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Course Handout

MECHANICAL MANUFACTURING

Intended for: 2nd Year License Students
Mechanical Engineering

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PREFACE

Machining by material removal is one of the processes of mechanical manufacturing. This machining represents the search for solutions that allow obtaining a conceivable part at a cost with good performance, by combining information relating to the chronological order of the operations performed, the use of skilled labor, machine tools, tools and equipment requested. This technique also allows us to produce parts with complex shapes and high precision without modifying the characteristics of the machined material. Material removal machining allows for very precise tolerances, which is crucial in many fields, such as aerospace, automotive and tool manufacturing. This process is applicable to a wide range of materials, including metals, plastics, composites and ceramics, making it a versatile technique for many industries. In addition, this method is also used for the repair or refurbishment of damaged or worn parts, thus extending their service life and avoiding the waste of valuable resources. In summary, material removal machining remains an indispensable pillar in modern manufacturing, combining precision, versatility and cost efficiency. This handout entitled "Mechanical Manufacturing" is intended for second-year students of the Academic License in Mechanical Engineering, Mechanical Construction option. It is designed to highlight knowledge of product manufacturing techniques, in particular mechanical products. It is written in a simplified manner with examples introduced after giving notions so that the student can assimilate the content of the course and have a clear vision of its application in the industrial sector.

This document is divided into two parts, the first part of which concerns the theory of metal cutting from the point of view of cutting materials, geometry of cutting tools, chip formation mechanism, cutting forces, heating and damage of cutting tools as well as the methodology for choosing cutting parameters.

The second part deals with machine tool technology, based on cutting movements, main components and kinematic chains for some machine tools.

PART I

THEORY OF METAL CUTTING

I.1. Introduction

The selection of a cutting material and grade is an important factor in the success of a machining operation. To make a good choice for a given application, it is necessary to have a basic knowledge of the properties of cutting materials and their performance.

I. 2. Definition

Cutting materials are components manufactured and used for cutting tools intended for mechanical machining.

I. 3. Different cutting materials

I. 3. 1. Tungsten steel (high-speed steel)

The invention of high-speed steels was made by the Americans Taylor and Whites in 1903. The basis of high-speed steel (HSS) tools is a low-alloy steel that has undergone heat treatment. Several HSS tools are available and are distinguished by their metallurgical composition. High-speed steels are made from an iron-carbon alloy (at least 0.7%). Tungsten is the first main addition element used (up to 20%) and a few addition elements (cobalt, manganese, chromium, vanadium, molybdenum). The hardness of these steels after quenching varies between (60 HRC to 70HRC) and will be maintained up to 550 ^{0}C. The cutting speeds for this type vary between 25 and 35 m/min for steels. They do not allow a high cutting speed because excessive heating eliminates the quenching of the tool, and therefore creates a rapid collapse of the cutting edge. They are mainly used for the manufacture of single-piece tools (turning tools, drills, milling cutters and reamers). The designations of Ordinary Speed Steel

- High Speed Steel: A.R.S (or HSS in English: High Speed Steel);
- Extra High Speed Steel: A.R.E.S.

The chemical composition of high speed steels is illustrated in Table I.1:

Steel	% C	% W	% C r	% V	% Mo	% Co
OSS	0,7	1,5	4	1,5	0,75	/
HSS	0,8	6,5	4	2	6,5	/
EHSS	0,8	20	5	2	2	10

Table I. 1: Chemical composition of high-speed steels.

I. 3. 2. Metallic carbides

A carbide is a chemical compound of carbon with a second chemical element such as tungsten carbide and titanium carbide, tantalum or niobium.

The carbide tool is the most used currently. It exists in all shapes for each type of material and for each type of machining. It is presented as a plate (figure I.1) that is quickly fixed on a tool holder.

Figure I.1: Carbide inserts intended for turning operations.

The cobalt or nickel used as a binder in the composition of the carbide is produced in the form of a plate using powder metallurgy through a sintering process (a process for manufacturing parts that involves heating a powder without melting it). Under the effect of heat, the grains weld together, which forms the cohesion of the part.

The addition of titanium or niobium carbide increases the high temperature properties (up to 1000°C) by reducing friction, therefore a choice of very high cutting speeds of up to 100 m/min, and this element also gives the tool a longer life than SS or HSS tools. The hardness of carbide tools is around 80 to 90 HRC, which allows very high cutting speeds: 4 times those of high-speed steels. Carbide-based tools can be classified into three categories:

- Tungsten carbide (monocarbide); composed mainly of tungsten carbide grains bonded with cobalt: 8% Co and 92% WC.
- Titanium-tungsten carbide (double carbide): 30% TiC; 4% Co; 66% WC
- Titanium-tantalum-tungsten carbide (triple carbide): 30% TiC and TaC; 12% Co; remainder 58% WC. Monocarbides are effective for machining cast iron and nonferrous alloys compared to double and triple carbides which are effective mainly for machining steels.

I. 3. 3. Ceramics

These are very hard aluminum oxide compounds, silicon nitride, agglomerated in chromium oxides Cr_2O_3 as a binder, sintered at 1800 °C. Ceramics have sufficient compressive strength (up to 5000 N/mm^2), high hardness (89 HRC to 95 HRC), with high thermal stability (1200 °C) and remarkable wear resistance. Ceramic tools are highly refractory (melting point above 1500 °C). They are well suited for high-speed machining and machining of very hard ferrous alloys up to 79 HRC. Ceramics allow a large flow rate of material to be removed but require high machine stability and strict compliance with cutting conditions. Ceramic inserts have several cutting edges for successive use.

Figure I.2 shows two ceramic plates.

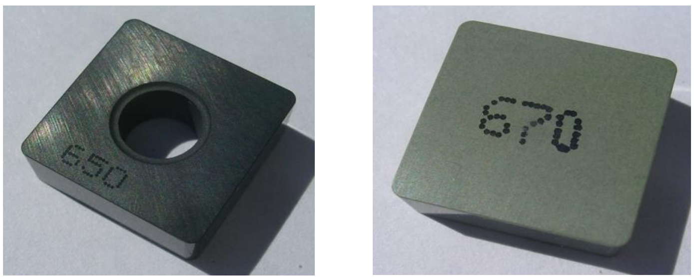


Figure I.2: Ceramic plates**.**

I. 3. 4. Cermets

Cermet is a term formed from: Cer comes from ceramic and met from metal. Cermets are materials produced by powder metallurgy, consisting of particles of hard metal compounds (carbides, nitrides, carbonitrides) bound by a metal (usually nickel). Their hardness is in the order of 1500 to 2000 HV. They do not lose their capacity when hot in high-speed machining or at extreme temperatures up to 1000°C. Cermets do not necessarily require lubrication, they are intended for finishing operations and precision machining that require work at high cutting speeds and low feeds. Their good wear resistance and high toughness allow working with lower cutting forces and give good surface finishes and high dimensional precision of the machined parts.Figure I.3 shows two cermet inserts.

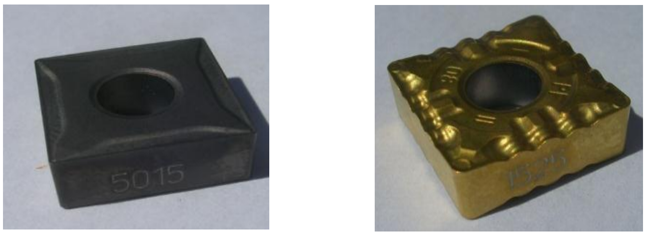


Figure I.3: Cermet plaques.

I. 3. 5. Diamonds

Diamond is a rare mineral, of natural origin, composed of carbon. It is the hardest natural substance known (7000 HV).

It has a low coefficient of friction and a low aptitude for adhesion (bonding, welding to metals). A high resistance to heat, a high resistance to wear.

The use of diamond is widespread as a constituent of grinding wheels, or grains for regrinding grinding wheels and for finishing work. It is very fragile. Its cost is high. It is heat resistant for a temperature of 1500 °C. It requires fast machine tools. The main mechanical properties toughness (toughness is the ability of a material to resist the propagation of a crack) and hardness for cutting tools are shown in Figure I. 4.

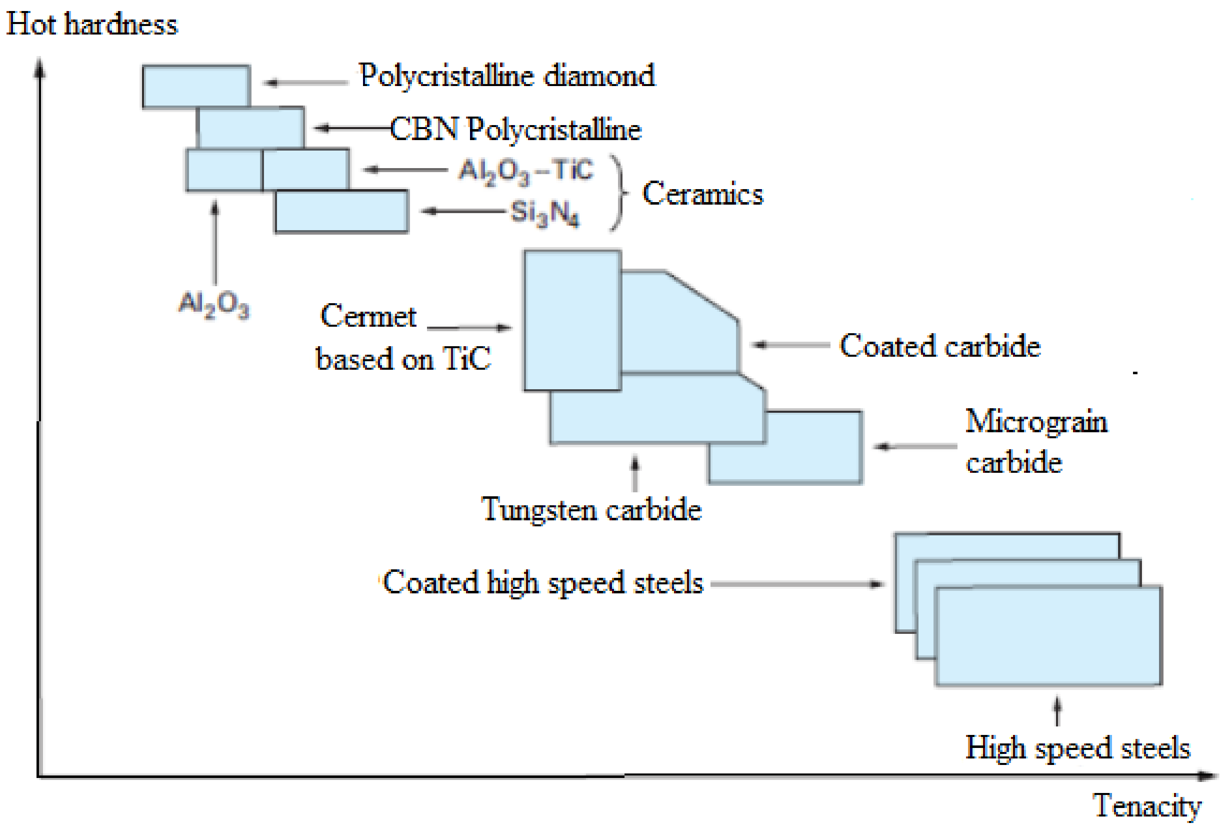


Figure I. 4: Hardness and toughness of cutting materials.

I. 3. 6. Choosing the cutting tool material

The material of the active part of the cutting tools must have certain properties, such as: Good resistance: To friction, wear, impact, penetration, high temperature (e.g. hot hardness), low adhesion and high chemical stability towards the machined material (air, cutting fluid) as well as availability and economical purchase price.

I. 3. 7. Coating of tools

High-speed steel or hard metal tools are often coated with various layers to improve their tool life, enabling higher machining speeds and better surface finish. Common coating types include titanium nitride (TiN), titanium carbonitride (TiCN), aluminum oxide (Al_2O_3) and silicon nitride (Si_3N_4), which belong to the class of ceramics and can be combined with other materials such as zirconium oxide (ZrO_2), titanium carbide (TiC) or silicon carbide (SiC). Diamond is used for machining non-ferrous metals and abrasive materials such as carbon or ceramics, while boron nitride is used for machining hardened ferrous metals.

I. 4. Cutting tool geometry

I. 4. 1. General

A cutting tool consists of a tool body with one or more active parts.

Each tooth of multi-edged tools (milling cutters, drills, etc.) behaves like an elementary tool whose reference model is the prismatic turning tool. The study of the active part of all cutting tools involves that of the prismatic turning tool.

The cutting insert is the active part in a machining operation. Cutting tools are characterized by their materials and by different geometric parameters. The geometry of the tools is studied to ensure easy chip formation, provide a robust cutting edge and fragment the chips into elements of an acceptable length.

I. 4. 2. Elements of a cutting tool

Generally, a cutting tool can be characterized by an edge geometry and an orientation in space defined by standardized cutting angles. In a cutting tool we find the following elements (figure I.5).

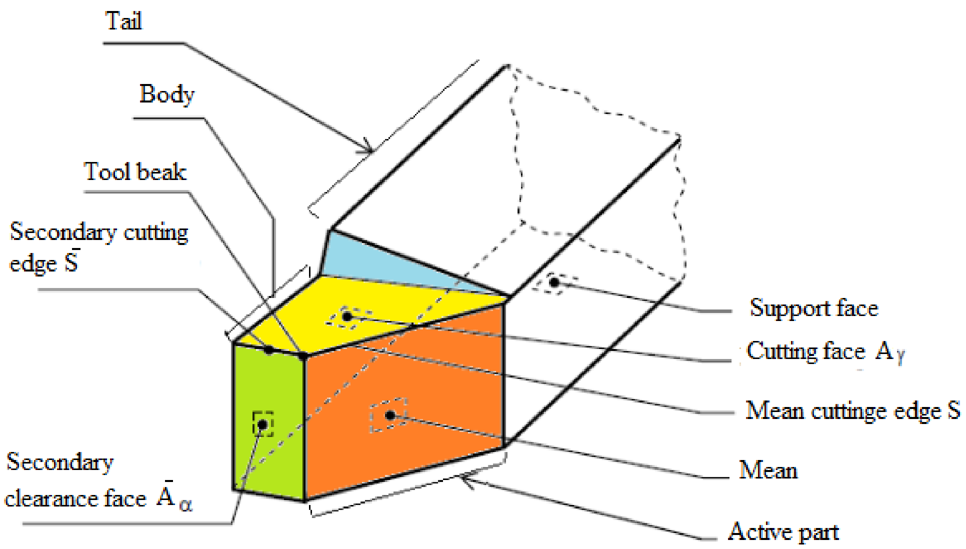


Figure I. 5: Elements of a cutting tool.

I. 4. 2. 1. Tail

Part of the tool that is used to fix it and position it on the machine. For milling cutters and drills, the "shank" is the element that allows the connection of the tool with the tool holder. The shank is cylindrical or conical (Morse taper CM or American standard SA).

I. 4. 2. 2. Tool body

Part of the tool carrying the cutting elements or inserts (sometimes the cutting edges can be cut directly into the body.

I. 4. 2. 3. Active part

This is the part that directly intervenes in the cutting operation. It is composed of the cutting face, the flank faces and the cutting stops. It is characterized by its shape and its material. The hardness of the active part must be greater than that of the metal to be machined.

I. 4. 2. 4. Cutting face A_γ and main clearance faces Aα and secondary A'_α

The rake face is the surface on which the chip slides during cutting, while the main clearance faces Aα and secondary A'_α are the faces in front of which the surface which has just been machined passes (figure I.6).

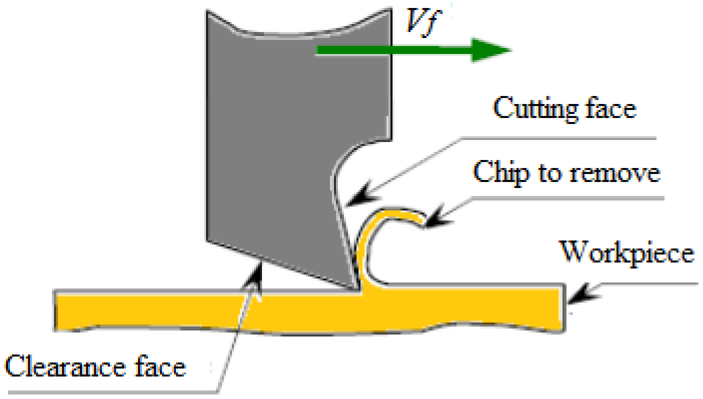


Figure I. 6: Main cutting face and clearance faces.

I. 4. 2. 5. Main cutting edge S

Major cutting edge is the intersection between the cutting face A_γ and the main clearance face Aα, intended for the removal of material.

I. 4. 2. 6. Secondary cutting edge S'

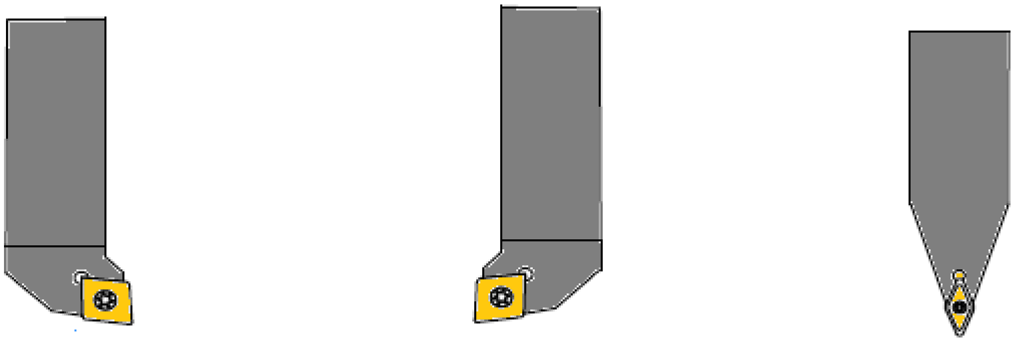
Intersection between the cutting face A_γ and the secondary clearance face A'_α.

I. 4. 2. 7. Tool beak r_ε : Junction of the main S and secondary edges S'

I. 4. 2. 8. Tool direction

The direction of the tool is defined by the position of the cutting edge (S). Considering the tool held vertically and the beak at the bottom:

- the tool is said to be right-handed if its cutting edge is oriented to the right (figure I.7a).
- the tool is said to be left-handed if its cutting edge is oriented to the left (figure I.7b).
- If the active part of the tool is symmetrical with respect to the axis of the tool, the latter works indifferently to the right and to the left, the tool is neutral (figure I.7c).



(a) (b) (c)

Figure I.7: (a) Straight carbide insert tool R; (b) Left carbide insert tool L; (c) Neutral carbide insert tool.

I. 4. 3. Identifying the tool plans

To be to study the characteristics of the tool, it is necessary to represent and define the tool planes (Figure I.8).

1) P_b : base plane, tool support surface.
2) M : cutting edge point.

V : Vector shows the cutting direction.

f : Vector represents the direction of feed.

3) Pr : reference plane, parallel to Pb and containing M and f.
4) Pf : conventional work plan, perpendicular to Pr and containing M, V and f.
5) Ps : tool edge plane, perpendicular to Pr and tangent to the cutting edge at M.

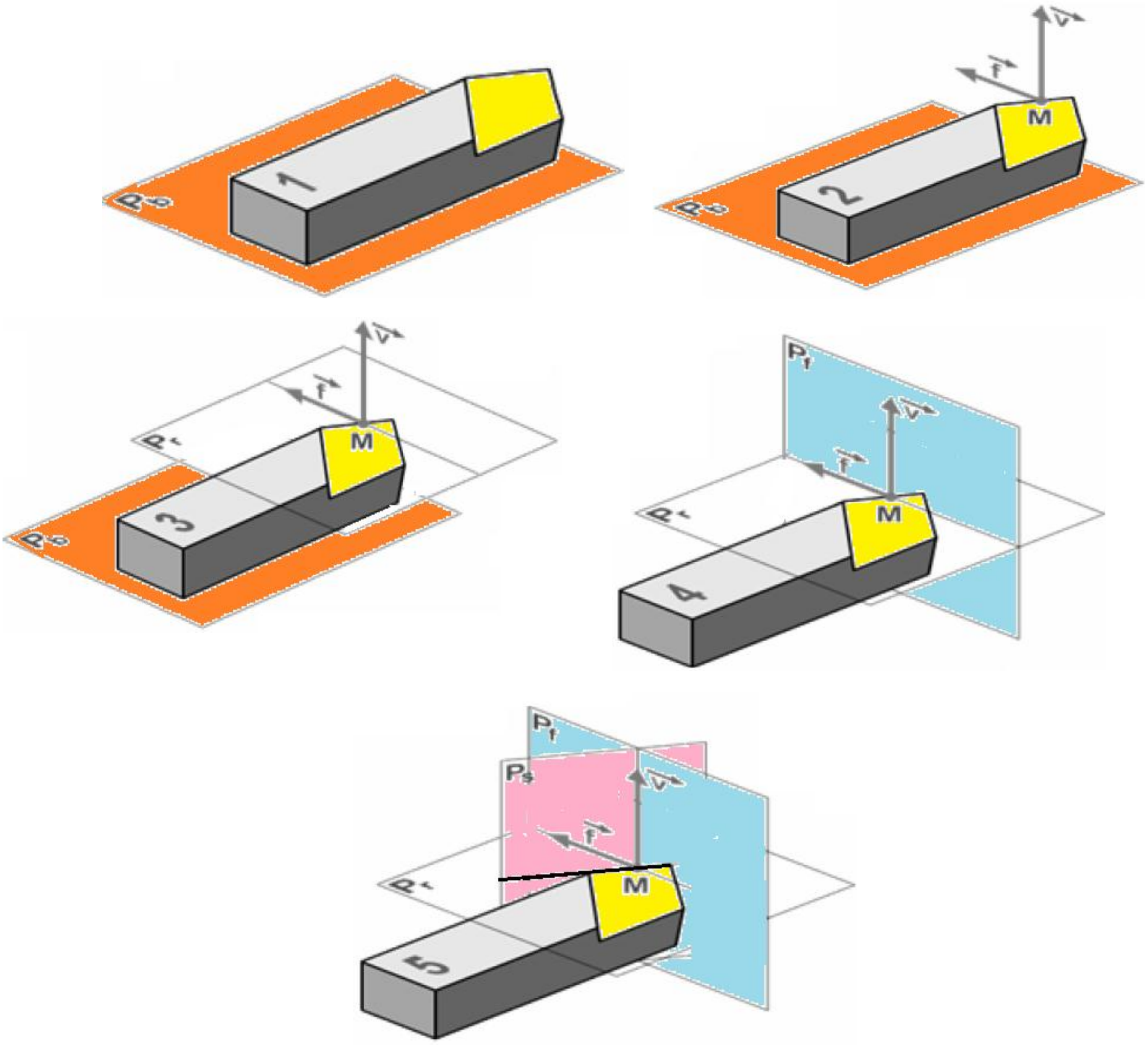


Figure I. 8: Tool plans.

I. 4. 4. Main plans of the active part of the tool

Figure I. 9 shows the different planes of the active part of the tool.

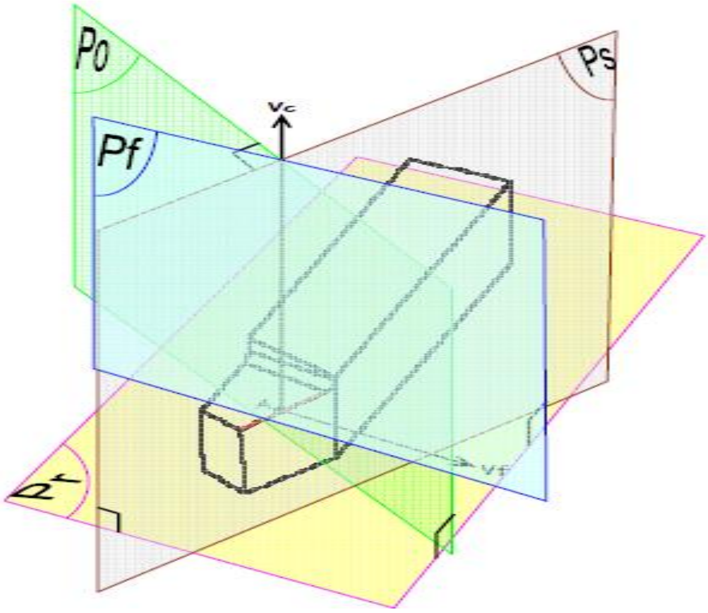


Figure I. 9: Plans of the active part of the tool.

I. 4. 5. Characteristic angles of the cutting tool

I. 4. 5. 1. Tool edge angles

- Edge tilt angle λ_S

Acute angle between Pr and the tangent to the edge, at point A. It can be positive or negative (figure I.10).

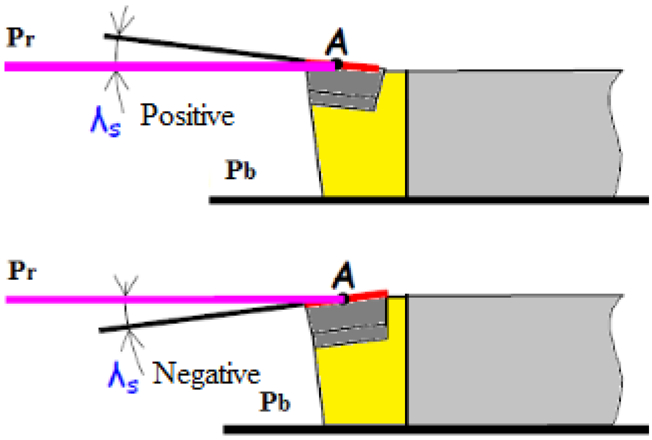


Figure I. 10: Tool edge angles.

- Edge direction angle *Kr*

Between Pf et Ps.

- Point angle *εr*

Between the main cutting edge S and the secondary cutting edge S'.

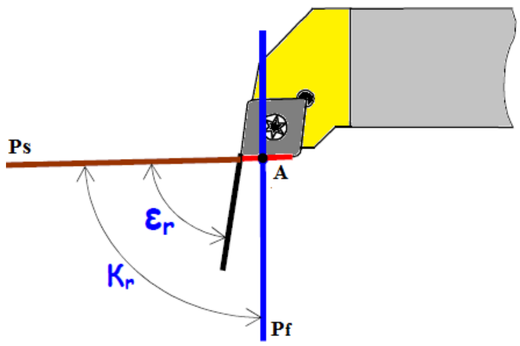


Figure I. 11: Edge and tip direction angles.

I. 4. 5. 2. Tool face angles

These angles are shown schematically in the figure I. 12.

- Orthogonal clearance angle α_o

Between Ps and Aα.

- Orthogonal cutting angle β_o

Between Aα et Aγ

- Orthogonal cutting angle γ_o

Between Pr et Aγ.

$\alpha_o + \beta o + \gamma_o = 90°$

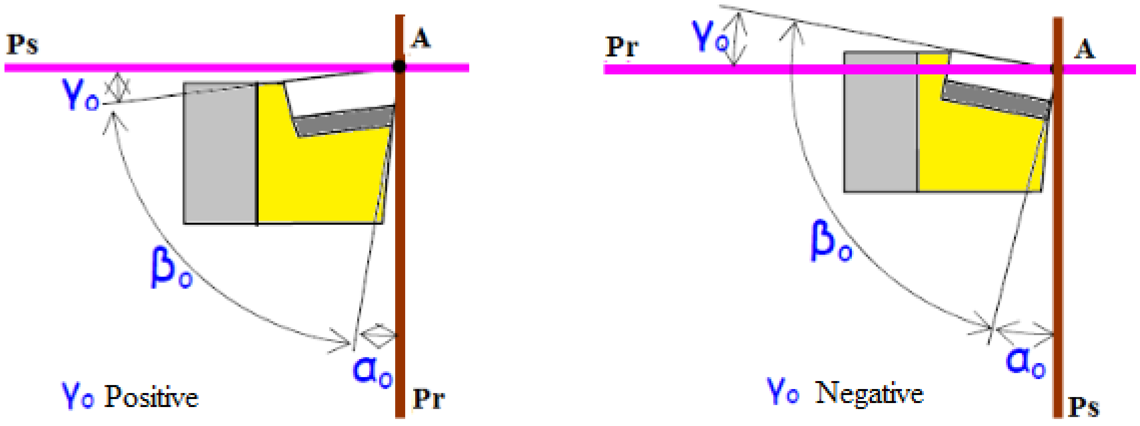


Figure I. 12: Tool Face Angles.

Figure I.13 shows the face angles for a working tool.

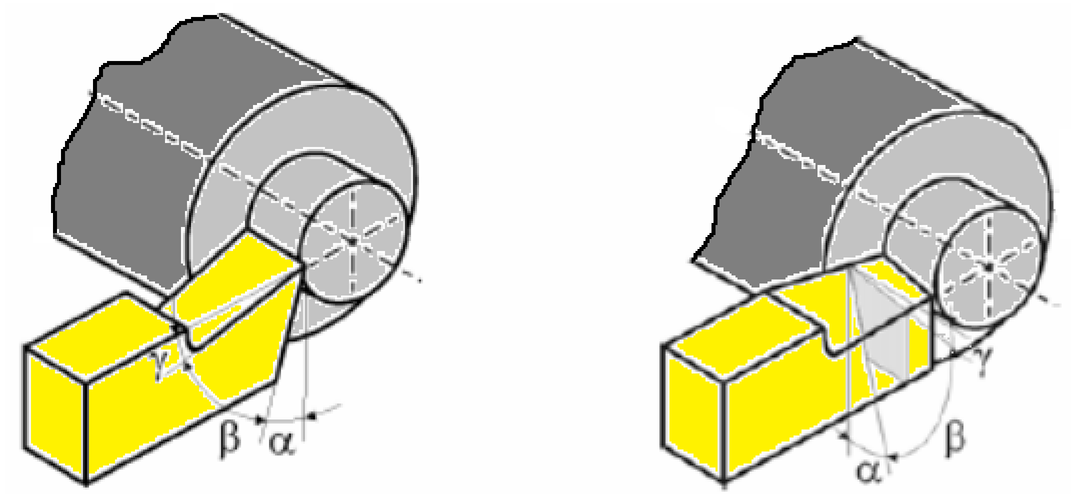


Figure I.13: Face angles for a working tool.

I. 5. Chip formation mechanism

I. 5. 1. Introduction

The machining operation is observed by the production of chips. The excess material to be removed is the layer that will form the chip under the complex mechanical action of a cutting tool.

I. 5. 2. Chip formation

The chip is formed by plastic deformation under complex mechanical actions. A chip is a small piece of material created following machine tool machining of a material such as wood, metal, plastic, etc.

The analysis and understanding of the chip formation process is necessary for the improvement and development of machine tools and cutting means. The accumulation of material in front of the tool generates action forces from the tool and reaction forces from the workpiece, until the material is removed.

- Whatever the material machined, the chip produced responds to the same characteristics which correspond to the three movements influencing the dimensions of the chip (figure I.14):

• Cutting movement: expressed in meters per minute (m/min), it corresponds to the developed length of the chip,

• Penetration movement: or depth of pass, expressed in mm, it corresponds to the width of the chip and influences the adjustment of the dimension of the part,

• Feed movement: expressed in millimeters per revolution, per stroke or per tooth; it corresponds to the thickness of the chip.

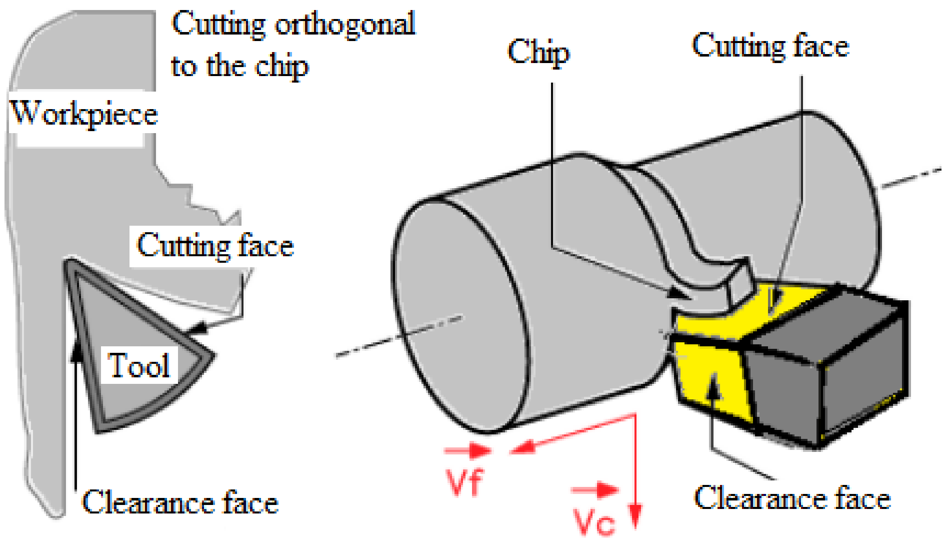


Figure I.14: Movements influencing chip dimensions.

I. 5. 3. Chip formation zones

Several studies have shown that when a part is machined close to the cutting edge, it presents very distinct stress zones. These zones are identified through the mechanical interaction of materials (thermomechanical analysis) and the cutting process (tribological analysis). By performing an orthogonal cut, four main zones are observed (Figure I.15).

Area 1: Is called the metal separation zone by the cutting edge at point (O). Given the significant compression forces, this results in temperature increases of around 600°C.

Area 2: Chip formation zone where we observe a sudden change in orientation and flow speed of the material (primary shear) with a significant heat flow transmitted to the tool.

Area 3: Sliding zone at the chip/cutting face interface (secondary shear). An adhesion phenomenon considerably slows down the flow of the material causing plastic shear of the material. The chip/cutting face friction is intense enough to generate heat of around 750°C.

Area 4 : This zone is located at the clearance face/machined surface interface, where sliding friction is observed, giving rise to adhesion phenomena leading to plastic shear.

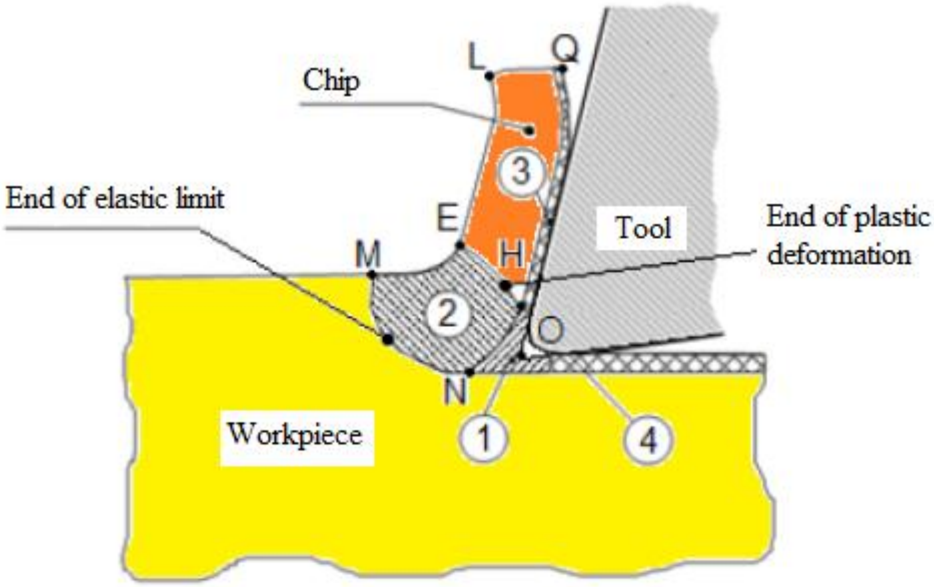


Figure I. 15: Chip formation areas.

I. 5. 4. Main factors influencing chip formation

Are: Cutting speed, feed rate, depth of cut, lubrication, tool geometry and tool and workpiece materials.

I. 5. 5. Different shapes of chips

Chips can be classified into two distinct types:

- Continuous: The continuous chipping occurs in cutting ductile metals.

- Discontinuous: Observed for cutting hard materials and another ductile type fracture mode is observed for less hard materials but at higher cutting speeds.

There are also other intermediate chips between a continuous chip and a discontinuous chip and other geometries. (Figure 1.16).

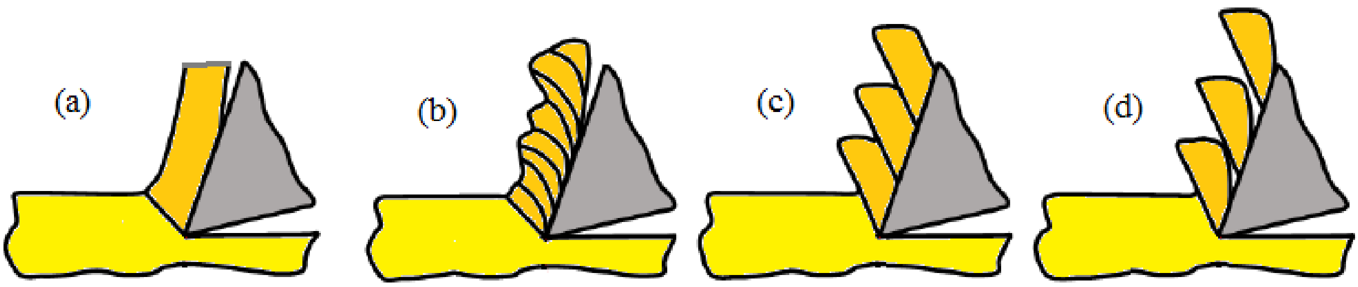


Figure I. 16: Chip shapes in orthogonal section: a) Continuous chip, b) Wavy chip, c) Segmented chip, d) Fragmented chip.

It is necessary to avoid:

- A long, stringy chip that results in reduced tool life, caused by excessive heating, chipping, a built-up edge, edge breakage.

- A very fragmented chip promotes the appearance of vibrations of the part with a rough surface condition.

Figure I.17 shows some chip shapes generated after machining.

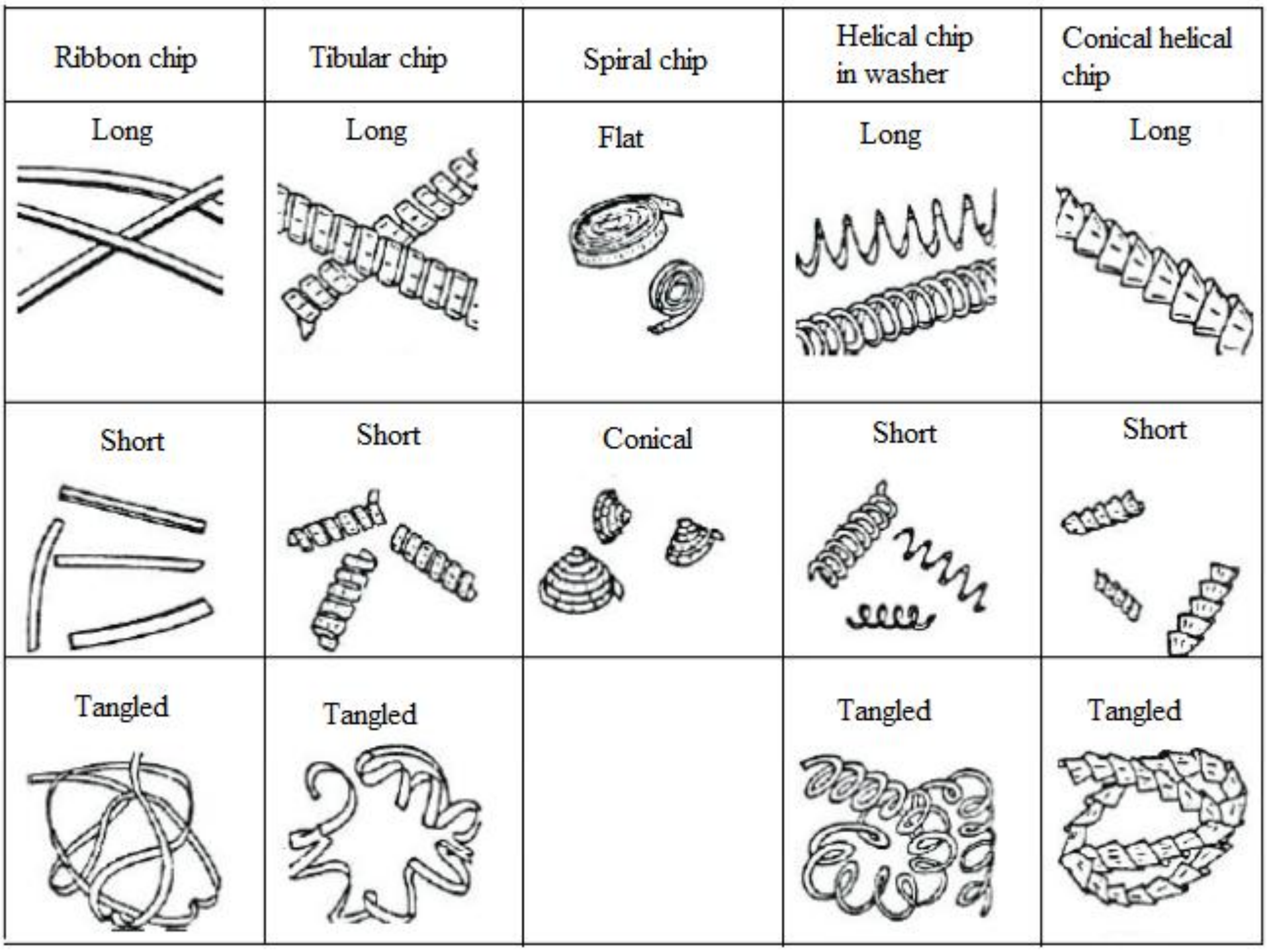


Figure I. 17: Chip shapes generated after machining.

I. 6. Cutting efforts

I. 6. 1. Introduction

Chip formation cannot take place without an essential force and therefore a cutting power Pc required at the spindle. The study and approximation of cutting forces are necessary to choose the tools and size the workpiece holder (the dimensioning of the machining fixtures), their directions make it possible to determine the direction of movement of the tools so that the supports of the fixture oppose these forces (the control of the clamping of the part and the tool.

I. 6. 2. Study of cutting efforts

In the example of a turning operation on a lathe, the chip slides on the cutting face.

The cutting force can be broken down into three main directions (figure I.18).

- Tangential force Ft (Fz): Main cutting force, due to the cutting movement. It is a component in the direction of the cutting speed.
- Axial force Fa (Fx): Feed force. It is a component in the direction of tool feed.
- Radial force *Fr* (F_y) : Penetration force, component in the direction perpendicular to the other two (in the direction of the penetration movement), called,

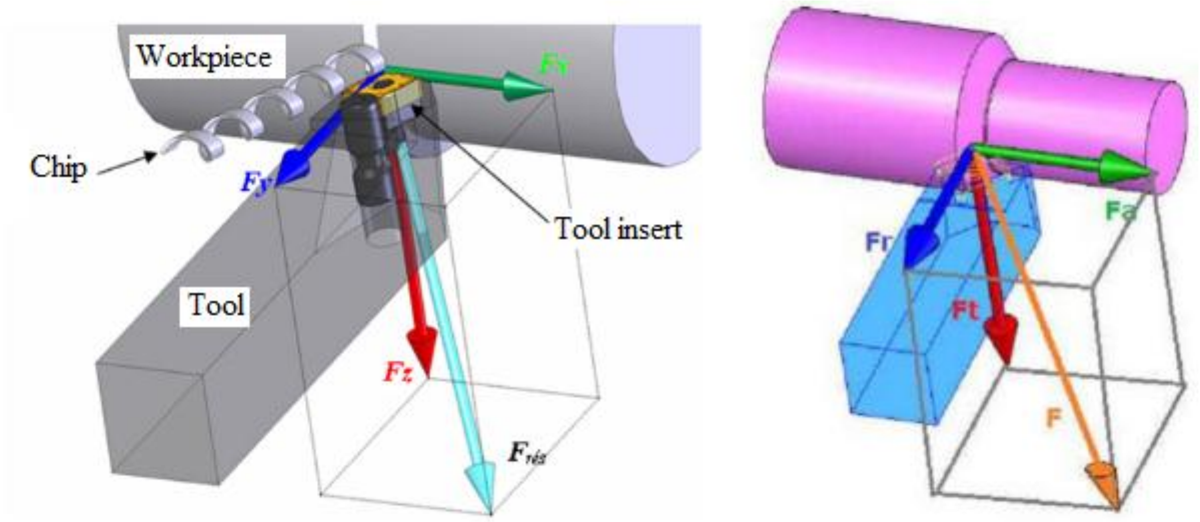


Figure I. 18: Cutting forces of a turning operation.

$$F_{rés} = \sqrt{F_X^2 + F_Y^2 + F_Z^2}$$

$F_a = (0,3\text{-}0,6).F_t$
$F_r = (0,1\text{-}0,4).F_t$

So the most important component is F_t.

The result can be :

$$\sqrt{(0.45.\ Ft)^2 + (0.25.\ Ft)^2 + (Ft)^2}$$

$$F = 1.2 * Ft \simeq Ft$$

I. 6. 3. Calculation of cutting forces and powers

I. 6. 3. 1. Cutting efforts

The cutting force is expressed by the relationship:

$F_c = K_s . S_c = K_s . a. f$

F_c : Cutting force (daN)

S_c : Chip section, $S_c = a. f$ (mm^2)

a : Depth of pass value.

f : Feed value.

K_s : Specific cutting coefficient (daN/mm^2)

The K_s factor is determined experimentally by a series of tests; it depends essentially on the nature of the material to be machined (table I.2).

Machined material		Specific cutting Coefficient Kc (daN/mm^2)			
Feed (mm/rev) →		*0,1*	*0,2*	*0,4*	*0,8*
General purpose steel	S 185 – S 275	360	260	190	140
	S 355	400	290	210	150
	E 330	420	400	220	160
	E 360	440	315	230	165
Alloy steels	Manganese steel	470	340	240	180
	Nickel chromium steel	500	360	260	180
	Chrme molybdenum steel	530	380	270	200
	Stainless steel	520	370	270	190
Unalloyed steels	C 40	320	230	170	125
	C 50	360	260	190	140
	C 60	390	290	210	150
Cast iron	FGL 150	190	140	100	70
	FGL 250	290	210	150	110
	Alloy cast iron	320	230	170	120
	Malleable cast iron	240	170	120	90
Copper alloy	Brass	160	110	90	60
	Bronze	340	240	180	130
Aliminum alloy	Rr<19	110	80	60	40
	19<Rr<27	140	100	70	50
	27<Rr<37	170	120	80	60

Table I. 2: Some values of the specific cutting coefficient.

Example of calculating the cutting force

Let's say a turning operation with a knife tool on an FGL150 axis (gross diameter: 100 mm, machined diameter: 96 mm). The machining will be done under the following conditions:

$V_c = 20$ m/min

$f = 0,4$ mm /tr

$K_c = 100$ daN/mm^2

The cutting force is:

$F_c = 100 \times 2 \times 0{,}4 = 80$ daN

I. 6. 3. 2. Cutting power

It is necessary for machining, the electrical power that the motor must provide is greater to ensure the rotation of the spindle and the movement of the saddle during the turning operation for example. During machining, there is power consumed by cutting and power lost by the friction of moving parts of the gearbox (figure I.19).

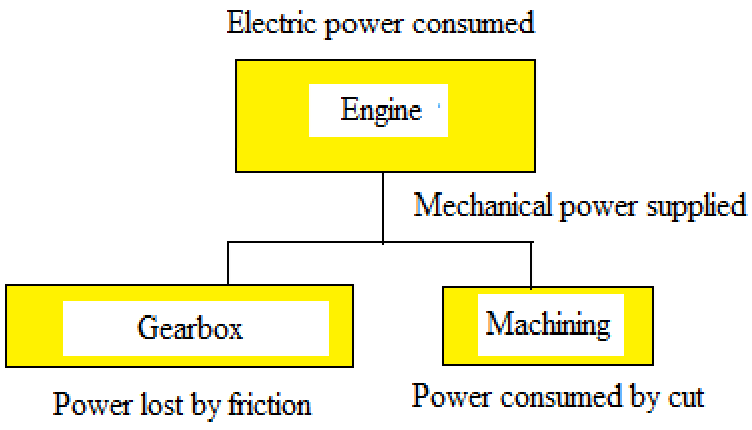


Figure I.19: Different powers during machining.

The cutting power (Pc) depends mainly on the cutting speed (Vc) and the tangential cutting force (Fc). $P_c = F_c.V_c/60$

V_c (m/min)

On the machine's motor nameplate, the power indicated corresponds to the mechanical power supplied by the motor shaft.

The efficiency of the machine's drive train η

η = Power consumed by the cut / Mechanical power supplied.

I.7. Heating (Cutting temperature)

Chip formation is accompanied by a significant release of heat due to the friction of the chip sliding on the rake face and the friction of the part on the clearance face of the tool. The cutting temperature represents an average value of the thermal field of a particularly stressed area, such as the tool/chip interface for a tool. Figure I. 20 shows the temperature distribution on the active part of the tool during dry machining of a steel with Vc = 60 m/min. The temperature gradient in the tool can reach 700°C/mm. The hardness of the cutting material decreases from certain temperatures. For high-speed steels: 500°C to 600°C, carbides: 800°C to 900°C and ceramic: 1400°C.

The temperature of the active part of the tool must be reduced so as not to cause it to lose its hardness.

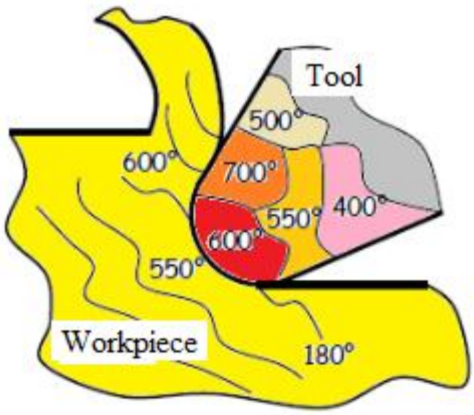


Figure I. 20: Temperature distribution on the active part of the tool.

- Effects of cutting temperature

Raising the cutting temperature is harmful to the cutting tool and the workpiece. The harmful effects on the cutting tool are:

-Rapid wear of the tool, which reduces its cutting life.

- Plastic deformation of cutting edges if the tool material is not hard enough.

-Damage to cutting edges due to thermal shock.

The harmful effects of temperature on the part:

-Lack of precision in the dimensions of the part due to the plasticity of the metal.

-Expansion and contraction during and after machining.

-Damage to the surface due to oxidation, rapid corrosion, inflammation.

Practical example of the effect of cutting temperature

Turning of an AL4G part with a carbide tool without lubrication (figure I.21). The measurement of L during machining (θ = 90 °C) gives us a length L_1 = 200.36 mm, another measurement carried out at the control station with θ = 20 °C gives us a length L_2 = 200.09 mm.

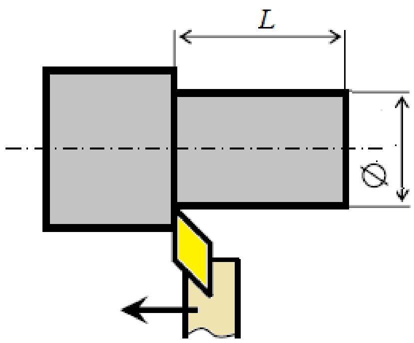


Figure I. 21: Turning a part in AL4G.

After cooling, the part has shrunk. Therefore, if the machinist does not take this into account, the dimension L may be out of tolerance and the same applies to the diameter of the part. If you want to do precision work, you must limit the temperature of the part being machined by lubrication.

I. 8. Damage to cutting tools

The localized temperature rise in the chip formation zones is the source of very complex physicochemical phenomena. This temperature rise is due to friction between the tool and the part and contact with the chips. This friction acts on the tool and causes its wear (damage) and consequently its rapid degradation, thus reducing its service life.

Cutting tool wear consists of a transfer of metal between the surfaces in contact (part, tool and chip). This transfer is caused by the mechanical and thermal stresses associated with cutting. During machining and depending on the cutting conditions, there are two types of tool wear (figure I.22):

Crater wear produced by intense friction of the chip on the cutting face (zone 1).

Crater wear causes brittleness of the edge. When wear has progressed to the secondary edge, the surface condition becomes poor.

- Flank wear produced by friction of the machined surface on the tool's flank surface (zone 2). Flank wear is the most significant. It directly influences the manufactured dimension and the surface condition.

The most important is the flank wear. It directly influences the manufactured dimension and the surface condition.

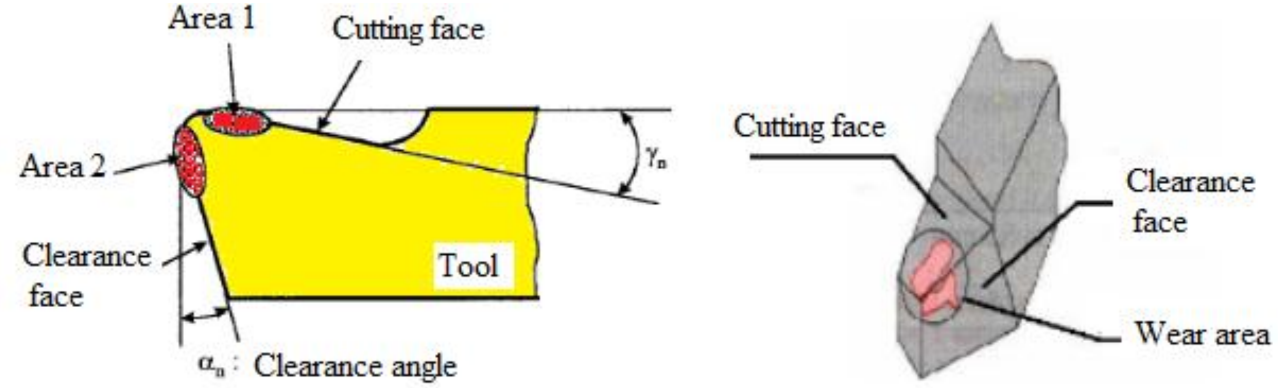


Figure I. 22: Types of tool wear.

Table I.3 shows some types of tool wear.

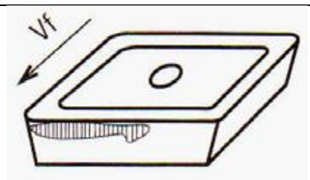
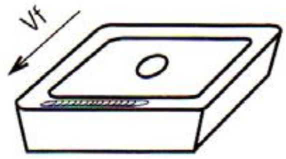
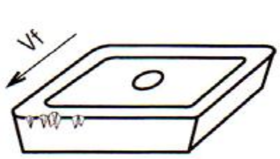
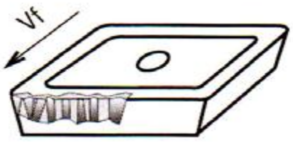
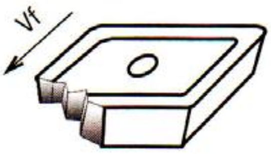
Default	Illustration	Causes	Remedies
Wear in undercut Usure en dépouille		Cutting speed too high Insufficient wear resistance Tool above center. Insufficient coolant.	Reduce cutting speed Choose a more resistant grade. Center the tool. Use coolant.
Crater wear Usure en cratère		Unsuitable cutting conditions. Diffusion wear due to excessive temperature on the cutting face.	Reduce the cutting speed or feed Choose a more resistant grade Choose positive γ of the tool.
Chipping of the edge		Too fragile grade Poor tool part stability Tool below center. Poorly chosen cutting conditions.	Take a tough grade. Improve stability. Center the tool. Reduce feed at the start of the cut.
Edge reported Adherent chip		*Vc* too low Tool geometry unsuitable for the machined material. Unsuitable feed .	Increase *Vc*. Use a chipbreaker. Increase the feed.
Burning of the edge	 High speed steel	Unsuitable cutting conditions. Tool geometry unsuitable for the material being cut Insufficient coolant.	Reduce cutting speed, Nozzle radius too small. Check coolant.
Tool breakage		Unsuitable cutting conditions. Impacts, poor clamping. Defect in the part.	Check all machining conditions. Take a tough grade.

Table I. 3: Types of tool wear.

I. 9. Methodology for choosing cutting parameters

To obtain a satisfactory work (good condition of the machined surface, speed of machining, moderate tool wear, ...) the cutting parameters must be adjusted.

The cutting parameters are constant or variable elements, which depend on each other in order to obtain the best possible compromise for machining. Determining the optimal cutting conditions is a task that has technical and economic importance.

I. 9. 1. Cutting parameters

First of all, it is necessary to clarify:

The type of machine used for machining (lathe, milling machine, drill) and its power.

The material cut (steel, cast iron, aluminum alloys, etc.).

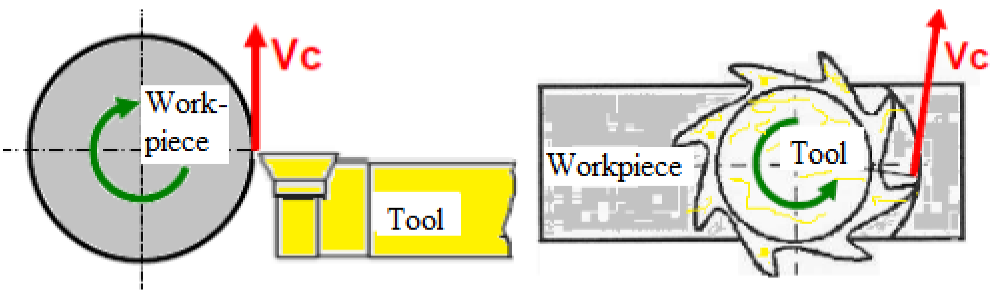
The cutting material (ARS, carbide, etc.).

The type of operation (sliding, dressing, roughing, finishing, surfacing, drilling, etc.).

It is necessary to determine certain specific parameters, such as:

I. 9. 1. 1. Cutting speed

The cutting speed is the speed of a point of the part in contact with the tool during turning (figure I.23a). In milling or drilling, it is the speed of a point of the cutting edge of the tool (figure I.23b). It is evaluated in circumferential path, that is to say in length of circumference traveled by the part.



(a) (b)

Figure I. 23: Cutting speed in machining.

By designating by D the diameter of the circle described in millimeters (mm), by N the rotation speed in revolutions per minute (rpm) and by V_c the linear speed in meters per minute (m/min),

we will have: $V_c = \pi . D. N$

In any machining problem, it is necessary for technological and economic reasons to determine the value of *Vc* best suited to the work to be carried out.

The cutting speed has a major influence on the tool life. It varies in particular with the material to be machined, the tool material, the nature of the operation (roughing or finishing), the choice of feed *f*, the lubrication conditions (dry or lubricated work) and the power of the machine. The cutting speed must be chosen correctly, since if it is too slow: Loss of time (economic criteria) and too fast: Increase in temperature (rapid deterioration of the tool). Tool manufacturers recommend cutting speeds established from laboratory experiments, they are mentioned in tables. These experiments make it possible to obtain the best compromise between the maximum tool life and the maximum material removal for economic purposes (the choice of cutting speed influences the cost price of the manufactured product).

The cutting speed *Vc* chosen is suitable for determining the rotation frequency *N*.

The values of *Vc* and the feeds f are indicated in tables I. 4, I.5. and I.6.

Material to be machined	Extrior fliming				Thread turning	
	High speed steel		Carbide		High speed steel	Carbide
Feed f mm/rev	0.05 à 0.1	0.1 à 0.2	0.05 à 0.2	0.2 à 03	f = pas du filet	
Unalloyed steel	50	40	250	200	35	120
Low alloy steel	30	20	150	130	20	80
High alloy steel	20	15	120	100	15	60
Low alloy cast steel	30	20	150	120	20	75
Stainless steel	25	20	150	130	20	90
Lamellar cast iron	40	30	80	60	20	30
Modular cast iron	30	25	100	80	15	40
Spheroidal cast iron	55	45	90	70	25	40
Low hardness Aluminum alloy without silicon AW2030	250	200	550	400	150	230
Hard Aluminum alloy without silicon AW2017, AW6060	120	80	250	200	90	110
Aluminum alloy with high silicon content more 12 percent	80	40	120	100	45	60

Table I. 4: Values of cutting speed and feeds in turning.

Material to be machined Feed f:mm/tooth/rev	Milling			
	High speed steel		Carbide	
	0.03 à 0.1	0.1 à 0.2	0.05 à 0.2	0.2 à 03
Unalloyed steel	50	40	140	120
Low alloy steel	30	25	100	80
High alloy steel	20	15	80	70
Low alloy cast steel	25	20	90	80
Stainless steel	20	15	100	90
Lamellar cast iron	35	30	100	90
Modular cast iron	30	25	80	70
Spheroidal cast iron	40	35	100	90
Low hardness Aluminum alloy without silicon AW2030	250	200	500	400
Hard Aluminum alloy without silicon AW2017, AW6060	120	80	300	200
Aluminum alloy with high silicon content more 12 percent	80	40	120	80

Table I. 5: Values of cutting speed and feeds in milling.

Material to be machined	Drilling		
	High speed steel	Coated high speed steel	Carbide
Unalloyed steel	30	45	70
Low alloy steel	20	40	60
High alloy steel	15	35	40
Low alloy cast steel	10	30	70
Stainless steel	12	20	40
Lamellar cast iron	25	50	80
Modular cast iron	15	30	80
Spheroidal cast iron	25	50	80
Low hardness Aluminum alloy without silicon AW2030	60	90	100
Hard Aluminum alloy without silicon AW2017, AW6060	60	90	100
Aluminum alloy with high silicon content more 12 percent	40	60	100
	Cutting speed Vc: m/min		

Table I. 6: Values of cutting speed and drilling feeds.

I. 9. 1. 2. Rotation frequency

The rotation frequency N is the angular speed of a point considered on the rotating element (part or tool) for a given diameter in revolutions per minute.

$$N = \frac{1000\ V_c}{\Pi\ D}$$

In turning: *D* is the diameter of the part in mm;

In milling: *D* is the diameter of the cutter in mm.

The rotation frequency depends on the diameter of the rotating element (part or tool) and the chosen cutting speed.

I. 9. 1. 3. Cutting feed

The feed f is called the displacement of the point considered on the cutting edge in millimeters for 1 revolution (mm/rev) in turning, also per tooth (mm/tooth) in the case of milling (figure I.24).

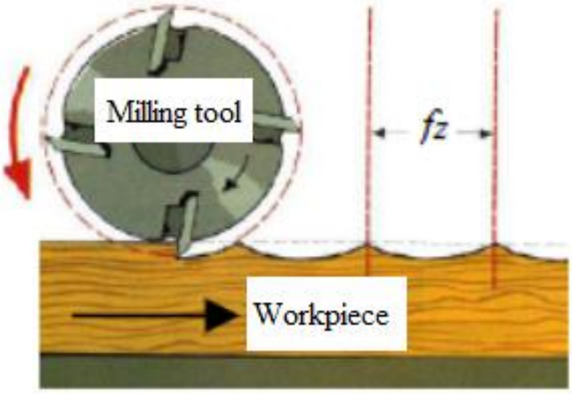


Figure I. 24 : Feed per tooth.

The feed is a key value to determine the quality of the surface condition of the machined part and to ensure that chip formation is well within the limits of the insert geometry. It is taken larger in roughing than in finishing, the feed values are also given by charts.

In roughing

The objective of the roughing operation is to remove a maximum volume of material in a minimum time and a minimum cost provided that the machine must be sufficiently powerful, as well as the part/part holder attachment. Table I.7 groups together some values of the feed f as a function of the radius rε of the tool in roughing operation.

Radius r_ε (mm)	0.4	0.8	1.2	1.6	2.4
Max feed *f* (mm/tr)	0.25 à 0.35	0.4 à 0.7	0.5 à 1	0.7 à 1.3	1 à 1.8

Table I. 7: Values of the feed f as a function of the radius r_ε in roughing.

In finishing

Finishing work is to respect the tolerance intervals and the surface condition requirements (roughness). The surface must be smooth; the dimensions must be correct. As the forces involved are lower than for roughing, the power of the machine is no longer a primary criterion.

The feed values for the turning operation are presented in Table I.8.

Materials to be machined	External carriage		External carriage	
	***f* in draft**	***f* in finishing**	***f* in draft**	***f* in finishing**
Mild steels	0,1 – 0,4	0,05 – 0,2	0,05 – 0,3	0,05 – 0,2
Hard steels	0,1 – 0,4	0,05 – 0,25	0,05 – 0,6	0,05 – 0,2
Cast irons	0,1 – 0,8	0,05 – 0,2	0,05 – 0,6	0,05 – 0,2
Hard cast irons	0,1 – 0,6	0,05 – 0,25	0,05 – 0,5	0,05 – 0,2
Aluminium alloys	0,1 – 0,8	0,05 – 0,25	0,05 – 0,5	0,05 – 0,05
Bronze	0,1 – 0,6	0,05 -0,25	0,05 – 0,5	0,05 – 0,2

Table I. 8: Feed values for the turning operation.

A finishing feed rate lower than the roughing feed rate is chosen. The roughness index R_a = 0.6 indicates a better surface quality than a roughness index Ra = 3.2.

I. 9. 1. 4. Feed rate V_f

The feed rate is the translation speed of a considered point of the tool or part that moves during machining (which has the feed movement M_f).

In the case of milling, the feed rate V_f [mm/min] is given by:

$$V_f = z.\ f_z.\ N \text{ [mm/min]}$$

Where z is the number of teeth on the cutter, f_z in mm/(rev.tooth) corresponds to the distance that the tooth will travel at each turn of the cutter.

In the case of turning, the feed speed Vf [mm/min] is given by:

$$V_f = f_z\ .\ N \text{ [mm/min]}$$

Too high a feed rate creates excessive stress on the part and on the tool, which can cause the tool to break.

I. 9. 1. 5. Depth of pass *a*

The depth of cut corresponds to the length of the cutting edge penetrated into the material, in the case of orthogonal cutting, and to the difference between the radius of the part before and after machining, in the case of turning. The depth of cut is always measured perpendicular to the direction of the feed and not along the edge of the tool (figure I.25.).

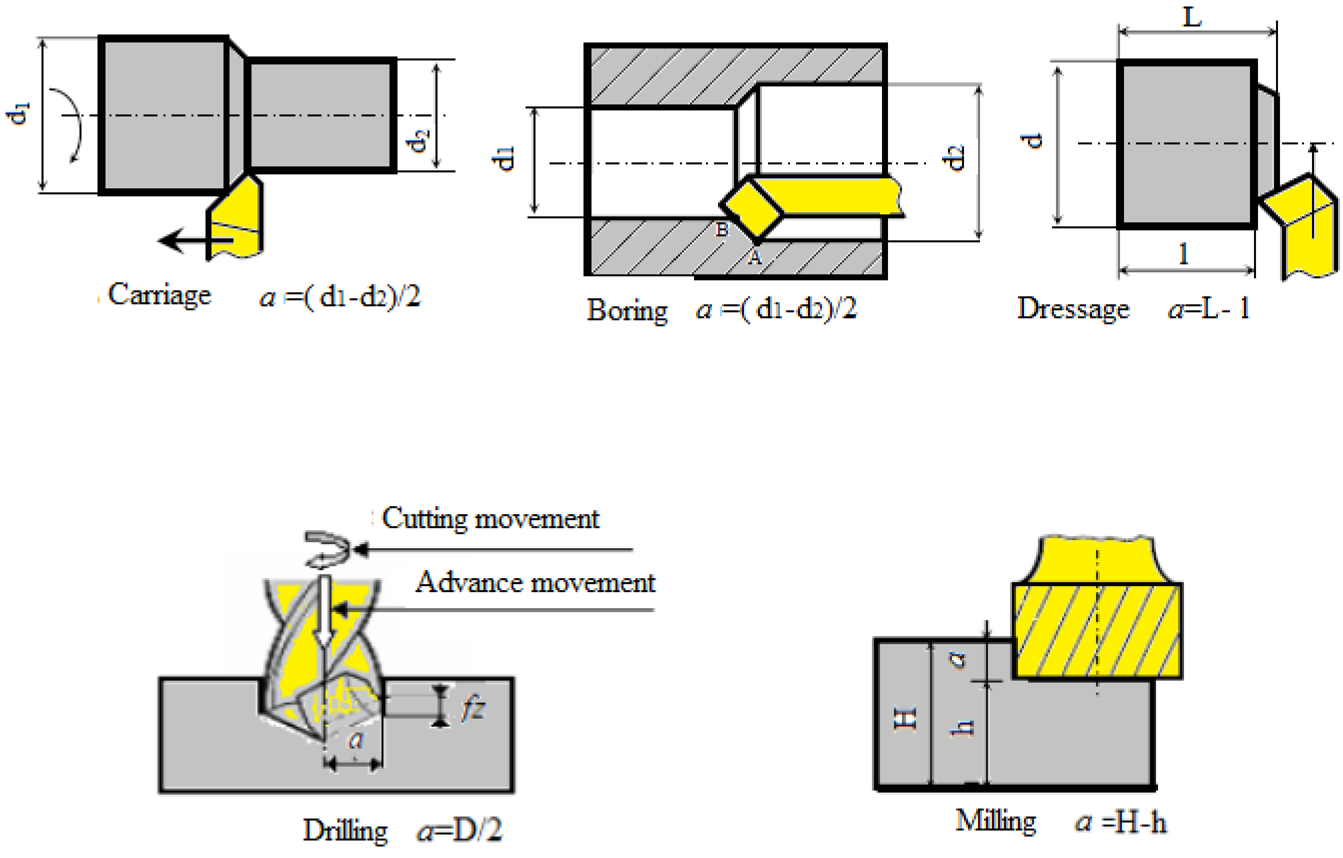


Figure I.25: Depth of pass.

The depth of pass parameter depends on the excess thickness of the material to be machined as well as the nature of the operation (roughing or finishing).

I. 9. 2. Cutting parameters in drilling

Drilling with a drill bit combines two movements: rotation and translation. These two movements are characterized by:

- Drill rotation speed: expressed in revolutions per minute and noted *N*, at the periphery of the drill (figure I. 26a), it corresponds to a speed:

$$N = \frac{1000\ V_c}{\pi\ D}$$

D : Drill diameter (mm)

- Feed

The feed expressed in mm per revolution and noted f(mm/rev).

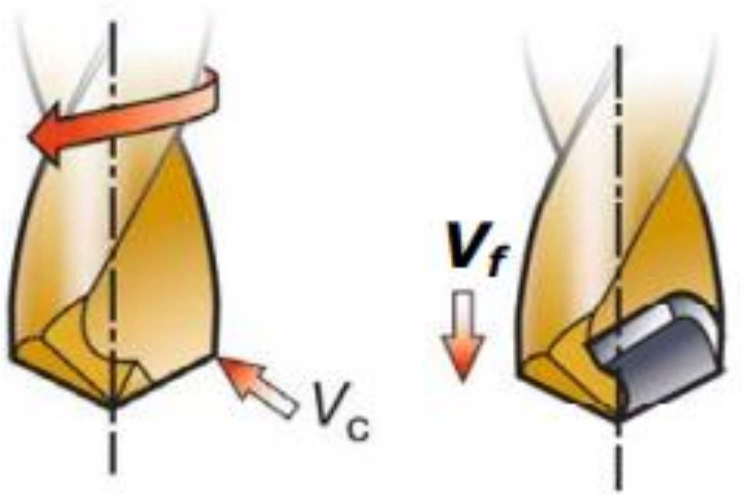
- Feed rate

Figure I. 26b shows the feed rate of the drill. The feed rate is given by:

$$V_f = 1000f.\ N$$

V_f (mm/min), f (mm/tr), N (tr/min)

If the drill has two main cutting edges, then the feed per edge is $f/2$.



(a) (b)

Figure I. 26: Rotation speed and feed.

PART II

MACHINE TOOL TECHNOLOGIES

II. 1. Introduction

Obtaining the required shapes of a part by removing material is generally ensured by a machine tool. The main function of this machine is to fix the part and the tool and then communicate the movements to them during cutting.

II. 2. Cutting movements

In machining, we distinguish three types of movement:

II. 2. 1. Cutting movement (*Mc*)

This is the movement directly responsible for the removal of material. It indicates the direction in which the latter occurs.

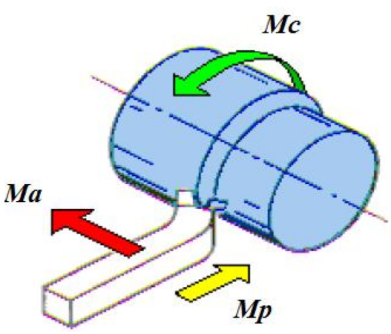
II. 2. 2. Advance movement (*Ma*)

This is the movement that allows the generation of the profile to be machined.

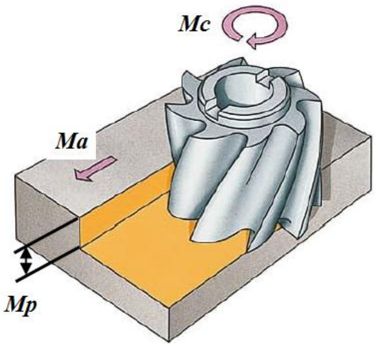
II. 2. 3. Penetration movement (*Mp*)

It is the movement that determines the cutting depth.

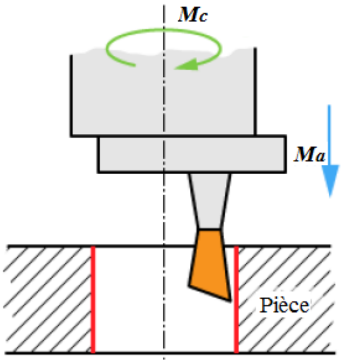
Figure II.1 shows these different movements as a function of some operations carried out on the machine tools.



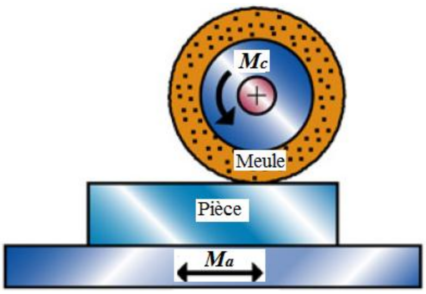
Turning



Milling



Bore



Correction

Figure II.1: Cutting movements.

II. 3. Characterization of a machine tool (Main organs)

A machine tool is a mechanical equipment designed to perform processes for manufacturing parts by removing chips. The main parts of a machine tool are: Spindle, frame and slides. Figure II.2 are machine tools, such as a lathe (figure II.2a) a milling machine (figure II.2b) and a drilling machine (figure II.2c). These machine tools contain the main parts such as:

II. 3. 1. Machine tool spindle

The machine tool spindle is a shaft from which five degrees of freedom of the workpiece are removed. The sixth degree of rotation of the spindle is removed by the power control. The machine tool spindle differs from other shafts in that the power output is achieved by means of chip formation. The input power corresponds to the power required to separate material particles (chips) from a workpiece.

II. 3. 2. Machine tool frame

The frame can be in one piece or in several pieces. All the fixed parts form a rigid and immobile system, generally, it is made of cast iron. In reality the frame and the reference part of the movement therefore it may not be fixed in the actual movement. The essential functions of a machine frame are to keep the main active elements of the machine in a constant position and to serve as a reservoir for the cutting fluid which ensures cooling functions (of the part, the tool, the chips) and chip transport. The tool holder carriage is thus positioned in relation to the spindle, to the tailstock; the column, which is a part of the frame, must rigidly position the slides which must themselves guide a carriage. The carriage, which is also one of the elements of the structure, must have the same characteristics of rigidity and precision which allow the machine to be precise. The frame is subjected to forces which tend to deform it, statically and dynamically. It is also subjected to heat flows (in particular, coming from the cutting of metals.

II. 3. 3. Slides

The main functions of the slides are:

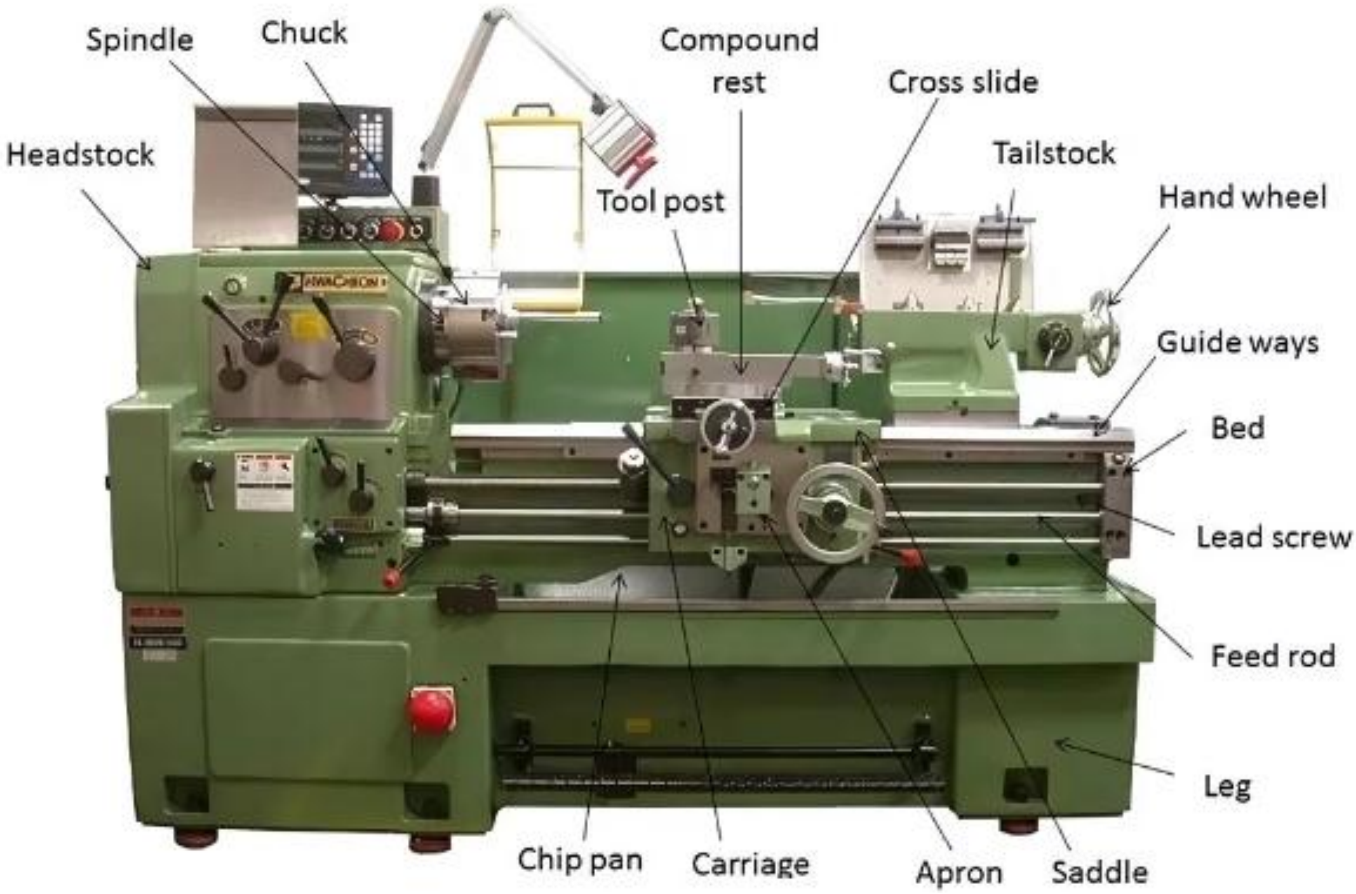
Cancellation to a carriage five degrees of freedom, the remaining degree of freedom is the translation. This translation is almost never the cutting movement.

Position the tool relative to the part, to adjust a diameter (lathe), the position of a plane (milling), the distance of two bores (boring);

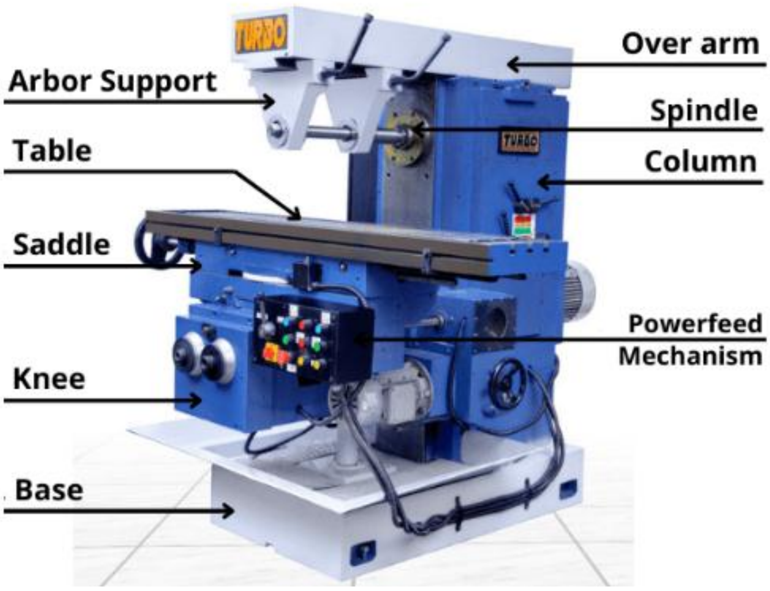
Produce the tool trajectory; this trajectory can be the reproduction of the slide

In terms of kinematics, it should preferably not leave any play in the carriage.

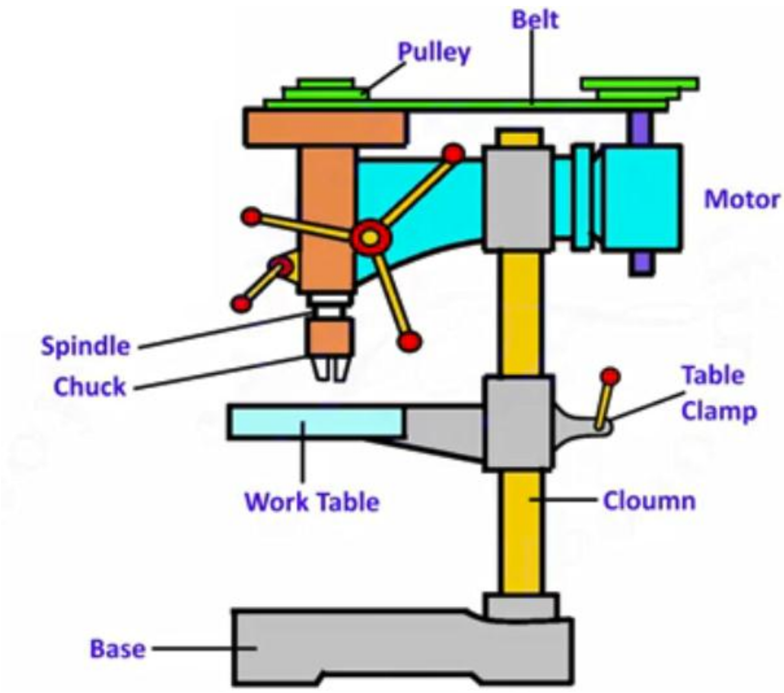
In terms of statics, always linked to kinematics, we should also be concerned with the contact rigidity between the slide itself and the carriage.



(a)



(b)



(c)

Figure II. 2: Main parts of: a) Lathe //; b) Universal milling machine; c) Sensitive drilling machine.

II. 4. Movement transmissions

II. 4. 1. Mechanisms for transmitting movements

During a study, a mechanism is represented in the form of an overall drawing. If the mechanism is complex, it will be useful to schematize it and represent it in the form of a kinematic diagram.

The kinematic diagram is a functional analysis tool, aims to represent the movements between various equivalence classes already defined. It is based on the graph of the connections and the analysis of the contact geometries of these connections to determine their name.

It is a representation of a mechanism that highlights the possibilities of relative movements between the kinematically linked groups.

A mechanism is made up of subassemblies connected by connections to accomplish a given function. However, understanding the overall plans can be complex, hence the need to simplify their representation.

This representation is done by mechanical connections.

II. 4. 2. Mechanical connections

A mechanical connection is a relationship between two solids by contact. Each connection restricts the space of degrees of freedom of the parts of the mechanism.

II. 4. 3. Symbols of mechanical connections

Table II.1, groups together some mechanical connections according to the ISO 3952 standard.

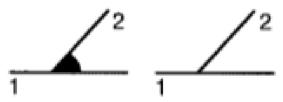
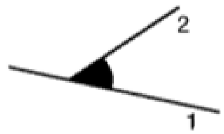
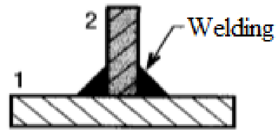
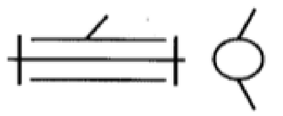
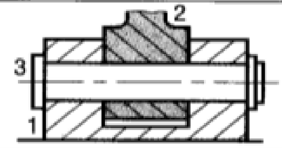
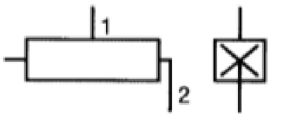
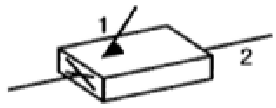
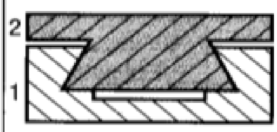
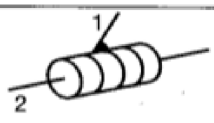
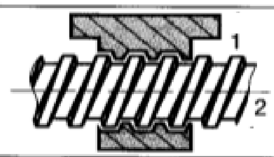
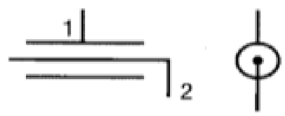
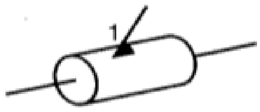
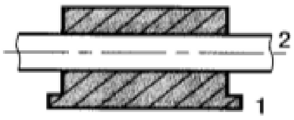
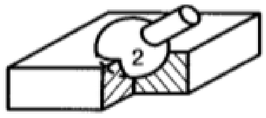
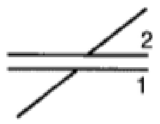
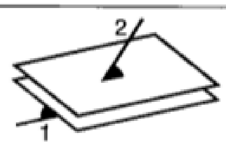
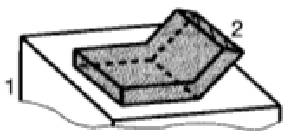
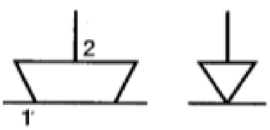
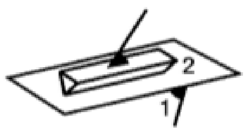
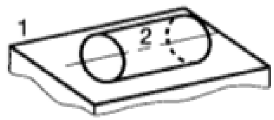
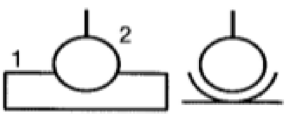
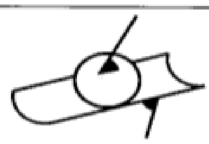
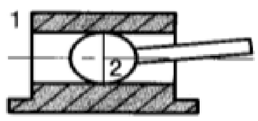
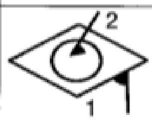
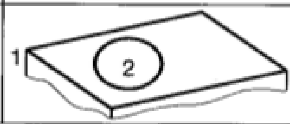
Liaison name	Translation	Rotation	Deg mob	Representation	Perspective representation	Example
Embedding or Fixed joint	0	0	0			
Pivot	0	1	1			
Slide	1	0	1			
Helical	1	1	1			
Sliding pivot	1	1	2			
Spherical	0	3	3			
Plan support	2	1	3			
Linear rectilinear	2	2	4			
Sphere Cylinder or annular linear	1	3	4			
Sphere - plan or point	2	3	5			

Tableau II. 1: Mechanical connections according to the standard ISO 3952.

II. 4. 4. Forms of power transmission

There are various methods of transmitting power, among which belts, chains and gears are commonly represented in their final configuration (figure II.3).

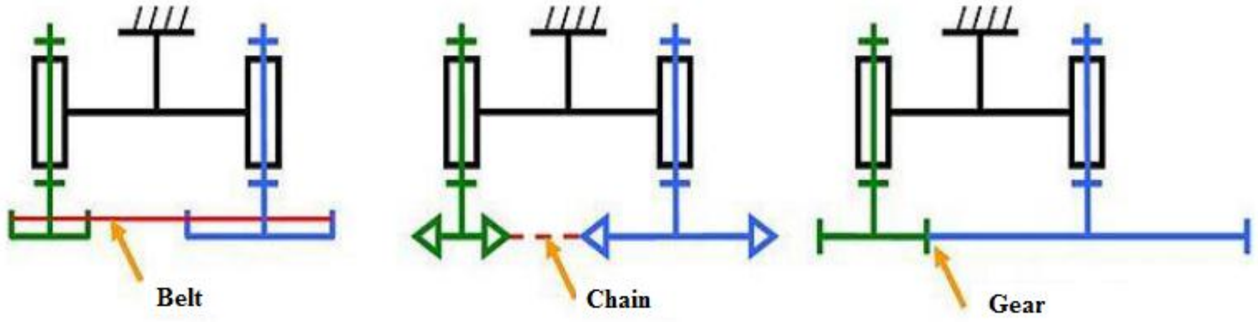


Figure II. 3: Means of power transmission.

II. 5. Drive train of a lathe

Figure II.4 is a parallel lathe with its main components and its movements obtained by the gearbox (rotational movement or cutting movement) and the feed box (feed movement or translational movement).

The cutting movement Mc is transmitted via the following components:

The motor, the gearbox, the spindle and the part.

The feed movement Mf is transmitted via the following components:

The motor, the feed box, the carriages, the tool holder and the tool.

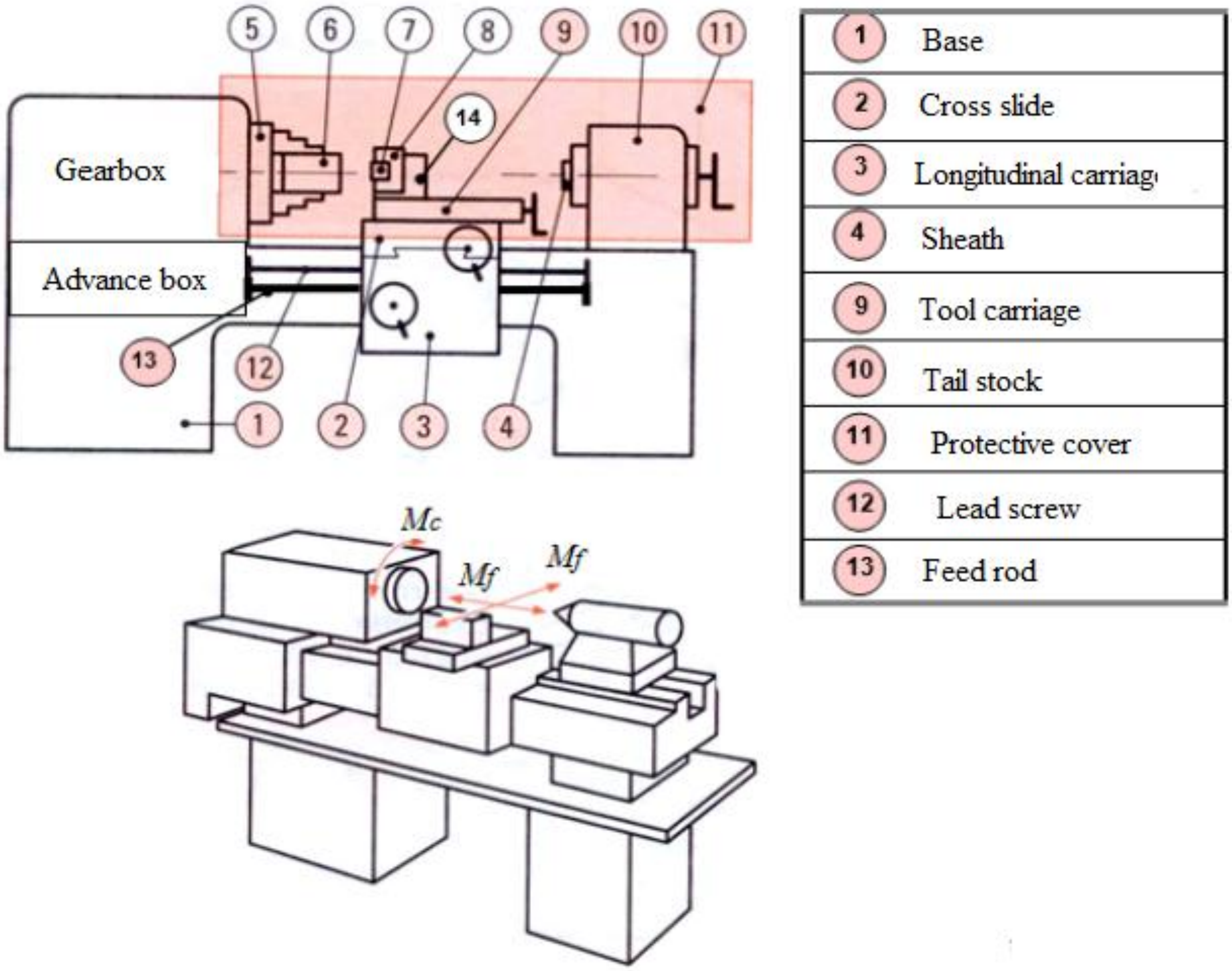


Figure II. 4: Parallel lathe with its movements.

Figure II. 5 is a flow chart of a lathe drive train.

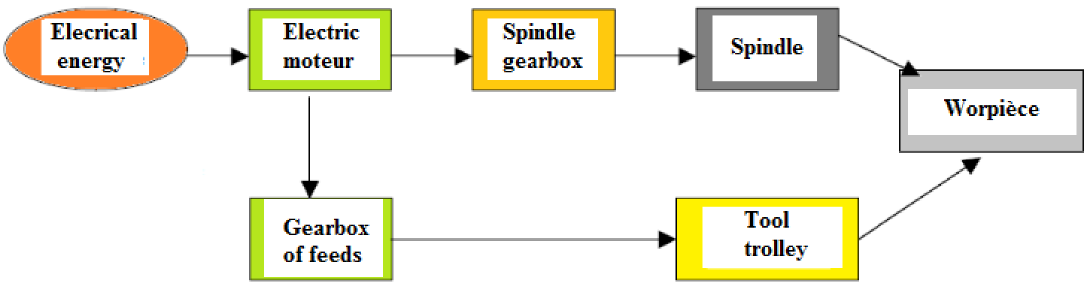


Figure II. 5: Flowchart of the kinematic chain of a lathe.

- Kinematic diagram of the lathe gearbox

The mechanism plan is started by a recessed connection between the pulley (24) and the shaft (1) (figure II.7), then the transmission continues to the gearbox from a transmission shaft.

The sliding gear (a) is on the shaft (1) and the sliding gear (b) on the shaft (10) in a position allowing to have the lowest speed which explains that the sliding gear (a) is placed such as to connect Z3 and Z6 because Z3 has the smallest diameter (sliding connection), it is the same for the sliding gear (b) which is placed so as to connect Z10 and Z12, with the gear wheel Z10 of smaller diameter. And finally, the spindle and the chuck receive the final torque.

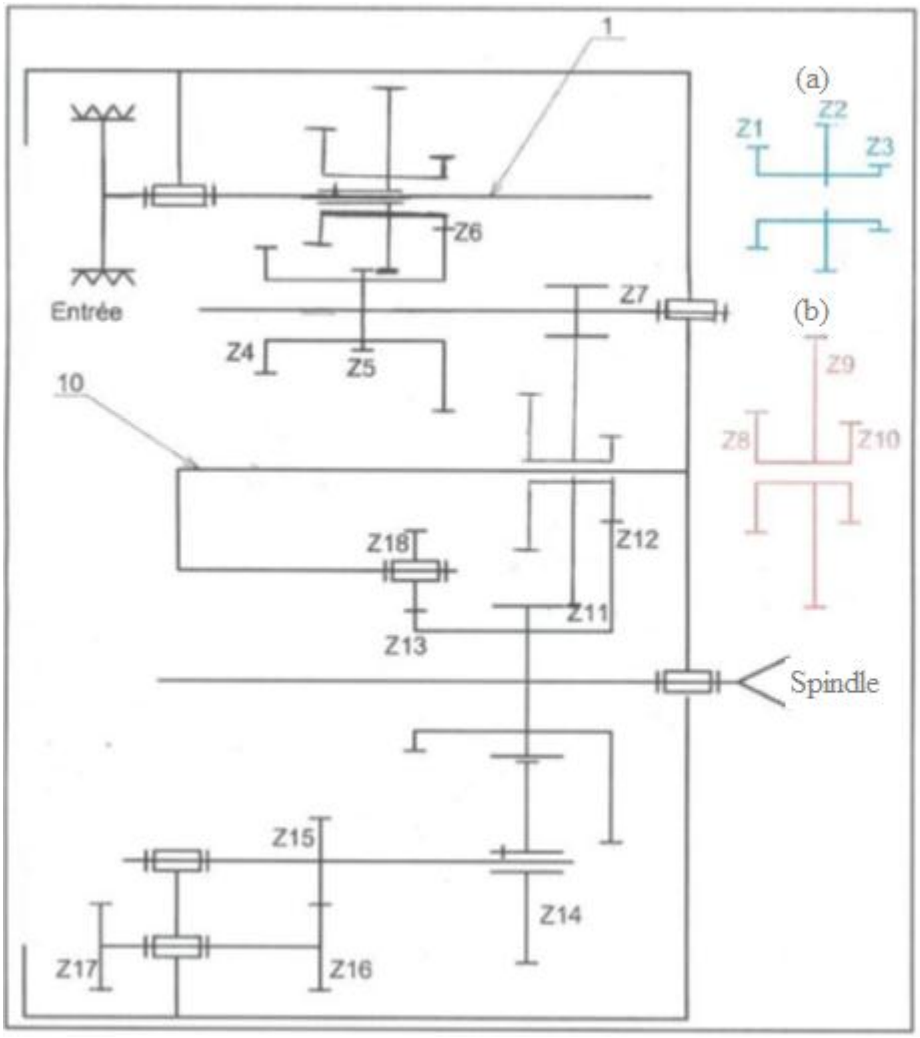


Figure II.7: Kinematic diagram of the lathe.

II. 6. Milling machine kinematic chain

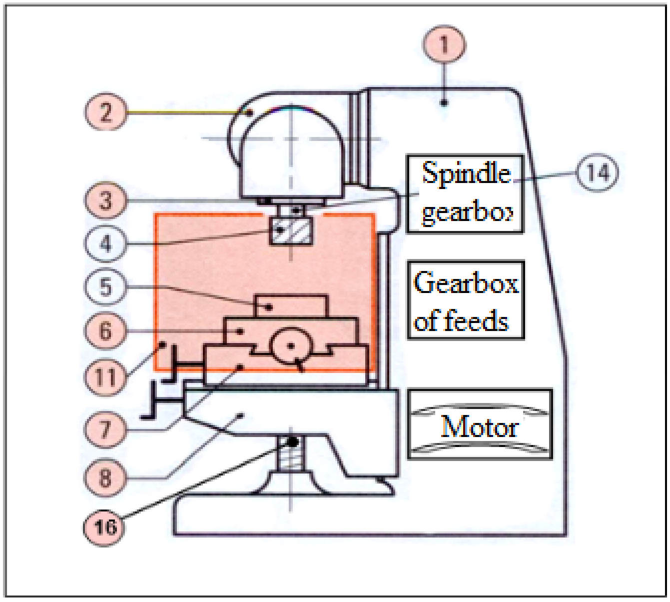
Figure II. 8 is a milling machine with its main components and its movements obtained by the gearbox (cutting movement) and the feed box (feed movement).

The cutting movement Mc is transmitted via the following components:

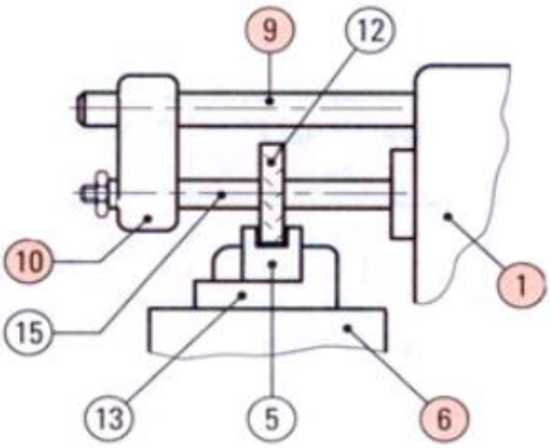
The motor, the gearbox, the spindle and the tool.

The feed movement Mf is transmitted via the following components:

The motor, the feed box, the carriages, the workpiece holder and the workpiece



Main elements of the machine	
1	Base
2	Universal head
3	Spindle
6	Table
7	Transversal carriage
8	Vertical carriage
9	Support arm
10	Arbor support
11	Protective cover
16	Column



Main external elements related to the machine	
13	Parallel jaw vice
14	Tool holder
15	Long shaft for milling cutter
5	Part
4	Tow edge milling cutter
12	Three edge milling cutter

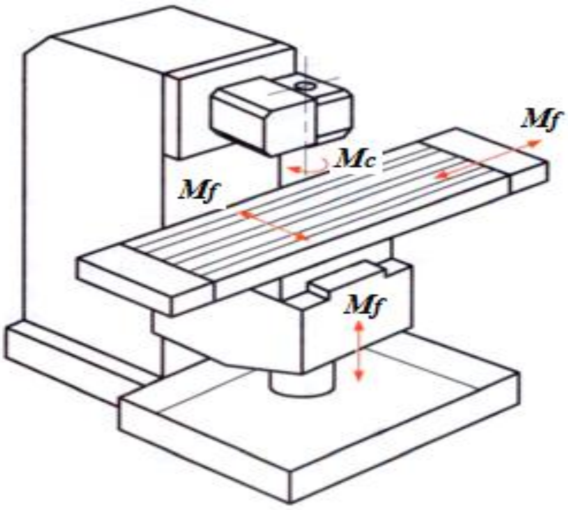


Figure II. 8: Milling machine with its main parts and movements.

Figure II. 9 is a flow chart of a milling machine drive chain.

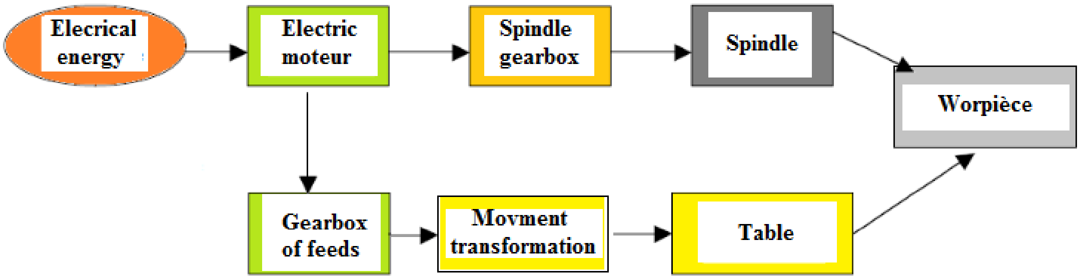


Figure II. 9: Flowchart of the kinematic chain of a milling machine.

- Drive train of a horizontal milling machine

Figure II.10 shows the kinematic chain of a horizontal milling machine where the transformation of the movement starts from the motor shaft to the spindle and the table.

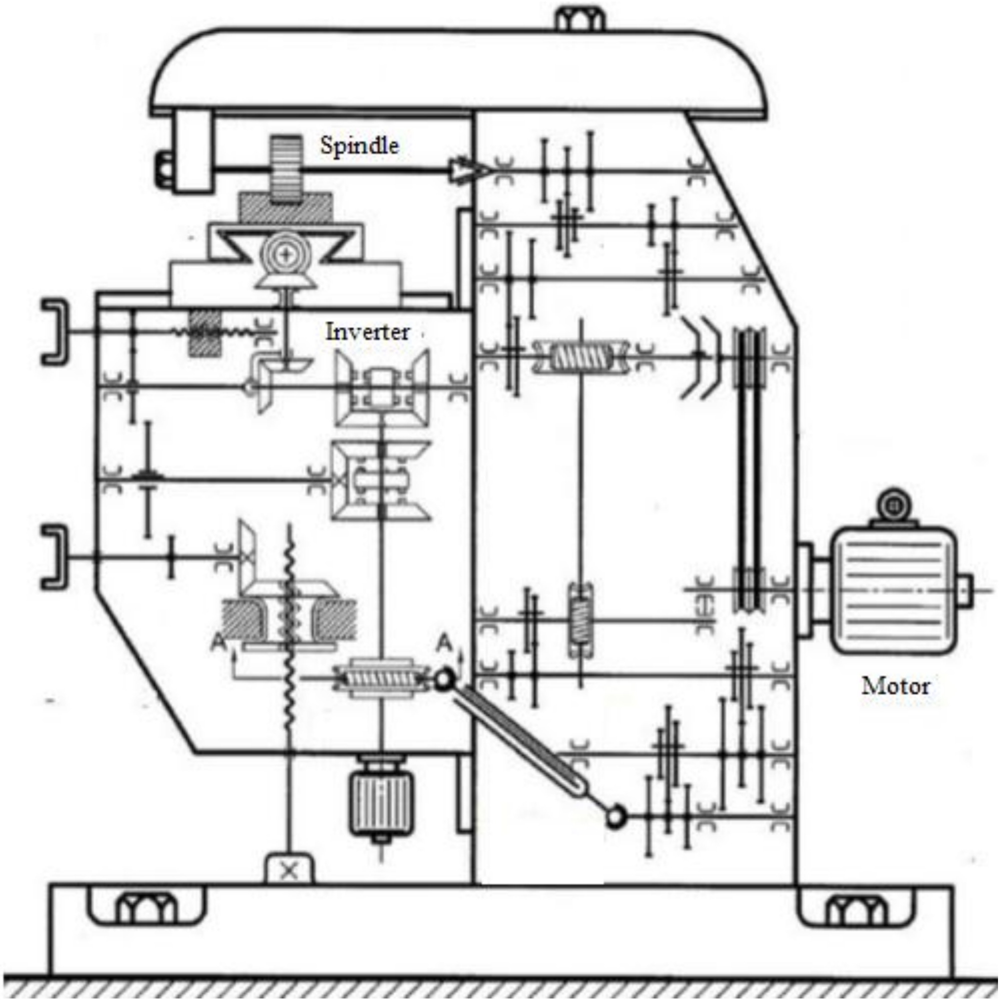


Figure II. 10: Milling machine drive train.

II. 7. Kinematic diagrams of a drill

II. 7. 1. Feed mechanism on drills

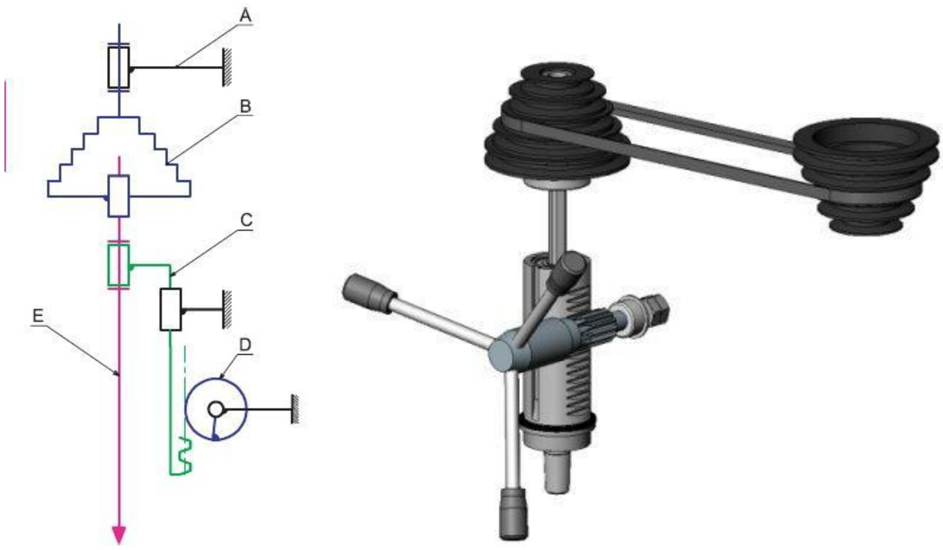


Figure II. 11: Feed mechanism on drills.

II. 7. 2. The kinematic chain of a drill

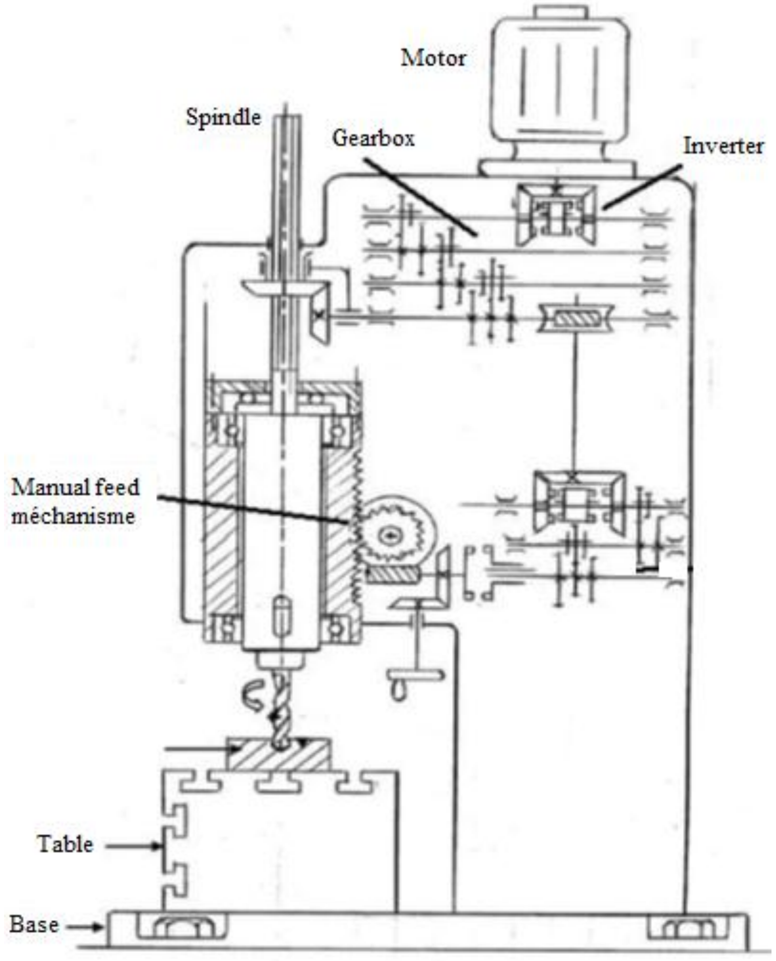


Figure II. 12: Kinematic chain of a drill.

II. 8. Kinematic diagrams of filing vice

- Definition

The filing vice is a machine tool used for machining and generating flat surfaces on metal parts. The non-rotating tool is fixed on a slide driven back and forth by a crank-connecting rod system (figure II. 13).

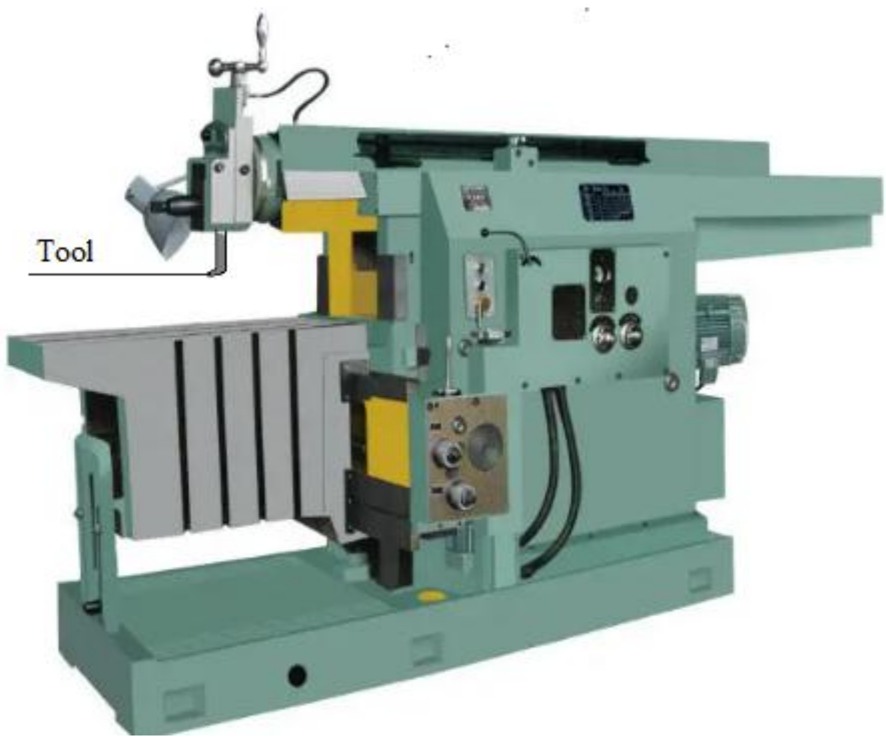


Figure II. 13: Filing machine vice.

Figure II.14 is the kinematic chain of a vice-filer, it represents the transformation of the movement from the motor shaft to the tool and the table.

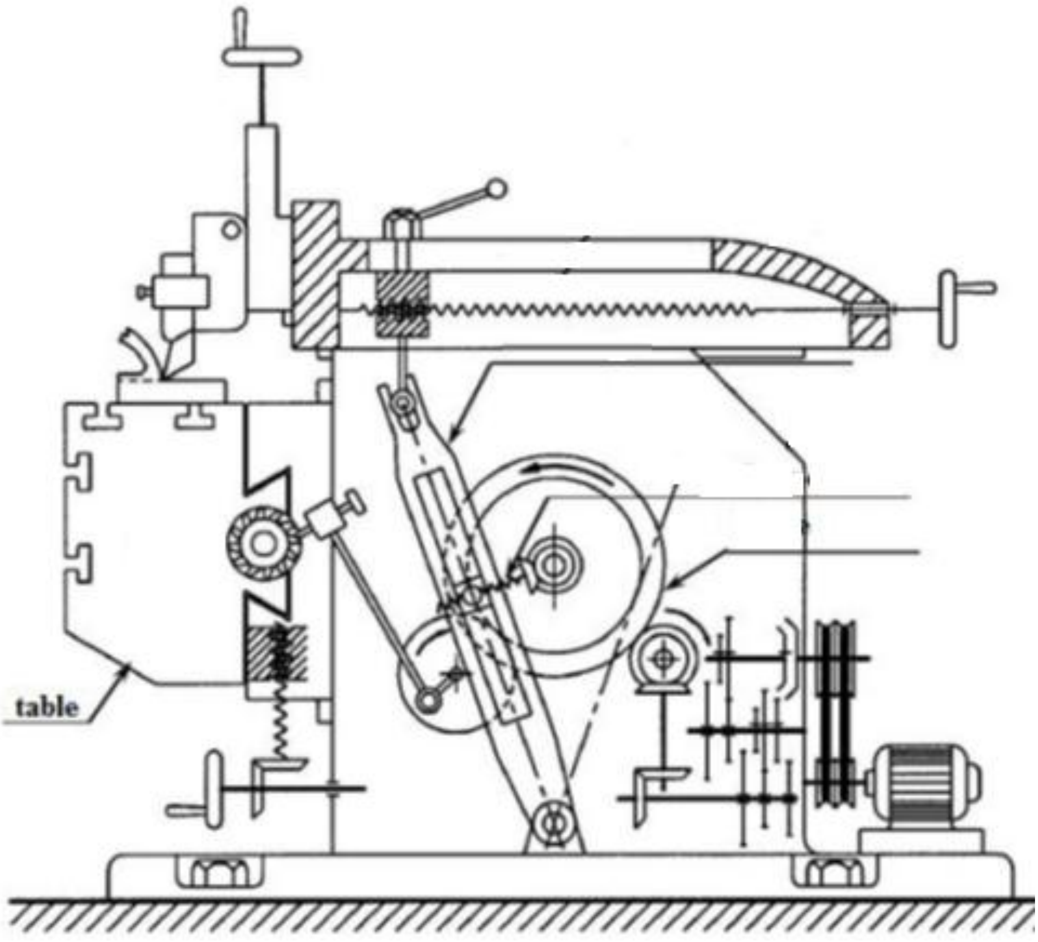


Figure II. 14: Drive train of a mechanically controlled filing vice.

II. 9. Mortising operation

Mortising consists of making a mortise (figure II.15), or obtaining a cavity with sharp angles, by digging a groove in a hollowed-out part. The keys can therefore have various sections: their housing is obtained by mortising in the pulley, by milling in the shaft.

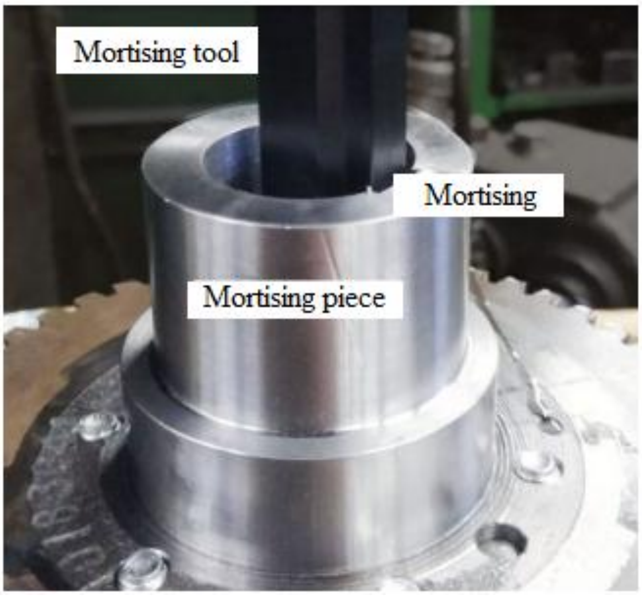


Figure II.15: Mortising operation.

- Kinematic diagram of a mortising machine

Figure II.16 is the kinematic diagram of a mortising machine, it represents on the right the mortising head, and on the left, the transformation of the movement from the motor shaft to the tool and the table.

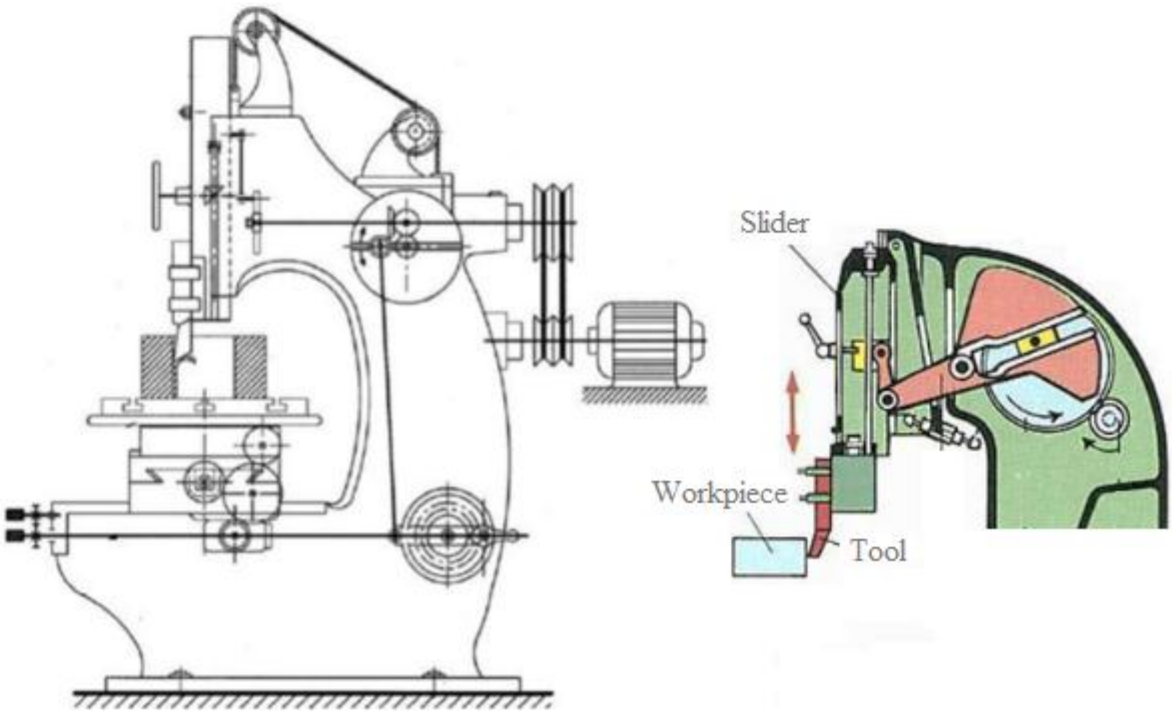


Figure II. 16: Kinematic diagram of a mortising machine.

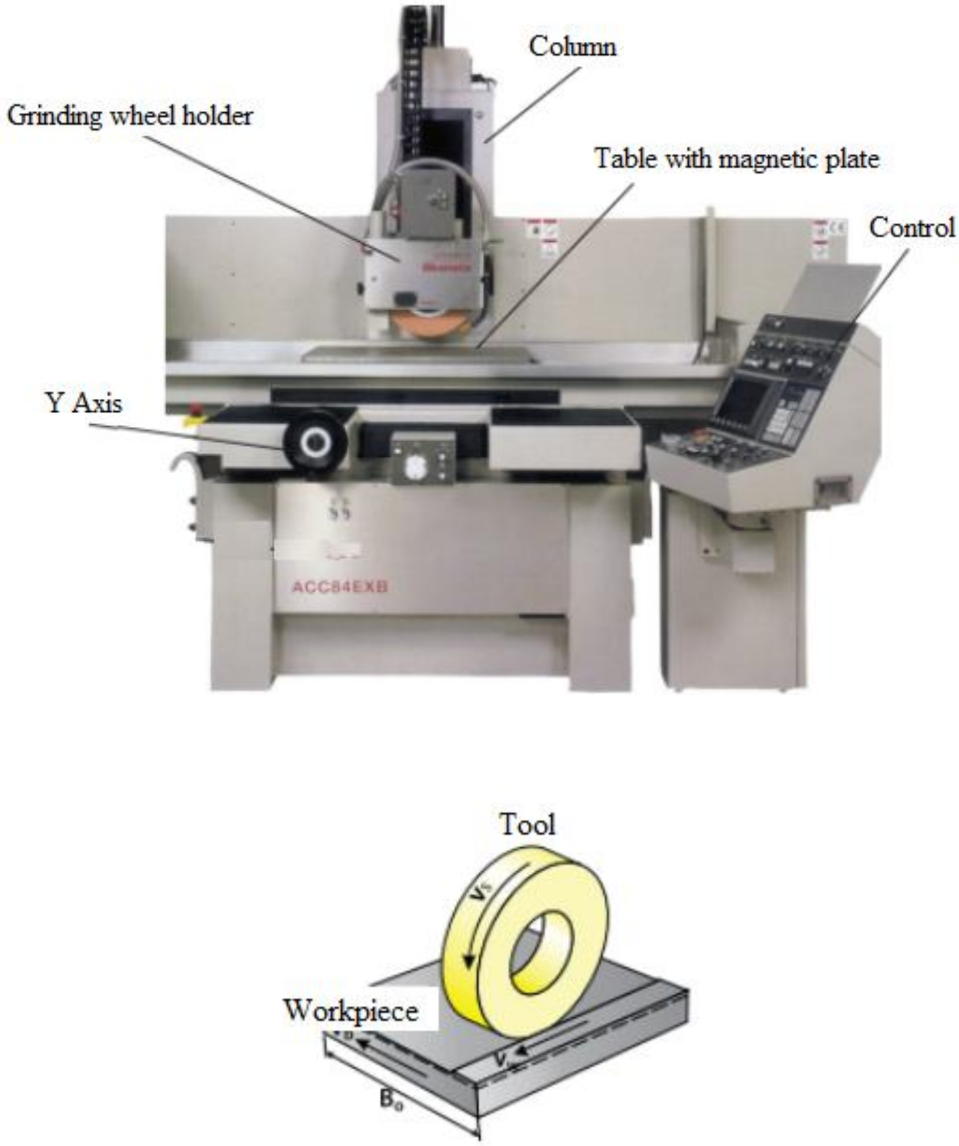
II. 10. Grinding machine

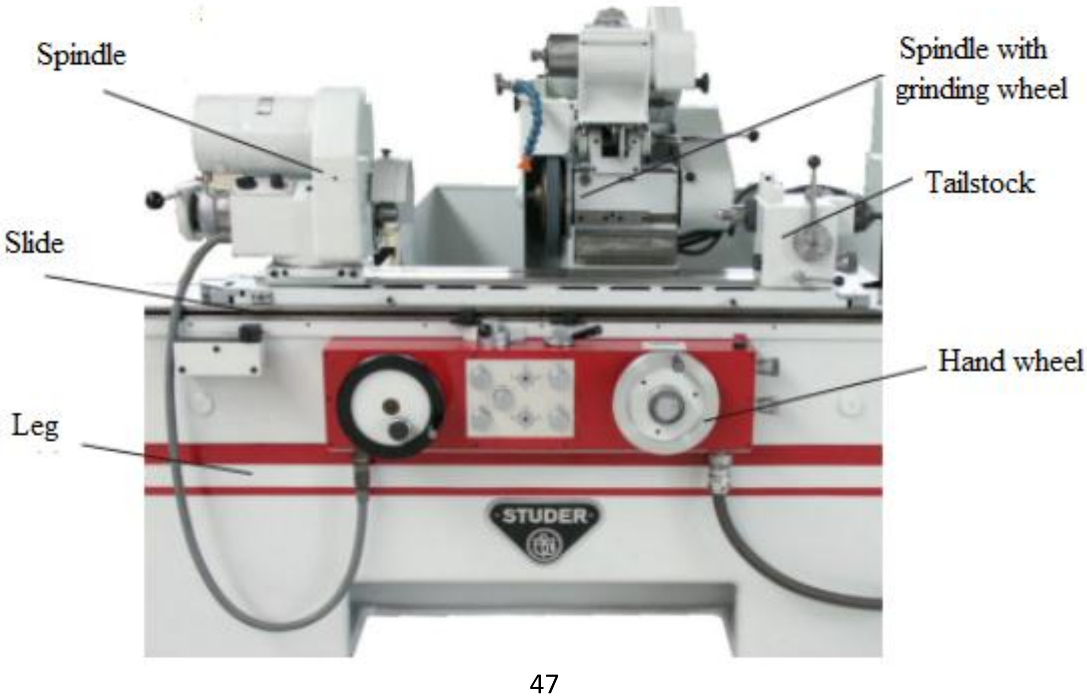
II. 10. 1. Definition of grinding

Grinding is a machining process on machine tools that consists of removing material, in the form of small chips, using a special tool called a grinding wheel. Grinding a mechanical part is an operation designed to perfect its surface condition.

II. 10. 2. Structure and movements of a grinding machine

Adapted to the needs of various machining tasks, there are a large number of grinding machines with various structures. These machines are generally named according to the type of task they perform, such as surface grinder (Figure II.17a) and cylindrical grinder (Figure II.17b).


Column
Grinding wheel holder
Table with magnetic plate
Control
Y Axis
ACC84EXB
Tool
Workpiece
(a)


Spindle
Spindle with
grinding wheel
Tailstock
Slide
Hand wheel
Leg
STUDER

(b)

Figure II.17 : a) Surface grinder; b) Cylindrical grinder

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