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High performance processing of lath details with a rotary tool, when the workpiece and the tool have intersecting axes at a 90º angle

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Abstract. A high-performance method has been developed for machining turning parts with a rotating tool when the workpiece and the tool have intersecting axes at an angle equal to 90º. The method is applicable to multi-functional CNC machines. The main advantage of the method is high productivity. The main disadvantage is that a surface with great roughness is obtained and a clean treatment is necessary. Therefore, the method is applicable for rough processing, where it is necessary to remove large additions of material. The method is very good for processing plastics, as a brittle chip is obtained.

Keywords: High performance, intersecting axes, rotary tool.

1. Basics

In the current scientific work, we are going to look upon the high-performance processing of lath details with a rotary tool, when the workpiece and the tool have intersecting axes at a 90 degrees angle. The method is much more characterized with its higher output to the conventional turning with a lathe blade, which determines the topicality. The aim of the following article is: to derive the trajectory equations of a point from the cutting edge of the tool, to determine geometric parameters and the change of the tool angles into working angles, to determine the parameters of the mode of cutting when processing for the three main lathe surfaces – cylindrical, conical and frontal.

2. Development of a high-performance processing method for machining lathes with a rotary tool when the workpiece and the tool have intersecting axes at an angle of 90 º.

When processing lathe surfaces with a rotary tool, positioned so that the axis of rotation of the workpiece and the tool should intersect at an angle of 90º, three basic cases are considered to be processed - cylindrical, conical and frontal surfaces.

Kinematic milling scheme of an external cylindrical surface of a centralized lathe pivot, when the axis of rotation of the workpiece and the tool intersect is shown on figure 1 [1]. When processing cylindrical surfaces, the tool and the workpiece execute the following movements:

- Rotation of the tool to its own axle – the main movement of cutting „Dc"
- Rotation of the workpiece to its own axis – enclosing movement „D_{f1}".
- Linear motion of the tool in parallel of the axle z of the workpiece – enclosing movement „D_{f2}":

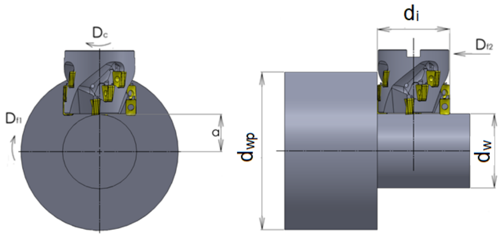

Fig. 1 Kinematic milling scheme of an external cylindrical surface of a centralized lathe pivot, when the axis of rotation of the workpiece and the tool intersects.

The trajectory of a point from the cutting edge is described by the equation 1.

$$x = a * \cos(\varphi_1) - \left(\frac{d_i}{2}\right) * \sin(i_{12} * \varphi_1) * \sin(\varphi_1)$$

$y = -(\, a * sin(\varphi_1)) - \left(\frac{d_i}{2}\right) * \sin(i_{12} * \varphi_1) * \cos(\varphi_1)$ (1)

$z = (\, h/360) * \, (\varphi_1)) \, - \, (d_i/2) * \sin(i_{12} * \varphi_1) * \cos(\varphi_1)$

Where:

a – the wheelbase of the tool and the workpiece.

d_w – diameter of the processed surface;

d_i – diameter of the tool;

d_{wp}– diameter of the workpiece;

i_{12} – gear ration showing how many times the tool has rotated around its axle for once cycle of the workpiece. $i_{12} = \varphi_2/\varphi_1$;

h – measure of the helical line;

φ_1 – angle of rotation of the workpiece: φ_1 changes from 0 to 360°;

φ_2 – angle of rotation of the tool:

$\varphi_2 = i_{12} * \varphi_1$;

On fig. 2 the trajectory of the point of the cutting edge is shown, described with equation 1. Obtained by the milling of an external cylindrical surface of a turning center, when the axis of rotation of the workpiece and the tool cross.

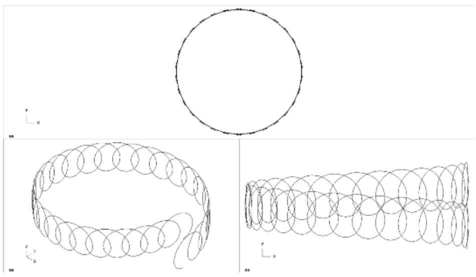

Fig. 2 The trajectory of the point of the cutting edge is shown, described with equation 1.

The kinematic milling scheme of the outer conical surface of the center, when the axis of rotation of the workpiece and the tool are crossed is shown on figure 3.

Linear motion of the center of rotation of the tool relative to the axis of rotation of the workpiece „Df2“. The perpendicular motion is parallel to the cone forming.

Fig.3 Kinematic milling scheme of an external conical surface of a centralized lathe pivot, when the axis of rotation of the workpiece and the tool intersects.

The trajectory of a point from the cutting edge is described the equation 2:

$x = hx * (\frac{1}{360}) * \varphi_1 * \cos(\varphi_1) - (d_i/2) * \sin(i_{12} * \varphi_1) * \sin(\varphi_1)$

$y = hx * (\frac{1}{360}) * \varphi_1 * sin(\varphi_1) - (d_i/2) * sin(i_{12} * \varphi_1) * cos(\varphi_1)$ (2)

$z \, = \, hz * \left(\frac{1}{360}\right) * \, \varphi_1 \, - \, \left(\frac{d_i}{2}\right) * cos(i_{12} * \varphi_1)$

Where:

hx – measure of conical screw line on the axis x;

hz – measure of conical screw line on the axis z;

к – angle of the cone – tang(к) = hz / hx

On fig. 4. Is shown the trajectory of point from the cutting edge described with the equation 2. The curve is a conical screw line described by an elongated epicycloid.

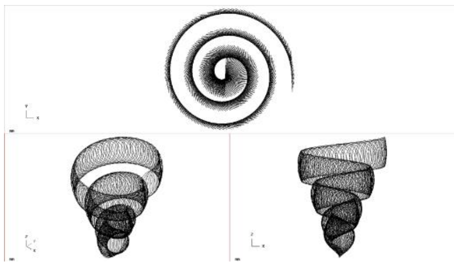

Fig. 4. The trajectory of the point of the cutting edge is shown, described with equation 2

Kinematic scheme of milling on the frontal surface of the lathe, when the axis of rotation of the workpiece and the tool cross as shown on figure 5. During processing of frontal surfaces, the tool and the workpiece perform the following movements:

Linear feed perpendicular to the axis of the workpiece, is performed from the periphery to the axis of the workpiece – feed movement „D_{f2}”:

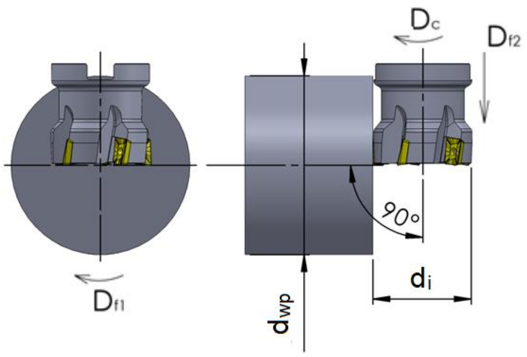

Fig. 5. Kinematic milling scheme of an external frontal surface of a centralized lathe pivot, when the axis of rotation of the workpiece and the tool intersects.

Trajectory of a point from the cutting edge of the tool can be described with equation 3.

$$x = h * \left(\frac{1}{360}\right) * \cos(\varphi_1) * \varphi_1 - \left(\frac{d_i}{2}\right) * \sin(i_{12} * \varphi_1) * \sin(\varphi_1)$$

$$y = -h * \left(\frac{1}{360}\right) * \sin(\varphi_1) * \varphi_1 - \left(\frac{d_i}{2}\right) * \sin(i_{12} * \varphi_1) * \cos(\varphi_1)$$

$$z = -\left(\frac{d_i}{2}\right) * \cos(i_{12} * \varphi_1)$$
(3)

Where:

h*(1/360) – parameter of Archimedean screw line.

On figure 6 the trajectory of a point from the cutting edge is shown, described with equation 3, formed by processing the frontal surfaces of lathe details with a spinning tool, when the workpiece and the tool are with crossing axis:

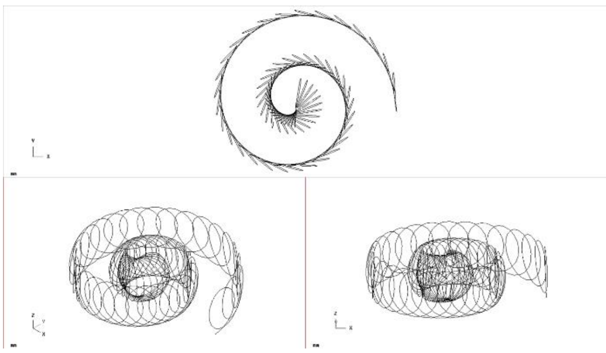

Fig. 6. The trajectory of the point of the cutting edge is shown, described with equation 3

3. Determination of geometrical parameters and change of tool angles in working angles, when processing turning surfaces with a rotary tool, when the workpiece and the instrument are with crossing axis.

For turning with a rotary tool on cylindrical surfaces, when the tool and the workpiece are with crossing axis, you can observe a change of the tool angles into working angels, at the three coordinate planes – 0xy, 0yz, 0xz. Changing the tool angles to working angles can be determined with the angle projections η respectively in each of the three planes. Determination of the angles η_{xy}, η_{yz} и η_{xz} is done through a analytic method.

Deriving the first derivatives of the trajectory of a point from the cutting edge with equation 4.

$$x' = -a * \sin(\varphi_1) - (d_i/2) * i_{12} * \cos(i_{12} * \varphi_1) * \sin(\varphi_1) - (d_i/2) * \cos(\varphi_1) * \sin(i_{12} * \varphi_1) \quad (4)$$

$$y' = -a * \cos(\varphi_1) - (d_i/2) * i_{12} * \cos(i_{12} * \varphi_1) * \cos(\varphi_1) + (d_i/2) * \sin(\varphi_1) * \sin(i_{12} * \varphi_1)$$

$$z' = (h/360) + (d_i/2) * i_{12} * \sin(i_{12} * \varphi_1)$$

Deriving the first derivatives of the trajectory of a point from the cutting edge only of the cutting motion of equation 5:

$$x' = -(d_i/2) * i_{12} * \cos(i_{12} * \varphi_1) * \sin(\varphi_1) - (d_i/2) * \cos(\varphi_1) * \sin(i_{12} * \varphi_1)$$

$$y' = -(d_i/2) * i_{12} * \cos(i_{12} * \varphi_1) * \cos(\varphi_1) + (d_i/2) * \sin(\varphi_1) * \sin(i_{12} * \varphi_1)$$

$$z' = (d_i/2) * i_{12} * \sin(i_{12} * \varphi_1) \quad (5)$$

Determination of the angle η_{xy} in the coordinate plane 0xy:

Determination of the instantaneous direction of the operating speed:

Angle μ_{xy}, is the one, that concludes the instantaneous direction of the operating speed with the positive axis direction of x. Angle μ_{xy} is determined with equation 6, using the first derivatives of equation 4:

$$\mu_{xy} = \tan^{-1}(y'/x') \quad (6)$$

Defining the instantaneous direction of cutting speed:

Angle ν_{xy} is the one, that concludes the instantaneous direction of cutting speed with the positive axis direction of x. Angle ν_{xy} is determined with equation 7, using the first derivatives of equation 5:

$$\nu_{xy} = \tan^{-1}(y'/x') \quad (7)$$

Angle η_{xy} is the one, that between the instantaneous direction of the cutting speed and the instantaneous direction of the working speed. Angle η_{xy} is determined with equation 8:

$$\eta_{xy} = \mu_{xy} - \nu_{xy} \quad (8)$$

Angle η_{xy} changes the tool angles into working in planes 0xy (уравнение 9):

$$\alpha_{fe}\, xy = \alpha_f\, xy - \eta_{xy} \quad (9)$$

$$\gamma_{fe}\, xy = \gamma_f\, xy - \eta_{xy}$$

Determining the angle η_{yz} in the coordinate plane 0yz and angle η_{xz} in the coordinate plane 0xz happens in a similar way. The value of the angle η_{yz} is determined with equation 10:

$$\eta_{xz} = \mu_{xz} - \nu_{xz} \quad (10)$$

Angle η_{yz} changes the tool angles into working in planes 0yz (equation 11):

$$\alpha_{fe}\, xz = \alpha_f\, xz - \eta_{xz}$$

$$\gamma_{fe}\, xz = \gamma_f\, xz - \eta_{xz} \quad (11)$$

During turning with a rotary tool on conical and frontal surfaces, when the tool and the workplace are with crossing axis, there is a change in tool angles into working angles in the three coordinate planes – 0xy, 0yz, 0xz. They are defined in a similar way.

4. Determination of cutting mode parameters for processing rotary surfaces when the workpiece and the tool have an intersecting 90º angles.

Processing of turning surfaces with a rotary tool, when the workpiece and the tool have intersecting axis, it is essentially a frontal cylindrical milling cutter.

In the frontal cylindrical milling, the cutting mode parameters are the cutting speed V_c, feed rate f; depth of cutting a. Cutting speed Vc is determined from equation 12.

$$V_c = \frac{\pi * d * n}{100} \quad (12)$$

Where:

n – frequency of rotation of the tool.

d – diameter of the tool.

Feed f – the path, passed by the tool in the feed direction for aa single turn of the cutting movement.

Two feeds are considered for the processing of a cylindrical surface:

- f_1 the feed observed in coordinating plane 0xy;
- f_2 the feed observed in coordinating plane 0xz:

The feed f_1 during the processing of a cylindrical surface, is determined from the movement of the axis of the tool against the axis of rotation of the workpiece. The axis of the instrument is moving in a screw line. The feed f_1 is determined with equation 13:

$$f_1 = P / i_{12} \quad (13)$$

Where:

P – the length of the circumference along which the axis of the tool moves – P=2×π×a.

a – wheelbase between tool and workpiece:

Feed of f_2 during procession of cylindrical surface is the path, that is passed from the axis of the tool along the axis z for a single turn of the cutting movement. The feed f_2 is defined as in equation 1 for the axis z=(h/360)*φ_1 and then replace φ_1=360°/i_{12} .

Feed f_2 is defined by equation 14:

$$f_2 = h / i_{12} \quad (14)$$

The axial depth of cut a_p is defined from t – the radial difference between the diameter of the workpiece and the diameter of the processed outer cylindrical surface. The axial depth of cut a_p is defined by equation 15.

$$a_p = t = \frac{D_{wp}}{2} - \frac{D_w}{2} \quad (15)$$

The radial depth of cut a_e is defined from the measure of the screw line h, along which the axis of the instrument moves. The radial depth of cut a_e should not exceed the length of the cutting edge situated on the front of the tool $a_e \leq h$.

For the treatment of a conical surface two feeds are considered:

- f_1 the feed that is viewed in the coordinate plane 0xy;
- f_2 the feed that is viewed in the coordinate plane 0xz:

The feed f_1 *is* determined from the movement of the axis of the tool according to the rotational axis of the workpiece. The axis of the tool moves across a conical screw line. For a single turn of the cutting movement, the workpiece has already rotated has rotated at an angle of $360/i_{12}$. The feed f_1, considered in the coordinate plane 0xy is equal to the length of the arc *l*, described on the axis of the tool for one for one revolution of the cutting movement. The length of the arc *l* formed from the angle of φ_1 for one cycle of the tool is defined by equation 16:

$$f_1 = \frac{2\times\pi\times h_x\times k}{i_{12}} \quad (16)$$

The feed f_2 defines the length, that the axis of the tool passes along the z axis for one cycle of the tool. Feed f_2 is defined as an equation 2 for the axis.

$z = (h_z/360)*\varphi_1$ replaced with $\varphi_1 = 360 / i_{12}$. The feed f_2 is defined by equation 17:

$$f_2 = h_z/i_{12} \quad (17)$$

Definition of the depth of cut during processing of conical surfaces.

Axial depth of cutting a_p – this is the incision of the main cutting edge into the workpiece, measured parallelly to the axis of the tool. The axial depth of cutting a_p is defined by t – the radial difference between the two diameters of the cone. Axial depth of cutting a_p is defined by equation 18:

$$a_p = t = \frac{D_2}{2} - \frac{D_1}{2} \quad (18)$$

Radial cutting depth a_e – incision of the main cutting edge into the workpiece, measured perpendicularly to the axis of the instrument. Radial cutting depth a_e is determined by measure h_z of the conical screw line measured along the z axis along which the axis of the tool moves. Radial depth of cutting a_e must not exceed the length of the cutting edge, located on the head of the tool (equation 19):

$$a_e \leq l_p \leq h \quad (19)$$

Feed f for the processing of the end surface, the feed through the end screw line is considered (equation 20):

$$f = l = \frac{a}{2} * \left(\varphi_1 * \sqrt{\left((\varphi_1^2 + 1)\right)} + \text{sech}^{-1}\varphi_1\right) \quad (20)$$

Where:

l – length of arch, formed by the frontal screw line to rotate the tool in one revolution.

a – Archimedean screw line parameter, showing the displacement of the axis of the tool when rotating the workpiece to angle φ_1.

a =h *(1/360).

h – measure of the front screw line;

φ_1 – angle of rotation of the workpiece per revolution of the tool.

i_{12}– gear ratio, indicating how many times the tool has rotated about its axis for one workpiece revolution.

Determination of cutting depths when processing the frontal surfaces.

Axial cutting depth a_p – incision of the main cutting edge into the workpiece, measured parallel to the axis of the tool. Axial cutting depth a_p is defined by equation 21;

$$a_p \leq h \quad (21)$$

Radial cutting depth a_e – incision of the main cutting edge into the workpiece, measuring perpendicular to the axis of the tool. The radial depth of cut a_e is determined by the additive for the processing of the frontal surface.

5. Conclusion:

Heavy duty methods have been developed for processing cylindrical, conical, face surfaces.

The equations for the trajectory of a point from the cutting edge are derived, geometric parameters are defined and the cutting mode parameters for cylindrical, cones and frontal surfaces.

6. Literature

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