(4) – Basic of milling

Peripheral milling

The flattening of surfaces with milling cutters can be done in two ways that differ enormously in the technical elements, namely: the use of milling cutters with cylindrical helical teeth simple or coupled and front milling with the use of cylindrical-frontal milling cutters constructed entirely in high speed steel or in case of significantly large surface, milling cutters with inserted blades or inserts in carbide.
The peripheral milling is so called because the surface is cut in all its wide by the peripheral teeth of the milling cutter so that they are strongly stressed.
We have already said that if the surface is very large, with the use of opposite helix is generating strong axial force that can be nullify with the use of coupled milling cutters with opposite helix direction.
This type of milling can also be associated to the hobbing operation . In this case the two movements of rotation of the cutter and feed of the piece must be added the movement of the gear tooth profile generation which introduces a further element of variation of chip thickness and the direction and intensity of the various forces involved.
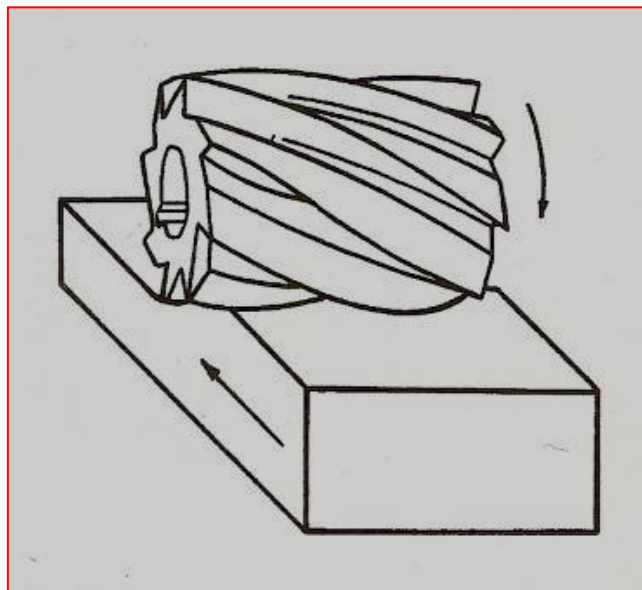

Fig.N°1- *Peripheral milling*

The peripheral milling can be done in two clearly distinguished ways: *climb milling* and *conventional milling.*
The *climb milling* is characterized by having a direction of feed contrary to the direction of rotation of the cutter. That is the piece moves towards the cutting edges of the cutter (figure N°2).
In this way the cutting edge starts to work in very unfavorable conditions because the section of the chip at the point of first contact is zero.
The cutting edge slide on the surface previously worked and compresses the material until the section of the chip is not big enough to be cut.
The cutting edge will wear very quickly. In addition, the separation of the chip happens in the maximum section with considerable difficulty and violence.
By analyzing the layout of cutting forces can be observed that a component is opposed to the feed of the piece and therefore cancel all the backlash between the screw and nut of the table, in other words, the screw is always "pull".

In this way is avoided the risk of breakage of the teeth.
This system is the only one that can take on old milling machines, without devices for automatic recovery of backlash in the kinematic chain.
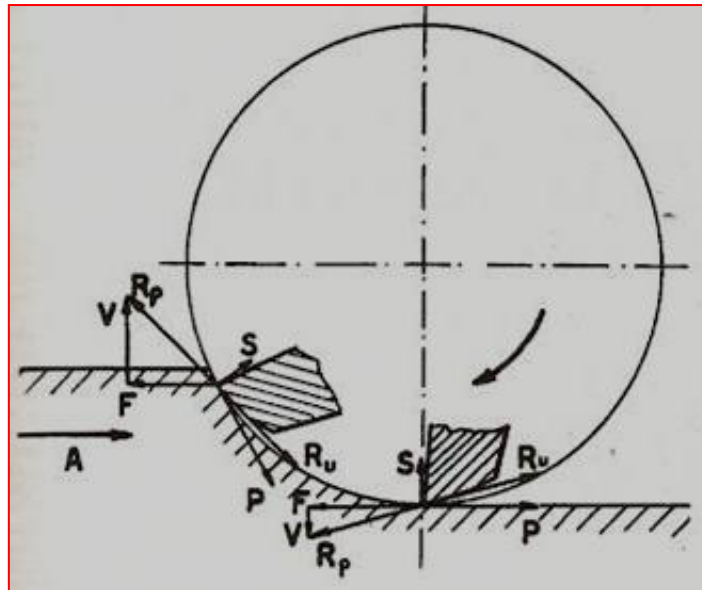

Fig. N°2- *Climb milling*

R_p = *Resulting force on the workpiece*
F = *Horizontal component*
V = *Vertical component*
S = *Peripheral force and reaction spindle*
R_u = *Resulting force on the milling cutter*

The vertical component V that in the first moment of contact is directed downwards at a certain point turns to trying to lift up the piece, then the spindle is excited by alternative forces and is subject to vibrate.
This trend of alternate forces tends to vibrate also the piece. This results in limitations of the cutting speed and feed, and the poor quality of the surface obtained with this method of milling.
In summary, the only advantage against the only advantage of spontaneous recovery of the backlash there are the following disadvantages:

➤ *Shorter life of milling cutters for the method by which the cutting edge attacks the piece;*
➤ *Limitations of the cutting speed and feed due to vibrations caused by the vertical component of cutting force; poor quality of the machined surface.*
➤ *Poor quality of the machined surface.*

The *conventional milling* so it is much more convenient and in fact all the modern milling machines are equipped with devices for automatic recovery of backlash.
This device is indispensable because the horizontal component of cutting force is in addition to the force produced by the feed of the table and could drag the piece under the milling cutter submitting to the cutting edges an excessive cutting section of material to be removed with consequent breakage of the teeth.
Of course in modern CNC milling machines are the same motors that are in charge of the automatic recovery of the backlash.
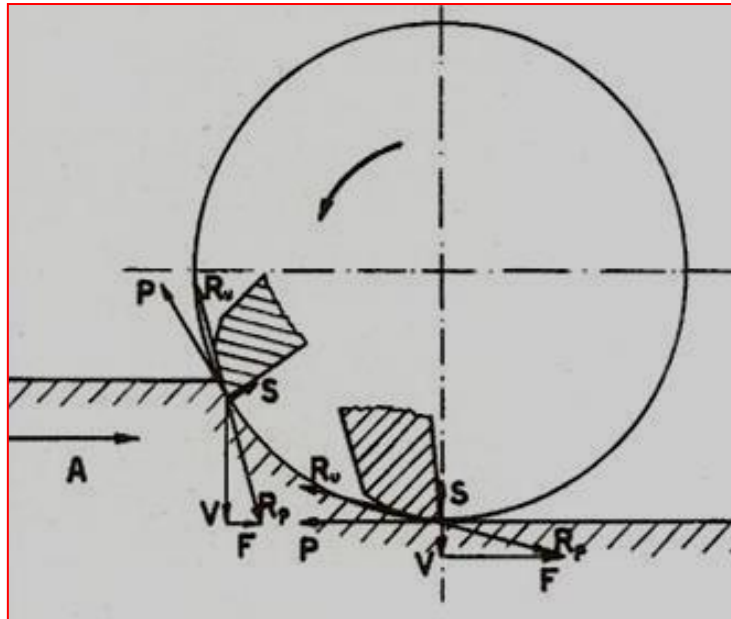
Fig.N°3- *Conventional milling*

R_p = *Resulting force on the workpiece*
F = *Horizontal component*
V = *Vertical component*
S = *Peripheral force and reaction spindle*
R_u = *Resulting force on the milling cutter*

The vertical component of cutting force is always downward helping to keep the workpiece firmly blocked against the table.
This feature is particularly useful in cutting thin pieces and easily deformable.
With this method, therefore, are reduced the causes of vibration of the spindle and the workpiece with the advantage of quality of the machined surface.
From the point of view of performance of milling cutter there have the advantage, perhaps the greatest, that the edges begin to cut in the point of maximum section of the chip.
Does not occur therefore friction because the cutting edge enters into the material immediately. In addition, the detachment of the cutting edge from the piece takes place gradually.
Under these conditions the life of the cutting edge is maximum.

Chip shapes in peripheral milling

The chip removed with peripheral milling is shaped like a comma more or less long, its size depends on four elements:

 ➤ *depth of cut "a";*
 ➤ *milling cutter diameter "D";*
 ➤ *feed per tooth "S_z";*
 ➤ *type of milling: conventional or climb milling*

In climb milling the chip is more elongated because, as shown in Fig. N°4, the shape of the chip is defined by the trajectory that the cutting edge would follow in the ideal case where the movements of rotation and feed were possessed by the milling cutter.
The trajectory is a elongated cycloid, but in the climb milling while, the arch of the cycloid which forms the chip has a smaller curvature, in the conventional milling the arc has a larger curvature, so in the first case, the chip will be longer and the second will be shorter.
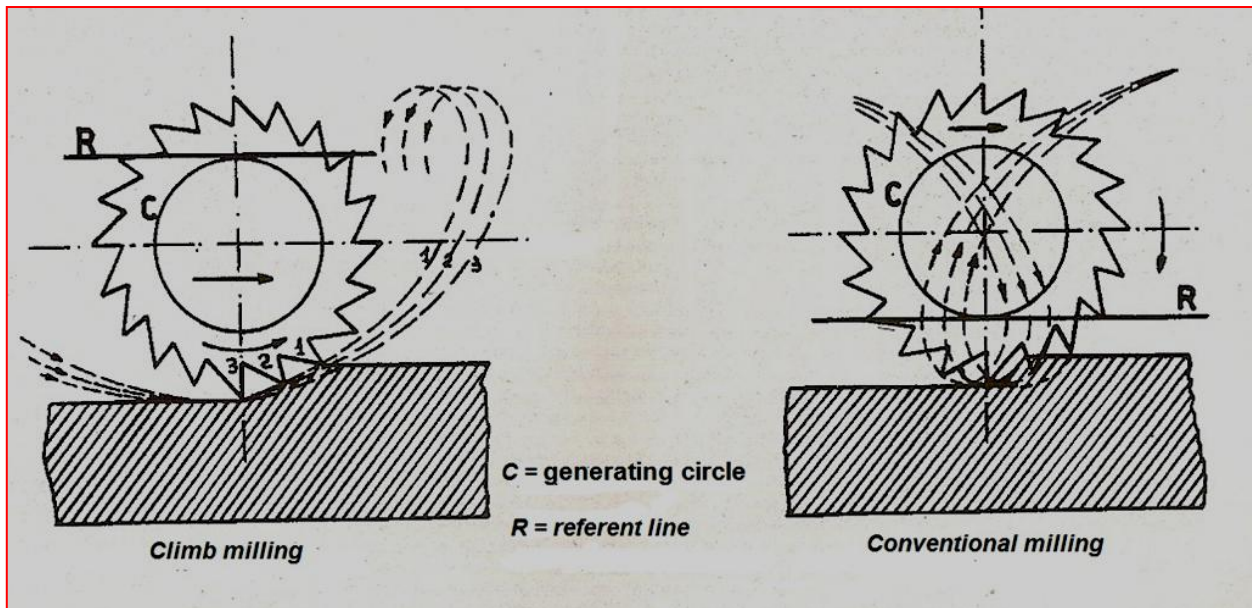
Fig. N°4- *Definition of trajectories of cutting edges (dashed lines)*

The calculation of the thickness of the chip that has great importance for the determination of the efforts of milling may be conducted in a simplified way but which gives results close enough to reality.
The approximation consists in supposing that the milling cutter has a discontinuous feed instead of continuous feed; in other words, the two curves that mark the section of the chip are treated as two arcs of circumference instead of two arcs of cycloids.
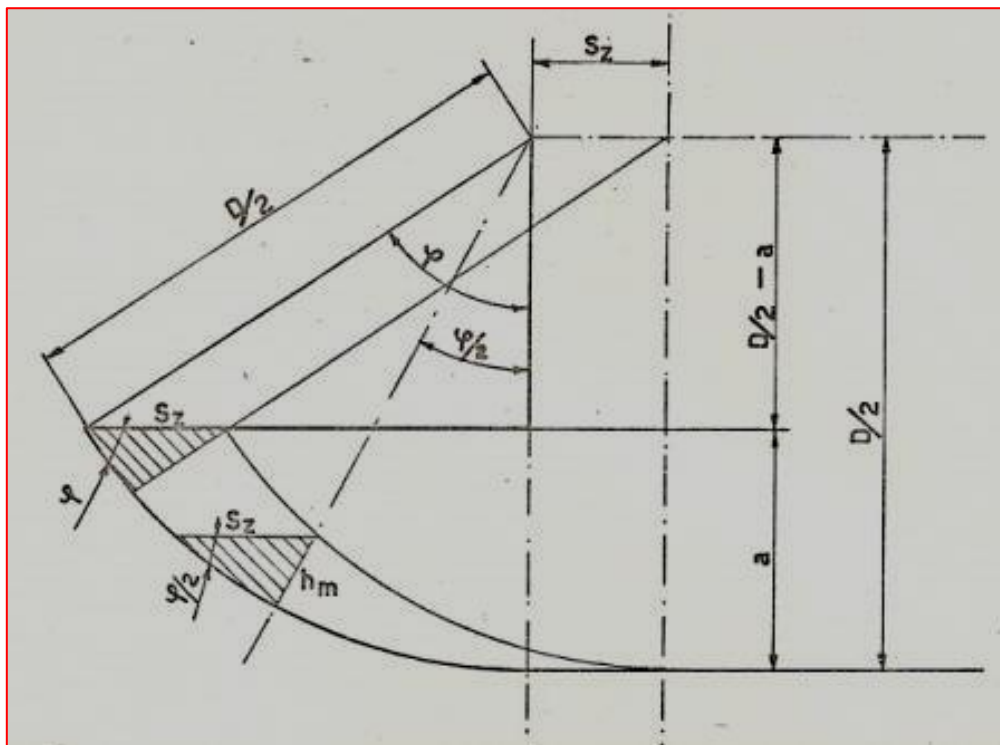Referring to figure N°5, you have the following formulas:

Fig.N°5 – *Determination of the shape and thickness of the chip*

$$\cos \varphi = \frac{\dfrac{D}{2} - a}{\dfrac{D}{2}} = 1 - \frac{2 \cdot a}{D}$$

But because we have that

$$\sin\frac{\varphi}{2} = \sqrt{\frac{1-\cos\varphi}{2}}$$

there is:

$$h_m = S_z \cdot \sin\frac{\varphi}{2} = S_z \cdot \sqrt{\frac{1-\cos\varphi}{2}} = S_z \cdot \sqrt{\frac{a}{D}}$$

The diagram in figure N° 6 gives the average chip thickness according to the diameter of the milling cutter, feed per tooth and depth of cut.
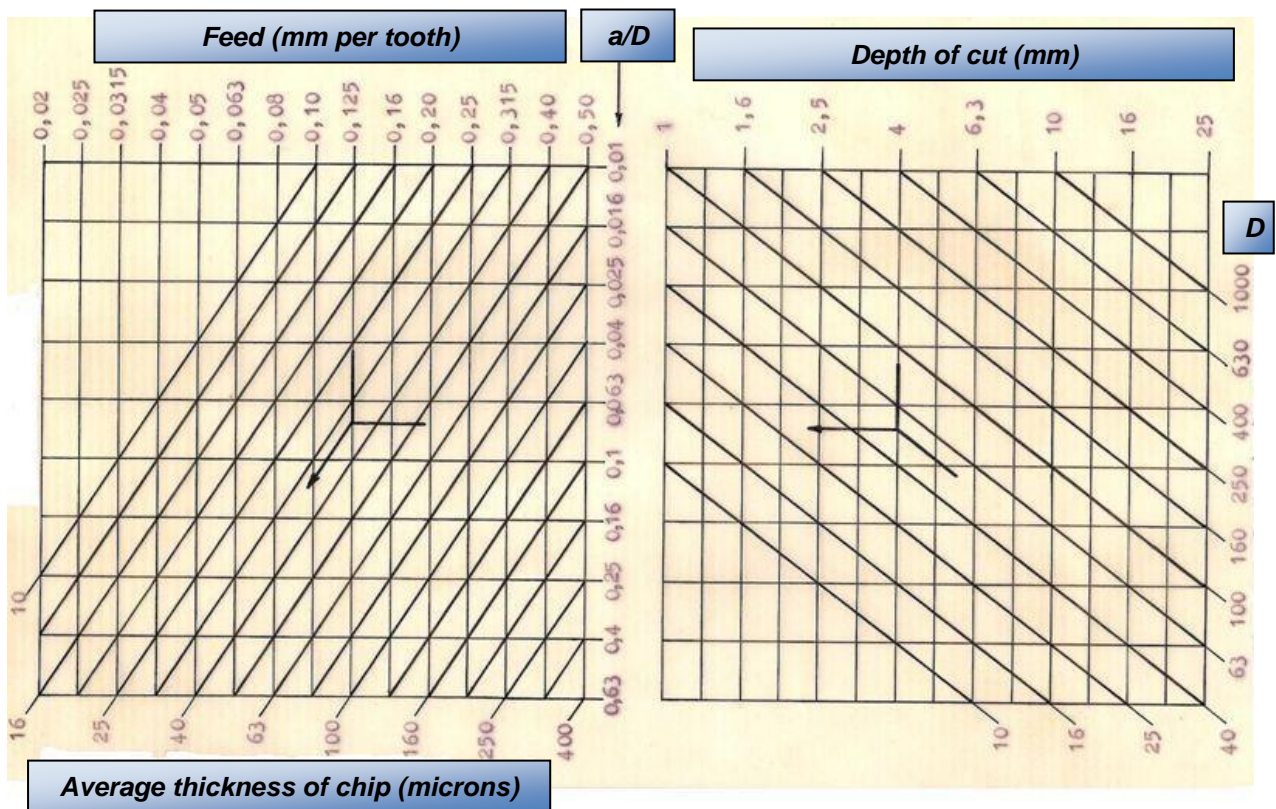

Fig. N°6- *Diagram for determining the average thickness of the chip*