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SOME PECULIARITIES OF CYLINDRICAL MILLING

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Abstract: This paper researches the variation of the chip thickness depending on the type of milling - conventional and climb. This requires a study of the chip parameters, also affecting the milling unevenness. A 3D model of a monolithic milling cutter and a working environment was created to perform the experimental research. When simulating the operation of the tool in a particular working trajectory is obtained changing of the area of the chip.
Key words: milling, area of the chip, thickness of the chip

1. INTRODUCTION

The milling with cylindrical milling cutters is performed in two ways: conventional and climb. In general, when rotation of the tool and rectilinear movement of the workpiece are carried out in opposite directions, the milling is counter, and in the same directions – climb. Conventional milling has a wider application.
It is known that the thickness of the cut metal layer is variable (Li et at., 2001), which causes the occurrence of some peculiarities of the cutting process. This requires a study of the chip parameters (Spiewak, 1995), also affecting the milling unevenness.

2. CHANGING THE THICKNESS OF THE CHIP IN DIFFERENT TYPES OF MILLING

In the case of conventional milling, each tooth at the beginning of cutting begins to operate at a zero thickness of the cut metal layer (Rao, 2005), and when it is out, it is maximum (fig. 1.a)). The path traveled by the tool is equal to the arc AM. At an angle δ=0°, a=0 mm, and at δ=max, a=0 max. The displacement of the milling cutter in the direction of the feed motion is equal to the distance O_1O_2, the milling cutter is rotated at an angle δ. At rotating one tooth from its initial position in point A at a central angle ψ the feed is s_z (relative displacement from the rectilinear motion). In fig.1.a) it can be seen that upon rotation at an angle δ the relative displacement is equal to:

$$q_0 = \frac{s_Z.\delta}{\varphi}, \quad (1)$$

where: φ - the angle of which the center of the circle moves, to its initial position.

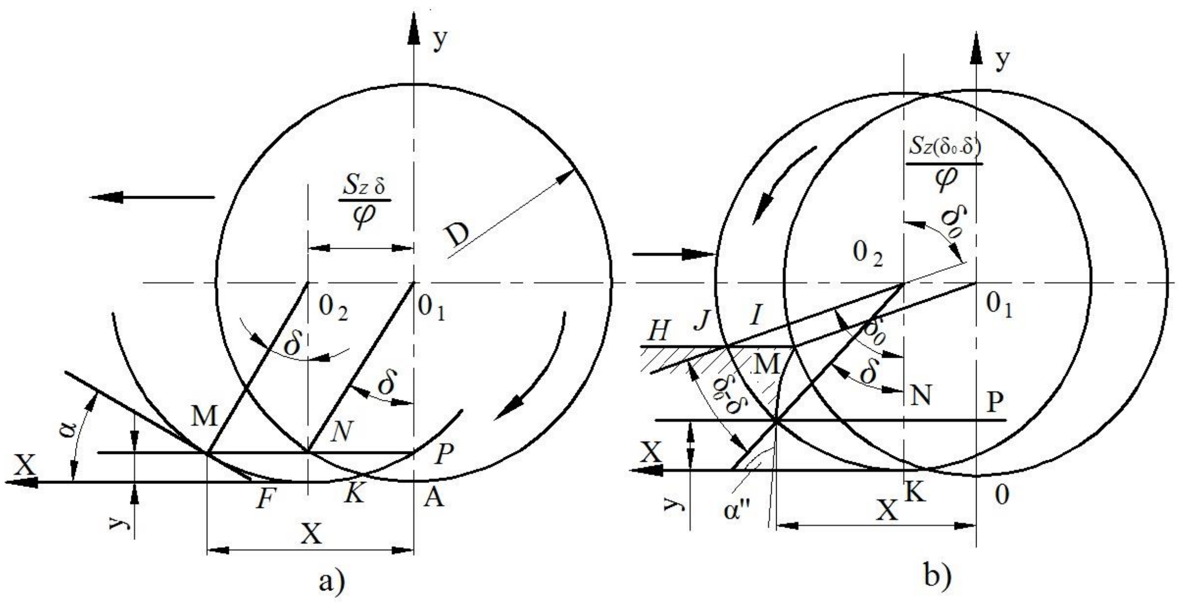


Fig. 1. Milling types
a) conventional milling; b) climb milling

Provided that the axes of the coordinate system pass through point A, the following coordinates are obtained:

$$x = \overline{\text{MN}} + \overline{NP};\ x = \frac{D}{2}.\sin\delta + \frac{s_z.\delta}{\varphi} \qquad (2)$$

$$y = \overline{\text{NK}};\ y = \frac{D}{2}.(1-\cos\delta)$$

In case of climb milling (figure 1b)), each tooth of the milling cutter first cuts a chip with a maximum thickness (a = max) when the tool enters and goes out with a chip thickness equal to 0 mm.

To describe the trajectory (the arc JM), the tooth rotates at an angle δ_0-δ. The displacement of the milling cutter, analogous to the conventional milling, is equal to O_1O_2. The displacement expressed by s_z is as follows:

$$q' = \frac{s_z}{\varphi}.(\delta_0 - \delta) \qquad (3)$$

Coordinates can be expressed as follows:

$$x = \frac{D}{2}.\sin\delta + \frac{s_z}{\varphi}.(\delta_0 - \delta) \qquad (4)$$

$$y = \frac{D}{2}.(1-\cos\delta)$$

When comparing the results of x and y coordinates in two ways of milling it can be seen that the trajectory of climb milling is shorter than that of the conventional milling. In the first case the curve gets steeper. The angles of inclination α` and α`` is expressed by the tangent to them, as one arm of the angle is tangent to the trajectory of the relative working motion:

For conventional milling:

$$\text{tg}\alpha' = \frac{\text{dy}}{\text{dx}} = \frac{D.\sin\delta}{D.\cos\delta + 2.\frac{s_z}{\varphi}} \qquad (5)$$

and for climb milling:

$$\text{tg}\alpha'' = \frac{\text{dy}}{\text{dx}} = \frac{D.\sin\delta}{D.\cos\delta + 2.\frac{s_z}{\varphi}.(\delta_0 - \delta)} \qquad (6)$$

Obviously, that α``>α`.

By comparing the trajectories described by the tooth in conventional and climb milling, when cutting at normal values and at the same angle δ, the angles of inclination of the trajectories are small and fluctuate from 1° to 30°.

The thickness of the chip "a" (figure 2) changes in the direction of the milling cutter radius. At each momentary position of the tooth on its trajectory it corresponds to a certain thickness of the chip (Лефтеров, 2013). It is determined by the feed of the tooth s_z and the current angle δ:

$$a_\delta = s_z.\sin\delta \qquad (7)$$

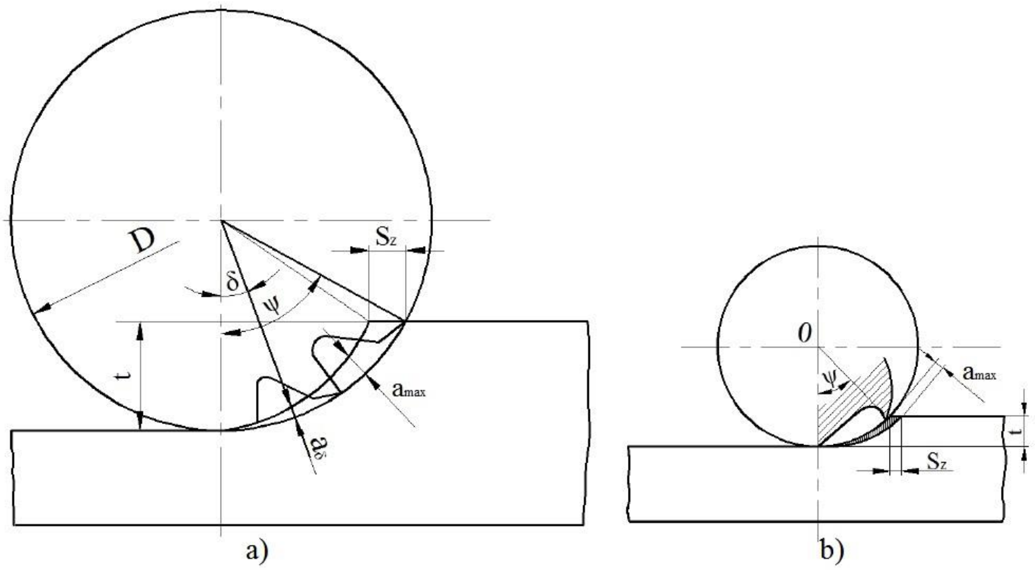


Fig. 2. A scheme for determination of a chip
a) conventional milling; b) climb milling

Therefore, changing the current angle δ from 0 to ψ also changes its value. The maximum chip thickness is obtained at a current angle δ = ψ (contact angle):

$$a_\delta = s_z.\sin\psi \qquad (8)$$

Thickness of the chip can also be presented depending on t, D and s_z (Lotfi et al., 2008). From the geometric dependence on figure 2, it follows that:

$$\cos\psi = \frac{\frac{\text{D}}{2} - t}{\frac{D}{2}} \approx \frac{D - 2.t}{D} = 1 - \frac{2.t}{D} \qquad (9)$$

In dependence $\sin\psi = \sqrt{1-\cos^2\psi}$ is replaced by cosψ from dependence (9) and is obtained:

$$\sin\psi = \sqrt{1-(\frac{D-2.t}{D})^2} = 2.\sqrt{\frac{t}{D}-\frac{t^2}{D^2}} \qquad (10)$$

The maximum chip thickness will be:

$$a_{max} == 2.s_z.\sqrt{\frac{t}{D}-\frac{t^2}{D^2}} \qquad (11)$$

Sometimes it is necessary to work with average thickness of the chip measured at angle ψ/2. Then $a_{\frac{\psi}{2}} = s_z.\sin\frac{\psi}{2}$ but since $\sin\frac{\psi}{2} = \sqrt{(1-\cos\psi)}.\frac{1}{2}$ and cosψ is known, it is:

$$\sin\psi = \sqrt{(1-\frac{D-2.t}{D}).\frac{1}{2}} = \sqrt{\frac{t}{D}}, \qquad (12)$$

then $a_{\frac{\psi}{2}} = s_z.\sqrt{\frac{t}{D}}$.

The cross section of the chip in a cylindrical milling for cutters with straight teeth is determined in the following manner:

$$f = B.a,[mm^2];\ f_{max} = B.a_{max} = 2.B.s_z.\sqrt{\frac{t}{D}-\frac{t^2}{D^2}} \qquad (13)$$

$$f_{\frac{\psi}{2}} = B.s_z.\sqrt{\frac{t}{D}} \qquad (14)$$

By analyzing the theoretical dependencies, it can be concluded that the parameters of the cut metal layer during milling can serve as a basis for the study of the parameters of the cutting process.

3. EXPERIMENTAL STUDIES

A 3D model of a monolithic milling cutter (figure 3) and a working environment (figure 4) was created to perform the experimental research (Василев, 2014). Modeling was done using SolidWorks software based on hybrid parametric modeling technology and a wide range of specialized modules. It creates fully realistic example models with or without limitations and is perfectly suited to solving the task (Merdol and Altintas, 2008).

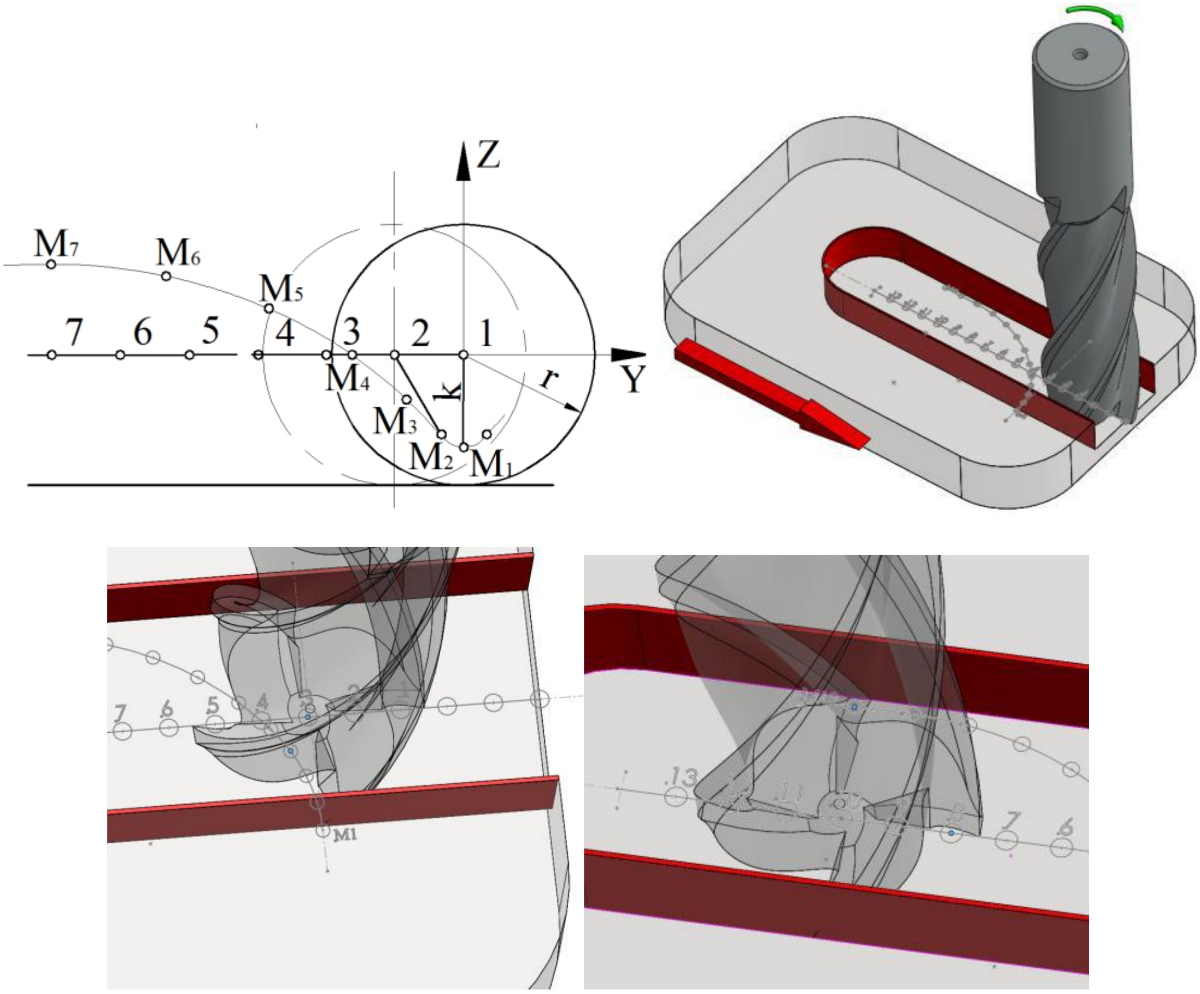


Fig. 3. A 3D model of a monolithic milling cutter

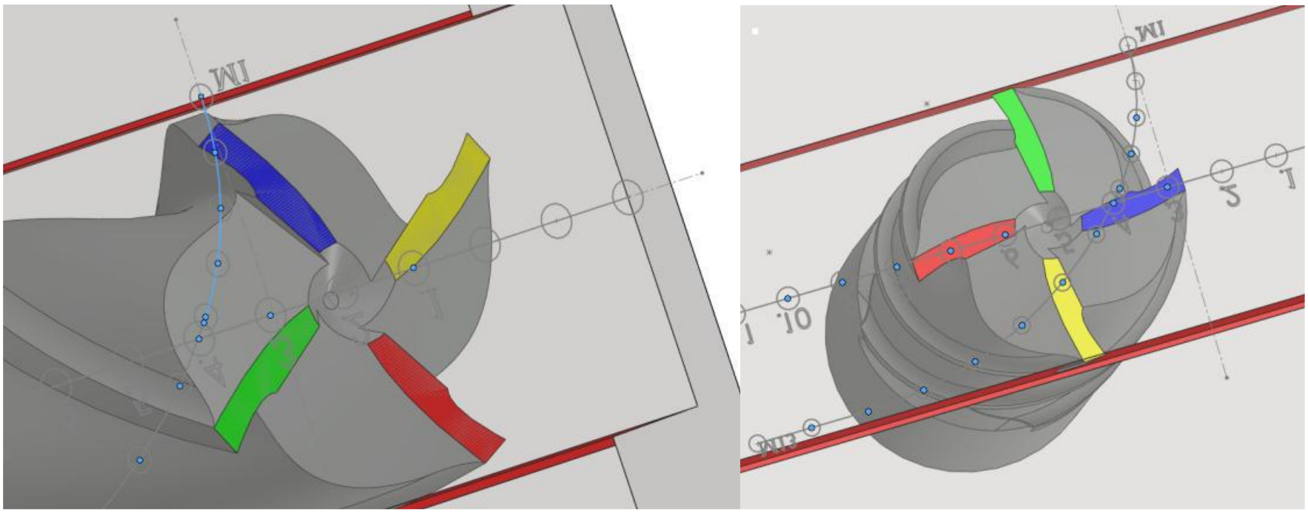


Fig. 4. A working environment

When simulating the operation of the tool in a particular working trajectory is obtained changing of the area of the chip for milling cutters with a diameter D=8; 15; 22 mm at different positions K_i (Figure 3) of the cutting edge, expressed by angle φ.

The obtained results are given in table 1, table 2 and table 3 and graphs shown in figure 5 a)-c).

Table 1. Changing of the area of the chip (D=8mm)

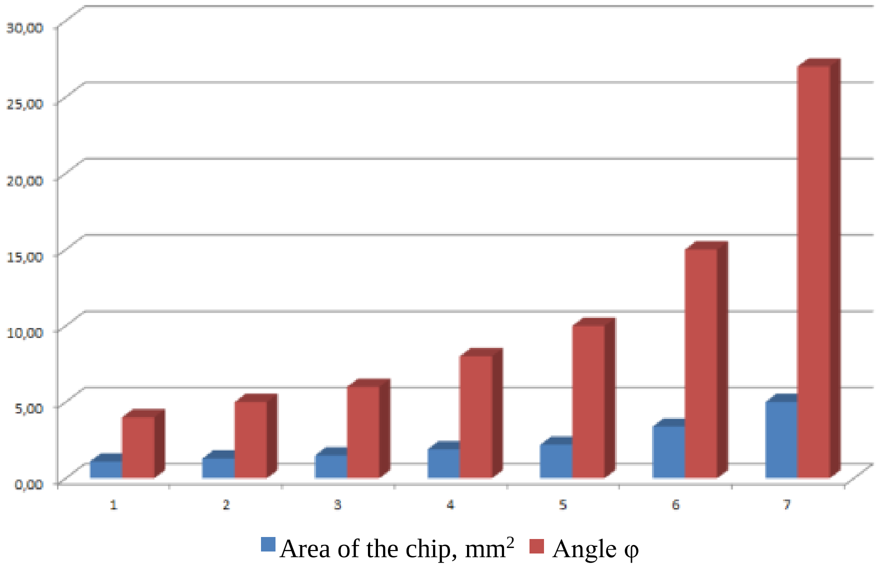
Different positions K_i of the cutting edge	Area of the chip, [mm^2]	Angle φ, [°]	K<r
1	1.10	4	Shortened hypocycloid
2	1.30	5	
3	1.50	6	
4	1.90	8	
5	2.20	10	
6	3.40	15	
7	5.00	27	

Table 2 Changing of the area of the chip (D=15mm)

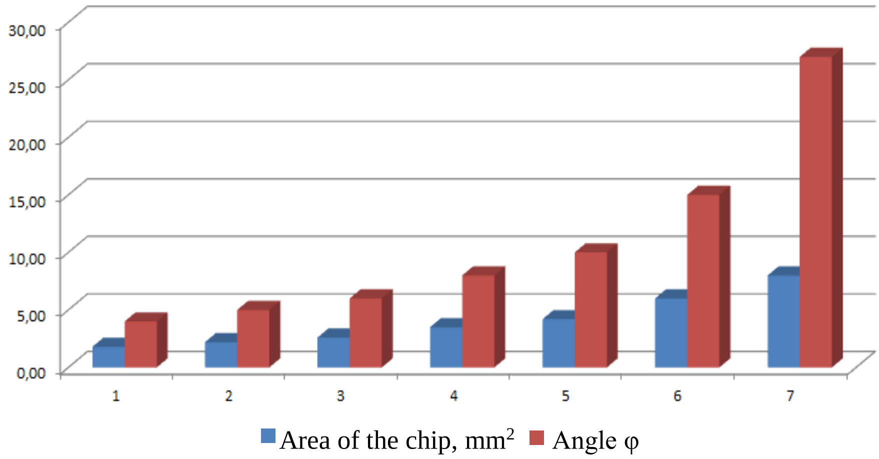
Different positions K_i of the cutting edge	Area of the chip, [mm^2]	Angle φ, [°]	K<r
1	1.80	4	Shortened hypocycloid
2	2.20	5	
3	2.60	6	
4	3.50	8	
5	4.20	10	
6	6.00	15	
7	8.00	27	

Table 3 Changing of the area of the chip (D=22 mm)

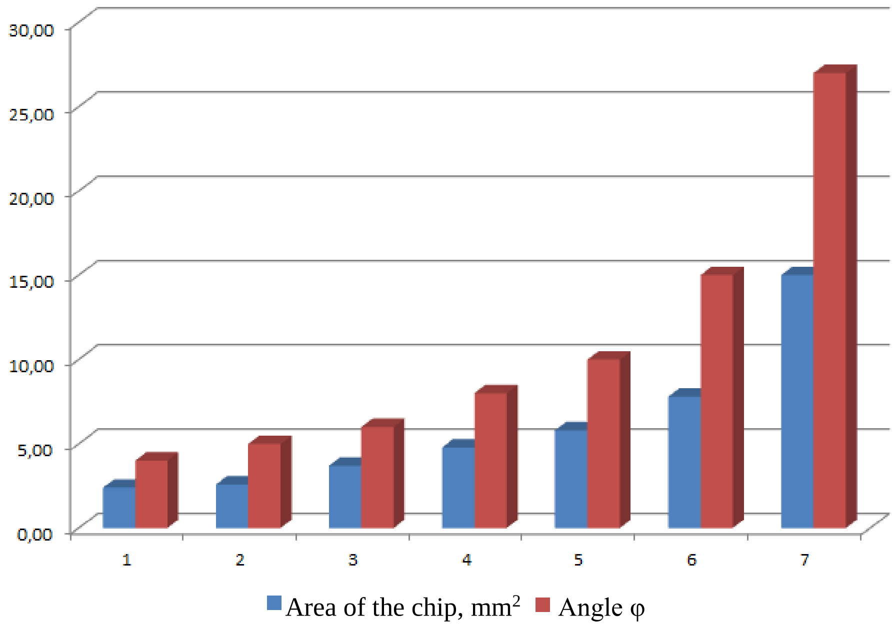
Different positions K_i of the cutting edge	Area of the chip, [mm^2]	Angle φ, [°]	K<r
1	2.40	4	Shortened hypocycloid
2	2.60	5	
3	3.70	6	
4	4.80	8	
5	5.80	10	
6	7.80	15	
7	15.00	27	



a)



b)



c)

Fig. 5. Changing of the area of the chip

a) result for D=8 mm; b) result for D=15 mm; c) result D=22 mm

4. ANALYSIS

Analyzing the theoretical dependencies developed in point 2 can be seen the following:

1. The chip thickness (a_δ and a_ψ) increases with the increase of the feed rate s_z and the milling depth t and decreases as the diameter of the milling cutter D increases.
2. Maximum chip thickness is obtained when using milling cutters with smaller diameter and work with a large depth t.
3. Studies of change in the area of the chip shows indirectly loading the tool and can assess the moment of incision and exit of the milling cutter from the workpiece.

5. CONCLUSIONS

When machining channels with triangular milling cutters, apparently is working with the greatest load.

Theoretical dependencies and 3D modeling cannot assess the change in chip parameters as they do not take into account the changes occurring as a result of the deformation processes in the cutting zone.

The thickness of the chip at a conventional and climb milling remained approximately the same assessed as a geometric figure.

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