KINEMATIC SCHEMES OF CUTTING IN MILLING

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Abstract: *The presented article analyzes the used kinematic schemes of cutting in milling. With their change and the change in the kinematic ratio of the velocities of the elementary movements, the type of the work surface can be changed.*

The mathematical dependences presented in the article, describing the trajectory of the relative work motion of a cutting edge point, are used to conduct theoretical studies of the geometric parameters of the milling cutter performed by simulation modeling in the environment of the software SolidWorks.

Key words: kinematical cutting schemes, cutting in milling, face milling

1. Introduction and actuality of the problem

The machining of the parts by cutting is based on certain movements performed by the tool relative to the workpiece. In order to perform a particular processing, the executive units of the respective machine need to transmit to the tool and the workpiece such movements that at the end of the working process result in a part with a certain accuracy of the shape and dimensions and the quality of the treated surface. In this sense, the movements of the tool and the workpiece for each particular processing are carried out according to a strictly regularity, observance of which is of decisive importance for the construction of a particular method of machining and if it is required for a particular processing machine [3].

Milling is one of the most productive cutting processes and therefore, the present work analyzes the used kinematic cutting patterns.

2. Task staging

The main concepts and definitions used are mainly taken up by the terminology of Acad. Grenovski GI, an active member of the Latvian Academy of Sciences [1]:

- A principal kinematic cutting scheme - this is a combination of the absolute movements of the tool and the workpiece during cutting;
- Trajectory of the relative working movement - when the points of the cutting edge of the tool are moved relative to the workpiece at a velocity and a sequence predetermined by the kinematic pair "tool-part";
- Forming scheme - illustrates the kinematic pair in working position, with the type and relation between the linear and angular velocities of the movements predetermined by the selected principle kinematical cutting scheme, providing quality indicators of the surface to be treated;
- Cutting scheme – the preliminary adopted sequential order to remove the additive from the workpiece to obtain the finished part.

The above requires the development of a complex approach to the development of processes for machining arising from the capabilities of CNC machines.

3. Kinematic features of the milling process

By changing the principle of the kinematical cutting schemes and the kinematic ratio of the velocities of the elementary movements the shape of the work surface of the workpiece changes [2].

The friction and the wear on the contact surfaces of the tool also largely depends on the suitably selected kinematic machining schemes.

Gerbert Ivanovich Granovski has classified the principle kinematics schemas in 8 groups, the main ones used in milling are in 4, 5, 7 groups [1, 2]. Fig. 1 shows the scheme for determining the number of principal kinematic cutting schemes (PKCS) of group 4.

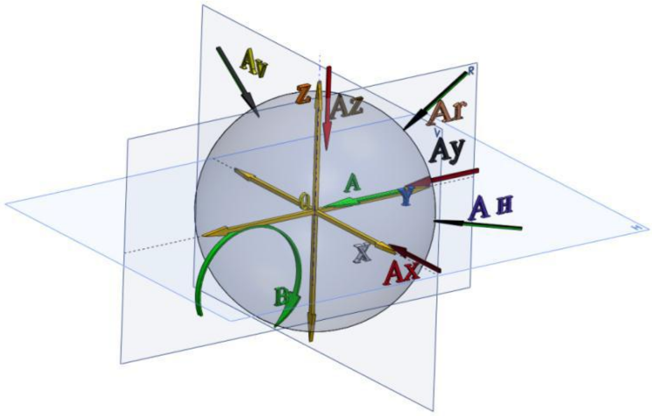


Fig.1 A scheme for determining the number of principal kinematic cutting schemes (PKCS) of group 4

The number of kinematic schemes in Group 4 is determined by the characteristic positions of the rectilinear motion A at a fixed rotational motion B and an axis parallel to the axis X of the coordinate system.

The third PKCS of the fourth group includes: a rectilinear uniform motion A carried out along the Y axis of a spatial coordinate system XYZ and evenly rotationally B with axis coinciding with axis X of the coordinate system (fig.2 a)).

In this case, two variants are possible, depending on who the two elementary movements belong to:

- I variant – movement A is on the tool, and B is the workpiece. In this kinematic scheme, the trajectory of the relative working movement is a helix (Fig. 2 b)) and cannot be used in milling;
- II variant – movement B belongs to the tool and the uniform rectilinear motion A of the workpiece. Ratio ε between the velocities of the movements of the kinematic scheme of cutting is in the range:

$$\varepsilon = \frac{V_A}{V_B} = 0{,}005 \div 0{,}05 \qquad (1)$$

The trajectory of the relative movement of a point on the cutting edge of the tool is a plane curve described in the YOZ plane [4], i.e. in the same coordinate plane in which both movements of the kinematic scheme operate. The relative trajectory is defined as a point associated with a circle that rolls without sliding on straight line. If point A is a point of a circle with radius r (Fig. 2 c)) and it is rolling on a straight line, then the same point A describes the trajectory sought. Its character is determined in the following order:

$$- y = r.\varphi - r.\sin\varphi \rightarrow y = r.(\sin\varphi - \varphi) \rightarrow r = \frac{y}{(\sin\varphi - \varphi)} \quad (2)$$

$$- z = r.\cos\varphi \rightarrow z = -r.\cos\varphi \rightarrow r = \frac{z}{\cos\varphi} \quad (3)$$

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

Therefore:

$$y.\cos\varphi + z.(\sin\varphi - \varphi) = 0 \quad (4)$$

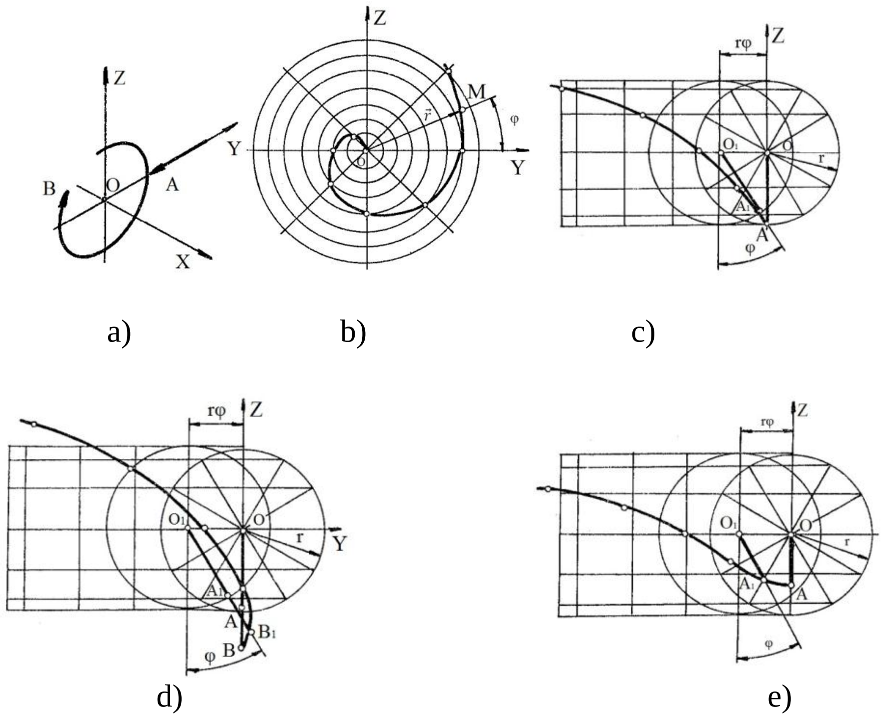


Fig.2 Principal kinematic cutting schemes and trajectories of the relative working movement

This expression represents the equation of the cycloid.

If the point associated with the circle is outside it (AB = a), then the trajectory of the relative work movement is described by point B (Fig. 2 d)). The character of this trajectory is determined in the following way:

$$- y = r.\varphi - (r + a).\sin\varphi \rightarrow y = r.(\sin\varphi - \varphi) + a.\sin\varphi \rightarrow r = \frac{y - a.\sin\varphi}{(\sin\varphi - \varphi)} \quad (5)$$

$$- z = (r + a).\cos\varphi \rightarrow z = -r.\cos\varphi - a.\cos\varphi \rightarrow r = -\frac{z + a.\cos\varphi}{\cos\varphi} \quad (6)$$

Therefore:

$$(y - a.\sin\varphi).\cos\varphi + (z + a.\cos\varphi).(\sin\varphi - \varphi) = 0 \quad (7)$$

This expression represents the equation of the extended cycloid.

The third possible case is when the point A describing the relative trajectory is a point of the radius of the circle (Fig. 2 e)) and if a = r-AO the character of trajectory is determined in the following order:

$$- y = r.\varphi - (r - a).\sin\varphi \rightarrow y = r.(\sin\varphi - \varphi) - a.\sin\varphi \rightarrow r = \frac{y + a.\sin\varphi}{(\sin\varphi - \varphi)} \qquad (8)$$

$$- z = (r - a).\cos\varphi \rightarrow z = -r.\cos\varphi + a.\cos\varphi \rightarrow r = -\frac{z - a.\cos\varphi}{\cos\varphi} \qquad (9)$$

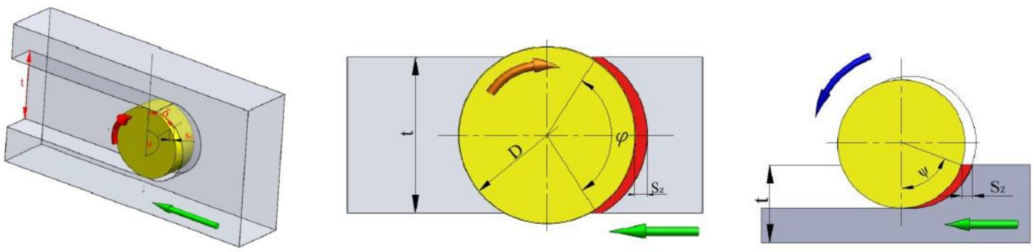
Therefore:

$$(y + a.\sin\varphi).\cos\varphi + (z - a.\cos\varphi).(\sin\varphi - \varphi) = 0 \qquad (10)$$

This is the equation of a shortened cycloid.

4. Technological aspects of milling of planar surfaces

Depending on the position of the front of the milling cutter in relation to the width of the workpiece, there are three possible ways of face milling (fig. 3 a) and b)).



a) b) c)

Fig. 3 Three ways for face milling
a) the tool start to cut with zero thickness of the chip; b) incompletely symmetrical milling; c) incomplete asymmetrical face milling

The teeth of the milling cutter (Fig. 3 a)) begin to cut a material with a zero thickness of the chip, which gradually increases to its maximum value at an angle $\psi = 90°$ [5]. With a further increase in the contact angle ($\psi > 90°$), the chip thickness decreases. At an angle $\delta = 90°$, the chip thickness is greatest. At incomplete symmetrical face milling the teeth of the milling cutter cut a chip of considerable thickness and with a cross-section corresponding to the section for the corresponding angle of the momentary position of the milling cutter's teeth: $\delta > 0$ and $t < D$ (Fig. 3b)).

At incomplete symmetrical face milling $t \leq D/2$ (фиг.3 c)). The teeth of the milling cutter at the beginning also cut a zero-thickness chip [6]. The area of cross-section of the cut metal layer is a multiplication of the width and thickness of the milling:

$$f = B.a, \ mm^2 \qquad (11)$$

From the trajectory of movement of the tool mainly depend on the working angles of the tool, such as the clearance angle must have the required maximum value at milling [7].

It is known that the angles of the tool change in the cutting process.

Fig. 4 illustrates the principle of variation at angle $\psi > 90°$:

$$\alpha_{kin} = \mathrm{arctg}\frac{s_0}{\sqrt{\pi^2 D^2 - s_0^2}} \qquad (12)$$

where: α_{kin} - kinematic clearance angle, °; D - diameter of the milling cutter, mm; s_0 – feeding per one revolution of the milling cutter, mm/rev.

The working clearance angle α_w is equal to:

$$\alpha_w = \alpha - \alpha_{kin} \qquad (13)$$

where: α – static clearance angle, °;

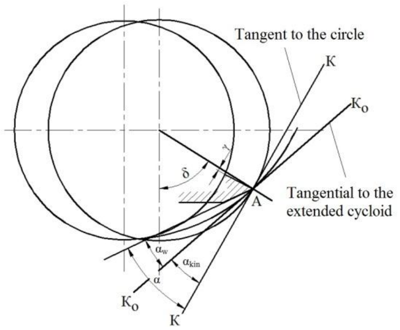


Fig.4 Changing tool angles

The rake angle is determined by the clearance angle:

$$\gamma_{kin} = -\alpha_{kin}, \text{ and } \gamma_w = \gamma + \gamma_{kin} \quad (14)$$

where: γ_w – working rake angle, °.

5. Results of theoretical research

The research was performed using simulation modeling using SolidWorks. Fig. 5 shows a scheme for determining of angle φ, diameter 50 mm on the milling cutter is selected (D = 15 mm, 22 mm, 36 mm, 50 mm), at R = 25 mm, K = 7. The parameter K represents the position of a certain point t from the cutting edge.

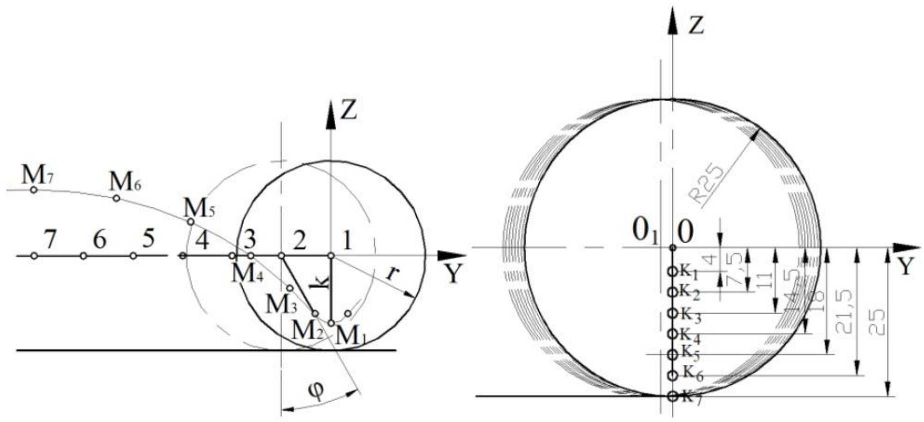


Fig.5 A scheme for determining of angle φ

The results for the change of angle α for different diameters of disposal at a point of the cutting edge (K) are shown in Tables 1 to 4.

Tabl.1 Change of angle α at D=15 mm

K	Chip area, mm^2	Angel φ, °	Angel α, °
1	1,80	4	5°
2	2,20	5	4°55’
3	2,60	6	4°53’
4	3,50	8	4°50’

Tabl.2 Change of angle α at D=22 mm

5	4,20	10	4°48’
6	6,00	15	4°46’
7	8,00	27	4°43’

K	Chip area, mm^2	Angel φ, °	Angel α, °
1	2,40	4	5°
2	2,60	5	4°52’
3	3,70	6	4°44’
4	4,80	8	4°36’
5	5,80	10	4°33’
6	7,80	15	4°30’
7	15,00	27	4°21’

Tabl.3 Change of angle α at D=36 mm

K	Chip area, mm^2	Angel φ, °	Angel α, °
1	3,40	4	5°
2	4,40	5	4°52’
3	5,30	6	4°44’
4	7,00	8	4°35’
5	9,00	10	4°27’
6	14,00	15	4°19’
7	25,00	27	4°12’

Tabl.4 Change of angle α at D=50 mm

K	Chip area, mm^2	Angel φ, °	Angel α, °
1	5,10	4	5°
2	6,30	5	4°52’
3	7,50	6	4°44’
4	11,00	8	4°35’
5	13,00	10	4°25’
6	19,70	15	4°15’
7	36,30	27	4°05’

6. Conclusions

6.1. In planar milling trajectory of the relative working motion is entirely dependent on the position of motion A (Figure 1), in each case the tool performs rotational movement.

6.2. The trajectory of the relative working motion is a planar curve, the variants are extended and shortened cycloid.

6.3. A suitable method for study the geometric parameters of the milling cutter is the virtual modeling and simulation approach describing the real movements of the milling cutter.

6.4. The change of the clearance angles at different points of the cutting edge of milling cutters with diameters D = 15, 22, 36, 50 mm is minimal and on the efficiency of the tool is influenced by the different cutting speed from the center towards the periphery.

References

[1] **Грановски Г. И.**, *Кинематика резания*, Машгиз, Москва, 1948г., p.150

[2] **Грановский Г.И., Грановский В.Г.**, *Резание металлов***,** Высшая школа, Москва, 1985, p.304

[3] **Лефтеров Е.**, *Оптимални методи и средства за механична обработка*, ИЦ на РУ „Ангел Кънчев“, Русе, 2013

[4] **Лефтеров Е.**, *Режещи инструменти*, Лазаров Дизайн ЕООД, Варна, 2017, p.482

[5] **Симеонов Н. Г., Лефтеров Е. Л.**, *Ефективност и приложимост на високоскоростното фрезоване*, сп. МТТ, Печатна база на ТУ-Варна, 2014, ISSN 1312-0859, p. 69-75

[6] **Симеонов Н. Г., Лефтеров Е. Л.**, *Материал и геометрия на режещи инструменти за високоскоростно фрезоване*, сп. МТТ, Печатна база на ТУ-Варна, 2014, ISSN 1312-0859, p. 64-69

[7] **Li J.L., Jing L.L., Chen M.,** *An FEM study on residual stresses induced by high-speed end-milling of hardened steel SKD11*, Journal of Materials Processing Technology, Volume 209, Issue 9, Elsevier, May, 2009, p. 4515-4520