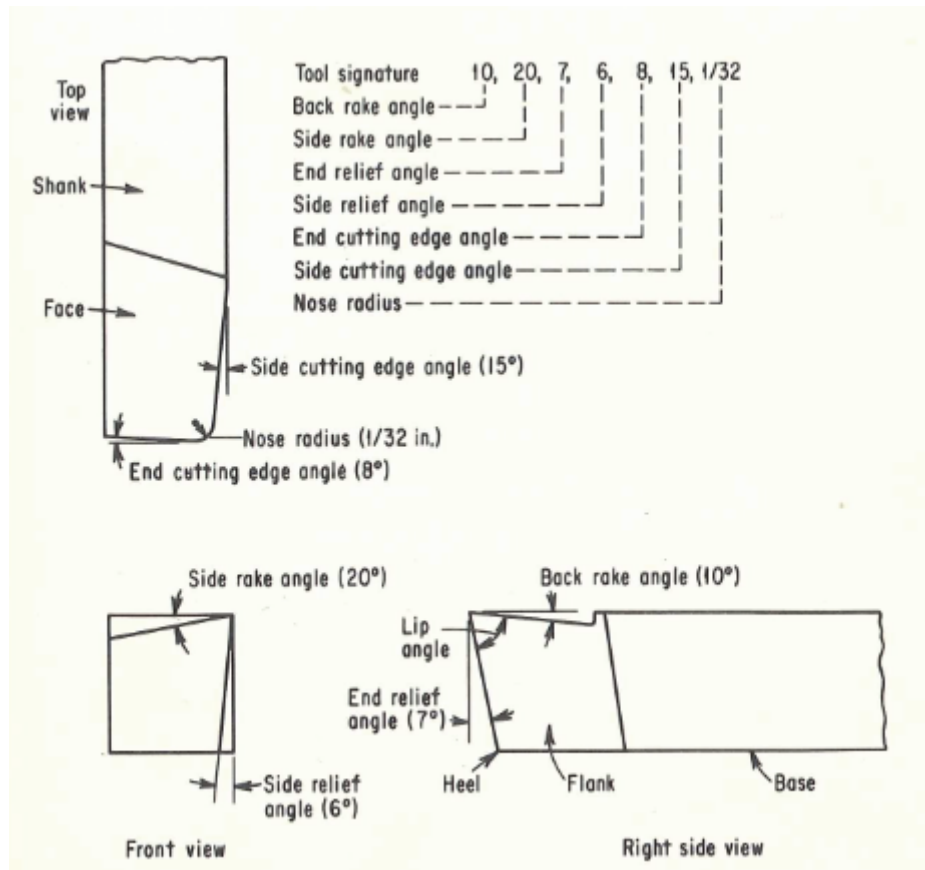


Figure 10.3. A straight-shank, right-cut, single-point tool, illustrating the elements of the tool signature as designated by the ASA. Positive rake angles are shown.[1]

**Side Relief Angle.** This is the angle between the side flank of the tool and a line drawn perpendicular to the base. Comments regarding end relief angles are applicable also to side relief angles. For turning operations, the side relief angle must be large enough to allow for the feed-helix angle on the shoulder of the workpiece.

**End Cutting Edge Angle.** This is the angle between the edge on the end of the tool and a plane perpendicular to the side of the tool shank. The purpose of the angle is to avoid rubbing between the edge of the tool and the workpiece. As with end relief angles excessive end cutting angles reduce tool strength with no added benefits.

**Side Cutting Edge Angle.** This is the angle between the straight cutting edge on the side of the tool and the side of the tool shank. This side edge provides the major cutting action and should be kept as sharp as possible. Increasing this angle tends to widen the thin chip and influences the direction of chip flow. An excessive side cutting edge angle may cause chatter and should be avoided. As the angle is increased, increased tool life and minor improvement in surface finish can be expected. However, these benefits will usually be lost if chatter occurs, so an optimum maximum angle should be sought.

**Nose Radius.** The nose radius connects the side and end cutting edges and should blend smoothly into each to facilitate grinding. Although straight chamfers are sometimes ground to form the nose, most satisfactory results are obtained when the nose is in the form of an arc. Sharp-pointed tools have a nose radius of zero. Increasing the nose radius from zero avoids high heat concentration at a sharp point. Improvement in tool life and surface finish and a slight reduction in cutting force usually result as nose radius is increased. There is, however, a limit



to radius size that must be considered. Chatter will result if the nose radius is too large; an optimum maximum value should be sought.

**Tool Signature.** The seven elements that comprise the signature of a single-point cutting tool are always stated in the following order: back rake angle, side rake angle, end relief angle, side relief angle, end cutting edge angle, side cutting edge angle, and nose radius. Figure 2 illustrates and lists the signature of a single-point tool as 10, 20, 7, 6, 8, 15, 1/32. It is usual practice to omit the symbols for degrees and inches/mm, simply listing the numerical value of each component. Unless specified, the rake angles are understood to be positive as shown. Negative rake angles are shown in Figure 10.4.

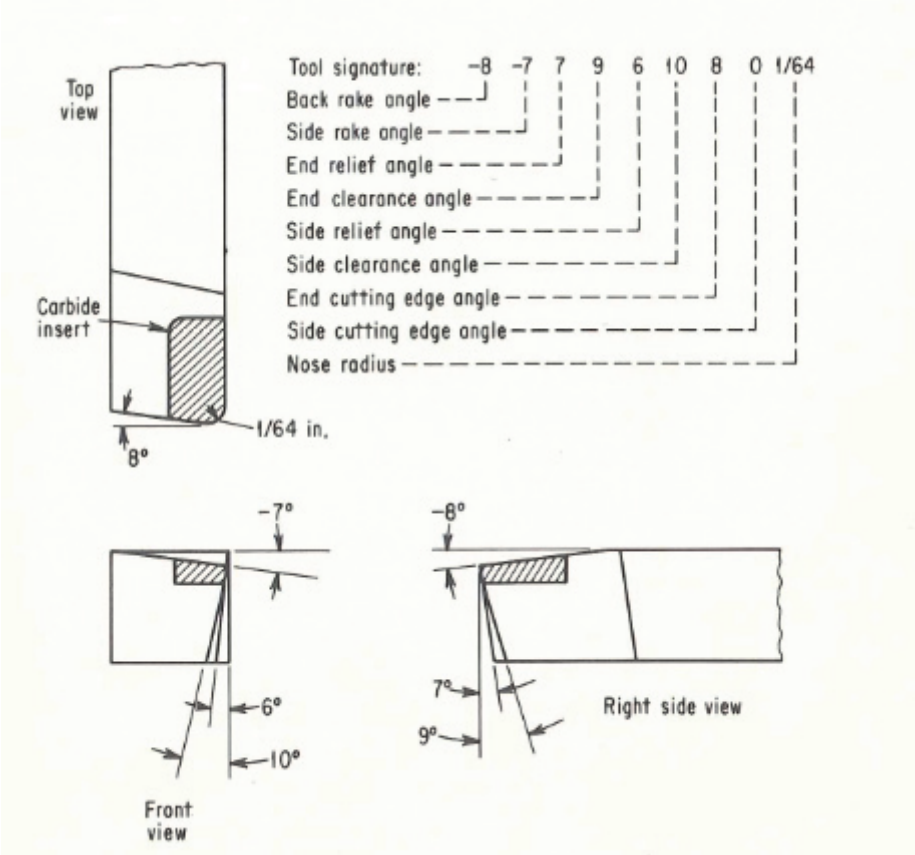


Figure 10.4. A straight shank, right-cut, sintered-carbide tipped, single-point tool. Rake angles are negative and secondary clearance angles on end and side are illustrated [1]

**II. Sharpening process of single-point cutting tool**

To shape the geometry of the turning tool, the following angles are formed in the first step: *side cutting edge angle*, *side relief angle* and in the second step: *end cutting edge angle* and *end relief angle*. The grinding operation is performed on the two-scale sharpener shown in the Figure 10.5.



*Figure 10.5. Single-point turning tool sharpener (double scale sharpening device)*

The next step is to shape the remaining angles, i.e. side rake angle, side relief angle, back rake angle. This procedure is performed on the three-scale sharpener shown in Figure 10.6.



*Figure 10.6. Triple scale sharpener from Malcus corporation (Sweden)*

The schematic view of triple scale sharpening device is presented in Figure 10.7. In the figure, location of each scales and rotational axes is shown. In Figure 10.8 the appropriate angles which need to be set on sharpening device is depicted.

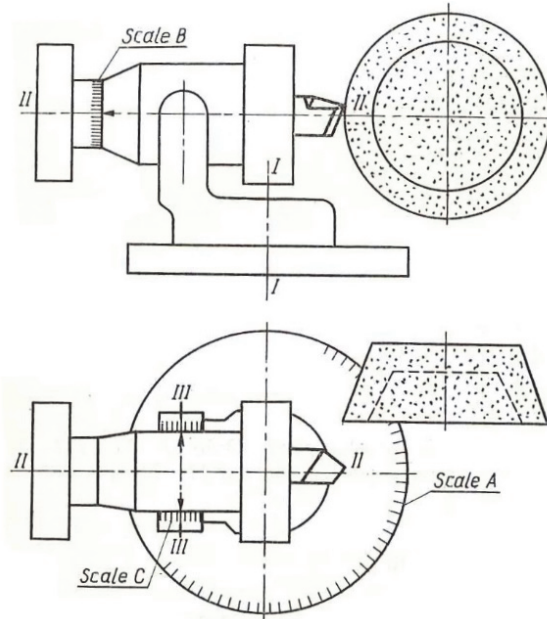


Figure 10.7. Triple scale sharpener tool holder type ONM [5]

The angles which need to be set on triple scale sharpening device is different than angles which need to be obtain on the cutting tool. The calculation need to be done in accordance to equation presented below. The upper signs go to positive  $\lambda$  angle, the lower signs to the negatives (according to the new notations, the  $\lambda$ , lambda angle is positive when the tip of the cutting tool is in the highest position). See in the Figure 10.3.

$$\cot \alpha_f = \sin \kappa \cdot \cot \alpha_o \mp \cos \kappa \cdot \tan \lambda \quad (10.1)$$

$$\cot \alpha_p = \cos \kappa \cdot \cot \alpha_o \pm \sin \kappa \cdot \tan \lambda \quad (10.2)$$

$$\tan \gamma_f = \sin \kappa \cdot \tan \gamma_o \mp \cos \kappa \cdot \tan \lambda \quad (10.3)$$

$$\tan \gamma_p = \cos \kappa \cdot \tan \gamma_o \pm \sin \kappa \cdot \tan \lambda \quad (10.4)$$

where\*:

$\kappa$  – entering angle ( $\kappa = 90^\circ - \psi$ );

$\alpha_o$  – side relief angle;

$\gamma_o$  – side rake angle;

$\lambda$  – back rake angle;

$\psi$  – side cutting edge angle.

\* in accordance to Polish nomenclature [5]

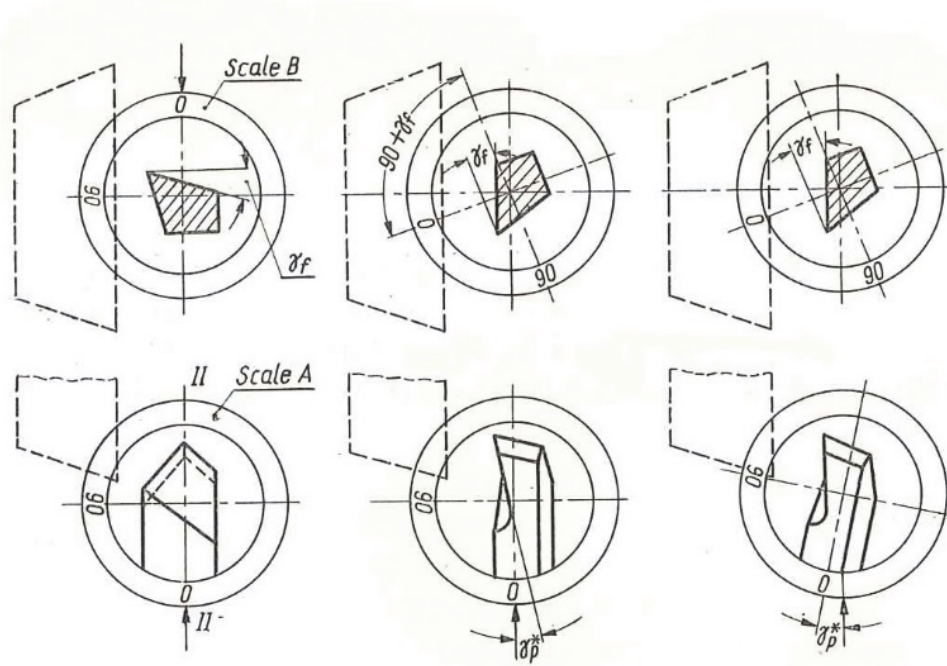


Figure 10.8. Schematic view of sharpening rake face of the tool [5]

The sharpening results can be checked using the special protractor shown in the Figure 10.9.



Figure 10.9. Special protractor for cutting tool angles measurements

### III. A Twist drill

In its most basic form a twist drill (Figure 10.10) is made from a round bar of tool material. It has a pair of helical *flutes* which form the cutting surfaces and act as chip conveyors. Relief is provided behind the two *cutting edges* or *lips*, The intersection of the two relief surfaces across the web between the two flutes is known as the *chisel edge*. The lands between the flutes are cut away to a narrow margin to reduce the area of contact between the lands and the wall of the

hole and/or guide bushing. The metal cut away to form the margin is known as *body diameter clearance*.

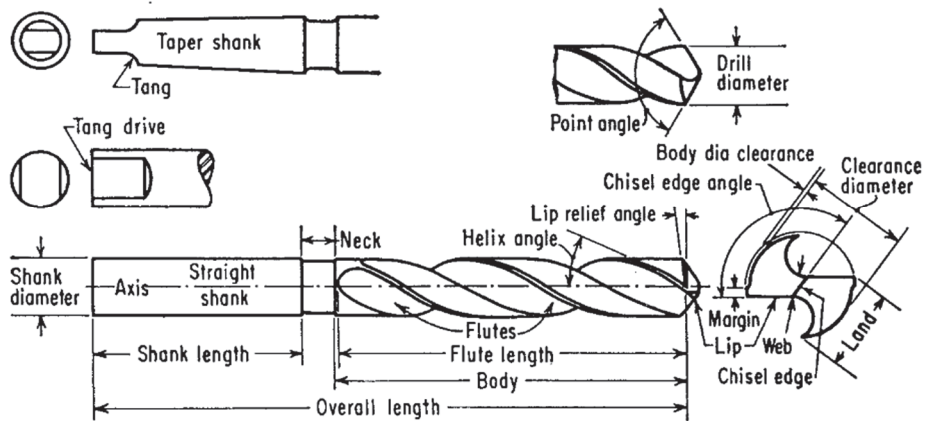


Figure 10.10. Nomenclature for twist drills [2]

Twist drills can be provided with a variety of shanks, but the straight shank and the Morse taper shank are the most common. Twist drills are ordinarily made of high-speed steel, but certain sizes and types are available, made from solid carbide or with carbide cutting tips.

Standard twist drills are available in a wide variety of designs, of which a few are shown in Figure 10.11, which adapt them to various materials and services. The most common variations are those of the helix angle and the web thickness. Tough materials usually require the use of rigid drills with heavy webs and reduced helix angles. Free-machining materials can be cut with drills having higher helix angles and lighter webs which provide for more efficient cutting and better chip ejection.

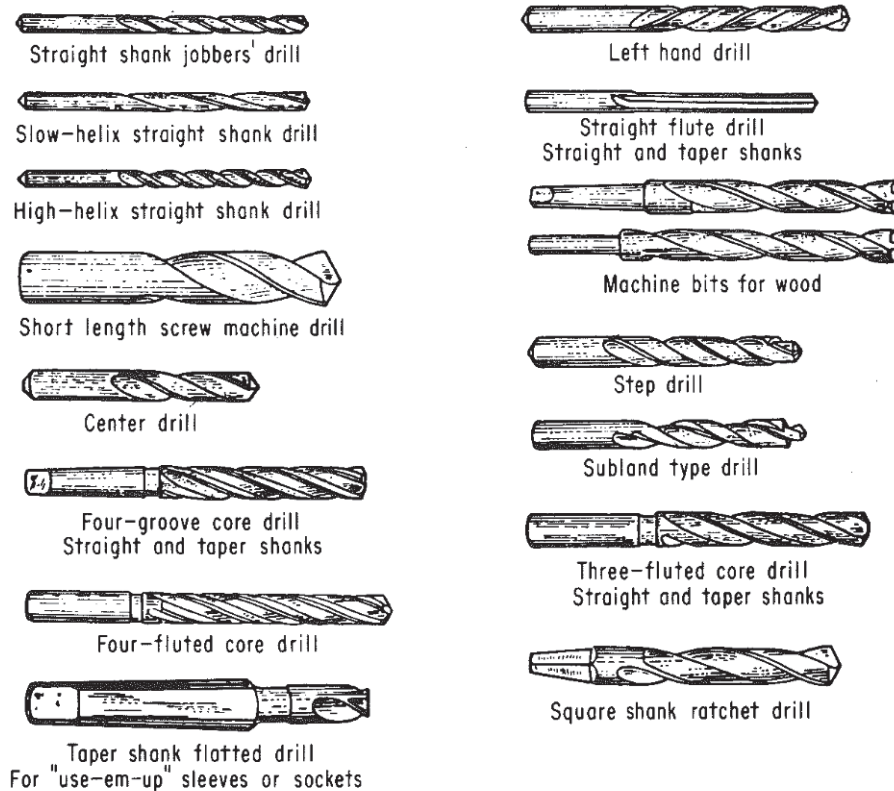


Figure 10.11. Conventional and special-purpose drills [2]

#### IV. Sharpening process of twist drill

There are four basic ways in which the main relief surfaces (Lands) can be shaped:

- a section of a conical surface;
- a section of the helical surface;
- planes;
- a section of a cylindrical surface.

Each of these methods has several varieties according to which drill sharpeners are built. The most common sharpening method is based on the method using a section of the conical surface, and there are two types of sharpening according to this method. In the first (Washburne) variant, the axes of the cones forming the relief surfaces form an angle of 90 degrees, while the tops of the cones and the relief surfaces formed by the cones are located on the opposite sides of the drill axis Figure 10.12a. In the second (Weisker) variant, the axes of the forming cones are perpendicular to the drill axis and their tips are on the same sides of the drill as the relief surfaces formed by them Figure 10.12b.

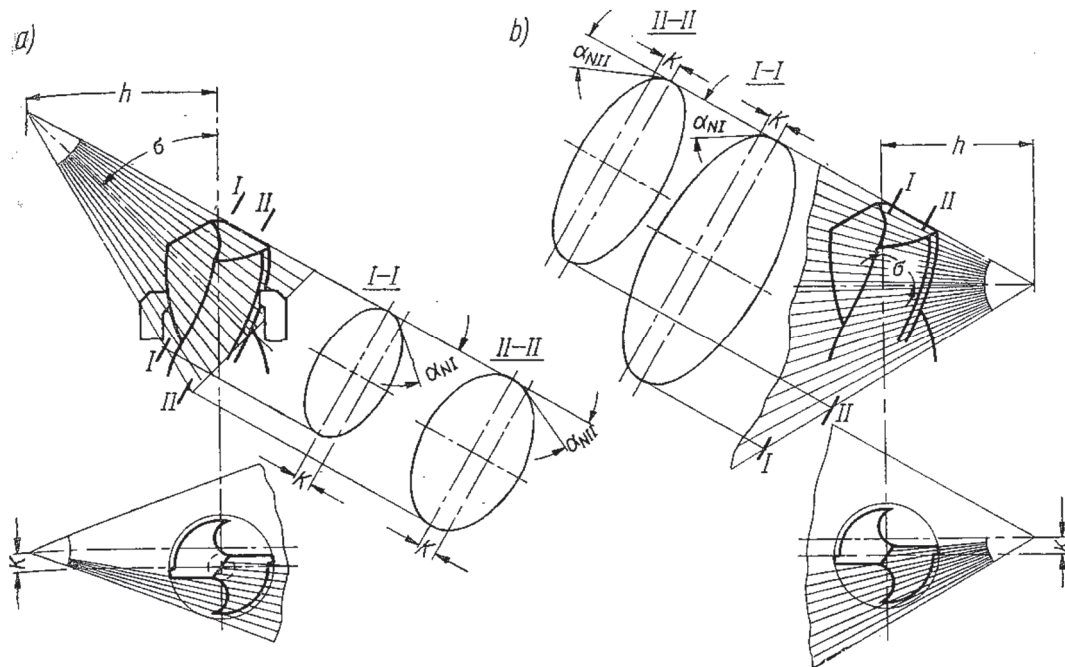


Figure 10.12. Cone sharpening methods: a) Washburne's, b) Weisker's [5]

The first (Washburne) method was used in our exercise. A view of the sharpener operating according to this method is shown in Figure 10.13.



Figure 10.13. Twist drill sharpener from Malcus corporation (Sweden)

## V. A Shell end mill cutter

When setting the clearance angle by raising or lowering the rest, the axes of the tool and the grinding wheel must be set so that they are shifted relative to each other by a height of  $H$ . The axis of the cup wheel spindle is set in relation to the tool axis at an angle less than 90 degrees by 0.5 to 1 degree [4, 6].

$$H = \frac{d}{2} \cdot \sin \alpha \quad (10.5)$$

where:

- $d$  – diameter of mill cutter [mm];
- $H_D$  – shift for bigger mill cutter diameter [mm];
- $H_d$  – shift for smaller mill cutter diameter [mm];
- $\alpha$  – relief angle [°].

Setting of the device for sharpening relief angle of shell end mill cutter has been illustrated in Figure 10.14a as a schematic view. Figure 10.14b shows inclination angle of grinding wheel from 0.5 to 1.0°.

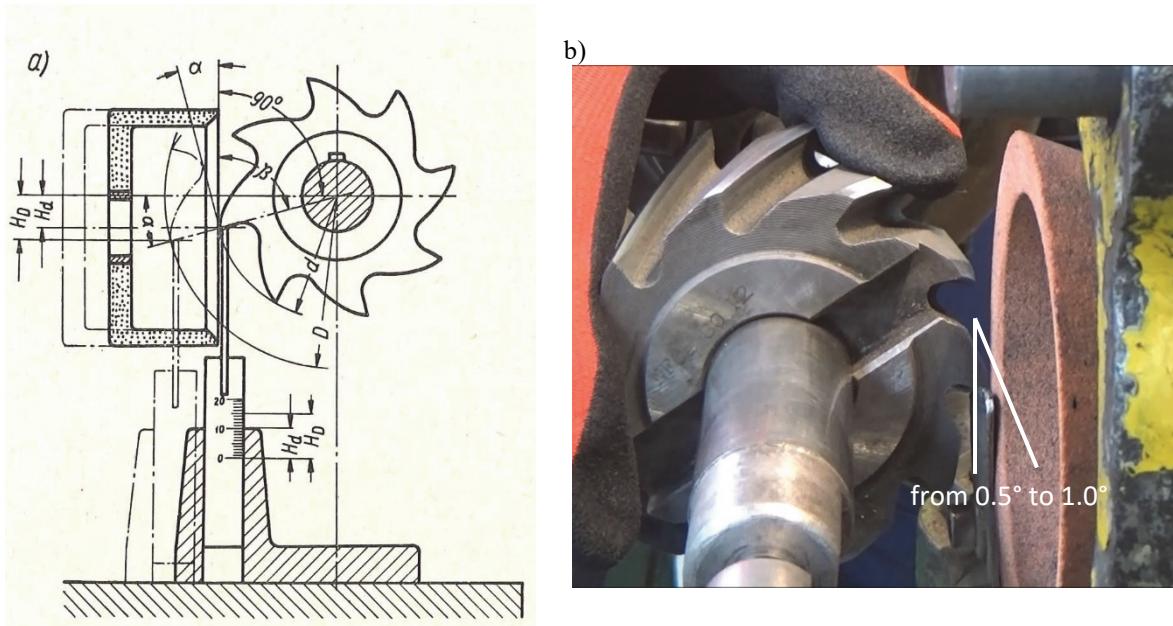


Figure 10.14. Setting of the device for sharpening relief angle

## VI. The Milling cutters nomenclature

In Figure 10.15 nomenclature for different types of mill cutters is presented.

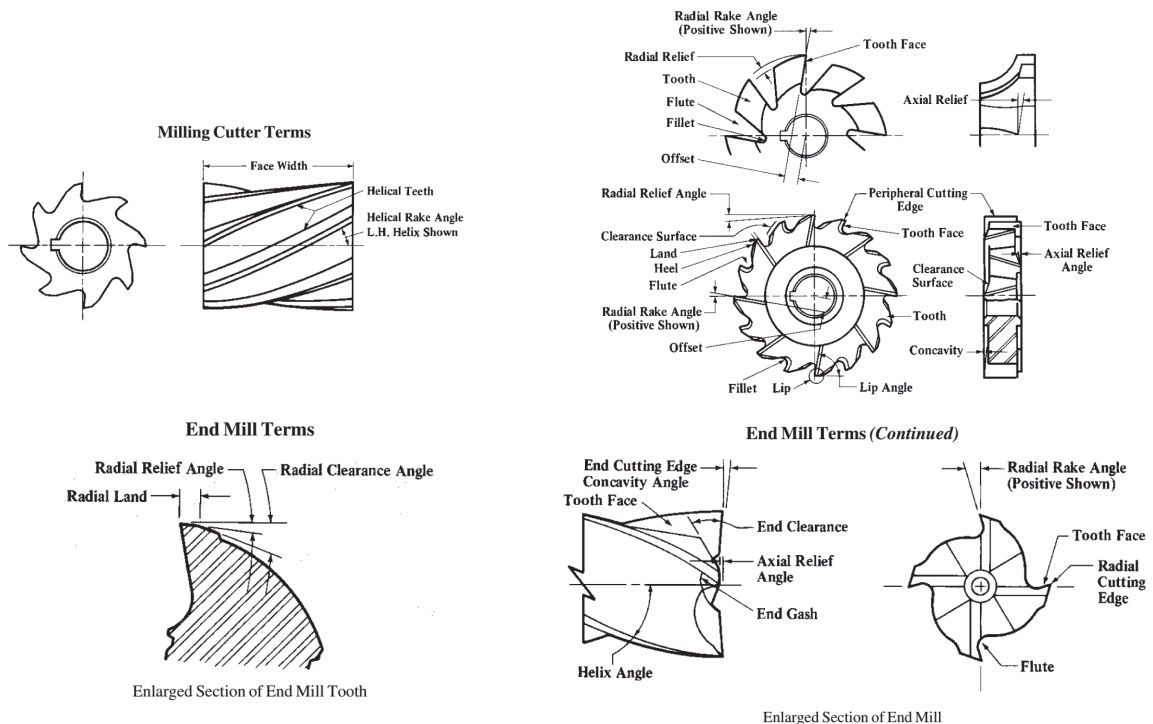


Figure 10.15. Mill cutters nomenclature [3]

## VII. A Form relieved cutter for gear teeth

Typically, adjusting the rake angle does not require as much accuracy as adjusting the relief angle. If the  $\gamma = 0$ , then it is enough to set the axis of the cutter exactly in the plane of the grinding wheel. Simple devices are used to adjust this axis, such as the ones shown in



Figure 10.16. According to the drawing presented in Figure 10.16a, a ruler is applied to the grinding wheel, which must simultaneously touch the mandrel, as can be seen in Figure 10.16b, placed in the centers, in the indexing head or in another holder [6, 7].

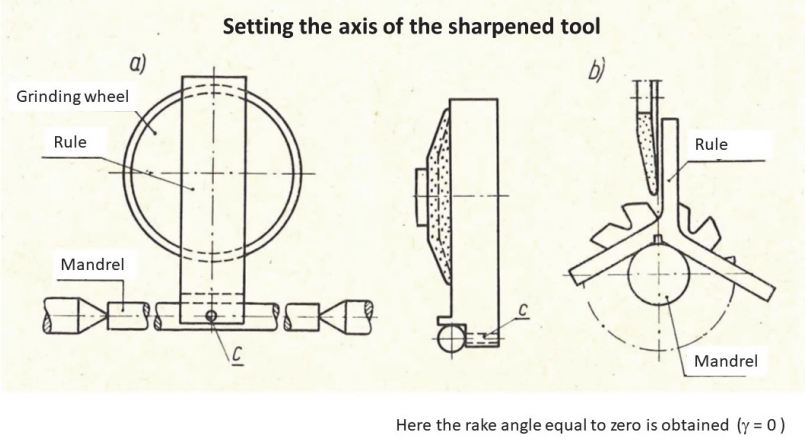


Figure 10.16. Setting the rake angle equal to zero [4]

If the rake angle  $\gamma$  need to be greater than zero, then setting the tool axis in the plane of the grinding wheel would give the position as in Figure 10.17b, i.e. grinding would not be good. To obtain a good position of the tool, it must be shifted relative to the grinding wheel by the dimension  $H$ , as shown in Figure 10.17c. The necessary offset  $H$  can be calculated from the formula:

$$H = \frac{d}{2} \cdot \sin \gamma \tag{10.6}$$

where:

- H – shift;
- d – diameter of mill cutter;
- $\gamma$  - rake angle;
- $\delta$  - cone angle.

For relieved milling cutters, the dimension  $H$  is often specified on the tool and can be used directly for setting. If the grinding wheel does not work with a plane, but with a conical surface, as in Figure 10.17d, which is sometimes needed, then the offset  $H'$  must also take into account the cone angle in accordance to formula:

$$H = \frac{d}{2} \cdot \sin(\gamma + \delta) \tag{10.7}$$

Setting the form-relieved cutter for gear teeth according to different values of required rake angles, greater than zero is shown in Figure 10.17. The variant presented in Figure 10.17a shows setting for rake angle equal to zero. Variant in Figure 10.17b shows incorrect position of grinding wheel in accordance to form-relieved cutter. The positions presented in Figure 10.17c and Figure 10.17d are correct. In Figure 10.17c a shift distance  $H$  must be applied for required rake angle  $\gamma$  in accordance to equation (10.6). The drawing in Figure 10.17d shows the applicability of cone shaped grinding wheel. The shift distance  $H'$  can be calculated by formula (10.7).

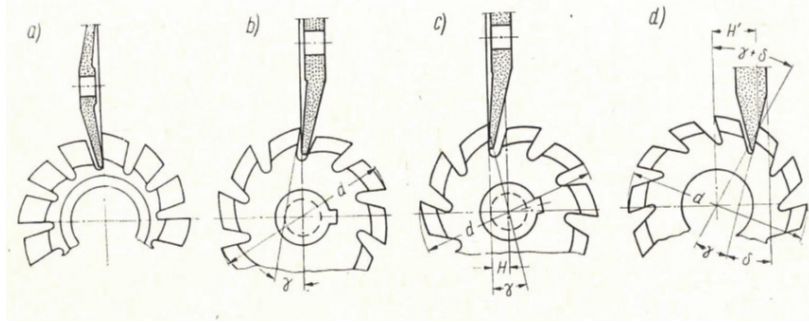


Figure 10.17. Setting the form-relieved cutter for gear teeth according to rake angle greater than zero [4]

The sharpening process of rake angle of relieved milling cutter for gear teeth is illustrated in Figure 10.18.

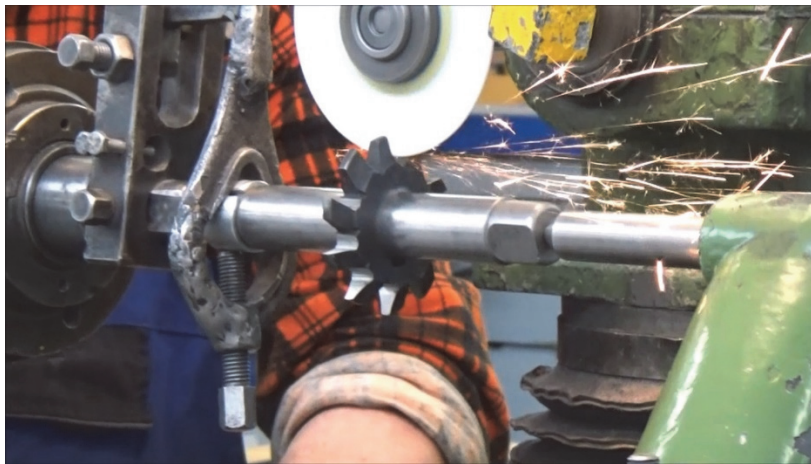


Figure 10.18. Universal sharpener for cutting tools

The results concerning the influence of sharpening procedure on the shape of the gear tooth is presented in Figure 10.19. On the base of the drawing we can observe effects of improper grinding of the rake angle on the shape errors of the teeth cut. The correct shape of the tools, rake face of the tooth cutter and the correct shape of the gear tooth are indicated by dashed lines. The continuous lines shows the results of different variants of sharpening conditions. The variant (a) shows proper conditions. In variant (b), positive rake angle error is shown. The resulted thickness of the gear tooth is too wide on tip diameter. Also asymmetric sharpening influences the amount of material removed from flanks of the tooth. The variant (c) shows negative rake angle error. In this case thickness of tooth on tip diameter is too narrow. Also asymmetry in material removal during sharpening of relieved cutter for gear teeth causes asymmetry in the shape of the gear teeth. The variant (d) shows improper results of cutting gears as an effect of pitch errors. It can be observed differences in required shape of rake face of the tooth cutter and results concerning the profile errors of gear teeth. These profile errors can cause the gear pair to malfunction and, in extreme cases, can cause damage.



The effect of improper grinding of the rake surface on the shape errors of the teeth cut:

- a) correct rake surface,
- b) surface with positive rake angle,
- c) surface with negative rake angle,
- d) pitch errors

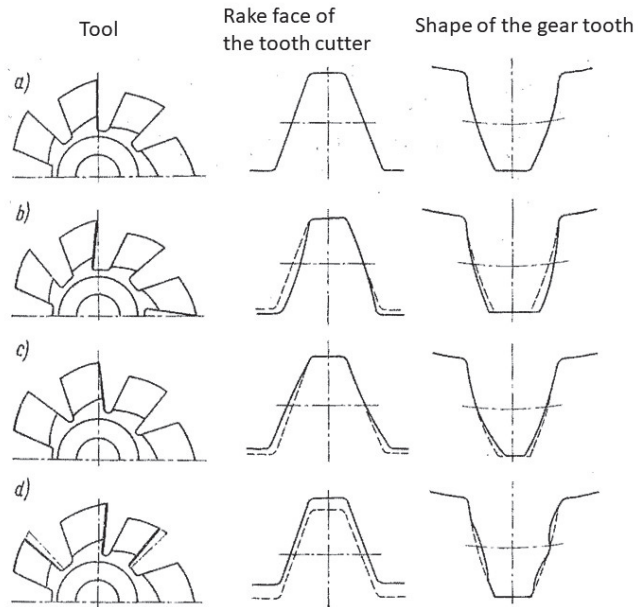


Figure 10.19. Effect of improper grinding of the rake angle on the shape errors of the teeth cut [5]

### VIII. A Hob

A hob is a generating-type rotary cutting tool which has its teeth arranged along a helical thread (Figure 10.20).

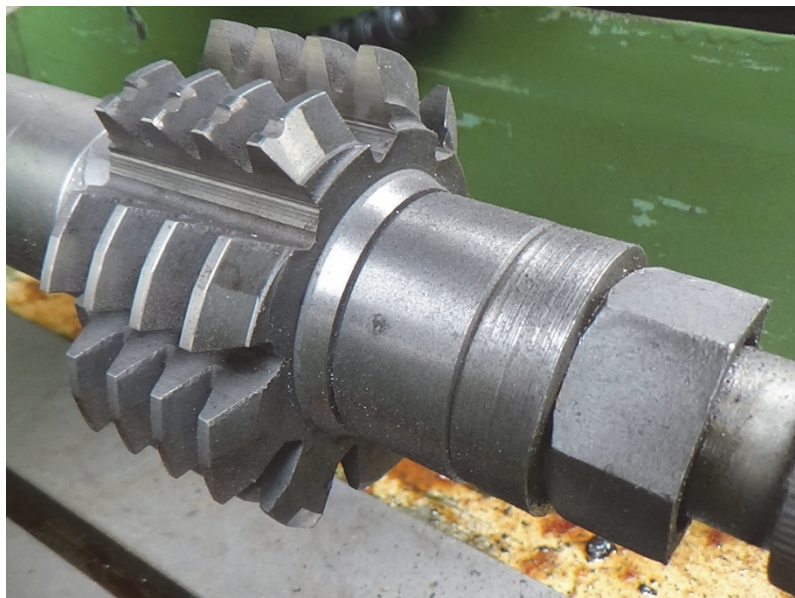


Figure 10.20. Hob cutter

Most hobs are designed for generating gear teeth or splines. Certain other evenly spaced forms on the periphery of a cylindrical workpiece can also be hobbled. There are some limitations on the shape of forms that can be generated by hobs. Most hobs are manufactured from high-speed steel. Carbide-tipped hobs are sometimes used for hobbing low-strength

abrasive nonmetallic materials. The sharpening operation can be done on the rake faces of the hob. The sharpening machine tool is presented in Figure 10.21.



Figure 10.21. Sharpening device for hob cutters

The geometrical parameters are the same as for form-relieved gear cutter. The main difference is that teeth of the tool are located on helical curve. The geometry of hob cutter is presented in Figure 10.22.

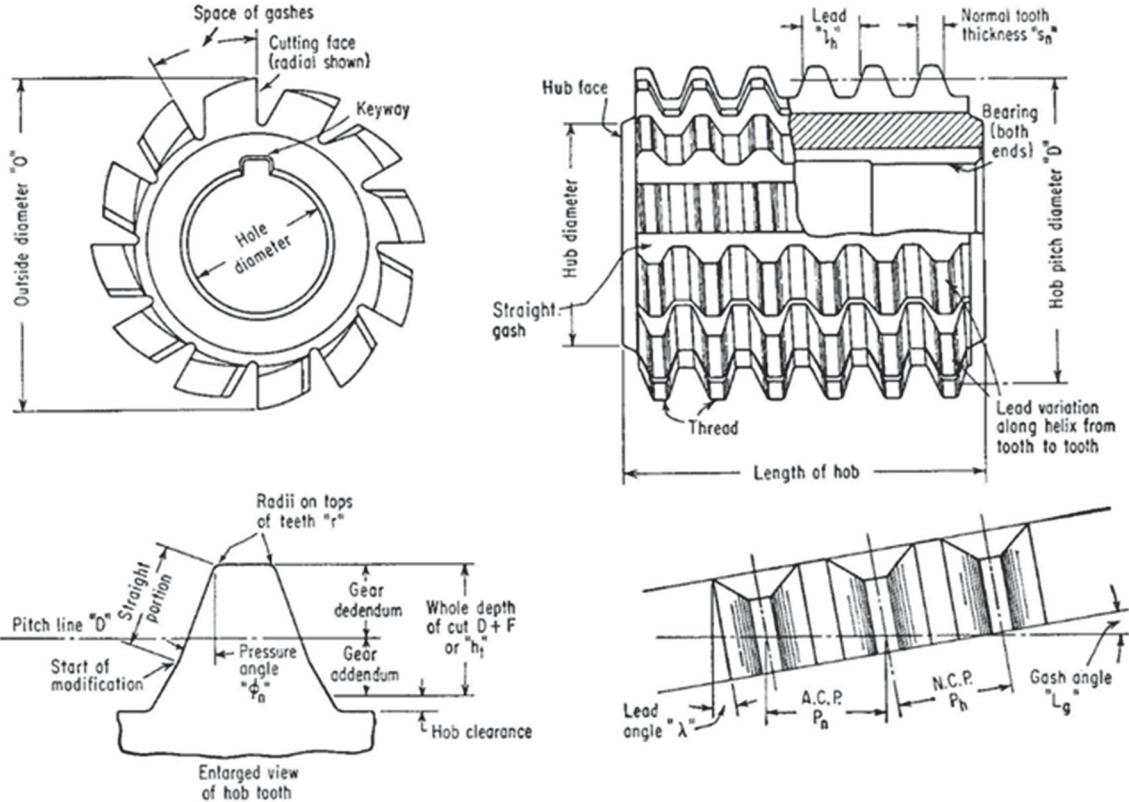


Figure 10.22. Nomenclature for hob cutter [1]

## IX. Literature

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- [2] **B. H. Amstead (et. al)** *Manufacturing Processes*, 8<sup>th</sup> edition John Wiley & Sons, ISBN 0-471-84236-2, United States of America and Canada (Books).
- [3] **E. Oberg, Franklin D. Johnes, Holbrook L. Horton, and Henry H. Ryffel Christopher J. McCauley**, editor: **Riccardo M. Heald**, associate editor: **Muhhamed Iqbal Hussain**, associate editor *Machinery's Handbook 27th Edition*, Industrial Press, Inc., New York, Copyright 2004, (Book).
- [4] **L. Burnat** *Ostrzenie i ostrzarki narzędzi*, wydanie 2, WNT Warszawa, 1968 (Book).
- [5] **J. Dmochowski (et. al)** *Technologia narzędzi skrawających*, wydanie 2 zmienione, WNT Warszawa, 1977 (Book).
- [6] **E. Górski, J. Harasymowicz** *Podstawy projektowania narzędzi skrawających wraz z zagadnieniami technologicznymi*, WNT Warszawa, 1976 (Book).
- [7] **E. Górski** *Frezy*, WNT Warszawa, 1977 (Book).

# LABORATORY 10 REPORT

## *Cutting tool design and sharpening*

Laboratory leader: Ph.D. Piotr Zgórniak

Date: .....

Grade: .....

Group: .....

**Task 1:** Use the protractor to measure the angles in the turning tool. Put the results in a table. Based on the results obtained, include a drawing of a turning tool along with the marked angles. Compose a tool signature.

*Table 1. Results of measurements*

Name of an angle	Value	Units
Back rake angle		[°]
Side rake angle		[°]
End relief angle		[°]
Side relief angle		[°]
End cutting edge angle		[°]
Side cutting Edge angle		[°]
Nose radius	0.4	[mm]

**Task 2:** Practical demonstration at the workshop of the method of sharpening a twist drill.

**Task 3:** Practical demonstration at the workshop of sharpening a relief angle of shell end mill cutter.

**Task 4:** Practical demonstration at the workshop of the method of sharpening a rake angle of form relieved mill cutter.

**Task 5:** Practical demonstration at the workshop of the method of sharpening a rake angle of hob cutter.

On the basis of the demonstrations and theoretical sources, students prepare a report on the presented methods of sharpening cutting tools and formulate final conclusions.

**Conclusions:**

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# Laboratory 11

## *Plastic deformation technologies and devices*

Laboratory leader: Ph.D. Bartłomiej Januszewicz

**Objective:** The aim of the laboratory is to familiarize students with the processes of cold working: punching and deep drawing, and to conduct the sheet pressing test by the Erichsen method.

### I. Introduction

**Cold working** is the plastic deformation of metals below the recrystallization temperature. In most cases of manufacturing, such cold forming is done at room temperature. Sometimes, however, the working may be done at elevated temperatures that will provide increased ductility and reduced strength but will be below the recrystallization temperature.

Advantages of cold working are: no heating required, better surface finish obtained, superior dimension control, better reproducibility and interchangeability of parts, improved strength properties, directional properties can be minimized.

Disadvantages: Higher forces required for deformation, heavier and more powerful equipment required, less ductility available. Metal surfaces must be clean and scale-free, strain hardening occurs (may require intermediate anneals), imparted directional properties may be detrimental, may produce undesirable residual stresses.

**Punching** is a machining process that involves the removal of scrap metal from a sheet of raw metal. It requires the use of a punch press to compress a tool through a sheet of raw metal. While punching is typically performed using sheet metal, it supports other materials like paper, plastic and various fibers. The punch press pressed through the sheet metal while placed against a die. Therefore, punched sheet metal takes the same shape as the die used. The scheme of punching process is presented in Figure 11.1.

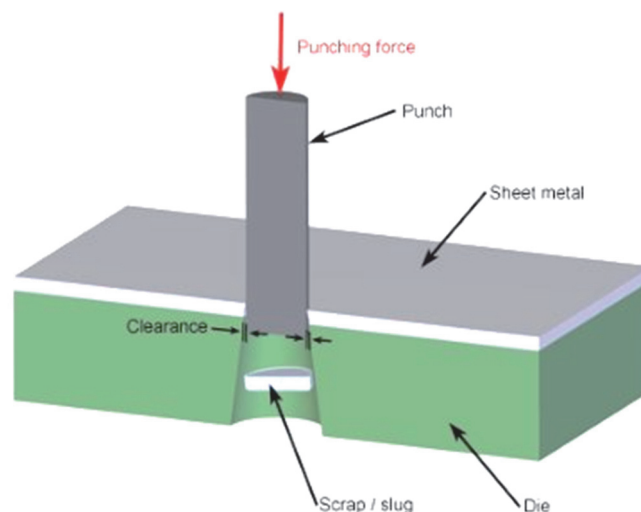


Figure 11.1. Punching operation scheme [1]

**Deep drawing** is a forming process which occurs under a combination of tensile and compressive conditions. A flat sheet metal blank is formed into a hollow body open on one side or a hollow body is formed into a hollow body with a smaller cross-section.

Deep drawing – see Figure 11.2, is a sheet metal forming process in which a flat sheet is radially drawn into a forming die by the mechanical action of a punch.

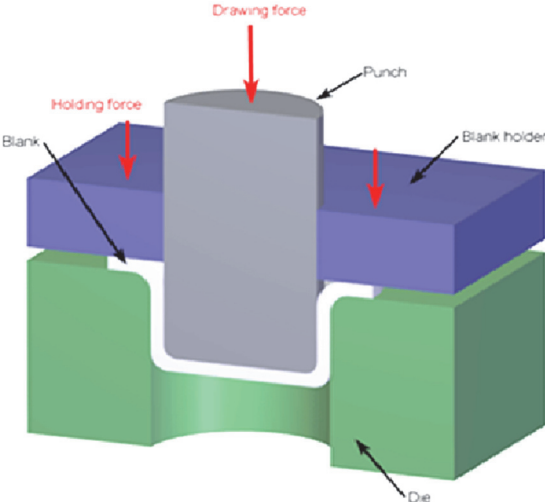


Figure 11.2. Deep drawing operation scheme [2]

**Wrinkling** may be defined as the formation of waves on the surface to minimize the compression stresses. There are two regions where wrinkling may take place first one is flange and second one is cup wall.

An example of wrinkling is presented in Figure 11.3.

Wrinkling on flange may be minimized by having optimum blank holder pressure but wrinkling on side walls cannot be prevented by any single parameters, so different parameters need to be set to minimize side wall wrinkling.



Figure 11.3. Deep drawing operation -wrinkling example [3]

**Erichsen test** – the Erichsen cupping test [4] is used to measure the stretch formability of the sheet. To proceed with the Erichsen test a sheet specimen blank is lubricated and clamped firmly between blank holders. The ball punch is forced onto the sheet till cracks begin to appear in the bulging dome. With the test, the indentation depth of a die is determined. Scheme of the test is presented in Figure 11.4.



The measured depth of the measurement, which corresponds to the die travel until crack, is the result of the test. The distance the punch travels is referred to as the Erichsen drawing index IE and is a measure for the formability of the sheet during stretch forming. At least three tests are performed, and the average value is indicated in millimeters.

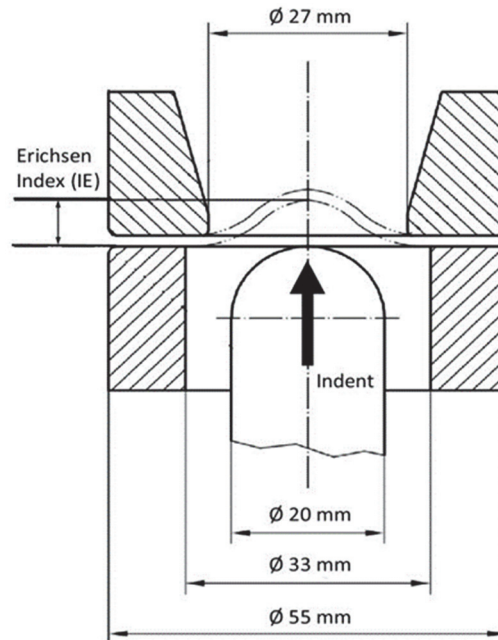


Figure 11.4. Erichsen test scheme [4]

## II. The course of the Laboratory

### Punching process:

1. acquaintance with the press construction and operation;
2. test preparation and machine set up;
3. test observations – 3 tests are performed;
4. collection of results – Table 1 to be fulfilled;
5. blank surface observations.

### Data:

- die diameter = 20 mm;
- blank diameter = 40 mm;
- blank thickness = 3 mm.

### Deep drawing process:

1. acquaintance with the press construction and operation;
2. test preparation and machine set up;
3. test observations – 6 tests are performed;
4. collection of results – Table 2 to be fulfilled;
5. drawn cup observations.

**Erichsen test:**

1. acquaintance with the Erichsen testing machine construction and operation;
2. test preparation and machine set up;
3. test observations – 6 tests are performed;
4. collection of results – Table 3 to be fulfilled;
5. test pieces surface observation.

**III. Literature**

- [1] <https://slidetodoc.com/an-open-educational-resource-on-manufacturing-processes-lesson-3/>
- [2] **N. Arab, E. Nazaryan** *Stress and strain paths in deep drawing of cylindrical cup*. Semantic Scholar 2013.
- [3] **Ghafar, Alimi & Abdullah, Ahmad Baharuddin & Mahmood, Johan** *Experimental and numerical prediction on square cup punch–die misalignment during the deep drawing process*. The International Journal of Advanced Manufacturing Technology. 113. 1-10, 2021.
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# LABORATORY 11 REPORT

## *Plastic deformation technologies and devices*

Laboratory leader: Ph.D. Bartłomiej Januszewicz

Date: ..... Grade: .....

Group: .....

**Task 1:** Describe punching test (setting, test, blank removal). Fullfill Table 1.

*Table 1. Punching process results*

Sample no	Punch diameter [mm]	Punching force [kN]	Blank removal force [kN]
1			
2			
3			

**Task 2:** Discuss dependences between punch diameters and measured forces.

**Task 3:** On the base of presented results discuss influence of blank holder on measured parameters and quality of the drawn cup. Fullfill Table 2.

*Table 2. Deep drawing process results*

Sample	Thickness, mm	Die diameter, [mm]	Blank holder	Drawing force, [kN]
1				
2				
3				
4				
5				
6				

**Task 4:** On the base of presented results discuss influence of blank holder on measured parameters and quality of the drawn cup.

**Task 5:** Describe the Erichsen test. Fullfill Table 3. Describe surface observations. Determine IE index and type of tested material.

Table 3. Erichsen test results

Sample	Plate thickness, [mm]	Indentation depth, [mm]
1		
2		
3		
4		
5		
6		

**Conclusions:**

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# Laboratory 12

## *Welding technologies and devices*

Laboratory leader: Ph.D. Bartłomiej Januszewicz

**Objective:** The aim of the laboratory is to familiarize students with the processes of basic welding and devices for their implementation.

### **I. Introduction**

**Welding** is a fabrication process whereby two or more parts are fused together by means of heat, pressure or both forming a join as the parts cool. Welding is usually used on metals and thermoplastics but can also be used on wood. The completed welded joint may be referred to as a weldment. The parts that are joined are known as a parent material. The material added to help form the join is called filler or consumable. The form of these materials may see them referred to as parent plate or pipe, filler wire, consumable electrode Heat is supplied by various means like oxyacetylene gas, electric arc plasma arc or laser [1, 2].

Fusion welding is composed of consumable and nonconsumable electrode arc welding and high-energy-beam welding processes.

The welded joint undergoes important metallurgical and physical changes, which, in turn, have a major effect on the properties and performance of the welded component or structure.

During fusion welding, the molten metal in the weld puddle (pool) is susceptible to oxidation so we must protect weld puddle (arc pool) from the atmosphere. There are some methods for this and they are weld fluxes, inert gases, vacuum [1].

Typical fluxes are  $\text{SiO}_2$ ,  $\text{TiO}_2$ ,  $\text{FeO}$ ,  $\text{MgO}$ ,  $\text{Al}_2\text{O}_3$ . They produce a gaseous shield to prevent contamination, act as scavengers to reduce oxides, add alloying elements to the weld and influence shape of weld bead during solidification.

Inert gases used are argon, helium, nitrogen and carbon dioxide. They form a protective envelope around the weld area and are used in MIG (metal inert gas) TIG (tungsten inert gas) and shield metal arc.

Vacuum produces high-quality welds is used in electron beam welding, for nuclear/special metal applications like Zr, Hf, Ti. It reduces impurities by a factor of 20 versus other methods but is expensive and time-consuming [2].

#### **1. Stick welding – basic ideas**

Arc is generated by touching the tip of a coated electrode against the workpiece and withdrawing it quickly to a distance sufficient to maintain the arc. The heat generated melts a portion of the electrode tip, its coating and the base metal in the immediate arc area. Tiny drops of metal enter the arc stream and are deposited on the parent metal. The molten metal consists of a mixture of the base metal, the electrode metal and substances from the coating on

the electrode. As molten metal is deposited a slag forms over the bead which serves as an insulation against air contaminants during cooling. Figure 12.1 presents the basic ideas of arc shielded welding.

After a weld ‘pass’ is allowed to cool, the oxide layer is removed by a chipping hammer and then cleaned with a wirebrush before the next pass. Best suited for workpiece thicknesses of 3 to 19 mm although this range can be extended easily by skilled operators using multiple-pass techniques.

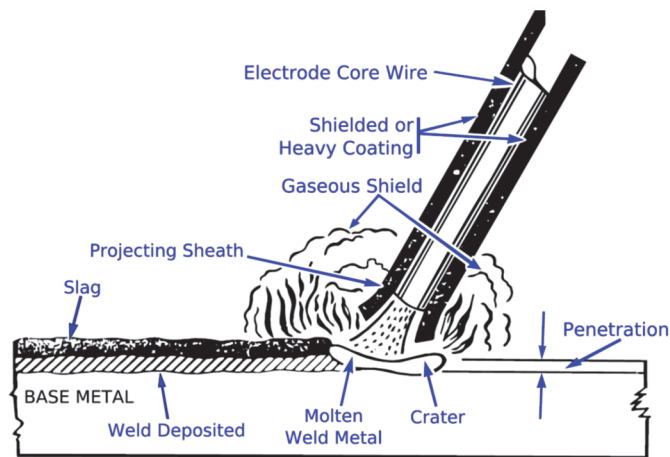


Figure 12.1. Arc shielded welding (stick welding) scheme [3]

## 2. Metal Inert Gas (MIG/ gas metal arc welding -GMAW)

Uses a consumable electrode (filler wire made of the base metal). Inert gas is typically argon (helium, carbon dioxide, or various other gas mixtures ) The consumable bare wire is fed automatically through a nozzle into the weld arc by a wire-feed drive motor. Deoxidizers usually are present in the electrode metal itself in order to prevent oxidation of the molten-weld puddle. Multiple-weld layers can be deposited at the joint Temperatures generated in GMAW are relatively low; this method is suitable only for thin sheets and sections of less than 6 mm; otherwise incomplete fusion may occur. Figure 12.2 presents the process idea of MIG.

The operation, which is easy to perform, is commonly used for welding ferrous metals in thin sections. Pulsed-arc systems are used for thin ferrous and nonferrous metals. The GMAW is used extensively in the metal-fabrication industry. The process is versatile, rapid, and economical and welding productivity is double that of the SMAW process [1, 3].

The GMAW process can be automated easily and lends itself readily to robotics and to flexible manufacturing systems.

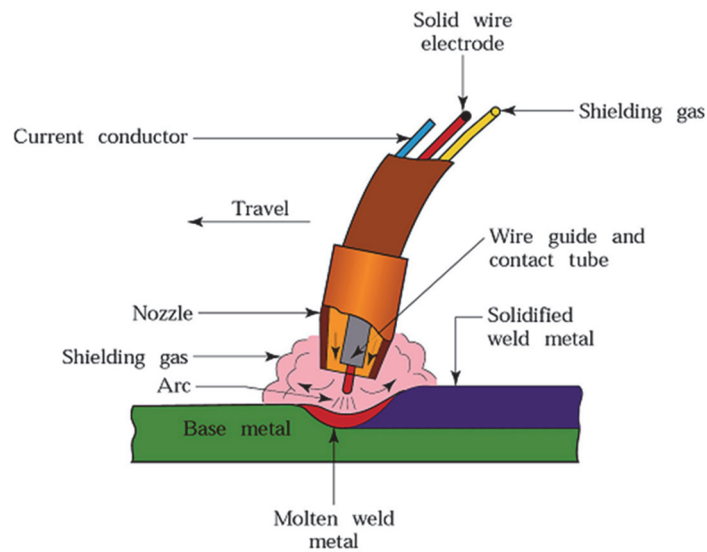


Figure 12.2. Metal Inert Gas (Gas Metal Arc Welding) scheme

### 3. Tungsten Inert Gas TIG (gas tungsten-arc welding GTAW)

Nonconsumable tungsten electrode acts as a cathode. A plasma is produced between the tungsten cathode and the base metal which heats the base metal to its melting point

Filler metal can be added to the weld pool. High temperatures produced cause that externally supplied shielding gas is necessary to prevent oxidation of the weld zone.

Typically DC (at 200A) is used, and its polarity is important (depends on type of electrode, metals to be welded, and depth and width of the weld zone). Straight polarity - the workpiece is positive (anode), and the electrode is negative (cathode). Produces welds that are narrow and deep. Reverse polarity - the workpiece is negative and the electrode is positive. Weld penetration is less, and the weld zone is shallower and wider. AC method (at 500A) causes arc pulsates rapidly. This method is suitable for welding thick sections and for using large-diameter electrodes at maximum currents [1, 3].

In GTAW the filler metal is supplied from a filler wire. The filler metals are similar to the metals to be welded and flux is not used. The shielding gas is usually argon or helium or their mixture. Welding with GTAW may be done without filler metals. AC is preferred for Al and Mg because cleaning action of AC removes oxides and improves weld quality. Thorium or zirconium may be used in the tungsten electrodes to improve their electron emission characteristics. Contact of the electrode with the molten-metal pool should be avoided because it can cause discontinuities in the weld.

TIG is used for metals, particularly aluminum, magnesium, titanium and the refractory metals. It is especially suitable for thin metals.

The cost of the inert gas makes this process more expensive than SMAW but provides welds of very high quality and surface finish. TIG is used in a variety of critical applications with a wide range of workpiece thicknesses and shapes. The equipment is portable. Schematic view of TIG process is presented in Figure 12.3.

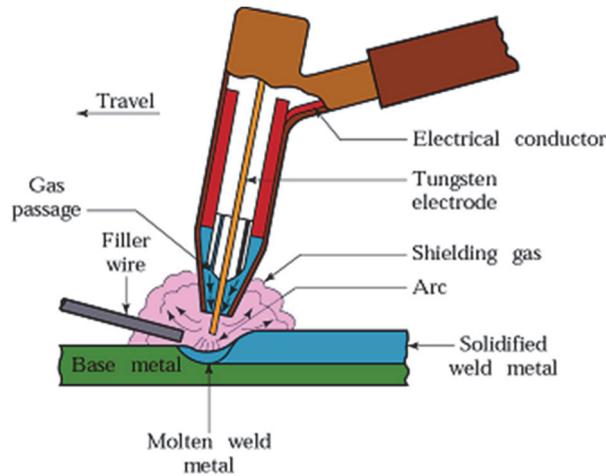


Figure 12.3. Tungsten Inert Gas scheme

#### 4. Thermite welding (Exothermic welding)

Exothermic welding, also known as exothermic bonding, thermite welding (TW), is a welding process that employs molten metal to permanently join the conductors.

The process employs an exothermic reaction of a thermite composition to heat the metal, and requires no external source of heat or current. The chemical reaction that produces the heat is an aluminothermic reaction between aluminum powder and a metal oxide.

In exothermic welding, aluminum dust reduces the oxide of another metal, most commonly iron oxide, because aluminum is highly reactive. Iron(III) oxide is commonly used:



The products are aluminum oxide, free elemental iron, and a large amount of heat. The reactants are commonly powdered and mixed with a binder to keep the material solid and prevent separation.

Commonly the reacting composition is five parts iron oxide red (rust) powder and three parts aluminum powder by weight, ignited at high temperatures. A strongly exothermic (heat-generating) reaction occurs that via reduction and oxidation produces a white hot mass of molten iron and a slag of refractory aluminum oxide. The molten iron is the actual welding material; the aluminum oxide is much less dense than the liquid iron and so floats to the top of the reaction, so the set-up for welding must consider that the actual molten metal is at the bottom of the crucible and covered by floating slag. Figure 12.4 presents real trams being weld by TW method.





*Figure 12.4. Tram tracks being joint by TW [4]*

## **II. The course of the Laboratory**

### **Stick Welding/MIG welding:**

1. acquaintance with the apparatus for SW and MIG welding;
2. preparation and machine set up;
3. welding process observations;
4. performing welds with use of SW and MIG welding machines;
5. performed welds observations.

### **TIG welding:**

1. acquaintance with the apparatus for TIG welding;
2. preparation and machine set up;
3. welding process observations;
4. performed welds observations.

### **Thermite welding:**

1. acquaintance with the elements for process realization;
2. performed welds observations.

## **III. Literature**

- [1] Welding Handbook Ninth Edition Volume 3 WELDING PROCESSES, PART 1; American Welding Society 2007.
- [2] Welding Handbook Ninth Edition Volume 3 WELDING PROCESSES, PART 2; American Welding Society 2007.
- [3] Learn to Weld: Beginning MIG Welding and Metal Fabrication Basics; Stephen Blake Christena; Quarry Books, 2014.
- [4] [https://en.wikipedia.org/wiki/Exothermic\\_welding#/media/File:Tram\\_Tracks\\_being\\_joined.jpg](https://en.wikipedia.org/wiki/Exothermic_welding#/media/File:Tram_Tracks_being_joined.jpg).

# LABORATORY 12 REPORT

## *Welding technologies and devices*

Laboratory leader: Ph.D. Bartłomiej Januszewicz

Date: ..... Grade: .....

Group: .....

**Task 1:** Describe and compare three methods of welding: SW, TIG and MIG.

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**Task 2:** Describe TW process with special emphasis given to special problems indicted during laboratory presentation.

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**Task 3:** Perform economic analyses of chosen two methods i.e compare TIG and SW methods.

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**Conclusions:**

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# Laboratory 13

## *Heat treatment technologies and devices*

Laboratory leader: Ph.D. Bartłomiej Januszewicz

**Objective:** The aim of the laboratory is to familiarize students with the practical realization of heat treatment processes in particular carburizing and nitriding and to familiarize students with process of graphene production.

### I. Introduction

**Heat Treatment** is defined as a controlled operation that involves the heating and cooling of a metal or alloy in the solid state for the purpose of obtaining certain desirable shape of metal. The process of converting the solid metal into desired shape by heating is known as heat treatment process. The properties of a metal depend upon its structure. The purpose of heat treatment is to cause desired changes in the metallurgical structure and thus in the properties of metal parts. Heat treatment can affect the properties of most metals and alloys, but ferrous alloys, principally steels, undergo the most dramatic increases in properties, and therefore structural changes in iron-carbon alloys are considered in this chapter. In general, the most stable steel structures are produced when a steel is heated to the high-temperature austenitic state (to be defined later) and slowly cooled under near-equilibrium conditions. This type of treatment, often referred to as annealing or normalizing, produces a structure that has a low level of residual stresses locked within the part, and the structures can be predicted from an equilibrium diagram. However, the properties that interest heat treaters the most are those exhibiting high strength and hardness, usually accompanied by high levels of residual stresses. These are metastable structures produced by nonequilibrium cooling or quenching from the austenitic state [1].

Within this laboratory topic special emphasis is given to nitriding and carburizing technologies -especially focusing on devices used.

Comparison of basic diffusion surface treatments is presented in Figure 13.1.

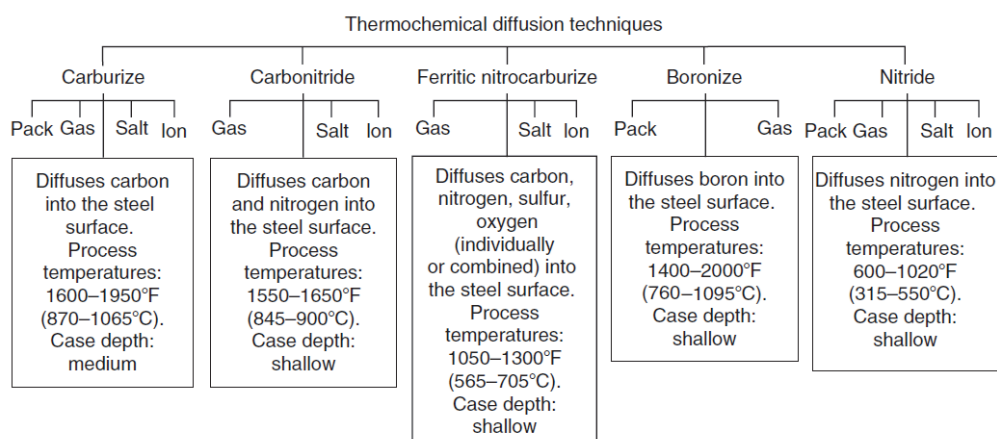


Figure 13.1. Comparison of various diffusion surface hardening techniques [2]

### Case Hardening – Carburizing

Carburizing is a case-hardening process in which carbon is dissolved in the surface layers of a low-carbon steel part at a temperature sufficient to render the steel austenitic, followed by quenching and tempering to form a martensitic microstructure. The resulting gradient in carbon content below the surface of the part causes a gradient in hardness, producing a strong, wear-resistant surface layer on a material, usually low-carbon steel, which is readily fabricated into parts. In gas carburizing, commercially the most important variant of carburizing, the source of carbon is a carbon-rich furnace atmosphere produced either from gaseous hydrocarbons or from vaporized hydro-carbon liquids.

Carburizing produces a hard and compared with their dimensions often shallow surface on relatively soft components when the surface microstructure of steels with a (core) carbon content of usually 0.15–0.25% is carburized to carbon contents in the range of 0.7–0.9 (1.0)% C and transformed to martensite. This treatment leads to the formation of a hardness gradient and to a distribution of residual stresses with compressive stresses in the surface microstructure due to the changes in volume during the martensitic transformation. The combined effect of these two parameters causes the main properties of the components, i.e., fatigue strength, rolling contact fatigue strength, and toughness to reach the highest values possible in one part. Carburizing thus comprises the processing steps carbon diffusion, with the result of a carbon gradient, and quenching with the hardness gradient and the distribution of residual stresses as results, where it is possible to establish equal carbon gradients in differently alloyed steels while the respective hardness gradients can differ because of the alloy dependence of the hardenability. Figure 13.2 presents typical multipurpose installation for low pressure carburizing process [1].



Figure 13.2. VPT furnace [6]

### Nitriding

Nitriding is a heat treatment process in which steel will heating in atmosphere of ammonia gas ( $\text{NH}_3$ ) at the temperature (1|2 – 1|3) carburizing process. At this temperature  $\text{NH}_3$  gas dissociate in nascent nitrogen and hydrogen. After this nitrogen will get diffused into steel in type of nitrides.

The industrial application of nitriding started with studies by Machlet [3] and Fry [4], who introduced the classical gas nitriding in ammonia atmospheres. This gas nitriding process as

recommended by Mach let and Fry is still applied to date as a treatment that causes minimal distortion in components consisting primarily of nitriding steels that have to endure abrasion, rolling fatigue, and fatigue. Depending on the desired nitriding hardness depth, a treatment time of up to 120 h is necessary. Based on studies by Kinzel and Egan, nitriding in cyanide-containing molten salts has subsequently been developed. In this procedure both carbon and nitrogen are introduced into the case, and the process is termed salt bath or liquid nitrocarburizing.

At standard pressure, solid and liquid iron dissolve only a small amount of nitrogen, up to an optimum of 0.005 wt % at 810°C (1490°F) on the transition to austenite, which at this temperature has also its maximum solubility of 0.035 wt% for nitrogen. According to Sieverts, solubility can be improved by increasing the partial pressure of nitrogen.

The main constituent of nitriding atmospheres is ammonia, NH<sub>3</sub>, which on decomposing causes the partial pressures of nitrogen to increase considerably, thus responsible for the formation of different solid phases at equilibrium. In technical application, processing is done mainly in the phase field of alpha-iron, which at 590°C (1094°F) dissolves a maximum of 0.115 wt% nitrogen. The low solubility of nitrogen in a-iron together with the necessity of producing high partial pressures for nitriding has so far made it almost impossible to use nitrogen potentials that lead to a nitrogen absorption only in the alpha-iron. The aim of the generous nitrogen supply is the formation of both nitrides and a microstructure that consists of a compound layer of nitrides and an adjoining diffusion zone. The nitriding atmospheres are at a nonequilibrium in this process, making a quantitative treatment such as in carburizing impossible. In actual practice, a processing characteristic indicating the nitriding power or nitriding potential or sensors are therefore used, allowing to adjust the gas composition to the desired microstructure.

An example of nitriding device is presented in Figure 13.3. Figure 13.4 presents installation for plasma nitriding process realization.

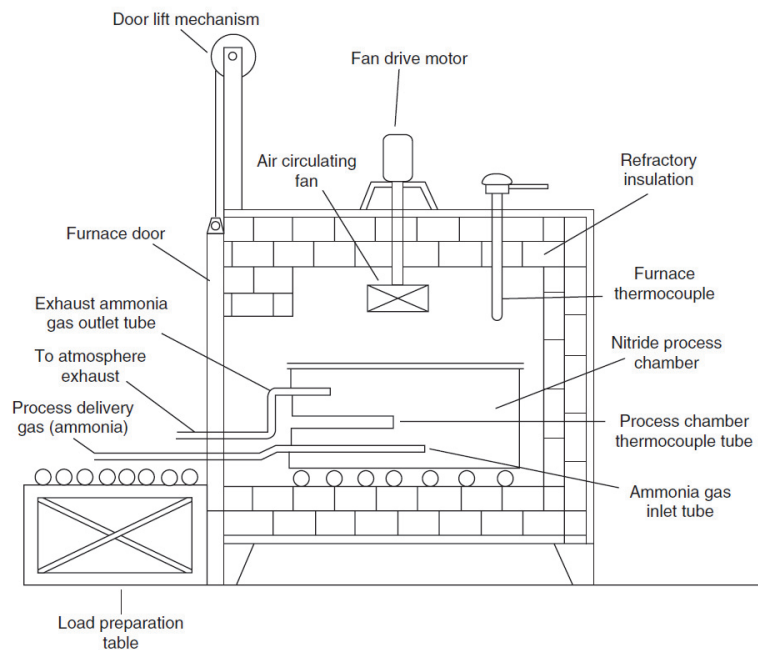


Figure 13.3. Simple ammonia gas nitriding furnace [2]

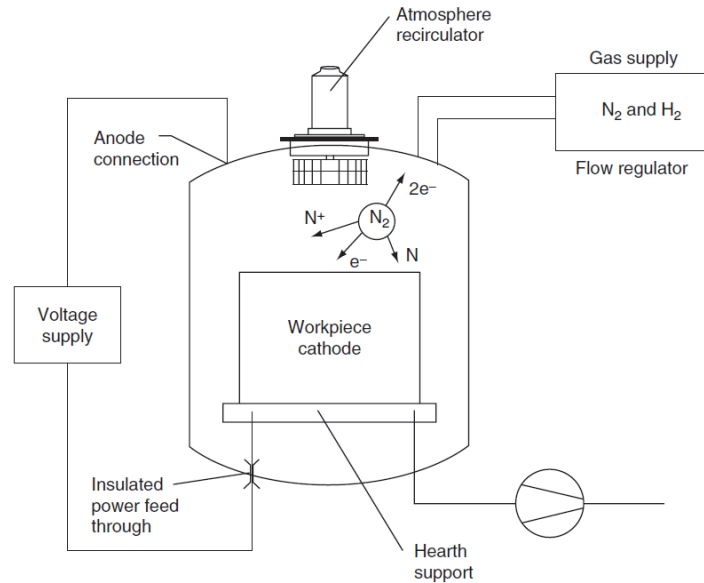


Figure 13.4. Schematic of a typical arrangement of a cold-wall, continuous DC plasma nitriding system [1]

## Graphene

The metallurgical graphene (HSMG®) is a new type of graphene material, characterized by increased durability and fewer defects. The size of a single grain in a layer reaches up to 1 mm. The graphene structure is uniform and continuous, because the growth process minimizes the overlapping effect (common defect on CVD graphene) [5, 7].

As in the case of theoretical graphene, HSMG® also has semiconductor properties. HSMG® is manufactured with a patented metallurgical growth on a liquid metal catalyst. The technology is implemented for mass production and enables the use of graphene on an industrial scale. The maximum length of our graphene sheets reaches up to 1 meter [7].

Graphene can be applied both to improve the properties of already existing products and to create new, innovative technologies. Applications are created in the following industries: construction materials, sensors, touch screens and panels, electronics, composites, space industry, filtration membranes, energy storage, sport equipment [5].

## II. The course of the Laboratory

A visit to the hardening plant. Overview of the construction, principles of operation and control methods of vacuum carburizing equipment (VPT furnace) and low-pressure nitriding (Nitrovac method). Requirements and preparation methods of elements for carburizing and nitriding treatment processes.

Discussion of the method of HSMG graphene production and presentation of the device for its implementation.

### III. Literature

- [1] *Steel Heat Treatment-Metallurgy and Technologies*; Edited by **George E. Totten**; Taylor&Francis Group; 2007.
- [2] **D. Pye** *Practical Nitriding and Ferritic Nitrocarburizing*, ASM International, Cleveland, OH, 2004.
- [3] **A.W. Machlet** U.S. Patent 1, 092, 925, April 14, 1914.
- [4] **A. Fry** *Stahl und Eisen* 23:1271 (1923).
- [5] Lecture materials.
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- [7] <https://advancedgrapheneproducts.com/>



# LABORATORY 13 REPORT

## *Heat treatment technologies and devices*

Laboratory leader: Ph.D. Bartłomiej Januszewicz

Date: .....

Grade: .....

Group: .....

**Task 1:** Describe the construction, principles of operation and control methods of vacuum carburizing equipment. Describe elements preparation. Use pictures taken or sketches made during laboratory.

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**Task 2:** Describe the construction, principles of operation and control methods of low pressure nitriding equipment. Describe elements preparation. Use pictures taken or sketches made during laboratory.

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**Task 3:** Describe the construction, principles of operation and control methods of HSMG production unit. Use pictures taken or sketches made during laboratory.

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**Conclusions:**

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# Laboratory 14

## *Sand casting process*

Laboratory leader: Assoc. Prof. D.Sc. Ph.D. Ryszard Władysiak

**Objective:** The aim of the exercise is to provide students with manufacturing castings with use of sand mould casting process. Students will be acquainted with the process of making a sand mould by hand molding, pouring the mould with Al alloy and analyzing of casting defects.

### I. Introduction

The casting mould is a negative of a casting reproduced by a pattern (a device shaped like a casting) in a moulding mass. To represent the internal shapes of the casting, we use cores, which are separately made parts of the mould.

The sand casting method uses expendable moulds made of moulding sand. Their main component is a solid refractory material called a matrix of mass, in most cases it is silica sand. To obtain the appropriate strength in the moulding mass, we use binding substances called a binder. The most used type of clay is called bentonite. Moisture (water) is an indispensable additive that gives bentonite binding properties. Table 14.1 presents exemplary proportions of components in the moulding sand and its strength.

*Table 14.1. Composition and properties of various moulding sands*

	Sodium bentonite	Fire clay	Calcium bentonite
Silica sand, weight %	95	88	95
Clay bond, weight %	5	12	5
Moisture, weight %	2.5	3.0	2.5
Permeability	110	60	108
Green compression strength, kPa	76.5	63.4	97.2
Dry compression strength, kPa	675.7	468.8	372.3

Examples of a typical sand casting mould are shown in Figure 14.1. This mould consists of two main parts divided into a horizontal parting line.

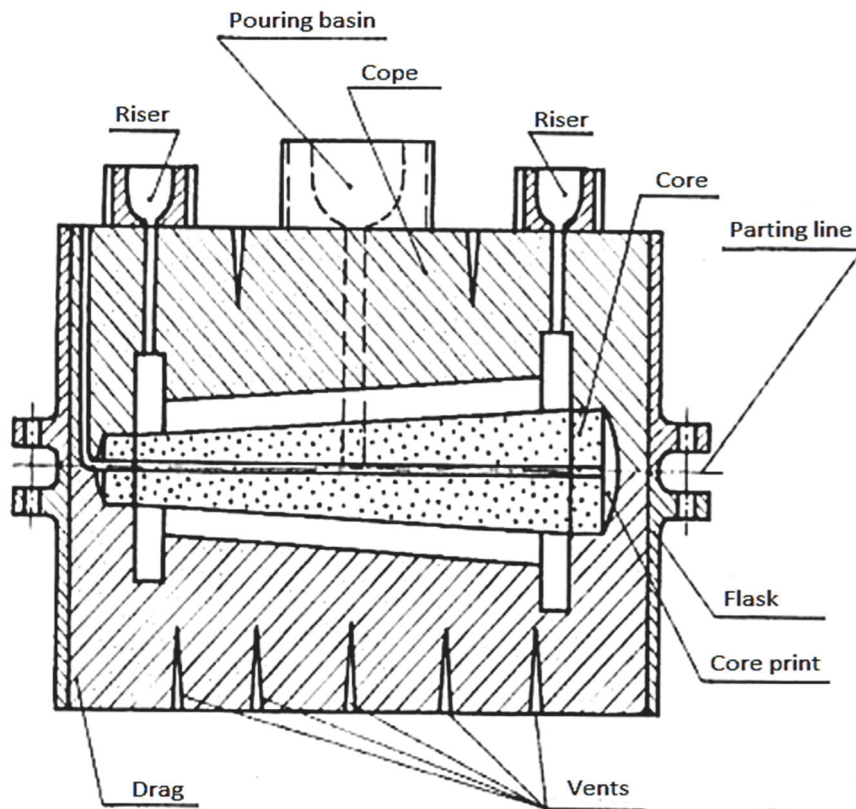
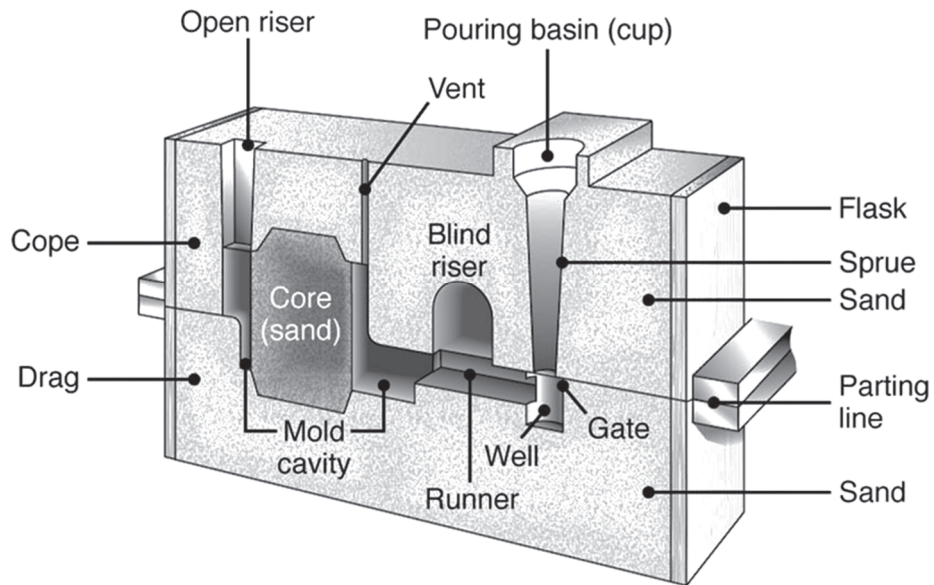


Figure 14.1. Examples of sand mould [10, 11]

The steps of hand moulding process are shown in Table 14.2. The essential parts in the process are: making a drag (the bottom part of the mould), making a cope (the upper part of the mould), removing a pattern, assembly of the core in the mould and finish assembly of mould.

Table 14.2. Operations of hand moulding process

No.	Action (operation)	Action time, min			
		$t_s$	$t_p$	$t_a$	$t_o$
1.	Choose the right set of the complete flask				
2.	Check the tools set				
3.	Check and clean the moulding board				
4.	Check and clean the patterns				
5.	Set the bottom frame of the flask (drag) on the moulding board				
6.	Set the bottom parts of the patterns and ingate pattern inside the drag properly				
7.	Sift the facing sand and press it around the pattern				
8.	Fill the rest of the drag flask to the top with use the backing sand				
9.	Ram the moulding sand in the drag using the moulder's rammer (by layers)				
10.	Strike off the sand excess over the drag using the strike rod				
11.	Punch the vent holes in the drag using a vent wire				
12.	Turn the drag upside down (by 180°)				
13.	Smooth the plane of parting line and lightly press the mould around the				
14.	Remove the scattered greensand from the work place				
15.	Set the cope on the drag				
16.	Set the upper part of the patterns				
17.	Set the cross-runner pattern correctly				
18.	Apply the dry parting to the parting plane				
19.	Remove the dry parting from the patterns				
20.	Sift the facing sand and press it around the patterns				
21.	Set the sprue pattern				
22.	Fill the rest of the cope to the flask top with use the backing sand				
23.	Ram the moulding sand in the cope using the moulder's rammer (by layers)				
24.	Strike off the sand excess over the cope using the strike rod				
25.	Punch the vent holes on external surface of the cope using a vent wire				
26.	Make the pouring basin in the crucible top				
27.	Remove the sprue pattern				
28.	Smooth the edges of the mould after removing the sprue and risers patterns				
29.	Take off the cope from the drag, turn it upside down and put it on the table				
30.	Smooth the parting plane				
31.	Measure the mould hardness at the parting plane				
32.	Remove the patterns from the cope and drag				
33.	Repair any damage of the mould cavities in the drag as well as in the cope				
34.	Blow out the sand from the cope and drag				
35.	Remove the scattered greensand from the work place				
36.	Insert the cores				
37.	Make the core vents				

38.	Assembly the mould				
39.	Place the mould on the casting station				
40.	Load the mould				
41.	Clean and organize the workplace				
<b>S U M</b>					

$t_s$  – setup time (time to prepare and to finish the process);

$t_c$  - cycle time (for making one piece);

$t_a$  – auxiliary time;

$t_p$  – processing time;

$t_o$  – operation time;

$t_b$  – complementary time (time of breaks, time of physiological needs).

$t_c = t_o + t_b$ ;  $t = t_s + n \cdot t_c$ ;  $t_o = t_p + t_a$ .

### Advantages

- This process enables complicated shapes of the casting to be obtained. The liquid material flows into any small sections in the mould cavity. As a result, many other finishing operations such as machining and welding can be minimized.
- It is possible to cast products practically from any ferrous or non-ferrous material.
- Necessary tools needed for casting moulds are very simple and inexpensive. It makes, this is an ideal method for trial production of a small batch.
- This process allows to reduce the weight of the structure, because during casting we put exactly the amount of material into the mould as needed.
- It is the only method that makes it possible to produce specific parts and made of metals and alloys, which can only be processed by this method.
- The size and weight of the product is not a restriction for the casting process.

### Limitations

- The main limitation of this method is the relatively low dimensional accuracy and surface finish of raw castings obtained in the sand casting process.
- The demand for castings with increased dimensional accuracy and surface finish has resulted in the development of many new casting methods such as die casting, investment casting process, vacuum moulding process and shell moulding process.
- The sand casting process is quite labour intensive and therefore requires many improvements such as machine moulding.

## II. Types of defects that can happen in the casting

### 1. Misrun, Incomplete casting

When the molten metal is unable to fill the mould cavity completely or molten metal solidify before filling the mould cavity completely and leave a space in mould called misrun.

### 2. Discontinuities, cracks

Discontinuities are also called as hot crack and hot tears and it is the formation of shrinkage crack during the solidification of weld metal. When metal in liquid condition it is weak and the residual stress or tensile stress in the material causes the casting fails as the liquid metal cools

down. The failure of casting in this case is looks like cracks and it is called as hot tear or hot cracking.

### **3. Blow holes**

It is a kind of cavities defects, which is divided into pinhole and subsurface blowhole. Pinhole is very tiny or small hole and subsurface blowhole only can be seen after machining. When gases entrapped by solidifying metal on the surface of the casting, which result in a rounded or oval blowhole as a cavity. This defects nearly always located in the cope part of the mould in poorly vented pockets and undercuts.

### **4. Sand burning**

Burning on defects also called as sand burning, which include chemical burn –on, and metal penetration. These defects occur to a great extent in the case of thick- walled casting and at high temperature.

### **5. Sand inclusion**

Sand inclusion are also called as scab or blacking scab and it look like small or middle holes with sand grains in the internal or on the surface of casting. This casting defect formed during abrasion of the mold surface by the metal flowing past and the associated thermo-mechanical stresses.

### **6. Mismatch defects**

Mismatch in casting is common defect, when casting does not match at the parting line or improper alignment of upper and lower portion of the casting.

### **7. Flash defect**

Its also known as flashing, fins or burns ,it also defined as when unwanted or excess material is attached to a moulded or cast product.

### **8. Shrinkage defects**

These defects occur when filling material is not available for shrinkage as the metal starts to solidify. Open shrinkage defects are open to the atmosphere and easier to notice, they can be caved surface or pipes that enter the surface of the casting. Closed shrinkage defects are difficult to spot, and they are hidden within the casting and causing structural impurities. These defects usually form at the top of the hot spots of casting.

## **III. Literature**

- [1] Springer Handbook of Mechanical Engineering, 2009. Editors: Grote, Karl-Heinrich, Antonsson, Erik K. (Eds.).
- [2] **J. S. Campbell** *Principles Of Manufacturing Materials And Processes*, Tata McGraw Hill, 1995.
- [3] **J. Campbell** *Complete Casting Handbook*, 2011. Published by Elsevier Ltd.
- [4] **M. Sahoo, S. S. Sahu** *Principles of Metal Casting, Third Edition*, 2014, McGraw-Hill Education: New York.

- [5] Journals: Archives of Foundry Engineering Archives of Metallurgy and Materials, [www.journals.pan.pl](http://www.journals.pan.pl)
- [6] <https://www.sciencedirect.com/topics/materials-science/sand-casting>
- [7] **P. N. Rao** *Manufacturing technology: foundry, forming and welding, 2nd Edition*, 1998, Tata McGraw-Hill.
- [8] <https://www.mechanicalbooster.com/2017/11/casting-defects.html>
- [9] <https://me-mechanicalengineering.com/casting-process-advantages-and-limitations/>
- [10] <http://mechanicalinventions.blogspot.com/2016/02/diferent-parts-of-sand-mold-features.html>
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- [12] **A. Górecki** *Technologia ogólna, podstawy technologii mechanicznej*. Wydawnictwo Szkolne i Pedagogiczne Warszawa 2009.
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# LABORATORY 14 REPORT

## *Sand casting process*

Laboratory leader: Assoc. Prof. D.Sc. Ph.D. Ryszard Władysiak

Date: ..... Grade: .....

Group: .....

**Task 1:** Complete the table of moulding sand composition used in the exercise

*Table 1. Moulding sand composition*

No.	Component	Fraction [%]	Discussion (the purpose of the application)
1.	silica sand		
2.	bentonite (clay)		
3.	coal dust		
4.	water		

**Task 2:** Evaluate the quality of the mould. Pay attention to the edges, drops and crumbles within the mould cavity and the hardness of both parts of the mould.

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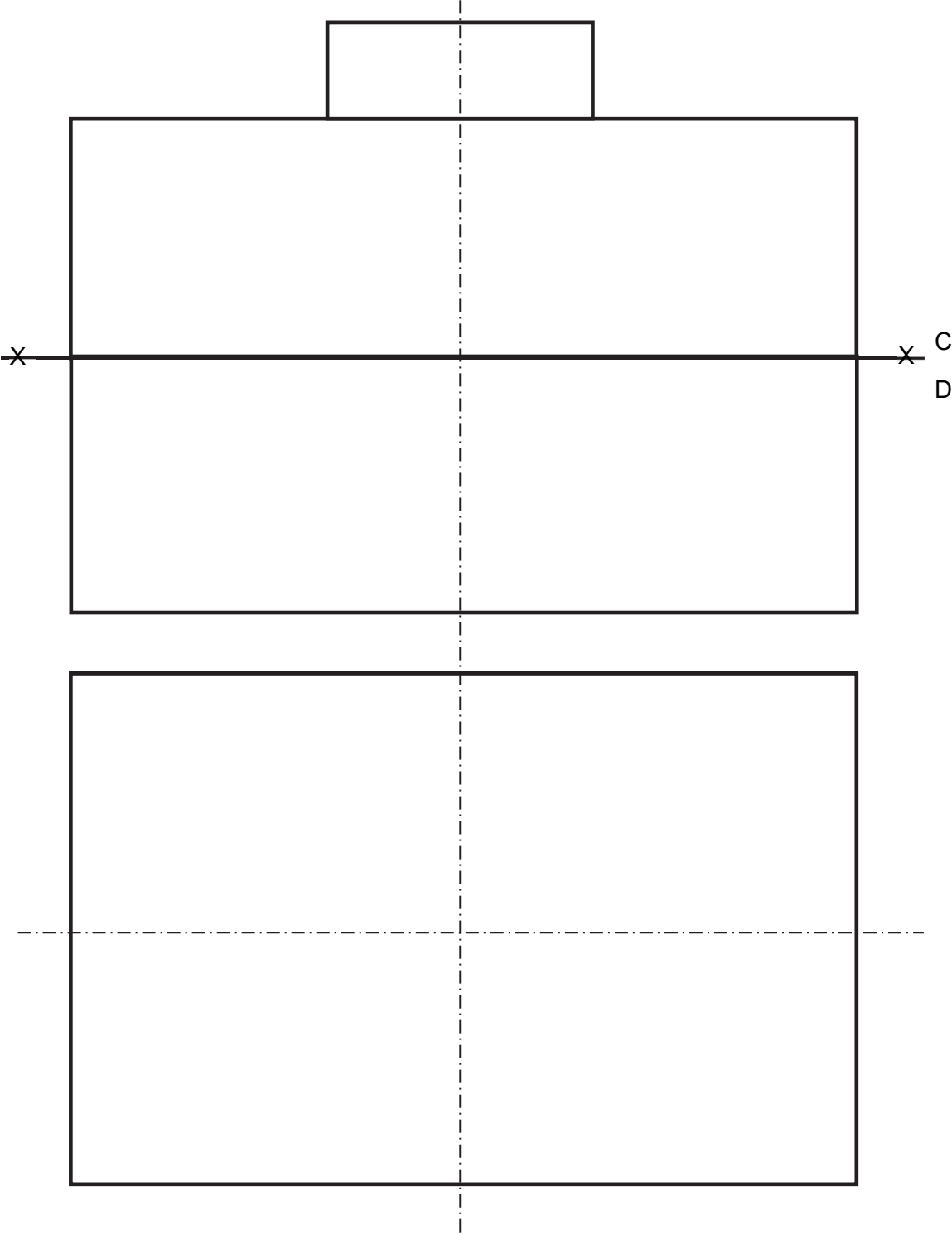
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**Task 3:** Make a sketch of the casting mould.



*Figure 1. Sketch of the casting mould*

**Task 4:** Evaluate the quality of the casting. Pay attention to the roughness of the surface in various places of the casting, mismatch defects, shrinkage defects, flashes etc.

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**Conclusions:** Find the relationships of the materials used, tools, work process to the quality of the casting and possibilities of casting quality improvement.

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# Laboratory 15

## *Permanent mould casting process*

Laboratory leader: Assoc. Prof. D.Sc. Ph.D. Grzegorz Gumienny

**Objective:** The aim of the exercise is to provide students with the process of permanent mould casting, changes in the temperature of the alloy and mould during above mentioned process as well as the measurement of the tensile strength of aluminum alloy castings.

### I. Introduction

Permanent mould casting (otherwise known as gravity die casting) is the process of castings production in metal moulds. In this process, liquid metal fills the mould under the action of gravity without additional pressure. This group of processes also includes low pressure die casting (LPDC), in which metal fills the permanent mould under a pressure not exceeding 0.2 MPa (most often  $0.01 \div 0.05$  MPa).

The permanent mould casting was invented in 1838 and patented in 1849. A combination of tin (Sn) and lead (Pb) was melted and then poured into a steel mould. For the first 30 years, permanent mould casting only served to help create type for printers. Typical permanent mould is presented in Figure 15.1.

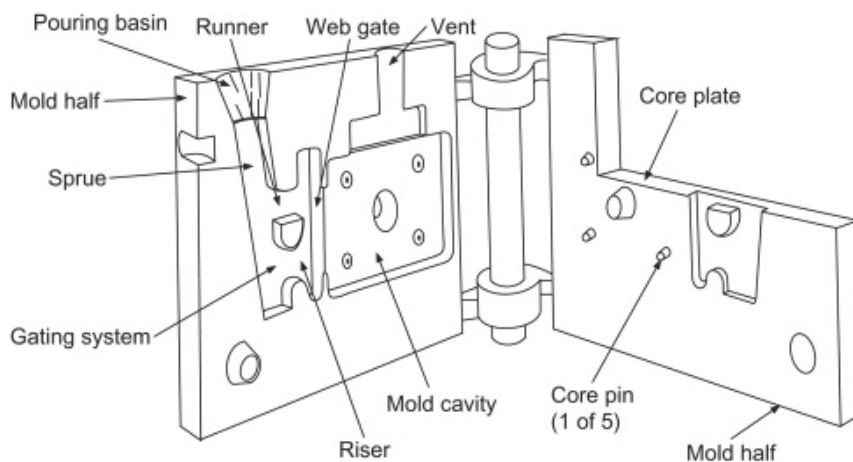


Figure 15.1. Example of a permanent mold for metal casting [1, 2]

The metal mould allows to produce of several hundred to several or even tens of thousands of castings, which is why it is called the permanent mould. Permanent moulds are also used in high pressure die casting (HPDC) as well as in centrifugal casting.

Permanent mould casting is mainly used for non-ferrous metal alloys, mainly aluminum, copper, zinc and magnesium. Permanent mould casting of cast iron, and especially cast steel, is very difficult and much less common.

Low pressure die casting is practically only used for light non-ferrous alloys.

Permanent moulds are made of:

- pearlitic gray cast iron – for castings of non-ferrous metals and small thin-walled cast iron castings;
- alloyed low-silicon gray cast iron containing up to 1 ÷ 2% Cu and low-alloyed nickel-chromium cast iron for casting alloys of non-ferrous metals and iron;
- ductile cast iron for casting mainly medium cast iron and cast steel castings;
- unalloyed cast steel, containing about 0.15 ÷ 0.25% C for casting large iron and steel castings;
- low-alloyed cast steel containing 2.0 ÷ 4.5% Cr; 1.0 ÷ 2.0% Mn and 0.2 ÷ 0.8% Mo used for medium and large castings of aluminum and iron alloys.

The process of permanent mould casting is as follows:

- cleaning the surface of metal mould and cores;
- heating the mould to the temperature of 150 ÷ 200°C;
- application of coating (about 0.05 ÷ 0.2 mm thick) on the surfaces of the cavity mould (e.g. a mixture of water (10-20%, fine-grained refractory materials (graphite, talc, chromium oxide, clay, etc.) and water glass (4 ÷ 5%));
- cleaning the mould cavity with compressed air;
- place core or cores into desired position in the mould cavity;
- assembling the mould parts and opening protection;
- pouring the alloy into the mould;
- shaking out of the metal cores, opening the mould and shaking out the casting.

The most important technological parameters of permanent mould casting are:

- permanent mould temperature;
- pouring temperature;
- casting temperature when it is removed from the permanent mould;
- the duration of the casting cycle.

The casting and mould temperatures change over time, but in the most simplified calculations it is assumed that:

$$t_{c\ av} = \frac{t_{c1} + t_{c2}}{2} \quad (15.1)$$

where:

- $t_{c\ av}$  – average casting temperature in the casting cycle;
- $t_{c1}$  – pouring temperature;
- $t_{c2}$  – casting temperature during shaking out from the mould;

$$t_{m\ av} = \frac{t_{m1} + t_{m2}}{2} \quad (15.2)$$

where:

- $t_{m\ av}$  – average permanent mould temperature in the casting cycle;
- $t_{m1}$  – initial temperature of the permanent mould;
- $t_{m2}$  – permanent mould temperature when the casting is shaking out.

As mentioned, permanent mould casting is very often used for aluminum alloys. The most widely used aluminum alloys in practice contain silicon as the main alloying additive. Therefore, Figure 15.2 shows Al-Si phase diagram.

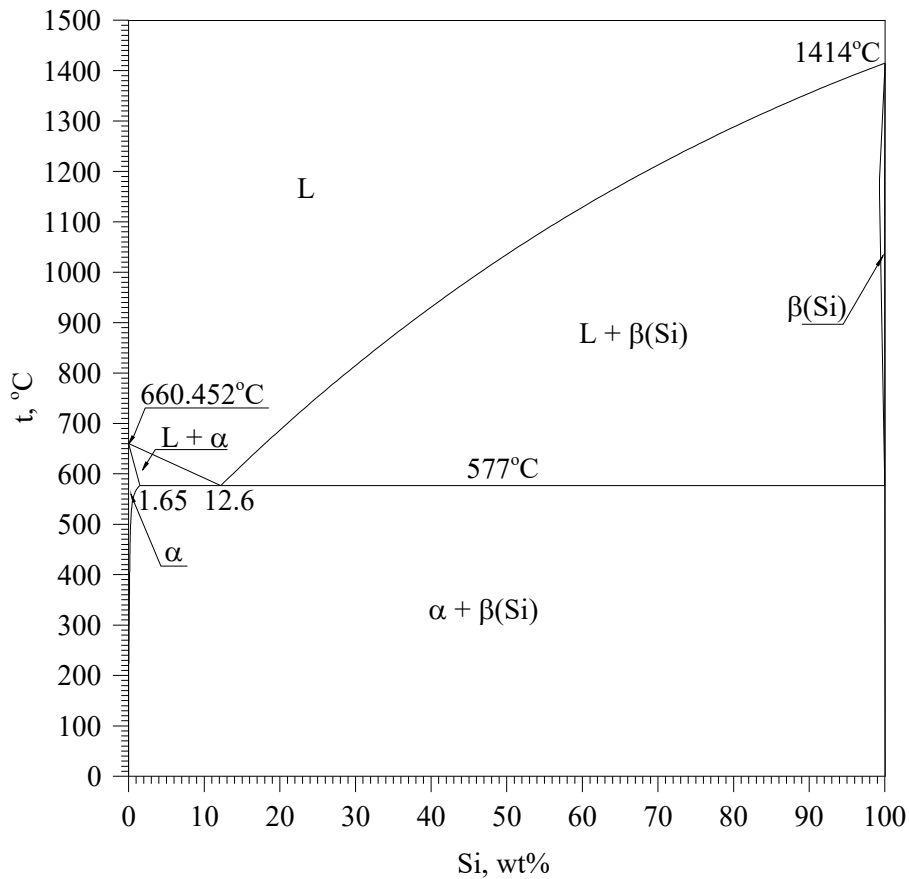


Figure 15.2. Al-Si phase diagram [3]

It is a two-component diagram with an eutectic transformation. Aluminum melts at a temperature of about 660°C. On the left there is a solid solution of silicon in aluminum ( $\alpha$ ). It can dissolve up to 1.65% Si at the temperature of eutectic transformation, i.e. 577°C. As the temperature decreases, the solubility of Si in Al decreases practically to zero. Silicon melts at a temperature much higher than aluminum, at 1414°C. The solubility of aluminum in silicon is negligible and it is assumed that at the eutectic transformation temperature it is 0.17%. Hence, it can be assumed that the solution of Al in Si( $\beta$ ) present on the right is practically pure silicon. On the eutectic transformation line there is an eutectic point at a concentration of 12.6% Si. Alloys for which such a transformation takes place in the process of crystallization and whose chemical composition is to the left of the eutectic point are called **hypoeutectic** and to the right – **hypereutectic**. Let us follow the process of hypoeutectic alloy crystallization.

In Figure 15.3, the vertical blue line shows the chemical composition of the alloy in question.

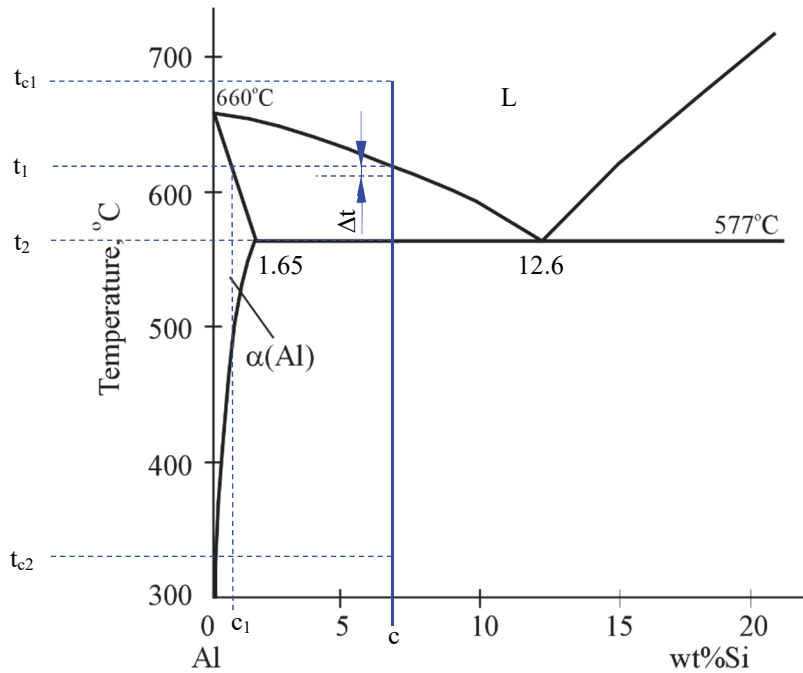
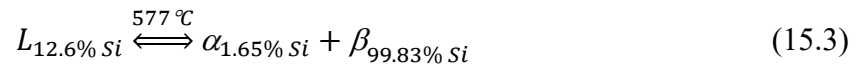


Figure 15.3. Part of the Al-Si phase diagram with the hypo-eutectic alloy crystallization process marked

The alloy with the chemical composition "c" is heated to the temperature  $t_{c1}$ , at which all its components are in the liquid state. Its crystallization starts at the temperature  $t_1$  when  $\alpha$  phase crystals precipitates from the liquid. Its chemical composition at this temperature is " $c_1$ ".  $\alpha$  phase crystallization process takes place in the temperature range  $t_1$ - $t_2$ , while the chemical composition of the  $\alpha$  phase changes from " $c_1$ " to 1.65% Si, and for the liquid from "c" to 12.6% Si. At the temperature  $t_2$  (577°C), the eutectic transformation takes place, which consists in:



When the eutectic transformation is complete, the alloy microstructure consists of  $\alpha$  phase and the mixture of the eutectic  $\alpha$  and  $\beta$  phases, and practically does not change when cooled to ambient temperature.

The crystallization process described above relates to equilibrium conditions, i.e. when the alloy is cooled infinitely slowly. In practice, cooling occurs at a certain speed that depends on many conditions. Therefore, above-mentioned phase transformations take place at a lower temperature than in theory ( $\Delta t$ , Figure 15.3). The difference between the equilibrium temperature of each phase transformation and the real one is called overcooling:

$$\Delta t = t_{theoretical} - t_{real} \quad (15.4)$$

Overcooling is called the driving force of the crystallization process. The greater overcooling, the higher cooling speed. In the permanent mould casting, heat transfer is much faster than in sand casting. Therefore, the overcooling is very high. It has a very significant effect on the alloy microstructure.

Figure 15.4 (a, b) shows a typical Al-Si alloy microstructure from a sand mould (a) and permanent mould (b).

The bright field is the  $\alpha$  phase, while the dark plates – the  $\beta$ (Si) phase, possibly intermetallic phases with other elements (Al-Si alloys usually also include Cu and Mg). The clearly finer microstructure of the alloy from the metal mould is due to the faster crystal nucleation during crystallization process. This principle is explained by Tammann's law, according to which the greater overcooling, the faster nucleation process and, consequently, the finer microstructure. The finer grain in the microstructure, the higher strength properties. It also significantly reduces the brittleness of the alloy.

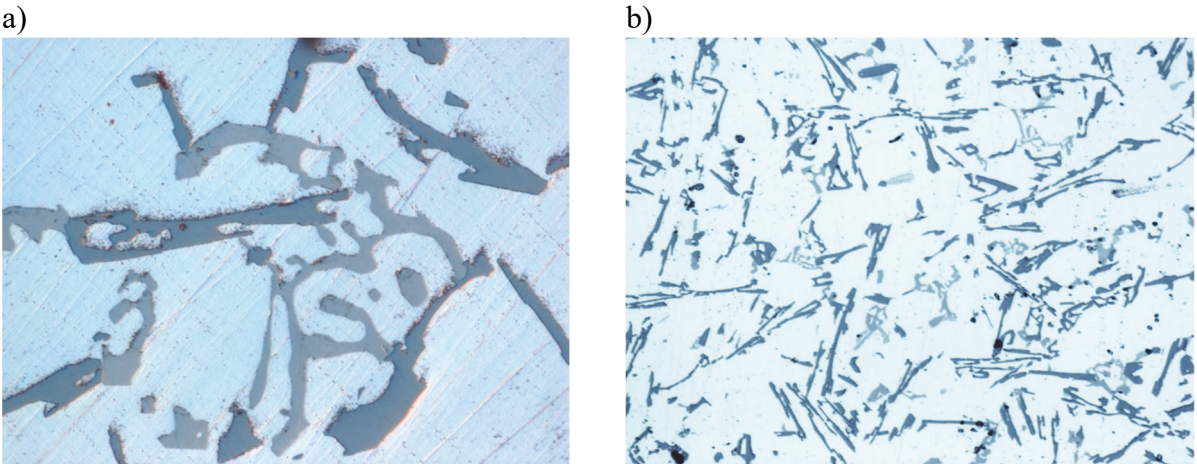


Figure 15.4. The microstructure of Al-Si alloy from the sand mould (a) and the permanent mould (b)

**II. Description of the test stand**

The scheme of the permanent mould casting machine where the exercise is carried out is shown in Figure 15.5.

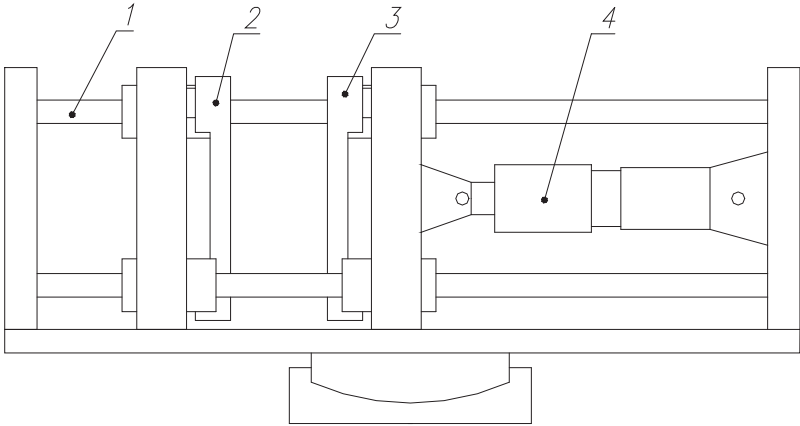


Figure 15.5. The scheme of the permanent mould casting machine: 1 – guides, 2 – immovable part, 3 – movable part, 4 – hydraulic cylinder

A scheme of the permanent mould fixed on the permanent mould casting machine is shown in Figure 15.6. Two castings for the tensile strength test are made inside the mould.



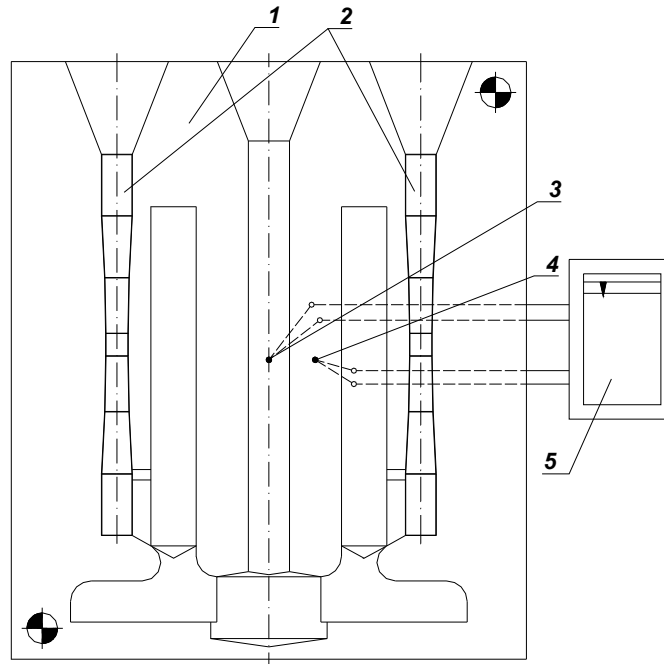


Figure 15.6. The scheme of the permanent mould with thermocouples: 1 – permanent mould, 2 – mould cavities in the shape of a strength specimens, 3 – thermocouple in the main gate for measuring the temperature of the metal, 4 – thermocouple for measuring the temperature of the mould, 5 – recorder

K-type thermocouples (NiCr-Ni) were used. After pouring the mould with Al-Si alloy, the temperature of the alloy as well as the mould is recorded. After solidification, the casting is shaking-out from the mould, the gating system is cut off and then the strength is measured.

### III. Literature

- [1] <https://www.sciencedirect.com/topics/engineering/permanent-mold-casting>, Access: 04.05.2021.
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# LABORATORY 15 REPORT

## *Permanent mould casting process*

Laboratory leader: Assoc. Prof. D.Sc. Ph.D. Grzegorz Gumienny

Date: ..... Grade: .....

Group: .....

**Task 1:** Describe the essence of permanent mould casting process.

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**Task 2:** Evaluate the quality of the casting (pay attention to surface roughness, flashes and shrinkage defects within the shrink bobs).

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**Task 3:** Complete main parameters of gravity die casting.

Data:

- a) pouring temperature  $t_{c1} = \dots\dots\dots \text{ }^\circ\text{C}$
- b) casting temperature during shaking out from the mould  $t_{c2} = \dots\dots\dots \text{ }^\circ\text{C}$
- c) initial temperature of the permanent mould  $t_{m1} = \dots\dots\dots \text{ }^\circ\text{C}$
- d) permanent mould temperature when the casting is shaking out  $t_{m2} = \dots\dots\dots \text{ }^\circ\text{C}$

Average casting temperature in the casting cycle:

$$t_{c \text{ av}} =$$

Average permanent mould temperature in the casting cycle:

$$t_{m \text{ av}} =$$

**Task 4:** Determination of the tensile strength of specimens made in the permanent mould as well as in the sand mould.

a) calculation of the tensile strength

Specimen type		Permanent mould casting		Sand mould casting
		with filter	without filter	
Data	Tensile force P, N			
	Specimen diameter d, mm			
	Specimen cross-section F, mm <sup>2</sup>			
Calculations	Tensile strength R <sub>m</sub> , MPa			
	Elongation A, %			

b) discussion of the difference in strength of the tested specimens (take into account the effect of casting microstructure on its strength, give reasons for different grain sizes in the casting from permanent as well as sand moulds)

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**Conclusions:**

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## Laboratory 16

### *The manufacturing of polymer products with use the screw injection moulding machine*

Laboratory leader: Ph.D. Paweł Just

**Objective:** The aim of the exercise is to provide students with the process of the manufacturing for producing plastic parts with use the screw injection moulding machine.

#### **I. Introduction**

Injection Molding is a manufacturing process for producing plastic parts in large volume. It is most typically used in mass-production processes where the same part is being created thousands or even millions of times in succession. Once the initial costs have been paid the price per unit during injection molded manufacturing is extremely low. The price also tends to drop drastically as more parts are produced. Other advantages include the following:

- injection moulding produces low scrap rates relative to traditional manufacturing processes like CNC machining which cut away substantial percentages of an original plastic block or sheet;
- injection moulding is very repeatable. That is, the second part you produce is going to be practically identical to the first one etc. This is a wonderful characteristic when trying to produce brand consistency and part reliability in high volume production.

#### **II. Polymers used in the injection molding process**

They are two types of plastic materials used in the injection molding process: thermoplastic and thermosetting plastic. Thermoplastics are very different from thermoset materials. They are both used in the injection molding process, but thermosets can only be heated and molded once. They cannot be changed or melted back into their original shape.

This makes them great for high-heat applications, but also makes thermoset plastics less versatile than thermoplastic materials. During the thermoset plastic curing process, polymers are linked together and form a permanent chemical bond. In contrast, no chemical bonding takes place during the curing process of thermoplastics, making it completely reversible. Thermoplastic or thermosoftening plastic, is a plastic material, a polymer that becomes moldable above specific temperature and solidifies upon cooling Thermoplastics can be remelted and remolded whenever its necessary.

The properties and uses of some common thermosoftening plastics are shown in the Table 16.1.

Table 16.1. Thermosoftening plastics material and its properties and principal uses

<b>Name</b>	<b>Properties</b>	<b>Principal uses</b>
Polyamide (Nylon)	Creamy colour, tough, fairly hard, resists wear, self-lubricating, good resistance to chemicals and machines	Bearings, gear wheels, casings for power tools, hinges for small cupboards, curtain rail fittings and clothing
Polymethyl methacrylate (Acrylic)	Stiff, hard but scratches easily, durable, brittle in small sections, good electrical insulator, machines and polishes well	Signs, covers of storage boxes, aircraft canopies and windows, covers for car lights, wash basins and baths
Polypropylene	Light, hard but scratches easily, tough, good resistance to chemicals, resists work fatigue	Medical equipment, laboratory equipment, containers with built-in hinges, 'plastic' seats, string, rope, kitchen equipment
Polystyrene	Light, hard, stiff, transparent, brittle, with good water resistance	Toys, especially model kits, packaging, 'plastic' boxes and containers
Low-density polyethylene (LDPE)	Tough, good resistance to chemicals, flexible, fairly soft, good electrical insulator	Packaging, especially bottles, toys, packaging film and bags
High-density polyethylene (HDPE)	Hard, stiff, able to be sterilised	Plastic bottles, tubing, household equipment

The properties and uses of some common thermosetting plastics are shown in the Table 16.2.

Table 16.2. Thermosetting plastics material and its properties and principal uses

<b>Name</b>	<b>Properties</b>	<b>Principal uses</b>
Epoxy resin	Good electrical insulator, hard, brittle unless reinforced, resists chemicals well	Casting and encapsulation, adhesives, bonding of other materials
Melamine formaldehyde	Stiff, hard, strong, resists some chemicals and stains	Laminates for work surfaces, electrical insulation, tableware
Polyester resin	Laminated, good electrical insulator, resists chemicals well	Casting and encapsulation, bonding of other materials
Urea formaldehyde	Stiff, hard, strong, brittle, good electrical insulator	Electrical fittings, handles and control knobs, adhesives

### III. Plastic injection molding - process characteristics

Injection moulding uses a ram or screw-type plunger to force molten plastic material into a mould cavity; this solidifies into a shape that has conformed to the contour of the mould (Figure 16.1). It is most used to process both thermoplastic and thermosetting polymers, with the volume used of the former being considerably higher. Thermoplastics are prevalent due to characteristics which make them highly suitable for injection moulding, such as the ease with which they may be recycled, their versatility allowing them to be used in a wide variety of applications, and their ability to soften and flow upon heating. Thermoplastics also have an element of safety over thermosets; if a thermosetting polymer is not ejected from the injection barrel in a timely manner, chemical crosslinking may occur causing the screw and check valves to seize and potentially damaging the injection moulding machine.

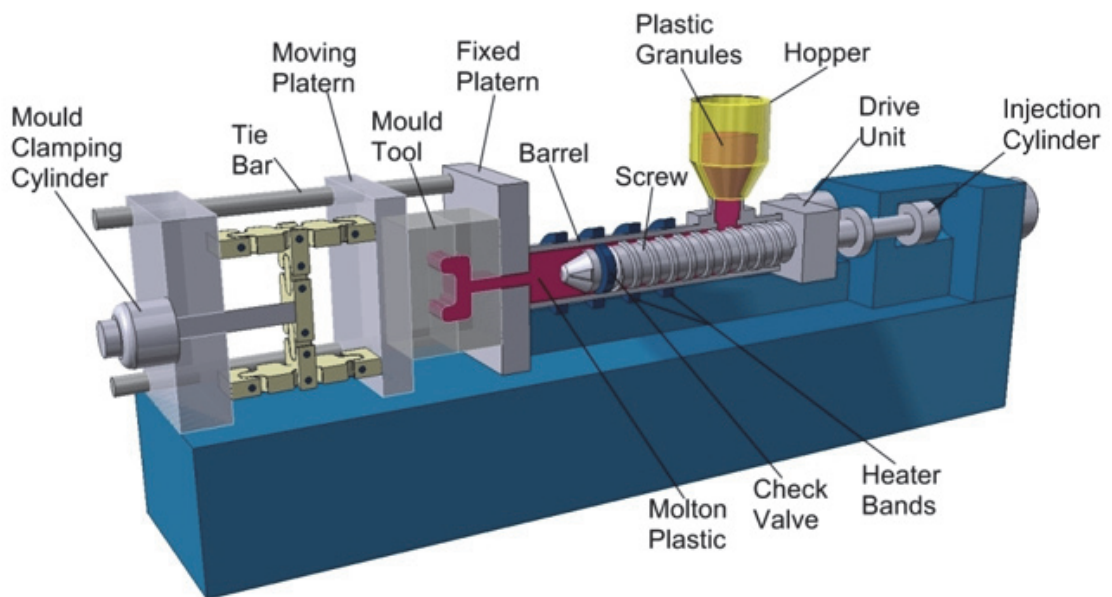


Figure 16.1. The injection molding machine [1]

Injection moulding consists of high pressure injection of the raw material into a mould which shapes the polymer into the desired shape. Moulds can be of a single cavity or multiple cavities (Figure 16.2).

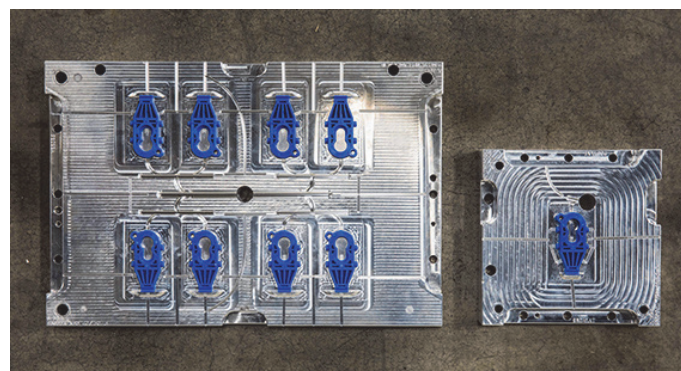


Figure 16.2. Injection mould: multiple and single cavity – view on shaping plate [2]

In multiple cavity moulds, each cavity can be identical and form the same parts or can be unique and form multiple different geometries during a single cycle [3, 4]. Typical moulds has a plate construction. The structure of a injection mold along with the marking of functional plates is shown in the Figure 16.3.

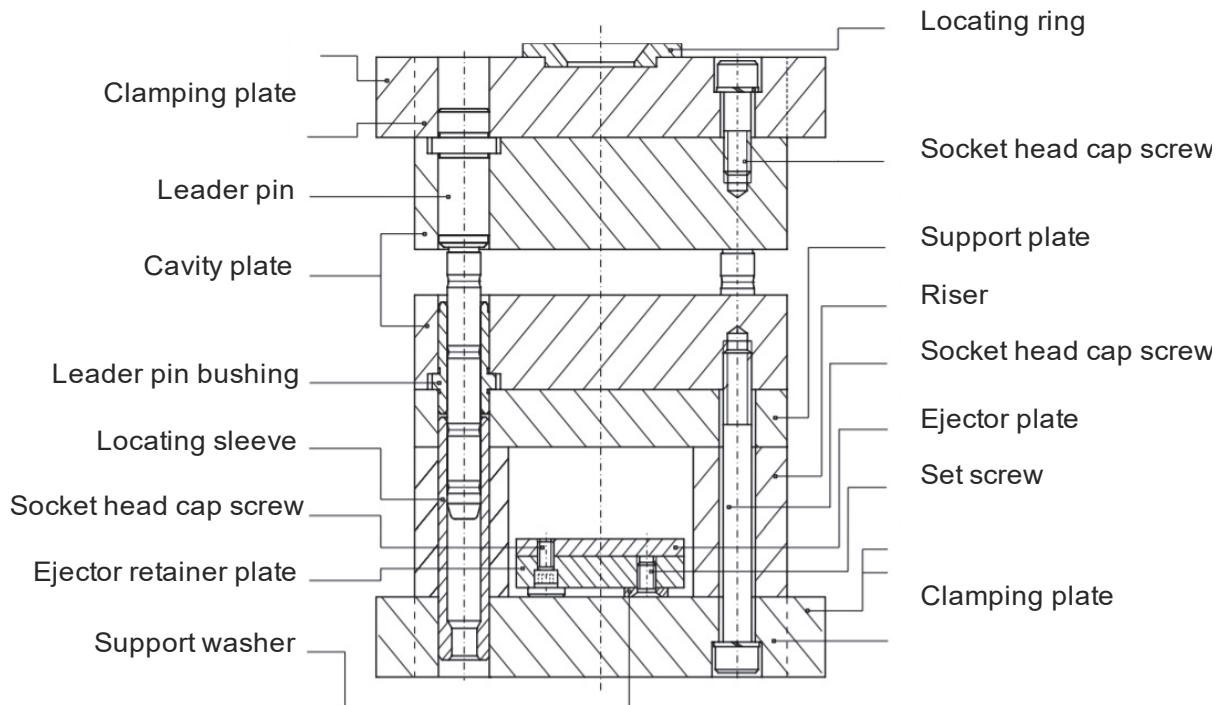


Figure 16.3. Plate construction of the injection mould [4]

Moulds part are generally made from tool steels, but stainless steels and aluminum moulds are suitable for certain applications. Aluminum moulds typically are ill-suited for high volume production or parts with narrow dimensional tolerances, as they have inferior mechanical properties and are more prone to wear, damage, and deformation during the injection and clamping cycles; however, aluminum moulds are cost-effective in low-volume applications, as mould fabrication costs and time are considerably reduced. Many steel moulds are designed to process well over a million parts during their lifetime and can cost hundreds of thousands of dollars to fabricate.

When thermoplastics are moulded, typically pelletized raw material is fed through a hopper into a heated barrel with a reciprocating screw.

Upon entrance to the barrel the temperature increases and the Van der Waals forces that resist relative flow of individual chains are weakened as a result of increased space between molecules at higher thermal energy states. This process reduces its viscosity, which enables the polymer to flow with the driving force of the injection unit. The screw delivers the raw material forward, mixes and homogenizes the thermal and viscous distributions of the polymer, and reduces the required heating time by mechanically shearing the material and adding a significant amount of frictional heating to the polymer. The material feeds forward through a check valve and collects at the front of the screw into a volume known as a shot. A shot is the volume of material that is used to fill the mould cavity, compensate for shrinkage, and provide a cushion (approximately 10% of the total shot volume, which remains in the barrel and prevents the screw from bottoming out) to transfer pressure from the screw to the mould cavity.



When enough material has gathered, the material is forced at high pressure and velocity into the part forming cavity. To prevent spikes in pressure, the process normally uses a transfer position corresponding to a 95–98% full cavity where the screw shifts from a constant velocity to a constant pressure control. Often injection times are well under 1 second. Once the screw reaches the transfer position the packing pressure is applied, which completes mould filling and compensates for thermal shrinkage, which is quite high for thermoplastics relative to many other materials. The packing pressure is applied until the gate (cavity entrance) solidifies. Due to its small size, the gate is normally the first place to solidify through its entire thickness. Once the gate solidifies, no more material can enter the cavity; accordingly, the screw reciprocates and acquires material for the next cycle while the material within the mould cools so that it can be ejected and be dimensionally stable. This cooling duration is dramatically reduced by the use of cooling lines circulating water or oil from an external temperature controller. Once the required temperature has been achieved, the mould opens and an array of pins, sleeves, strippers, etc. are driven forward to demould the article. Then, the mould closes and the process is repeated.

For thermosets, typically two different chemical components are injected into the barrel. These components immediately begin irreversible chemical reactions which eventually crosslinks the material into a single connected network of molecules. As the chemical reaction occurs, the two fluid components permanently transform into a viscoelastic solid. Solidification in the injection barrel and screw can be problematic and have financial repercussions; therefore, minimizing the thermoset curing within the barrel is vital. This typically means that the residence time and temperature of the chemical precursors are minimized in the injection unit. The residence time can be reduced by minimizing the barrel's volume capacity and by maximizing the cycle times. These factors have led to the use of a thermally isolated, cold injection unit that injects the reacting chemicals into a thermally isolated hot mould, which increases the rate of chemical reactions and results in shorter time required to achieve a solidified thermoset component. After the part has solidified, valves close to isolate the injection system and chemical precursors, and the mould opens to eject the moulded parts. Then, the mould closes and the process repeats.

Pre-moulded or machined components can be inserted into the cavity while the mould is open, allowing the material injected in the next cycle to form and solidify around them. This process is known as Insert moulding and allows single parts to contain multiple materials. This process is often used to create plastic parts with protruding metal screws, allowing them to be fastened and unfastened repeatedly. This technique can also be used for In-mould labelling and film lids may also be attached to moulded plastic containers.

A parting line, sprue, gate marks, and ejector pin marks are usually present on the final part. None of these features are typically desired, but are unavoidable due to the nature of the process. Gate marks occur at the gate which joins the melt-delivery channels (sprue and runner) to the part forming cavity. Parting line and ejector pin marks result from minute misalignments, wear, gaseous vents, clearances for adjacent parts in relative motion, and/or dimensional differences of the mating surfaces contacting the injected polymer. Dimensional differences can be attributed to non-uniform, pressure-induced deformation during injection, machining tolerances, and non-uniform thermal expansion and contraction of mould components, which experience rapid cycling during the injection, packing, cooling, and ejection phases of the process. Mould components are often designed with materials of various coefficients of thermal

expansion. These factors cannot be simultaneously accounted for without astronomical increases in the cost of design, fabrication, processing, and quality monitoring. The skillful mould and part designer will position these aesthetic detriments in hidden areas if feasible.

#### IV. The basic production sequence

The cycle sequence of the machine is displayed in symbols (Figure 16.4) Each symbol stands for a certain process in the cycle. The machine cycle starts on the left of the panel with the “Cycle start“ symbol. The order of the symbols corresponds to their order in the machine cycle.

The basic sequence is the most simplest form of machine production sequence. The symbols represent are the minimum set of processes required for a production sequence.

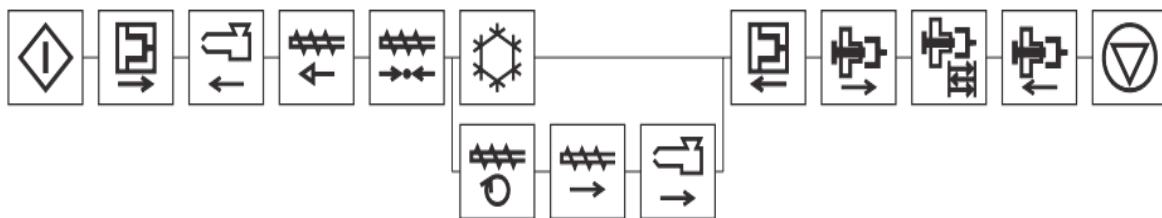


Figure 16.4. The basic sequence of the injection molding machine cycle [5]

Basic sequence the controller offers the following basic cycles which are compiled of the following processes (from the left in Figure 16.4):

1. cycle start;
2. mould closing (delay time, clamping force);
3. nozzle advancement;
4. injection (volume, injection pressure);
5. holding pressure;
6. cooling (passive or active);
7. dosage (simultaneous with cooling);
8. decompression;
9. nozzle retraction;
10. mould opening;
11. ejector advancement;
12. ejector short-strokes;
13. ejector retraction;
14. cycle end.

#### V. Common defects in plastic part

Injection moulding is a complex technology with possible production problems. They can be caused either by defects in the moulds, or more often by the moulding process itself.

Common defects in plastic parts are listed below.

1. **Blistering** – raised or layered zone on surface of the part.  
Causes: tool or material is too hot, often caused by a lack of cooling around the tool or a faulty heater.
2. **Air burn/gas bur/gas marks/blow marks** – black or brown burnt areas on the part located at furthest points from gate or where air is trapped.  
Causes: Tool lacks venting, injection speed is too high.
3. **Colour streaks** – localized change in colour.  
Causes: Master batch is not mixing properly, or the material has run out and it's starting to come through as natural only. Previous coloured material “dragging” in nozzle or check valve.
4. **Delamination** - thin mica like layers formed in walls.  
Causes: Contamination of the material e.g. PP mixed with ABS, very dangerous if the part is being used for a safety critical application as the material has very little strength when delaminated as the materials cannot bond.
5. **Flash** – excess material in thin layer exceeding normal part geometry.  
Causes: Mould is over packed or parting line on the tool is damaged, too much injection speed/material injected, clamping force too low. Can also be caused by dirt and contaminants around tooling surfaces.
6. **Flow marks** – directionally “off tone” wavy lines or patterns.  
Causes: Injection speeds too slow (the plastic has cooled down too much during injection, injection speeds should be set as fast as is appropriate for the process and material used).
7. **Sink marks** – localized depression in thicker zones.  
Causes: Holding time/pressure too low, cooling time too short, with sprueless hot runners this can also be caused by the gate temperature being set too high. Excessive material or walls too thick.
8. **Short Shot** – partial part.  
Causes: Lack of material, injection speed or pressure too low, mould too cold, lack of gas vents.
9. **Void**s – empty space within a part.  
Causes: Lack of holding pressure (holding pressure is used to pack out the part during the holding time). Filling too fast, not allowing the edges of the part to set up. Also mould may be out of registration (when the two halves do not centre properly and part walls are not the same thickness). The provided information is the common understanding, Correction: The Lack of pack (not holding) pressure (pack pressure is used to pack out even though is the part during the holding time). Filling too fast does not cause this condition, as a void is a sink

that did not have a place to happen. In other words, as the part shrinks the resin separated from itself as there was not sufficient resin in the cavity. The void could happen at any area or the part is not limited by the thickness but by the resin flow and thermal conductivity, but it is more likely to happen at thicker areas like ribs or bosses. Additional root causes for voids are un-melt on the melt pool.

**10. Weld line** – discoloured line where two flow fronts meet.

Causes: Mould or material temperatures set too low (the material is cold when they meet, so they don't bond). Time for transition between injection and transfer (to packing and holding) is too early.

**11. Wrapage or twisting** – distorted part.

Causes: Cooling is too short, material is too hot, lack of cooling around the tool, incorrect water temperatures (the parts bow inwards towards the hot side of the tool) Uneven shrinking between areas of the part.

**12. Cracks** – improper fusion of two fluid flow.

Causes: Threadline gap in between part due to improper gate location in complex design parts including excess of holes (multipoint gates to be provided), process optimization, proper air venting.

## VI. Literature

- [1] <https://industrialin.com/sites/default/files/images/Injection-Moulding.jpg>
- [2] <https://www.protolabs.com/media/1011217/multicavity-mold-image-dt.jpg>
- [3] **V. Goodship** *Practical Guide to Injection Moulding Rapra technology limited and ARBURG limited*. Shawbury UK 2004.
- [4] **R. Sikora** *Przetwórstwo tworzyw wielkocząsteczkowych*. Wydawnictwo Edukacyjne Zofii Dobkowskiej, 1993.
- [5] <https://www.proplastica.pl>
- [6] <https://www.arburg.com>
- [7] <https://polymeracademy.com/injection-moulding>

# LABORATORY 16 REPORT

## *The manufacturing of polymer products with use the screw injection moulding machine*

Laboratory leader: Ph.D. Paweł Just

Date: ..... Grade: .....

Group: .....

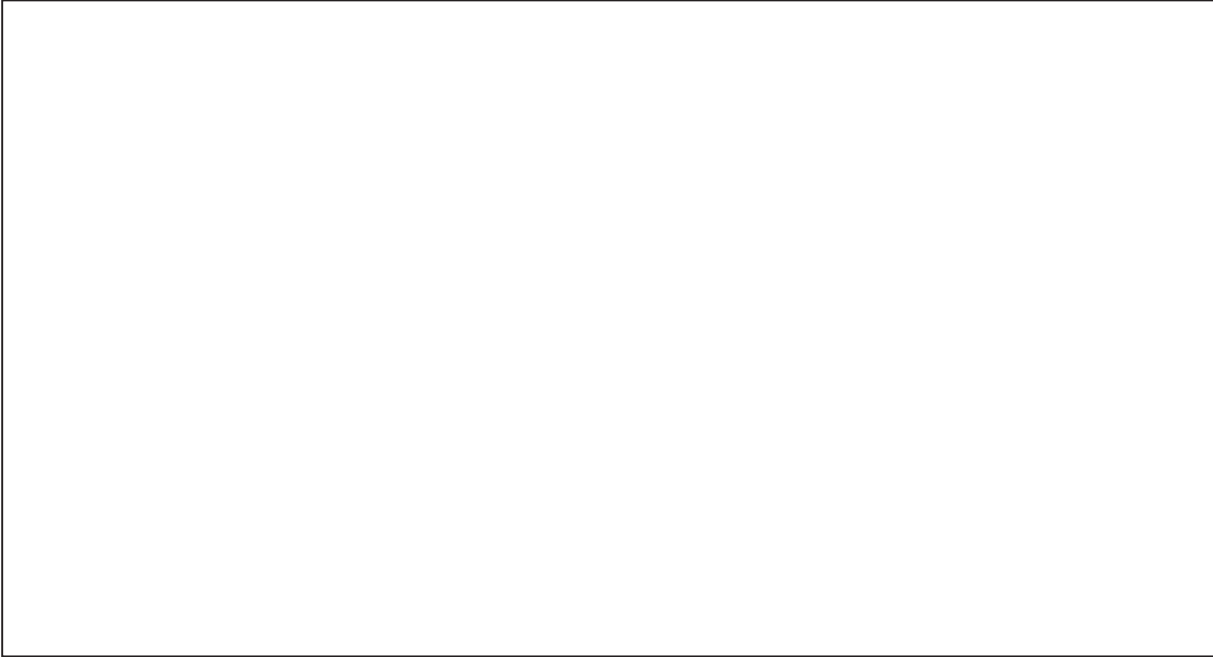
**Task 1:** Describe the injection molding technology (*types of materials, stages of the production process, technological parameters of plastic moulding*).

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**Task 2:** Evaluate the quality rating of the product (*pay attention to surface roughness, flashes and shrinkage defects*).

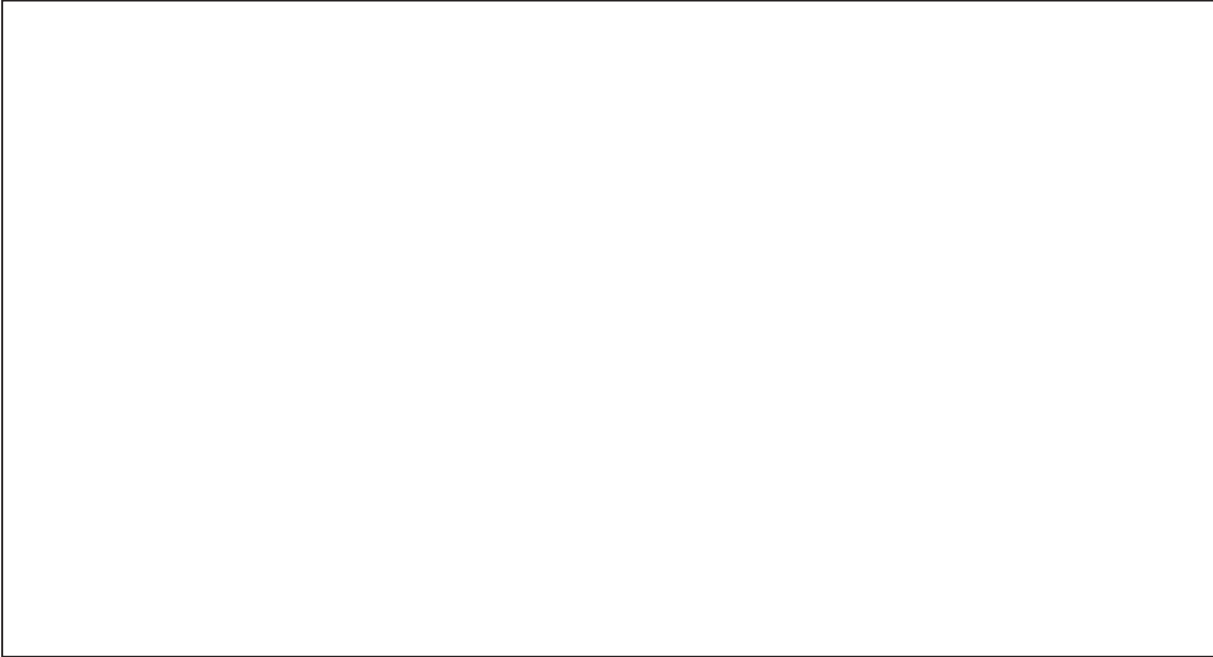
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**Task 3:** Draw and describe the injection molding machine.



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**Task 4:** Draw and describe the construction of the injection mold.



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**Conclusions:**

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ISBN 978-83-66741-39-3



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