

# Researching the behaviour of movable two-cutter blocks in case of skiving apertures

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## 1. Introduction

Machining of the deep light apertures is relevant to difficulties engendered by the low stability of the tools and the necessity of led way to the receipt chips often with unsuitable dimensions and shapes. With the increase of the aperture lengths (the correlation  $L/D$  of their dimensions), the problems of their skiving are aggravated and most frequently solved by using skiving tools guided along the processed surface. However, such a location of the skiving parts of the tools is aimed at that the radial forces of cutting are balanced within the system of the tool and the round billet so that their resultant is minimum or equal to zero. One of the most popular and reliable solutions is using immovable or movable two-cutter blocks supplied with cutting parts with the same geometry and located at  $180^\circ$  [1, 2].

With immovable two-cutter blocks (Fig. 1, a), the asymmetry in the radial location of the two cutting parts, caused by either inaccuracy with defining or purposefully set to balance two particular passages, leads to differences in depths of skiving. This results in the formation of an out-coming radial force which causes elastic strains influencing the size of the dynamic adjustment. Thus the accuracy possibilities of the tools are reduced, and their application with high quality requirements of apertures is restricted [3-5].

With movable two-cutter blocks (Fig. 1, b), the dimensions of the dynamical adjustment are formed based on the continuous tendency towards dynamic equilibrium between the radial components of the two cutting forces whose action is limited within the system of the tool and the round billet. This creates conditions for relative immobility of the block in radial direction. This immobility is slightly influenced by the stability of both the tool and the round billet and turns out to be the main reason for the comparatively common application of such an instrument with skiving deep apertures.

Under pre-set requirements [6], the fluctuation of the allowance practically does not reflect the size of the dynamic adjustment, and this is an important prerequisite for reaching high accuracy with the size and the shape in cross-direction. The most essential of the above mentioned requirements with rectilinear cutting edges is that they are situated in a plain perpendicular to the turning axis (with main fixing angles of  $\kappa_{r1} = \kappa_{r2} = 90^\circ$ ) or are positioned opposite to the generant of a truncated cone with the symmetry axis concurrent with the turning axis ( $\kappa_{r1} = \kappa_{r2} < 90^\circ$ ). It is possible to fulfill this requirement with certain accuracy. If, however, this accuracy should be

higher, the production and assembly expenses of the tool equipment will increase. Practically the indicated requirement is not met, and one of the two leading cutting edges of the two cutting parts is activated earlier in the skiving process surpassing the other one by the extent of their displacement in axis direction. This leads to widening of the processed aperture equal to the increased diameter, as compared to the size of static adjustment of the movable block. The reason for this is redistribution of the forces of the two cutting parts determining radial location of the block towards the turning axis, and this directly influences the length of the new diameter.

## 2. Development of thesis

Ignoring the intensity of wearing and taking into consideration the same geometry of the two cutting parts, we can proceed from the hypothesis that the cutting forces are in direct ratio to the area, and they are not greatly influenced by the shape of cross-section of the layer processed. That is a reason enough to accept that the equilibration of their radial components starts with the equilibration of the sizes of the processed areas of the cutting layer section by the opposite cutting parts.

With movable two-cutter blocks, the prerequisite mentioned above is answered; no matter what the value of axis displacement of the leading cutting eagles is, the efficiency of the tool is not affected. The purpose of the present work is to research the theory of the influence of this displacement over the diameter of the processed surface.

As we know [7], under certain conditions, including geometrical and cutting regime parameters, the two skiving parts influence each other. This results in a change of the size and/or the shape of the layers cut by them. This change is different with immovable or movable two-cutter blocks and can be easily illustrated if the following limitations are set: the symmetry axes of the block, the boring bar, and the aperture are concurrent with the turning axis; the main and the subsidiary fixing angles are  $90^\circ$  and  $0^\circ$  accordingly; the elastic strains within the technological system are ignorable; the diversions of the shape aperture of the round billet are insignificant; the friction forces in the guides of the movable block are not counted for; the main motion is performed by the round billet and the feeding motion – by the tool.

The immovable cutting block functions as an ordinary two-edged tool and its feed  $f$  is divided between the two cutting parts (Fig. 2), of which the lower part is conditionally accepted as first.

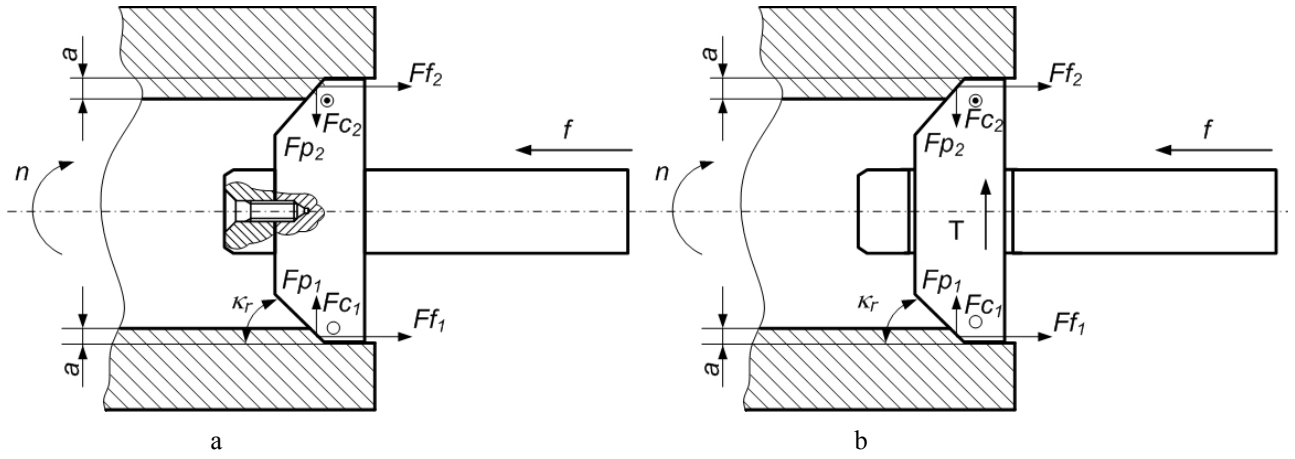


Fig. 1 Scheme of cutting with skiving tools with: a - immovable cutting blocks; b - movable cutting blocks  $f$  – feeding;  $a$  – cutting depth;  $F_x$ ,  $F_z$  and  $F_y$  – cutting forces

With axis displacement where  $0 < X < f/2$  (Fig. 2, b), the feed, loaded on the second cutter, decreases equaling the size of the displacement  $X$ , and the feed of the first cutter increases with the same amount, i.e.:  $f_1 = f/2 + X$ ;  $f_2 = f/2 - X$ ;  $f_1 > f_2$ .

It should be pointed out that, in fact, both cutting parts move at a certain speed  $f$ , but they split the section of the cutting layer, which, otherwise, will be performed by only one of the two. To ease the research, from all the parameters characteristic for the separate sections, not the thickness of cutting layers but the feeding is chosen.

With axis displacement where  $X = f/2$  (Fig. 2, c), the upper cutting part stops the cutting, and  $f_1 = f$ ;  $f_2 = 0$ ;  $S_2 = 0$ . It is obvious that this displacement value is a borderline case, i.e. the case also characteristic for  $X \geq f/2$ .

In all three cases, the diameter of the cutting surface  $D$  remains equal to the size of static adjustment of the block  $L_{adj}$  measured as the distance between the apexes of its cutting parts projected onto the plain perpendicular to the turning axis. Moreover, thickness of the layers cut is identical to the size of feedings, and cutting depths can be defined as follows

$$a_1 = a_2 = \frac{L_{adj} - D_0}{2} \quad (1)$$

where  $D_0$  is the diameter of the round billet aperture.

$F_{y1} > F_{y2}$  in the cases presented in Fig. 2, b, c, and a resultant force is initiated searching to move the block in radial direction.

The movable cutting block is notable for not bearing the presence of the resultant radial force. During the process of cutting, irrespective of the variation of the allowance, this block searches equilibrium with relation to the radial forces at the expense of any parameter changes in the layers cut by the two skiving parts.

With axis displacement where  $X = 0$ , the shape and sizes of the cutting layer sections, as well as the diameter, correspond to the ones shown in the Fig. 2, a.

With axis displacement where  $0 < X < f/2$ , a redistribution of feedings  $f_1$  и  $f_2$  and areas  $S_1$  и  $S_2$  appears, described with immovable block (Fig. 2, b). In this case, the movable block is moving radially toward the second cutting part under force  $\Delta F_y = F_{y1} - F_{y2}$  until the moment comes when  $\Delta F_y = 0$ . The resulting changes in the shape and

sizes of the layer cut are shown in Fig. 3, a. The following additional marks are also introduced in Fig. 3, a:

$S_{10}$  and  $S_{20}$  – contours of the cutting layer sections, first and second cutting parts, respectively, with  $X = 0$  (Fig. 2, a), and new aperture diameter of  $D = L_{adj}$ ;

$S_{1x}$  and  $S_{2x}$  – respective to the above-mentioned cutting layers contours, with the second cutting part lagging behind with  $X$ , and new aperture diameter of  $D > L_{adj}$ ;

$\Delta r_x$  – radial displacement of the bock in the direction to the second cutting part as a result of displacement  $X$ .

To reach diameter  $D_x$ , radial displacement  $\Delta r_x$  should be defined since

$$D_x = L_{adj} + 2\Delta r_x \quad (2)$$

As a result of displacement  $X$ , the sections of the cutting layer from the first cutting part increases its thickness by  $X$  and decreases its width by  $\Delta r_x$ . Meanwhile, cross-section of the cutting layer from the second cutting part decreases its thickness by the  $X$  and compensates for area loss by a layer with a  $2\Delta r_x$  width. As a result of these changes, cross-sections of the cutting layers  $S_{10}$  and  $S_{20}$

turn into sections  $S_{1x}$  and  $S_{2x}$ , where they get shapes and dimensions according to the figure. It is obvious that the first section changes only its dimensions reaching thickness  $f_1$  and width  $a_1$ , and the second – both its dimensions and its shape where the areas with different thicknesses and widths form. According to definition, these changes do not occur when equilibration of the radial forces corresponding to their surface equation is reached.

The areas of the cutting layer from the first and second cutting parts are as follows

$$S_1 = f_1 a_1 = (f/2 + X) a_1 \quad (3)$$

$$S_2 = f_2 a_2 + 2\Delta r_x (f/2 + X) = (f/2 - X) a_2 + \Delta r_x f + 2X \Delta r_x \quad (4)$$

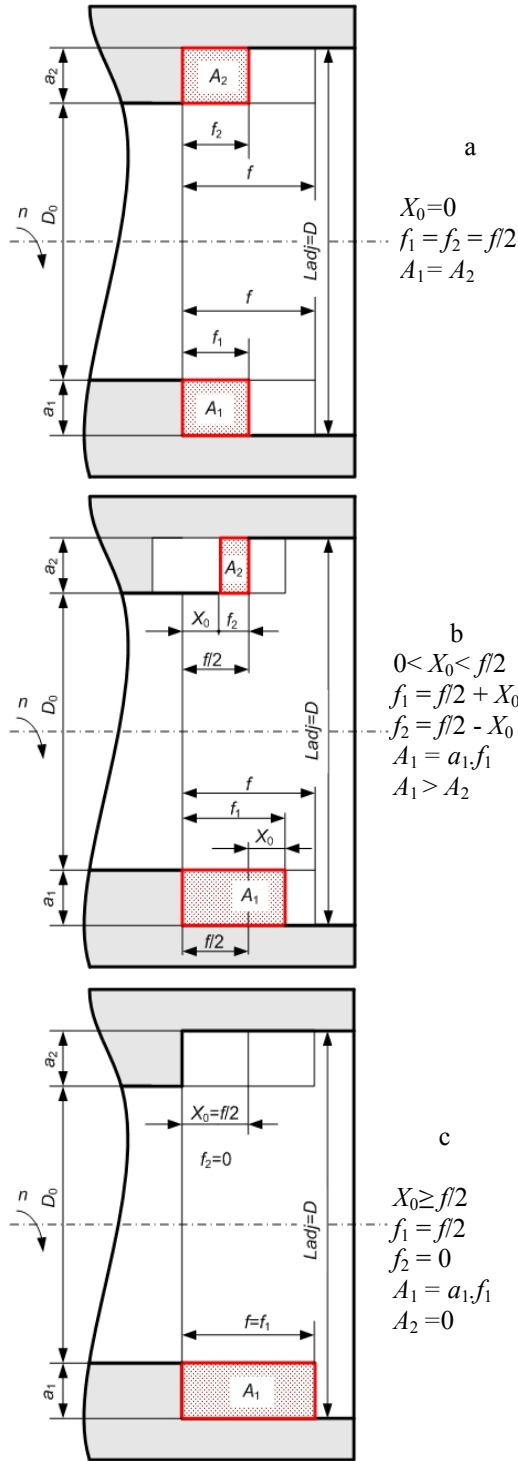


Fig. 2 Influence of the displacement  $X$  to the cross-sections of the cutting layers in immovable cutting blocks

After equalizing (3) and (4) and substituting

$$a_{1,2} = \frac{L_{adj} - D_0}{2} \mp \Delta r_x \quad (5)$$

The new equation is

$$\Delta r_x = \frac{X(L_{adj} - D_0)}{2(X + f)} \quad (6)$$

After substituting (6) in (2) and (5) as the diameter of the skiving surface and cutting depth, the result is

$$D_x = L_{adj} + \frac{X(L_{adj} - D_0)}{X + f} \quad (7)$$

$$a_{1,2} = \frac{L_{adj} - D_0}{2} \left( 1 \mp \frac{X}{X + f} \right) \quad (8)$$

With axis displacement of  $X \geq f/2 = X_{lim}$  (Fig. 3, b), cross-sections of the cutting layers of the two cutting parts do not overlap and do not affect each other in terms of feeding motion. Making the areas equal accounts for a change in their dimensions only in radial direction by moving the block by distance  $\Delta r$ , where the cross-sections get the same shapes and dimensions. Therefore, this is considered the maximum radial displacement of the block; to calculate this displacement,  $X$  in formula (6) must be substituted by  $f/2$ , where

$$\Delta r = \frac{L_{adj} - D_0}{6} \quad (9)$$

If the same substitution is performed in formula (7) and  $a_1 = a_2 = 2\Delta r$  is considered as diameter of the skiving surface and depths of cutting, the result is

$$D_{lim} = L_{adj} + \frac{L_{adj} - D_0}{3} \quad (10)$$

and

$$a_1 = a_2 = \frac{L_{adj} - D_0}{3} \quad (11)$$

If  $\kappa_r = 90^\circ$  is excluded from the accepted limitation, to determine the aperture diameter and the depths of cutting with displacement  $X=0$  and  $X \geq X_{lim}$  the same considerations and subordinations, presented in  $\kappa_r = 90^\circ$ , will be valid. This, however, does not apply to a displacement of  $0 < X < X_{lim}$ .

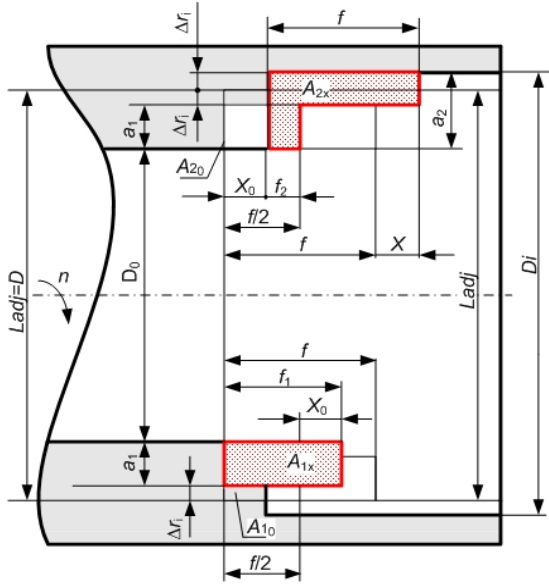
With  $\kappa_r < 90^\circ$ , the limited axis displacement is  $X_{lim} > f/2$ , and the radial displacement  $\Delta r_x$  can difficultly be calculated by equalization of the areas of the two cross-sections of the cutting layers. To determine  $X_{lim}$  and  $\Delta r_x$ , Fig. 4 is used, in which the data is the same as in Fig. 3, and the graphic design of Fig. 4 is done following these considerations:

1. The contours of the cutting layer's sections of the two parts with  $X=0$  correspond to the starting (initial) position of the block, and they are marked as  $S_{1_0}$  and  $S_{2_0}$ .

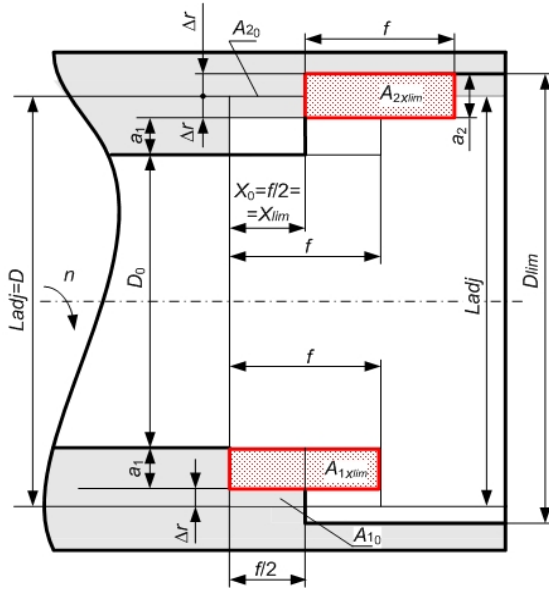
2. If the second cutting part takes axial displacement of  $X \geq X_{lim}$ , the block moves to the maximum radial distance  $\Delta r$ , where the section contour takes the position marked as  $S_{2_{X_{lim}}}$  and the section contour of the first part takes the position of  $S_{1_{X_{lim}}}$ .

Besides, the work performed by the first cutting part enlarges the aperture opening from  $D_0$  to  $D_1$ , and the work performed by the second one enlarges the opening from  $D_1$  to  $D_{lim}$ . The mirror-image of  $S_{1_{X_{lim}}}$  contour is  $S_{1'_{X_{lim}}}$ . The middle line of the latter is placed at a distance of  $f/2$  from its ends in an axis direction coinciding with the

bordering position of the leading cutting edge of the second cutting part and determining if the two sections will influence each other. In the frame of reference  $XOY$ , displacement  $X_{lim}$  is the abscissa of the intersection point  $M$  of the middle line and the line parallel to axis  $OX$ , with  $\Delta r$  as ordinate.



a  
 $0 < X_0 < f/2$   
 $f_1 = f/2 + X_0$   
 $f_2 = f/2 - X_0$



b  
 $X_0 \geq f/2$

Fig. 3 Influence of the displacement  $X$  to the cross-sections of the cutting layers and the diameter of the skiving surface in movable cutting block and  $\kappa_r = 90^\circ$

3. When the second cutting part is moved from  $X=X_{lim}$  to  $X=0$ , the block moves in radial direction to the first cutting part ( $\Delta r$  drops to 0), and the middle line of contour  $S_{1X_{lim}}$  is pushed so as to coincide with the middle line of contour  $S_{2_0}$ . The zone, where the two cutting parts

share feeding  $f$ , is locked between the middle line and the surpassing position of the leading cutting edge.

4. With axis displacement of  $0 < X < X_{lim}$ , the section contour of the second cutting part is marked as  $S_{2x}$  and that of the second one –  $S_{1x}$ . The mirror-image of the latter contour over the second cutting part is marked as  $S_{1'x}$ . The area, where the cross sections of the cutting layers from the two parts interact is located between the middle line of that contour and contour  $S_{2x}$ , and its size is in the axis direction and equals feeding  $f_2$ .

5. All the above mentioned contours in the axis direction have length  $f$ , except for  $S_{2x}$ , which also comprises an area with length  $f_2$ .

Based on proportion requirements between the section area and the cutting forces, for each displacement  $X$  within the interval  $0-X_{lim}$ , the edge of the second cutting part lies on the line  $a$  (which may be accepted practically like straight) crossing its two bordering positions – points 0 and  $M$ . The equation of this line in the specified frame of reference is as follows

$$\Delta r_x = \frac{\Delta r}{X_{lim}} X \quad (12)$$

The bordering displacement can be calculated by the following formula

$$X_{lim} = f/2 + 1 \quad (13)$$

where in the MNP right-angled triangle

$$l = \frac{2\Delta r}{\text{tg}\kappa_r} \quad (14)$$

The result of this consecutive substitution, of (9) in (14) and (13) is

$$X_{lim} = \frac{f}{2} + \frac{L_{adj} - D_0}{3 \text{tg}\kappa_r} \quad (15)$$

After substituting (9) and (15) in (12) the result is

$$\Delta r_x = \frac{X(L_{adj} - D_0) \text{tg}\kappa_r}{3f \text{tg}\kappa_r + 2(L_{adj} - D_0)} \quad (16)$$

Substituting (16) in (2) and (5) makes it possible to specify the diameter of the skiving surface and the corresponding cutting thicknesses in the following equation

$$D_x = L_{adj} + \frac{X(L_{adj} - D_0) \text{tg}\kappa_r}{1.5f \text{tg}\kappa_r + L_{adj} - D_0} \quad (17)$$

In this case, the two cutting parts form the cross-sections of the layers they have cut through three different feedings –  $f_1$ ,  $f_2$  and  $f$ . Moreover, to determine  $f_1$  it is essential to know  $f_2$  since  $f_1 = f - f_2$ . The result is only possible by equalizing the cross-section areas of the two cutting parts (the hatched areas), where

$$a_{1,2} = \frac{L_{adj} - D_0}{2} \left( 1 \mp \frac{X \operatorname{tg} \kappa_r}{1.5f \operatorname{tg} \kappa_r + L_{adj} - D_0} \right) \quad (18)$$

$$f_{1,2} = \frac{f}{2} \pm \frac{fX}{1.5f - X + \frac{L_{adj} - D_0}{\operatorname{tg} \kappa_r}} \quad (19)$$

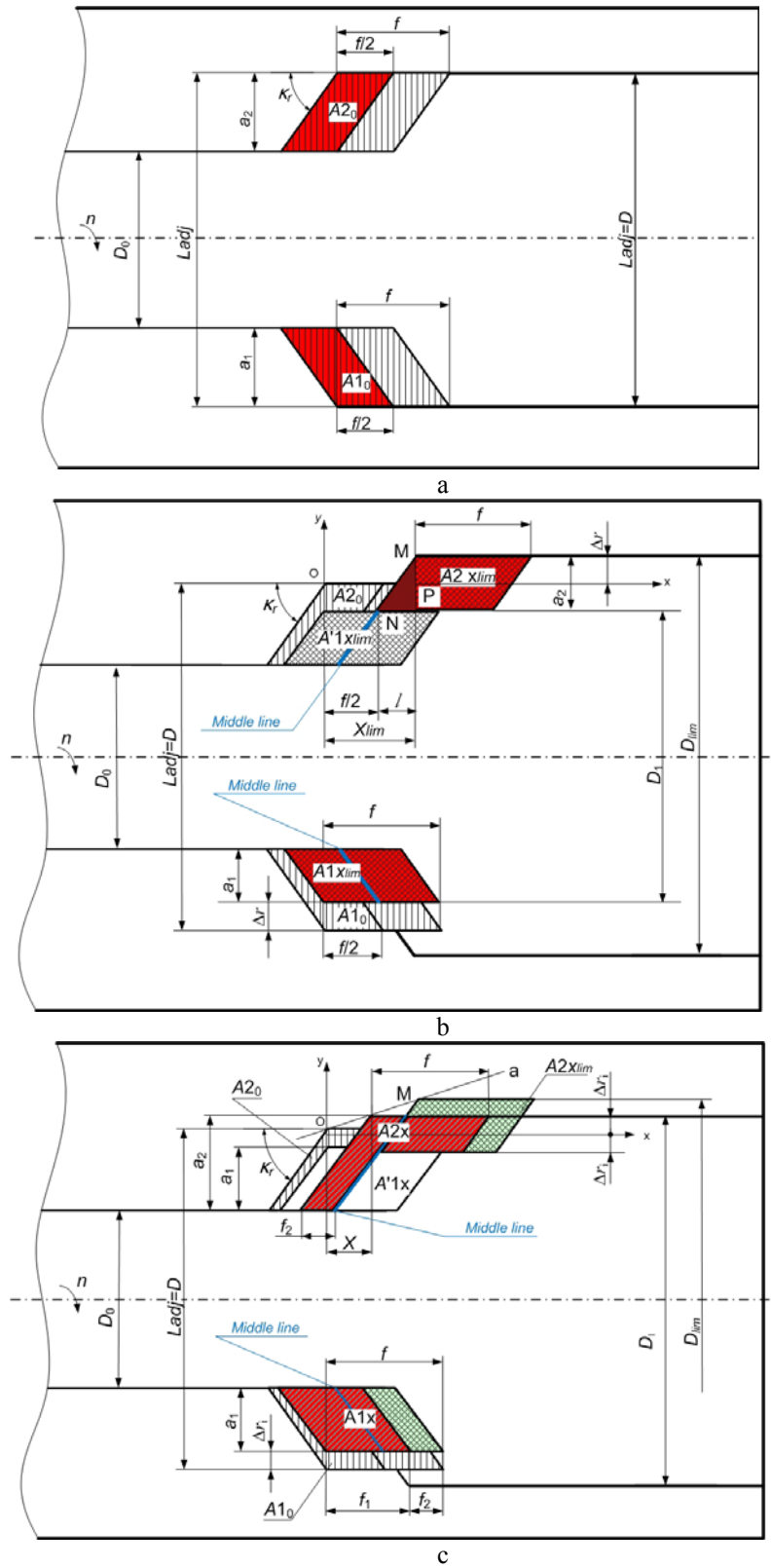


Fig. 4 Influence of the displacement  $X$  to the cross-sections of the cutting layers and the diameter of the skiving surface in movable cutting block and  $0 < \kappa_r < 90^\circ$ : a -  $X_0 = 0$ ; b -  $0 < X_0 < X_{lim}$ ; c -  $X_0 > X_{lim}$

### 3. Conclusions

As a result of this theoretical research, a possibility opens to prognosticate the diameters of the skiving surfaces by cutting light apertures with movable two-blade blocks depending on the displacement of their leading cutting edges in axial direction. This is essential when designing tools both for independent use and in combination with tools for surfacing plastic deformation if requirements for the surface quality are high. The regulated increase of their diameter lengths toward the size of the static adjustment of the cutting block is essential with cutting deep apertures when taking the tool and the chips out.

The final proportions to calculate the bordering displacement and the parameters of the cutting layers provide a possibility for technical solutions to be searched for and improve the movable cutting blocks with respect to increasing the processing productiveness without changing the geometrical quality characteristics of the skiving surfaces.

It has been established that the cutting depth of the subsidiary part (as a result of the axis displacement) is bigger than the one of the leading cutting part with the size of the radial placement of the block doubled. With displacement  $0 < X < X_{lim}$ , it determines the size of the addition to be taken off, which equals  $2a_2$ . In bordering cases, the cutting depths of the two cutting parts are equal, and with  $X=0$ , the addition is  $2a_1=2a_2$ , while with  $X=X_{lim}$ , the addition equals  $2(a_1+a_2)$ .

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### STUMDOMO DVIEJŲ PJOVIMO ĮRANKIŲ BLOKO DARBO YPATUMO TYRIMAS TEKINANT SKYLES

R e z i u m ė

Tekinant galias, palyginti mažo skersmens skyles, dažnai naudojamas dviejų peilių, išdėstytų  $180^\circ$  kampu, judantis įrenginys. Šis įrenginys užtikrina didelį technologinės sistemos stabilumą bei reikiamą matmenų tikslumą. Straipsnyje teoriškai nagrinėjama įrankių bloko ašinio stūmimo įtaka apdirbamų skylių briaunų tiesumui visu skylės perimetru. Galutiniai kiekybinių tyrimų rezultatai gali būti taikomi praktikoje.

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### RESEARCHING THE BEHAVIOUR OF MOVABLE TWO-CUTTER BLOCKS IN CASE OF SKIVING APERTURES

S u m m a r y

A movable cutter assembly with two blades situated at  $180^\circ$  is often used for cutting deep light apertures. This assembly provides high stability of the technological system and accuracy with the final dimensions. In this paper, a theoretical analysis of the influence of their axis displacement with the rectilinear leading skiving edges over the diameter of the working aperture is presented. The final correlations on the quantitative value of that influence also have practical application.

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### ИССЛЕДОВАНИЕ ПОВЕДЕНИЯ ПОДВИЖНОГО БЛОКА С ДВУМЯ РЕЗЦАМИ ПРИ ТОЧЕНИИ ОТВЕРСТИЙ

Р е з ю м е

При точении глубоких отверстий сравнительно малого диаметра, часто используется подвижное устройство с смонтированными под углом  $180^\circ$  двумя резцами. Это устройство обеспечивает высокую стабильность системы и нужную размерную точность отверстия. В статье теоретически исследуется влияние осевого передвижения блока резцов на прямолинейность грани отверстия по всему ее периметру. Количественная оценка конечных результатов исследований имеет практическое применение.

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