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KINEMATICS OF THE CUTTING PROCESS WITH COMPLEX IMPOSED VIBRATIONS DURING MACHINING OF HOLES

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ABSTRACT— *In modern mechanical engineering interest are new cinematic schemes which provide high performance coupled with the ensuring the quality requirements of machined surfaces. This paper proposes a new kinematic cutting scheme with complex imposed vibrations in machining of holes. The specificity of the process consists in the additional setting of the tool to axial and rotational oscillations simultaneously, resulting in a change in the primary and the feed motion. Construction of a vibrator for simultaneously setting the axial and rotary oscillations is shown.*

Keywords: cutting process, machining of hole, vibration

1. INTRODUCTUON

The processes of drilling and machining of holes (Astakhov, 2011) with tools having guiding smoothing supporting elements (Лефтеров, Николов,1989; Лефтеров, 2017) can greatly alleviate if in technological system are applied to the tool or workpiece complex imposed vibrations.

The advantages that give this type of machining are (Rincon, Ulsoy, 1994; Todić, Bartulović, 2016; Dref et. al., 2016):

- reliable chip shredding;
- increasing tool life;
- enhancing the exploitation capabilities of tools of this type, especially when machining hardly workable materials;
- reduction of forces and temperatures in the cutting process;
- reduction the impact of harmful vibrations arising in the technological system;
- reducing the impact of the unbalanced forces acting on drills on the basis of their periodic unloading and the elastic restoration of the position of the axis of their bodies.

This paper examines a new, more complex case of combining the imposed vibrations with their use specifically for drilling and smoothing the machined holes.

2. THEORETICAL DESCRIPTION OF THE NEW KINEMATIC SCHEME

The principle kinematic cutting scheme with complex imposed vibrations in machining of holes is shown in fig.1.

The specificity of the process consists in the additional setting of the tool to axial and rotational oscillations simultaneously, resulting in a change in the primary and the feed motion.

The vibrations are set by a hydraulic vibrator (fig.4) mounted on the tool body allowing changing the frequency and amplitude of the oscillation as well as the removal of one or the other vibrational movement or combining them.

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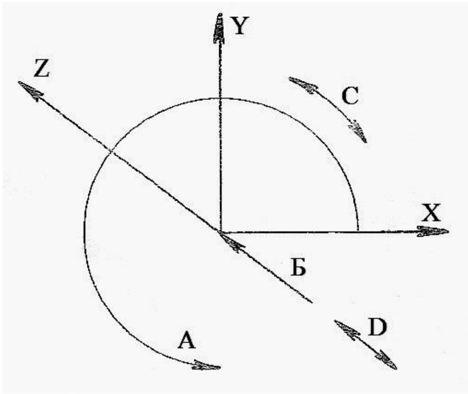

Fig.1 *Principle kinematic scheme*
A – primary working motion; B – main feed motion; D – additional vibrational motion along the axis; C – additional vibrational motion around the axis

Upon rotation the angular velocity of motion A together with the rotating vibrations is described by the equation:

$$\omega_n = \omega_{no} + A_n . sinK_n t \quad (1)$$

where: ω_{no} – initial speed of movement A; A_n – set amplitude of vibrational movement C; K_n – set frequency of vibrational movement C.

In the case under consideration, along with the rotating vibrations, there are also axial vibrations on the Z axis.

The equation for the point of the cutting edge without vibration, only flat rotation (motion A) is (fig. 2):

$$\begin{aligned} x &= r.cos\varphi \\ y &= r.sin\varphi \end{aligned} \quad (2)$$

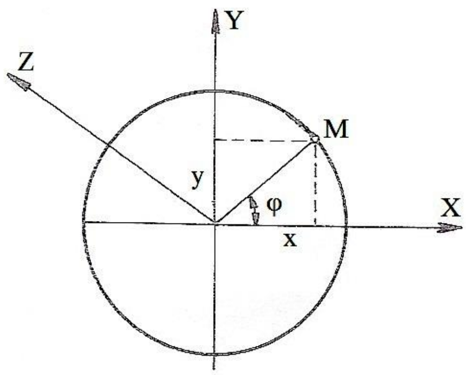

Fig.2 *A scheme showing a point on the cutting edge without vibration*

It is known that the angular velocity ω is the first derivative of the angle of rotation φ, and from equation (1) then:

$$\varphi = \omega_{no}t - \frac{1}{K_n}.A_n.sinK_nt \tag{3}$$

Including motion along the Z axis, the motion equation along the same axis is:

$$z = V_o t + A_n.sinK_nt \tag{4}$$

where: Vo – initial speed of movement B.

The general appearance of the trajectory equation of the cutting edge of the tool in the presence of the described complex imposed vibrations is:

$$\begin{aligned} x &= r.cos.(\omega_{no}t - \frac{A_n}{K_n}.cosK_nt) \\ y &= r.\sin(\omega_{no}t - \frac{A_n}{K_n}.cosK_nt) \\ z &= V_o t + A_n.sinK_nt \end{aligned} \tag{5}$$

The speed of the considered point from the cutting edge can be expressed as follows:

$$\bar{V} \begin{matrix} V_x = \dot{x} \\ V_y = \dot{y} \\ V_z = \dot{z} \end{matrix} \quad \begin{aligned} x &= -r.(\omega_{no} + A_n\dot{.}sinK_nt).\sin(\omega_{no}t - \frac{A_n}{K_n}.cosK_nt) \\ \dot{y} &= r.(\omega_{no} + A_n.sinK_nt).\cos\left(\omega_{no}t - \frac{A_n}{K_n}.cosK_nt\right) \\ \dot{z} &= V_o + A_n.K_n.cosK_nt \end{aligned} \tag{6}$$

The velocity is determined by the formula:

$$V = \sqrt{V_x^2 + V_y^2 + V_Z^2} = \sqrt{x^2 + y^2 + z^2}$$
$$V = \sqrt{r^2.(\omega - A_n sinK_nt)^2 + V_o^2 + A_n^2.K_n^2.cos^2K_nt + 2.V_o.A_n.K_n.cosK_nt} \tag{7}$$

The direction of the velocity vector is given by the indicated cosines $\cos(V,x) = \frac{\dot{x}}{V}$; $\cos(V,y) = \frac{\dot{y}}{V}$; $\cos(V,z) = \frac{\dot{z}}{V}$:

$$\begin{aligned} \cos(V,x) &= \frac{-r.(\omega_o + A_n\dot{.}sinK_nt).\sin(\omega_o t - \frac{A_n}{K_n}.cosK_nt)}{\sqrt{r^2.(\omega_o + A_n sinK_nt)^2 + (V_o + A_n.K_n.cosK_nt)^2}} \\ \cos(V,y) &= \frac{r.(\omega_o + A_n.sinK_nt).\cos\left(\omega_o t - \frac{A_n}{K_n}.cosK_nt\right)}{\sqrt{r^2.(\omega_o + A_n sinK_nt)^2 + (V_o + A_n.K_n.cosK_nt)^2}} \\ \cos(V,z) &= \frac{V_o + A_n.K_n.cosK_nt}{\sqrt{r^2.(\omega_o + A_n sinK_nt)^2 + (V_o + A_n.K_n.cosK_nt)^2}} \end{aligned} \tag{8}$$

The current value of the thickness of the cut metal layer will be obtained from two adjacent transitions of the tool:

$$S_t = S_o - 2.A_x.\sin n_i.\sin(k_t + n_i) \quad (9)$$

To facilitate the examination of the thickness of the cut metal layer, the following transformations are made:

$$\sin K_n t = \frac{\omega_n - \omega_{n10}}{A_n} \quad (10)$$

From equation (1) $K_n t = \arcsin\frac{\omega_n - \omega_{no}}{A_n} = \psi$ or $t = \frac{\psi}{k_n}$

substituting in equation (4), then:

$$S_t = S_o - 2.A_x.\sin n_i.\sin(k.\frac{\psi}{K_n} + n_i) \quad (11)$$

where: K – number of complete periods of fluctuations being applied totally in time to one turnover of the workpiece; i – the ratio of the rest of the fluctuation period, but in the time of one turnover of the workpiece.

The orthogonal clearance in the cutting process lies between the tangent to the trajectory of the work movement (in this case the movement described by equation (5) and the tangent to the intersection of the major flank of the tool with the cylindrical surface on which the complex movement is performed.

The tangent to the trajectory of the complex working movement is obtained by finding the first derivative of equation (5):

$$\begin{gathered}\frac{dx}{dt} = -r.(\omega_o + A_n.\sin K_n t).\sin(\omega_o t - \frac{A_n}{K_n}.\cos K_n t)\\ \frac{dy}{dt} = r.(\omega_o + A_n.\sin K_n t).\cos\left(\omega_o t - \frac{A_n}{K_n}.\cos K_n t\right)\\ \frac{dz}{dt} = V_o + A_n.K_n.\cos K_n t\end{gathered} \quad (12)$$

The equation of the tangent is:

$$\frac{X - x_o}{-r.(\omega_o + A_n.\sin K_n t).\sin(\omega_o t - \frac{A_n}{K_n}.\cos K_n t)} = \frac{Y - y_o}{r.(\omega_o + A_n.\sin K_n t).\cos\left(\omega_o t - \frac{A_n}{K_n}.\cos K_n t\right)} = \frac{Z - z_0}{V_o + A_n.K_n.\cos K_n t} \quad (13)$$

The equation of the major flank of the tool is:

$$-x.d'.c' + y.Y'.c' - z.d'.c' + r.d'.c' = 0 \quad (14)$$

The equation of the cylinder of the working movement is:

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Issue 3, pp. 62-69, September, 2018

$$\phi = x^2 + y^2 - r^2 = 0 \tag{15}$$

The equation of the intersection of these two surfaces is:

$$\frac{X-x}{2.y.d'.r'} = \frac{Y-y}{-2.x.d'.r'} = \frac{Z-z}{-2.y.d'.c'-2.x.r'.c'} \tag{16}$$

The angle between these two tangents is the actual major flank:

$$\cos\alpha_{oc} = \frac{-2.r.d'.r'.(\omega_o+A_n.\sin K_n t).\left[y.\sin\left(\omega_o t-\frac{A_n}{K_n}.\cos K_n t\right)+x.\cos\left(\omega_o t-\frac{A_n}{K_n}.\cos K_n t\right)\right]-2.(V_o+A_n.K_n.\cos K_n t).c'.(y.d'+x.r')}{\sqrt{r^2.(\omega_o+A_n\sin K_n t)^2+(V_o+A_n.K_n.\cos K_n t)^2}+\sqrt{y.d'^2.r'^2.(y^2+x^2)+(-2.y.d'.c'-2.x.r'.c')^2}} \tag{17}$$

where:

$$x = r \qquad c' = \left(r.\frac{tg\kappa_r}{tg_\alpha} \pm h\right).tg\alpha$$

$$y = -(d-h) \qquad r' = \left(r.\frac{tg\kappa_r}{tg_\alpha} \pm h\right).\frac{tg\alpha}{tg\kappa_r} \qquad d = \frac{r.tg\kappa_r}{tg\alpha}$$

$$z = c = r.tg\kappa_r \qquad d' = (d+h)$$

3. CONSTRUCTION OF A VIBRATOR FOR SIMULTANEOUSLY SETTING THE AXIAL AND ROTARY OSCILLATIONS

The proposed construction is a hydraulic vibrator built on the basis of thin-walled steel pipes (Лефтеров, 1981) shown in fig. 3 a), b) and (c).

The device comprises a body 1 and cover 2, between which is mounted a vibrating element 3. In the space between the vibrating elements 3, body 1 and cover 2 there are mounted thin-walled steel tubes 5 and 6 arranged two by two oppositely in two mutually perpendicular planes. The tubes 5 and 6 are pressed by means of pins 7 to the vibrating element 3 and to the body 1 by means of screws 8 having a conical forming line at its tip.

The connecting diagram (fig. 3) includes an electric motor 10 driving a four-cylinder piston pump 9 and tubing connecting it to the thin-walled tubes 5 and 6.

The hydraulic vibrator operates in the following way: the vibrator is rigidly secured to the clamping device of the machine by means of a conical or cylindrical tail. In the conical or cylindrical hole of the vibrating element 3, is mounted the cutting tool. The piston pump 9 (Figure 4) is free of pressure valves, which allows after each injection the pressure to falls to zero atmospheres and enables the system to be closed.

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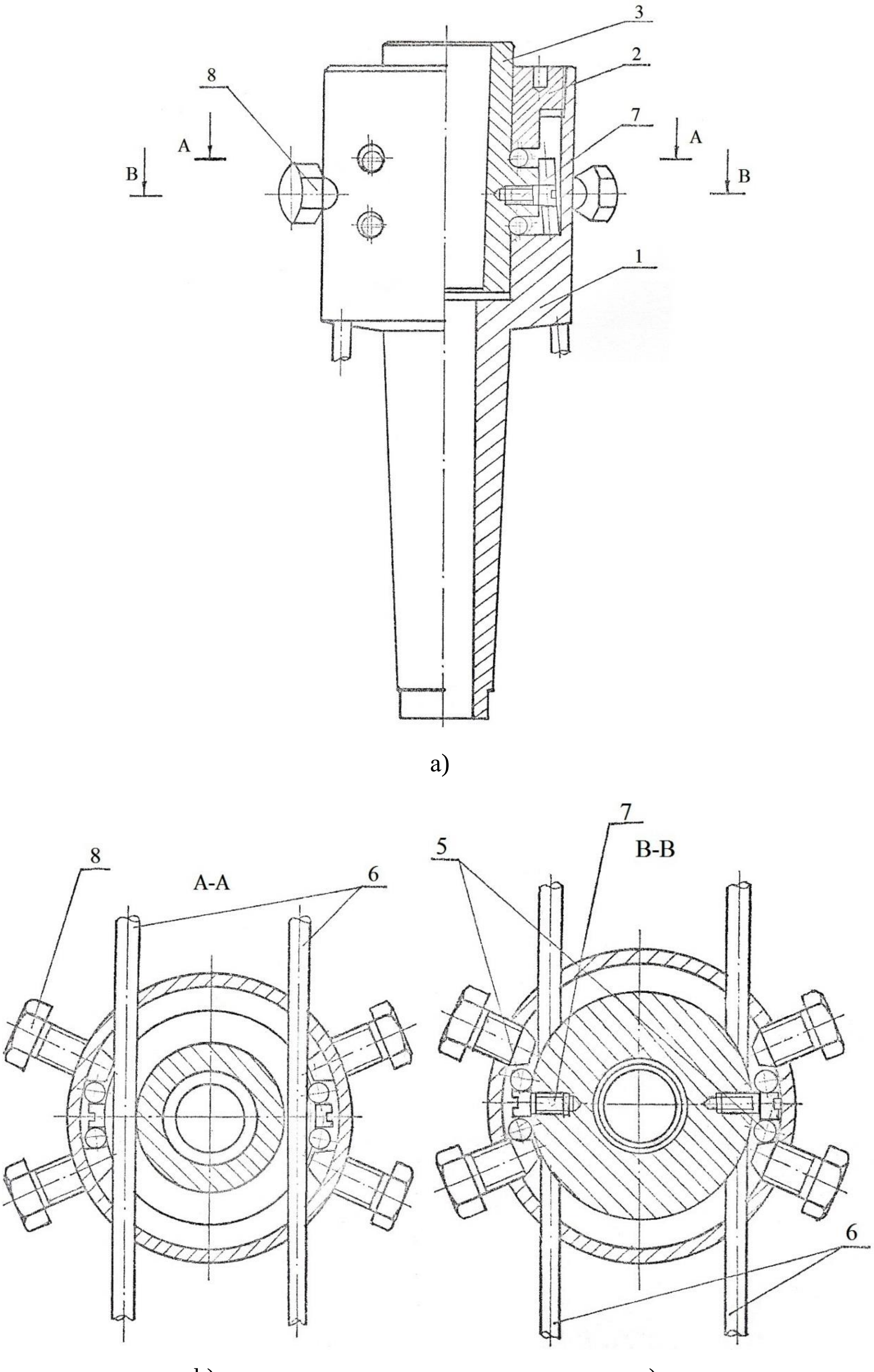

Fig.3 *Design of the vibrator*

a) view of the vibrator; b) section A-A; c) section B-B

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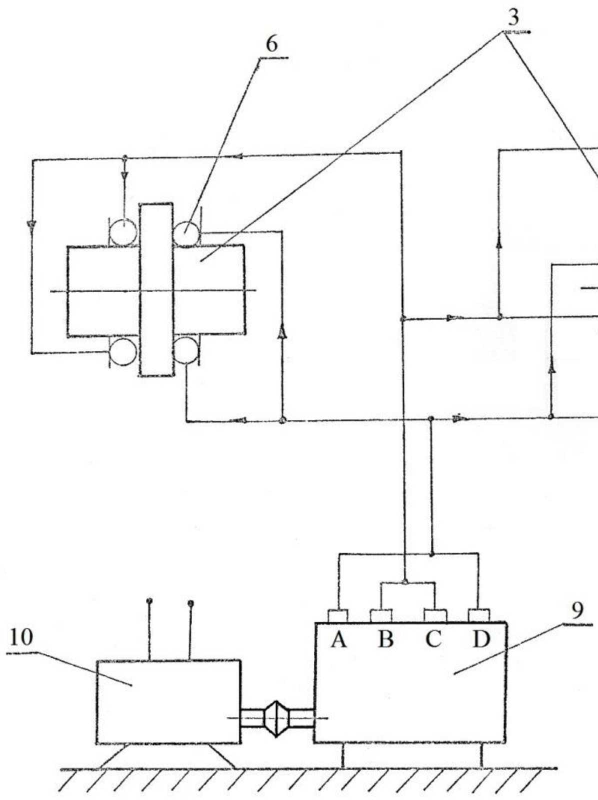

Fig.4 *Hydraulic vibrator connection diagram*

Upon supplying a pressure impulse from section A of the piston pump 9, fluid is fed to two of the thin-walled tubes 5 and 6 which swell elastically and rotate the movable part of the vibrator counterclockwise and provide axial displacement to the left. At this point, the opposite tubes 5 and 6 do not swell elastically due to the absence of a pressure impulse therein.

Upon submitting a new pressure impulse from the section C the fluid is fed to the next two thin-walled tubes 5 and 6 whereby the movable part of the vibrator receives a clockwise rotation and axially displaced to the right. Thus, for one revolution of the pump, four linear displacements and four turns are obtained.

4. CONCLUSIONS

- A theoretical methodology has been developed to describe a new kinematics scheme containing two additional displacements having a cyclic nature (fig.1).

- Dependencies are derived for calculating the change in thickness of the chip removal and the working clearance angle αoε.

- A hydraulic vibrator construction has been developed to implement the developed kinematics scheme.

- Vibration amplitude adjustment is carried out by varying the fluid pressure, and the frequency is varied by changing the pump speed.

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