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About cutting forces for skiving by a movable two-blade block

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1. Introduction

The high requirements for accuracy of the dimensions and shapes are one of the present day problems in machine building.

The practical application with machining of deep apertures ($L/D > 5$) combined tools with two cutting inserts which are opposite located in common block are found. The block has a possibility of free movement in a plane which is perpendicular to the turning axis of the machine [1-3]. When neglecting friction forces in guides the movable two-blade block will be in continuously dynamical equilibrium in radial direction, which is expressed by an equality of the opposite operative radial cutting forces [4, 5]. In the real circumstances an ideal condition is unattainable because of friction forces' the resistance against radial movement of the movable two-blade block and deviations of the symmetry axis of the machining apertures. Location of the block toward to the two axes exercise influence too as a result of faults of the establishment of the detail and the tool and from its elaboration. As the result a variation of magnitude, direction and correlation of the active (cutting) and reactive (friction) forces are received. They cause movements of the block in radial and tangential directions, which have influence over the shape of the receiving aperture.

The aim of the present paper is to determine force loading of the movable two-blade block for skiving in dependence of the mutually location of the block and the machining aperture in the plane of dimension creation YOZ.

2. Expose

The process of the aperture's machining is divided conditionally into three periods in dependence of its behaviour when it gets into contact with the detail [4]:

- opening period of self-establishment;
- period of established cutting;
- period of final self-establishment.

The opening period of self-establishment starts at the moment when one of the two opposite location blades gets in to contact with the entrance frontal surface of the detail. It will finish at the moment when each one of them will reach the cutting depths which are defined by the dimension of the block's static adjustment. The second period will pass with these depths.

The opening period of self-establishment is divided in to two stages:

- opening stage of self-establishment without incision (without chip's removing);
- opening stage of self-establishment with incision (with chip's removing).

The beginning of the period of established cutting coincides with the end of the first stage and its end is determined from the moment when the apexes of the one or the two cutting blades get into the surface where the ending frontal surface of the detail lies.

The period of final self-establishment starts with finishing of the second stage and can have zero duration if there is no axis dislocation between two opposite location blades or it is directly connected with the magnitude of such dislocation [4, 5].

Kinematical behaviour of the block is determined using an assumption that radial forces of the two cutting inserts are equalized at the every moment of the block's work.

Dynamical behaviour of the block in each stage of its interaction with the detail and the holder of the tool is the same as the kinematical behaviour, but rising forces in contact areas enforce additional restrictions, which provide its working capacity. Their analysis is made with the following preconditions:

- the cutting inserts have straight cutting edges without axis disposition;
- in the more general case symmetry axes of the aperture, block and the holder of tool do not coincide with each other and with turning axis of the machine but for research aims special cases which do not change the results are examined;
- symmetry axis of the block is displaced according to symmetry axis of the detail's aperture before it gets in a contact with the detail;
- cutting forces and friction forces are disregarded;
- elastic deformations are insignificant.

The made preconditions describe circumstances, which are maximum close to the real. They are reflected on the block's behaviour during separated stages of the interaction with the detail which were differentiated in the kinematical analysis.

2.1. Interaction of the block the detail and the tool-holder in opening period of self-establishment

In Fig. 1 the opening stage of self-establishment without incision is shown. Its passing is described in details in [4]. It is analyzed according to the circumstance that *I* is symmetry axis of the block which has initial displacement *e* toward to the concurrent symmetry axes of the aperture and the tool-holder with turning axis of the machine *II*.

At the time of getting in touch of one of the cutting edges with the machined detail during feeding in contact place normal force F_N, which is directed perpendicular toward to the cutting edge, appears (Fig. 1). Its magnitude depends of the cutting edge angle of the blade κ_r and friction resistance of the cutting edge with the detail and the block with its guidebars. As a result of the friction the real normal force $F_{N\partial}$ in fact is displaced and it has different magnitude.

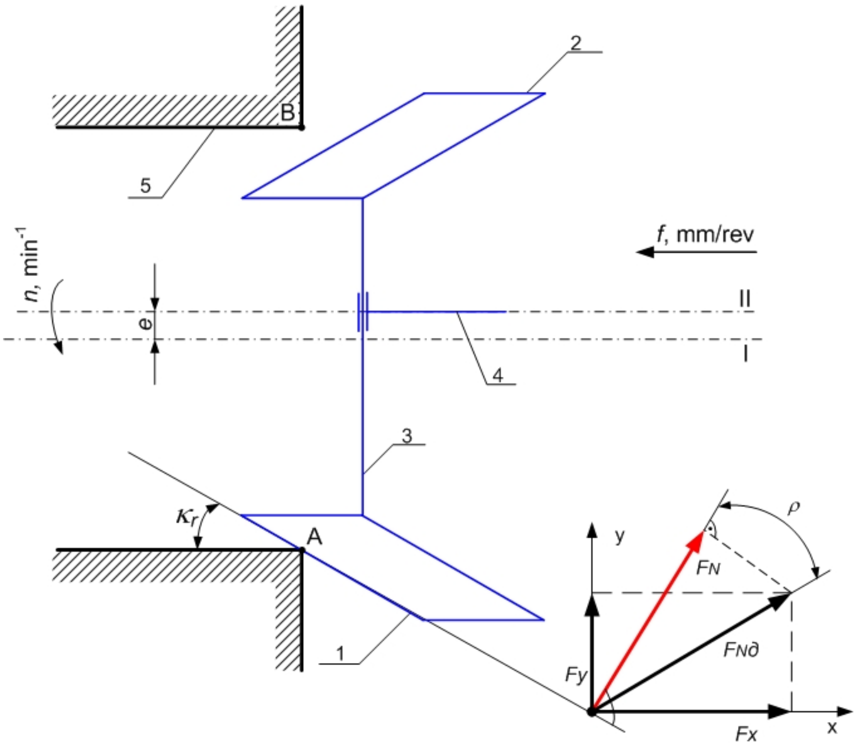

Fig. 1 The scheme of the opening stage of self-establishment without incision: *1*, *2* – cutting inserts; *3* – guidebars of the block; *4* – holder of the tool; *5* – detail

$$F_{N\partial} = \frac{\cos\rho}{F_N} \quad (1)$$

where F_N is normal force to the cutting edge; ρ is friction angle.

Moreover the friction angle is determined from the dependence

$$\rho = arctg\left(\mu_1 + \mu_2\right) \quad (2)$$

where μ_1 is friction coefficient between the cutting edge and the detail; μ_2 is friction coefficient between the block and its guidebars.

The projections of the force $F_{N\partial}$ onto coordinate axes are

$$F_X = F_{N\partial} \sin(\kappa_r + \rho) \quad (3)$$
$$F_Y = \cos(\kappa_r + \rho) F_{N\partial} \quad (4)$$

For the correlation between the two forces it is received

$$\frac{F_X}{F_Y} = tg(\kappa_r + \rho) \quad (5)$$

During self-establishment process under the action of radial component F_Y motion of the movable two-blade block is in progress. Friction force F_T in the block's guidebars is resisting to it. The movement is possible under the following condition

$$F_Y > F_T \quad (6)$$

If this condition is not satisfied the cutting process will pass with working of only one of the cutting edges, i.e. as cutting with stiff established tool.

From equation (5) the radial force is

$$F_Y = \frac{F_X}{tg(\kappa_r + \rho)} \quad (7)$$

If friction of the cutting edge in detail is disregarded and the friction force F_T is expressed with axis component of normal force, then:

$$F_T = \mu_2 F_X \quad (8)$$

After substitution of Eq. (6) with Eqs. (7) and (8), it is received an expression, which determines the condition for tool's self-establishment before starting the chips' removing process, when only one of the cutting edge contacts with the detail

$$\frac{1}{tg(\kappa_r + \rho)} > \mu_2 \quad (9)$$

It is obvious (from the last inequality) that for assuagement of this stage it is necessary κ_r to be decreased. Fiction of the cutting edge in detail and of the movable block in its guidebars depends (for preliminarily chosen angle κ_r) on the friction coefficients μ_1 and μ_2. If the contacted materials are homogeneousness, then it is accepted that $\mu_1 = \mu_2 = \mu$, and

$$\rho = arctg 2\mu \qquad (10)$$

The borderline values of the cutting edge angle κ_r in different cases of the friction can be determined, based on the dependences (9) and (10). For steel materials the friction coefficient μ has values in the area 0.05-0.3 [6]. The magnitude of the cutting edge angle κ_r (for all values of μ in this area), above which the normal self-establishment can not begin, is determined graphically according the presented dependence $\kappa_r = f(\mu)$ in the Fig. 2.

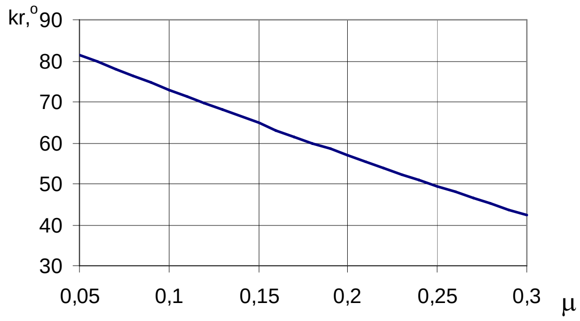

Fig. 2 The borderline values of the cutting edge angle κ_r, guaranteed opening self-establishment without incision

It is obvious that the borderline value of the cutting edge angle κ_r decreases with the increase of the friction coefficient μ.

The beginning of the stage of incision coincides with commencement of chips' removing. An additional friction arises in the groove of the tool-holder under the action of the moment due to tangential cutting forces and increase of axial forces. The specifying its duration has considerable meaning for the geometrical characterization of the surface in the beginning of the machining aperture.

The stage of incision finishes when the elements of the cutting layer reach their maximum dimensions. The stage of established cutting starts from this moment and theoretically the removed augmentation must be distributed between two cutting parts of the movable two-blade block. In this way radial components of the cutting forces will be completely equilibrated. Due to the variety of reasons, this is impossible and it is a subject of additional examinations.

2.2. Interaction of the block with the detail in stage of established cutting

Notwithstanding, theoretically, equal cutting depths in real circumstances ideal equilibrium status is unattainable because of: strength of the friction forces against to the radial movement of the movable two-blade block; deviation of symmetry axis of the machining aperture toward to turning axis of the machine and of location of the block toward two axes. They are the result of establishment mistakes of the detail and the tool and of the tool's manufacture. The expected consequence from these deviations is a variation of the magnitude, direction and proportion of active (cutting forces) and reactive (friction forces) forces which cause motion of the movable two-blade block in radial and tangential directions. They have an influence over the received aperture.

When deep apertures skive with tool-holder and movable two-blade block there is an aspiration for coincidence of block's symmetry axis with the axis of the detail's aperture (Fig. 3).

Symmetry axis of the aperture in cross direction does not coincide with turning axis of the machine in every moment during axis feeding of the tool. If it is accepted that deviations of the aperture's shape in such section are slight there can be seen that for one full revolution around the machine axis O the axis of the detail's aperture $O_з$ will describe a circle with the radius, which will be equal to the transitory deviation *e* between two axes (Fig. 4). One of the three possible cases, when symmetry centre of the block *C* coincides with turning axis of the machine *O*, is examined and all possible positions of the aperture's section of the detail toward to the movable two-blade block are geometrically described.

In Fig. 4 the four borderline positions toward axes *Y* and *Z* are shown. This is done under the assumption that the block has dimension $L_H = AB$ and it is immovable toward the tool-holder and the elastic deformations are zero. It is not difficult to determine that position *1* is identical with position *3* and position *2* - with position *4*.

In these circumstances there will be variations of the cutting depth, respectively of the cutting forces which will depend on the magnitude of the block's operating adjusted dimension $L_н$ and on the deviation *e*. This deviation will be bigger in tangential direction *Oz* than in radial direction *Oy*.

If the situation which is shown in Fig. 4 is examined with a movable two-blade block the aspiration for equilibration of the radial cutting forces F_{pA} and F_{pB} will lead to the recurrent moving of the block toward positions *2* and *4* of the detail's aperture in such a way that the centre C will coincide with $O_з^2$ and $O_з^4$. The motion is realized under the action of the force $\Delta F_p = |F_{pA} - F_{pB}|$ and will continue until $\Delta F_p > F_T$, where F_T is the force of friction between the guidbars and the block. The block will be immovable toward tool-holder when $\Delta F_p \le F_T$. This situation corresponds of the approximately equality of the cutting depths, respectively of the cutting forces of the two inserts.

Turning of the detail's aperture from position *2* to position *3* or from position *4* to position *1* leads to increasing of the cutting depths, respectively – the cutting forces, which give reflection over the force loading and the circumstance for block's equilibrium.

For the determination of force dependences which are result of the nonconcurrence of the axes in Fig. 5 geometrical analysis of the forces which act over the mo-

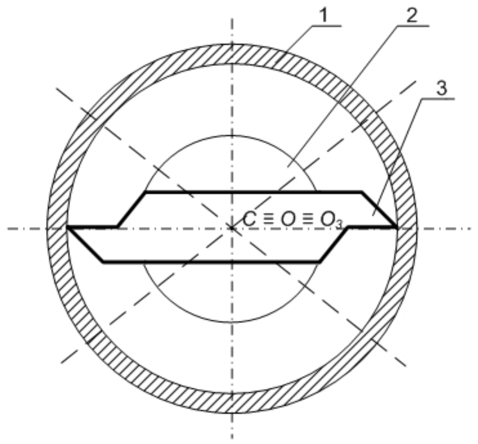

Fig. 3 Scheme of skiving detail's aperture with movable two-blade block: *1* – detail; *2* – tool-holder; *3* – cutting block

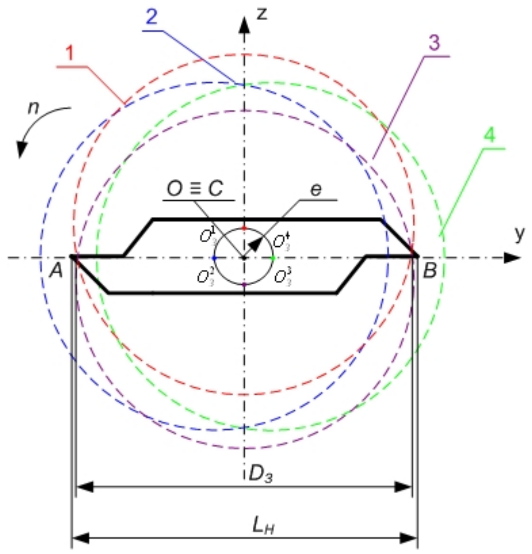

Fig. 4 Verged positions of the detail's aperture with immovable two-blade block

vable two-blade block for position *3* from Fig.4 is done. Besides the specified circumstances, it is accepted additionally that the two cutting parts have the same geometry and intensity of wearing and their apexes lie in the plane which is perpendicular to the turning axis of the machine. It is accepted also that cutting depths of the two cutting parts are the same and the change of its geometry is slight.

As a result of the deviation e of axis O (Fig. 5) toward to symmetry axis O_3^3 of the detail's aperture the cutting depth a increases by Δa. Furthermore the cutting forces are decreased and a diameter $D = L_H + 2\Delta a$ is received. Also the radial cutting forces F_{pA} and F_{pB} cause the rise of transverse forces F_A^H and F_B^H, which act in a direction opposed to the deviation *e*.

If we define the increased cutting depth, the increasing of the cutting forces can be determined from the well-known experimental dependences [7]

$$a_A = a_B = \frac{D - D_3}{2} \tag{11}$$

where D is passing diameter of the machining aperture.

From geometrical conception of Fig. 5 it is obvious that

$$a_A = a_B = a + \Delta a = \frac{L_H - D_3}{2} + \Delta a \tag{12}$$

and

$$\Delta a = O_3^3 B - \frac{L_H}{2} \tag{13}$$

where L_H is dimension of block's static adjustment.

From the triangle $O_3^3 GB$

$$O_3^3 B = \sqrt{O_3^3 G^2 + BG^2} = \sqrt{\left(\frac{L_H}{2}\right)^2 + e^2} \tag{14}$$

whereat

$$\Delta a = \frac{L_H}{2}\left(\sqrt{1 + \left(\frac{2e}{L_H}\right)^2} - 1\right) \tag{15}$$

After substitution (15) in to (12)

$$a_A = a_B = \frac{L_H}{2}\sqrt{1 + \left(\frac{2e}{L_H}\right)^2} - \frac{D_3}{2} \tag{16}$$

After the determination cutting forces' the following formulas are received

$$F_A^H = F_{pA} sin\psi = F_{pA}\frac{2e}{\sqrt{L^2_H + 4e^2}} \tag{17}$$

$$F_B^H = F_{pB} sin\psi = F_{pB}\frac{2e}{\sqrt{L^2_H + 4e^2}} \tag{18}$$

The angle ψ can by defined from $\Delta O_3^3 GB$

$$tg\psi = \frac{BG}{O_3^3 G} = \frac{2e}{L_H} \tag{19}$$

Position *3* (Fig. 4) is a moment of detail's uniform rotary motion in the indicated direction, and from this position thereafter the provisionally equality between the cutting forces will be violated. The detail's aperture will move to position 4 and the block – to the cutting part B under the action of force ΔF_p. Moreover the cutting depth is decreasing and reaching to its minimal value $\frac{L_H - D_3}{2}$ in position *4*.

During the complete cycle of detail's turning around the axis O, cutting forces and transverse forces F_A^H and F_B^H periodically change their magnitude and it is expected that they cause influence over the forces of friction, which show resistance against the motion of the block in direction O_Y. In the described construction of the guide-bars those are forces F_{T_A} and F_{T_B}, which appear

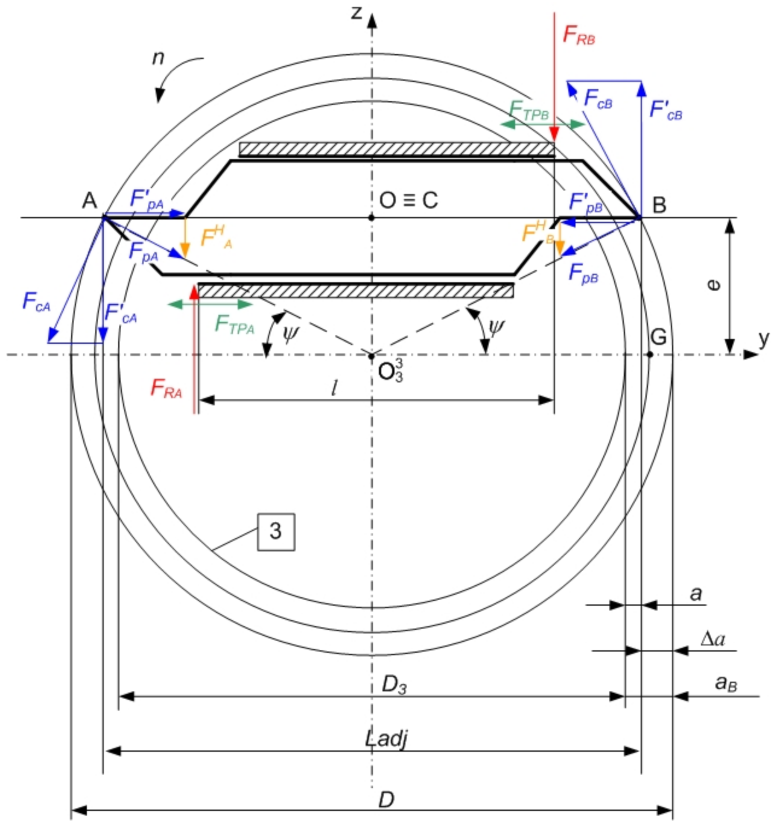

Fig. 5 Scheme of force loading of the movable two-blade block with the deviation toward turning axis in tangential direction

due to tangential cutting forces F_{cA} and F_{cB}, and friction force F_{T_X}. The last one is caused by not marked in the figures axial cutting forces F_{fA} and F_{fB}.

The total force of friction between the block and its guidebars will be

$$F_T = F_{T_A} + F_{T_B} + F_{T_X} \tag{20}$$

The friction forces can be received from the dependences

$$\left.\begin{aligned} F_{T_A} &= F_{RA}\mu \\ F_{T_B} &= F_{RB}\mu \\ F_{T_X} &= \left(F_{fA} + F_{fB}\right)\mu \end{aligned}\right\} \tag{21}$$

where μ is friction coefficient between the block and its guidebars.

For the determination of F_{RA} and F_{RB} (couple forces, which equalized the moment of the action of the tangential cutting forces and the transverse forces) the circumstances of force equilibrium along axis O_Z and of the moments about the centre O are used

$$F_{cA} + F_A^H - F_{RA} + F_B^H + F_{RB} - F_{cB} = 0 \tag{22}$$

$$\left[\left(F_{cA} + F_A^H\right) + \left(F_{cB} - F_B^H\right)\right]\frac{L_H}{2} - \frac{l}{2}\left(F_{RA} + F_{RB}\right) = 0 \tag{23}$$

where l the length of the guidebars.

According to the thesis for balancing of the cutting forces

$$\left.\begin{aligned} F_{cA} &= F_{cB} = F_c \\ F_{pA} &= F_{pB} = F_p \\ F_A^H &= F_B^H = F^H \end{aligned}\right\} \tag{24}$$

As a result of system salvation, which is received from Eqs. (22) and (23), according to Eqs. (17), (18) and (24), it is received

$$F_{RA} = \frac{L_H}{l}F_c + \frac{2e}{L_H}F_p;\; F_{RB} = \frac{L_H}{l}F_c - \frac{2e}{L_H}F_p \tag{25}$$

After substitution of Eqs. (21) and (25) and (20) with reading that $F_{fA} = F_{fB} = F_f$ the expression for the determination of the total friction force obtains the form

$$F_T = 2\mu\left(\frac{L_H}{l}F_c + F_f\right) \tag{26}$$

The dependence Eq. (26) allows the determination - the friction force in the guidebars between the movable two-blade block and tool-holder depends on the tangential and axial components of the cutting force and on the length of the guidebars of the tool-holder as the influence of tangential component is stronger.

During the period of final self-establishment, the equilibration of the radial cutting forces is violated and the behaviour of the block is changed. This gives reflection over the machining surface.

According to the pointed prerequisites (axis displacement $X_0 = 0$), during the stage of incision and the period of final self-establishment, the cutting forces respectively increase to maximum or decrease to zero but the force loading of the block is analogous to the period of established cutting. With axis displacement $X_0 \neq 0$ the equilibrium between the radial cutting forces, which leads to ending effects (increasing of the aperture's diameter) is violated.

From exploitation standpoint the dimension creation is decisive during the period of established cutting. It is realized in the plane of radial cutting forces' action and its precision depends on sensitivity of the block to difference between them with appearing of different reasons. There is a threshold of sensitivity to this difference and which is determined from magnitude of the friction force (depends on the values of other two cutting forces).

3. Conclusions

During skiving with movable two-blade block and determination of the basis, the noncoinciding of the machine's turning axis with symmetry axis of the cross section of the aperture, leads to the periodical change of the cutting depths, respectively of the cutting forces. There are dependences received for their determination and if the deviation *e* between axes will be in the plane which is perpendicular to the direction of radial movement of the block, then its maximum values will be received. The transverse forces, which appear in this plane, have one way action and cause loading over the tool-holder or the guidebars. It is proved that they do not cause influence over the total force of friction between the block and its guidebars. The sensitivity of the block to the difference between the radial cutting forces depends on the deviation *e* by its reflection over the cutting forces' magnitude - F_c and F_f.

The noncoinciding of the mentioned axes, from these results, will lead to shape mistake in cross-section, which is expressed as increasing of the diameter of the machining surface in direction O_c. In case $O \equiv C$ the increasing is symmetrical in two directions. It is expected, in other cases, an asymmetry with stronger expression of the diameter increasing in the direction of dislocation of the centre *C* toward the axis *O*.

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STUMDOMAME DVIEJŲ PJOVIMO ĮRANKIŲ BLOKE VEIKIANČIOS PJOVIMO JĖGOS IŠTEKINANT SKYLES

R e z i u m ė

Dėl klaidų, atsirandančių technologinėse sistemose, skylių ištekinimo metu kinta pjovimo gylis, o tai turi įtakos pjovimo jėgoms. Šiame straipsnyje nustatyta, kaip pjovimo jėgos, veikiančios ištekinant skyles, priklauso nuo bloko padėties.

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ABOUT CUTTING FORCES FOR SKIVING BY A MOVABLE TWO-BLADE BLOCK

S u m m a r y

Because of the technological system's mistakes, there is received variation in cutting depths which have influence over the cutting force. In this article is determined the dependency between the action forces in skiving and mutually location of the block and the machining holes.

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СИЛЫ ДЕЙСТВУЮЩИЕ В ПОДВИЖНОМ БЛОКЕ С ДВУМЯ РЕЗЦАМИ ПРИ ТОЧЕНИИ ОТВЕРСТИЙ

Р е з ю м е

Из-за технологических ошибок, возникающих в технологических системах при выточке отверстий, меняется глубина резания, что оказывает влияние на силы резания. В статье определена зависимость между силами резания при выточке отверстий в зависимости от положения блока резцов.

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