THE INFLUENCE OF CUTTING FORCES ON POWER CHARACTERISTICS OF HIGH-SPEED CHUCK

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ARTICLE INFO	ABSTRACT
	The effect of cutting forces on the clamping force in high-speed chucks been analyzed at different rotational speeds of the spindle, these speeds determine the magnitude of the centrifugal forces of the unbalanced chucks. the above considerations, design schemes and analytical dependencies can be used to design high-speed clamping chucks under given cutting conditions.

1. INTRODUCTION

Existing progressive cutting tools allow a high cutting speed. Therefore, to increase the processing capacity, modern CNC lathes provide high spindle speeds (up to 20,000 rpm) [4,8]. However, as the machine spindle speed increases, the action of the centrifugal forces on the clamping chuck (CC) cams increases significantly, reducing the clamping force, limiting the cutting regimes, which reduces the processing capacity and reduces the possibility of maximum utilization of the machine's power. This circumstance requires the creation of new designs of high-speed clamping chucks (HSCC) capable of operating at high speeds of the spindle and retaining the clamping force at high cutting conditions [1-6].

In some cases, the calculation of clamping forces has a verification nature. The required clamping force, calculated from the processing conditions, must be less than or equal to the force developed by the clamping device being used. If this condition is not met, then the processing mode is changed in order to reduce the necessary clamping force and perform a verification calculation. The solution of the problem can be carried out in the reverse order. Then, according to the known clamping force of the available device, the permissible cutting forces are determined and the processing conditions are set.

The main objective of this study is so establish the effect of the cutting force on the force behavior of high-speed clamping chucks.

2. FORCE ANALYSIS OF HIGH-SPEED CLAMPING CHUCKS

When new devices are designed, the calculation of clamping forces can be reduced to solving the static problem on the workpiece equilibrium under the external forces action, applied to it [7-9]. All external forces are conditionally divided into disturbing and balancing workpiece (Fig. 1). Perturbing forces lead to the displacement of the workpiece from the position established at its basing. These include: the components of the cutting force; volumetric forces (workpiece weight, centrifugal forces and inertia forces). The forces balancing the workpiece include: frictional forces that arise when the workpiece is fixed; force of direct action of power mechanisms on the workpiece; reaction of supports.

If the cutting forces are always taken into account when calculating the clamping forces, then the volume forces are only for certain processing conditions. In particular, the weight of the workpiece is valid and is taken into account when it is installed on vertical and inclined elements. Centrifugal forces arise and are taken into account in the processing when the center of gravity of the workpiece is displaced relative to its axis of rotation.

Forces of inertia arise and are essential in two cases: when the workpiece performs reciprocating translation motion; at a sudden change in the speed rotational speed. The volume forces are determined from the relations given below.

Workpiece weight

$$G = mg \,, \tag{1}$$

where m is the mass of the workpiece; g - acceleration of gravity.

Centrifugal force

$$F_{u} = mr\left(\frac{\pi n}{30}\right)^{2}, \tag{2}$$

where n is the rotational speed of the workpiece; r is the distance between the axis of rotation and the mass center of the workpiece.

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The force of inertia $F_u = ma$,   (3)

where a is the acceleration of the workpiece.

The frictional force is the main force factor that ensures the workpiece immobility from the action of disturbing external forces. It arises as a result of the action of the fixation force and is determined from the relation

$$F_{mp} = Q.f \qquad (4)$$

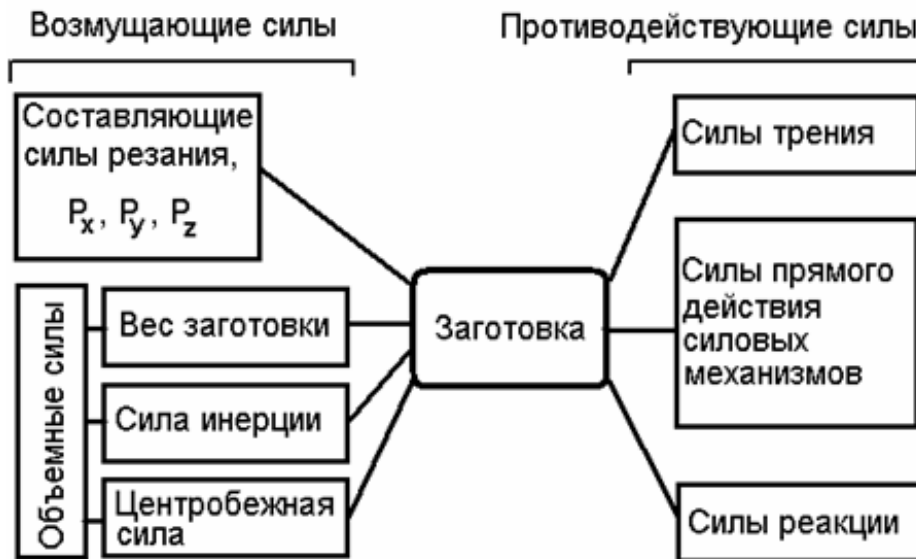where Q is the fixing force; f is the coefficient of friction.

Fig. 1. Forces acting on the workpiece

To calculate the binding forces, it has to exist:

1 - Working drawing of the workpiece for the operation (operations) performed, indicating the surface to be treated (surfaces);

2 - Detailed drawing of the part to be obtained when machining using the tool;

3 - Methods of processing the given surface (surfaces) of the workpiece and the necessary equipment and tools;

4 - Cutting modes (cutting speed, depth of cut and feed) and cutting force components;

5 - Workbench basing schemes and machine tooling system;

6 - Values of friction coefficients for various conditions of contact of workpiece surfaces with adjusting and clamping elements of devices;

7 - Values of safety factors for various conditions of fastening and processing of blanks.

To determine (in general form) the binding force when turning an external cylindrical surface with a passing cutter [10], let us consider the scheme of forces acting on the workpiece being processed (Fig. 2). Let us consider the action of external disturbing forces. The circumferential (tangential) component force P_z has the greatest absolute value at turning and acts along the tangent to the workpiece. It creates a moment that tends to rotate the workpiece around its axis. The radial component force P_y, depending on the processing conditions, is (0.3 ... 0.9) P_z and acts normal to the machined surface from the periphery to the center of the workpiece. It is opposed by the reaction from the cams. Since the radial force does not cause displacement of the workpiece, then, usually, the reaction scheme is not shown. The axial component force P_x, depending on the processing conditions, is (0.1 ... 0.7) P_z and acts on the workpiece in the direction of tool delivery. At the same time, it tries to move the workpiece along the

axis, the workpiece is fixed by the force of fastening Q, applied to the workpiece from the chucks of the cartridge.

In this case, the value of the fixing force must be such that the possibility of turning the workpiece in the cartridge from the action of the circumferential force, its displacement along the axis caused by the axial force, is excluded. The possibility of rotating the workpiece around the Ox axis in the cartridge and its displacement along the Ox axis is eliminated by the action of friction forces F_1 and F_2. They arise as a result of the action of the binding force at the point of contact between the cams of the cartridge and the base surface of the workpiece. And its part Q_1 counteracts the rotation of the workpiece around its axis, and Q_2 counteracts the displacement of the workpiece along the axis. Then, the fixing force will be

$$Q = k\sqrt{Q_1^2 + Q_2^2} \qquad (5)$$

where Q_1 is the part of the clamping force counteracting the rotation of the workpiece around the axis; Q_2 - part of the clamping force counteracting the displacement of the workpiece along the axis; k - the safety factor depends on the specific processing conditions.

To ensure the immobility of the workpiece under the action of all external forces, we will compose the equations of static equilibrium

$$\sum M_{ox} = nF_{mp2}\frac{D_2}{2} - P_z\frac{D_1}{2} = 0 \qquad (6)$$

$$\sum P_{ox} = nF_{mp1} - P_x = 0 \qquad (7)$$

where n is the number of cams of the cartridge, for the three-jaw chuck $n = 3$; is the diameter of the surface to be treated; D_2 is the diameter of the reference surface; P_x is the axial component of the cutting force; P_z is the tangential component of the cutting force.
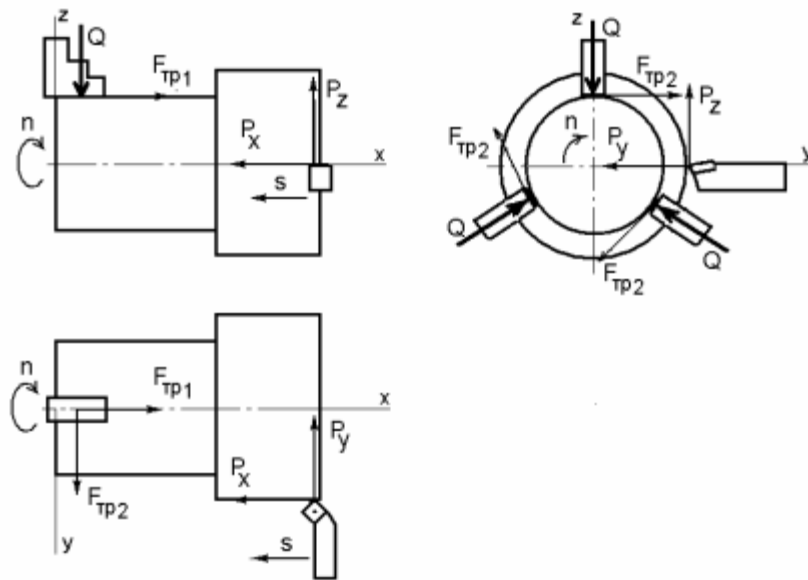
Fig. 2. Calculation scheme for determining the fastening force for turning

Table 1
Cutting forces components

Component of cutting force	Tool Material	Processed metal							
		Steel, alluminium alloys				Cast iron, bronze			
		C_p	xp	yp	zp	C_p	xp	yp	zp
P_x	Hard alloy	0.21	1.2	0.65	1.5	0.51	1.2	0.65	1.1
	High Speed Steel	0.21	1.2	0.65	1.5	1.6	1.2	0.65	1.1
P_y	Hard alloy	0.027	0.9	0.75	2	0.45	0.9	0.75	1.1
	High Speed Steel	0.027	0.9	0.75	2	1.3	0.9	0.75	1.3
P_z	Hard alloy	35.7	1	0.75	0.75	51.4	1	0.75	0.55
	High Speed Steel	27.9	1	0.75	0.35	63.5	1	0.75	0.55

As can be seen, in all two equations, the action of all external disturbing forces (components of the cutting force) is completely compensated. From the volume forces only the weight of the workpiece acts, which has incomparably less value than other external forces.

Substituting the value of the frictional force into Eqs. (6) and (7), $F_{mp1} = fQ_1$; $F_{mp2} = fQ_2$ we obtain

$$\sum M_{Ox} = 3fQ_2 \frac{D_2}{2} - P_z \frac{D_1}{2} = 0 \qquad (8)$$

$$\sum P_{Ox} = 3fQ_1 - P_x = 0 \qquad (9)$$

From the equations (8) and (9) we find:

$$Q_1 = \frac{P_x}{3f}, \qquad (10)$$

$$Q_2 = \frac{P_z D_1}{3fD_2}, \qquad (11)$$

After the transformations, we obtain the formula for calculating the binding force:

$$Q = k\sqrt{\left(\frac{P_x}{3f}\right)^2 + \left(\frac{P_z D_1}{3fD_2}\right)^2}$$

Components of the cutting forces

$$P_x = C_p.t^{xp}.S^{xp}.HB^{xp} ;$$
$$P_y = C_p.t^{yp}.S^{yp}.HB^{yp} ;$$
$$P_z = C_p.t^{zp}.S^{zp}.HB^{zp} .$$

where S is the feed rate (mm / tr); t- depth of cutting (mm); HB- hardness; C_p -values of the coefficient; xp, yp, zp - exponents of the degree

The values of the coefficient C_p and exponents of the powers of xp, yp, zp in the equations of cutting force components are given in Table 1.

We will perform a theoretical analysis of the power characteristics of the HSCC (patent of Ukraine for invention No. 15246 "Lathe chuck") under various conditions [11] with hydraulic clamping drive.

1. Clamp with the spindle stopped ($n = 0$), Fig. 3

The gain of the cartridge is $k_k = \frac{Q}{S}$, where Q is the radial clamping force of the workpiece developed by one cam, S is the axial force of the actuator per cam and is equal to $S = p.F_h.\eta$ (p - liquid pressure in the hydraulic cylinder, F_h - useful area of the hydraulic cylinder, $\eta = 0.95$ - efficiency hydraulic drive, taking into account the leakage and friction in the seals).

2. Clamp with rotating spindle ($n \neq 0$), Fig.4.

The centrifugal force of the unbalanced cam of the cartridge: $F_K = m_K.R.\omega^2 = m_K.R\left(\frac{\pi n}{30}\right)^2 = 0.11.m_K.R.n^2$

The CFI is $k_n = \frac{Q - F_u}{S}$.

3. Clamping with the rotating spindle ($n \neq 0$) and balancing the centrifugal forces (Fig. 5).

The introduction of a counterweight - a load on the shoulder p from the opposite side of the cam leads to an increase in the coefficient of amplification of the lever transmission to the great

$$k_p = \frac{R_2}{R_1} \qquad (12)$$

where R_1 - the force on the arm a of the lever, which becomes smaller due to the force of the $F_{\text{ЦГ}}$ when receiving the same force R_2.

It follows from (12): $R_2 = R_1 . k_P$

$$F_{\text{ЦГ}} = m_\Gamma . R . \omega^2 = m_\Gamma . R . \left(\frac{\pi n}{30}\right)^2 = 0.11 m_\Gamma . R . n^2$$

The CFI is

$$k_n = \frac{Q - F_{\text{ЦК}} + F_{\text{ЦГ}}}{S}$$

3. CONCLUSION

The above considerations, design schemes and analytical dependencies can be used to design high-speed clamping chucks under given cutting conditions.
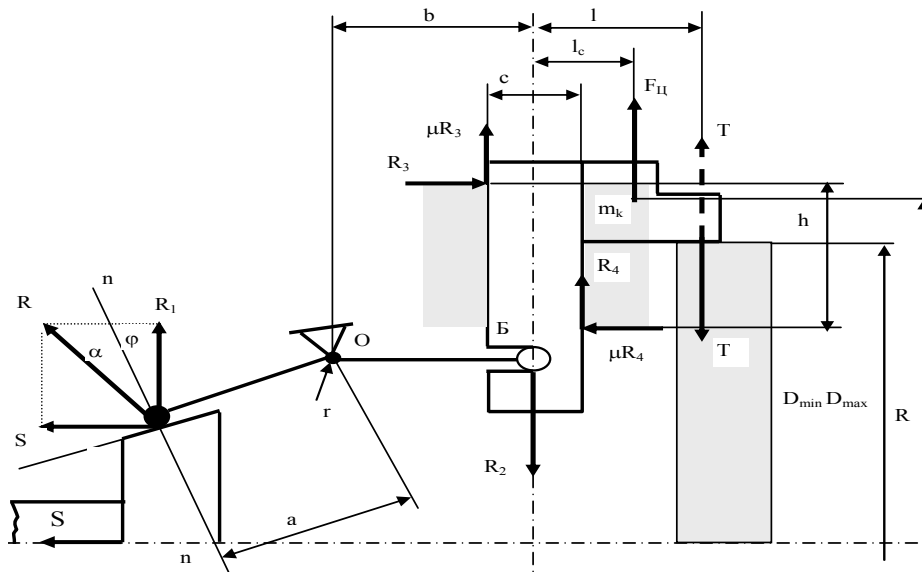

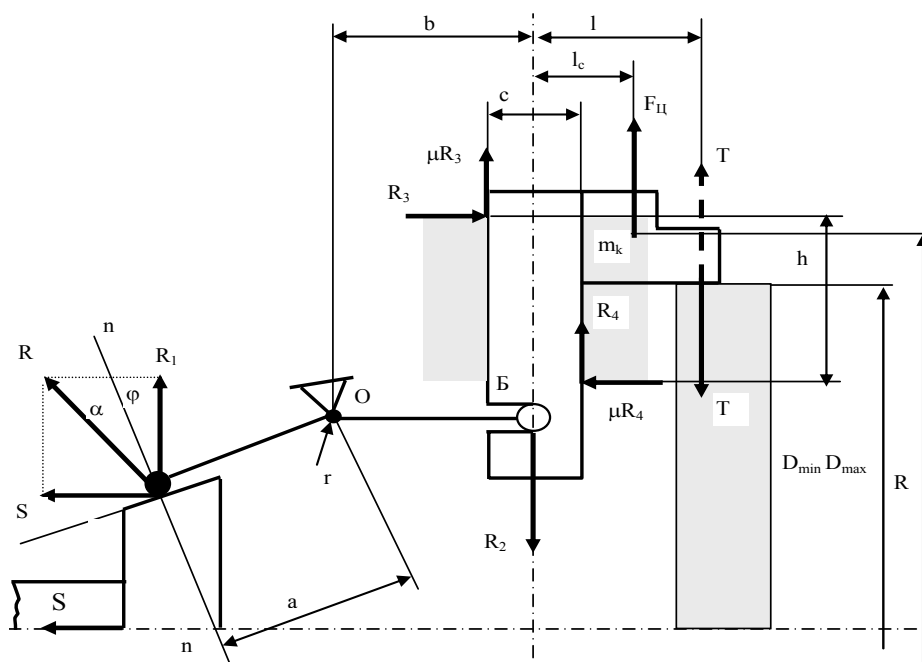Fig. 3. Scheme of the action of forces on the elements of the cartridge with a nonrotating spindle

Fig. 4. The scheme of the forces acting on the elements of the cartridge with a rotating spindle
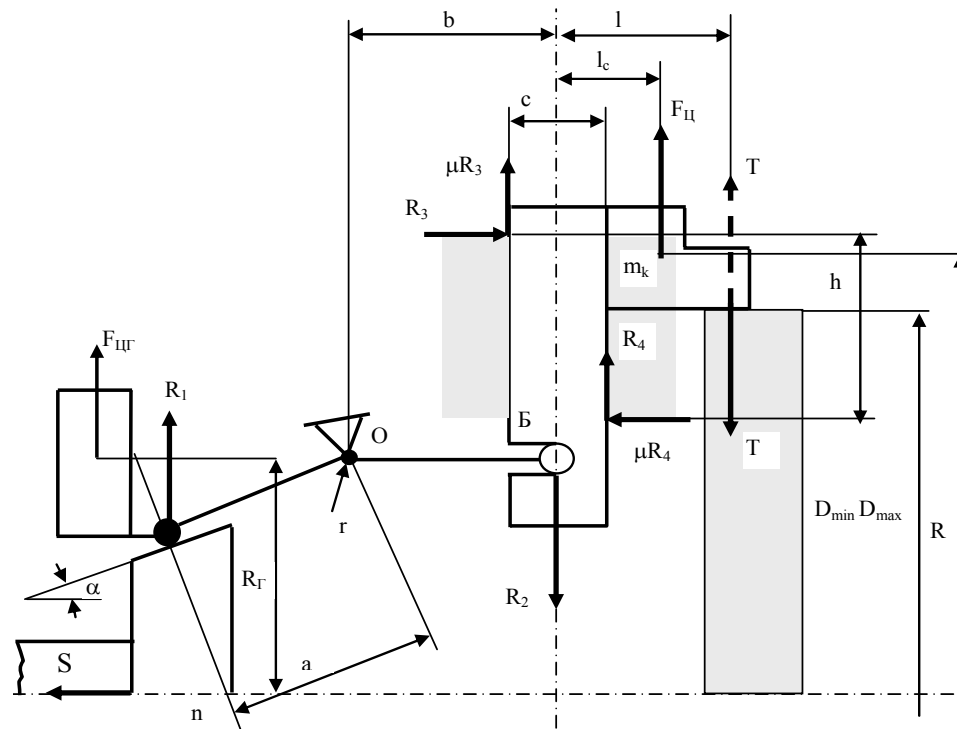
Fig. 5. The scheme of the forces acting on the elements of the cartridge with a rotating spindle and balancing the centrifugal forces

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