INVESTIGATIONS ON THE TRAJECTORY OF ECCENTRIC CIRCULAR KNIFE BLADE MOVEMENT IN BOOK CUTTING PROCESS

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Abstract
Analysis of kinematic parameters of book block cutting shows, that by using eccentric circular cutting knife the cutting process may be realized in two different modes: continuous cutting – with the constant contact between cutting edge and cut material, and intermittent cutting process – with the impulse cutting knife action to treated material which is book block. The paper describes the trajectory of circular knife blade movement in book cutting process. It was found that the greatest influence on the length of the road of the knife blade going through in the paper are: feed rate of the book, distance between the block and the knife rotation axis, knife rotation speed and others. The calculations allow selecting of the kinematic parameters of the cutting process, taking into account the road of knife blade inside the paper of the book during cutting with the circular knife, in order to minimize the blade wear.
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Selected parts of rotating knife blade during cutting process have a longer contact with paper than it is when the cutting process is made with flat knife. That phenomenon can lead to accelerate blade wear under in certain conditions.

The aim of the study was he analysis of the cutting knife edge movement and to calculate the road path which is overcome by the blade of eccentricity circular knife in the cutting process of book blocks.

In contrast to centric positioned circular knife [1], the trajectory of selected blade knife points in eccentricity positioned circular knife are different to each other and may depend on the rotation radius ρ, the size of eccentric e and the ratio of the linear speed of the knife blade to the feed rate of the book block.

On the Fig. 1 the trajectory of three different points (A,B,C) on the eccentricity positioned circular knife was showed. For example the B point trajectory, which is located on the blade knife edge may be described by the following parametric equations as a function of time t (it is assumed that the rotatation speed of the knife and the feed rate of the book block are constant):

Synchronous cutting (1) –

$$x_B = -v_0 t - \rho_B \cdot \sin(\omega t + \alpha); \;\; y_B = \rho_B \cdot \cos(\omega t + \alpha)$$

Anty-synchronous cutting (2) –

$$x_B(t) = -v_0 t + \rho_B \cdot \sin(\omega t + \alpha); \quad y_B(t) = \rho_B \cdot \cos(\omega t + \alpha),$$

where the distance B from the axis of rotation ρ is defined as a function of the angle α in the direction of rotation (3):

$$\rho_B = e \cdot \cos(\alpha) + \sqrt{e^2 \cos^2(\alpha) + R^2 - e^2}$$

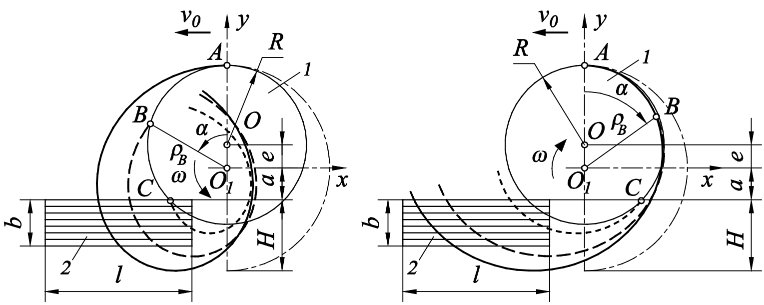

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Fig. 1. Trajectory of three different points (A,B,C) on the eccentricity positioned circular
a – Synchronous cutting, b – Anty-synchronous cutting
1 – circular knife, 2 – book block

During cutting process, each point on the blade of the knife leaves conventional marks in the form of traces after cutting on the surface of the cut material – an extended cycloid, which is described by the equations (1 and 2). Traces which have been "left" on the book block by the movement of the selected knife blade points were considered. When cutting the book block, each point on the knife's blade will come into contact with the cut part of the book block several times and leave a few "marks" – cuts arranged at equal distances from each other within each full rotation of the knife (Figure 2).

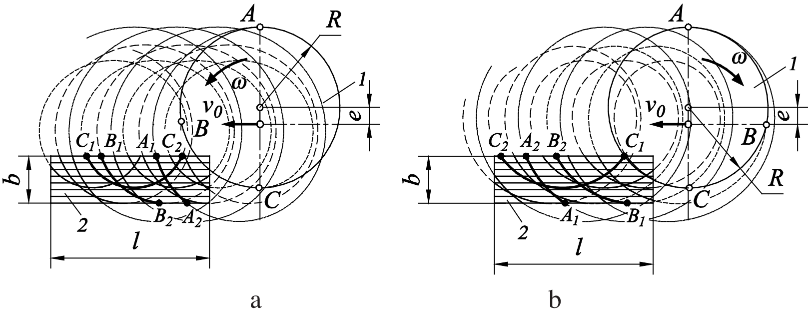

Fig. 2. Traces which have been "left" on the book block by the movement of the A, B, C points on the eccentricity positioned circular knife
a – Synchronous cutting, b – Anty-synchronous cutting
A_1, B_1, C_1 – point input, A_2, B_2, C_2 – point output,
1 – circular knife, 2 – book block

In the case of a knife positioned without an eccentric, the shape and length of cutting marks on the surface of the book block are the same for each point of the blade [1]. As can be seen from Fig. 2 in the case of a knife positioned with the eccentric, the shape and length of the cutting marks for different points A, B and C differ significantly, and for example point C does not cut the book block in whole.

Research which has been done [2] revealed that when the geometry and kinematic parameters of the cutting process are properly selected, two different intermittent cutting processes may occur – with a complete detachment of the knife edge from the book block in the cutting process and when part of the knife blade alternately cuts the incomplete height of the book block, and then the full amount of the book block.

The trajectory shape of the cutting marks depends on the position of the point on the knife, the direction of knife rotation, knife radius *R*, eccentricity *e*, block distance from the rotation axis a, the thickness of the book b, the rotational speed of the knife ω and the feed speed rate v_0. With continuous cutting, the trajectory of movement marks of the knife blade points does not intersect during cutting, but the density of traces (distances between traces) changes (Fig. 3, a), while with intermittent cutting, during the knife blade reverse movement the cutting periodically breaks, and the trajectory of the traces of neighboring points of the blade intersect (Fig. 3, b).

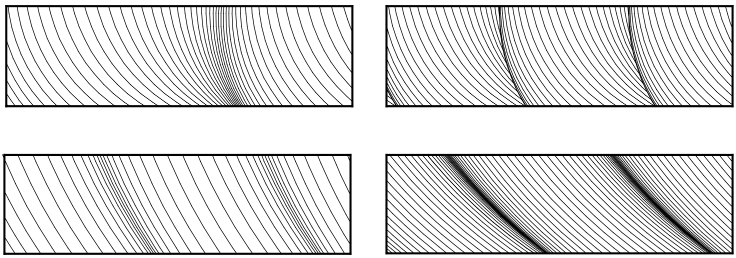

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Fig. 3. View of the trajectory of movement marks of knife blade points during cutting of book blocks at different distances of set-up book block from the knife rotation axis
a – continuous cutting, b – intermittent cutting

The calculations carried out with the help of the Mathcad software showed the possibility of existence specific sectors on the perimeter of circular knife blade (only when specific parameters of process are adapted):

- sector of the knife blade, where book block is being cut in the full range of its height
- sector of the knife blade, where the book block is being cut in the partial range of its height
- sector of the knife blade, where the knife doesn’t participate in cutting process

The size of these sectors depends on the geometrical and kinematic parameters of cutting process.

According to [4], point path calculations were made. Calculation of the road path which is traversed by the one of the points on the circular knife blade edge positioned centrally. Moreover process parameters were determined to reduce this path, and consequently the blade wear level reduce.

Comparatively to the calculations made in [1], the track was calculated, the track which is overcome by *B* cutting point of the eccentric knife blade during cutting process. The track *L* of a single trace of point B of the knife blade during cutting (Fig. 2) can be found from the formula (4):

$$L_B = \int_{t_{B1}}^{t_{B2}} \sqrt{v_0^2 + \omega^2 {\rho_B}^2 \pm 2v_0 \omega \rho_B \cos(\omega t + \alpha_B)}\, dt$$

where, tB1 and tB2 accordingly input and output time of point B (point on the edge of knife blade) in/out book block (fig. 2, B1 and B2 points). In formula (4). The “plus” character corresponds to the – Synchronous cutting, and the “minus” sign – Anty-synchronous cutting.

The time of entry of the blade into the book block and the output time of the blade from the book can be calculated on the basis of trajectories of the point B of the blade (1) – (2) [3]. The total number of cutting marks (paper path) left by point B in book of length l is: $z = \frac{\omega \cdot l}{2\pi v_0}$

The length of a single trace of the point of the cutting edge depends on its distance from the axis of rotation of the knife, i.e. on the knife edge.

To calculate the total length of the cutting path a special algorithm was developed, while using the Mathcad software, simulation calculations of the cutting process of the book block with an eccentric circular knife were performed.

Fig. 4 and 5 present the results of calculations of the relative cutting length (blade path in the book block) of the eccentric circular knife depending on different process parameters and compared to the path of cutting the circular knife positioned without eccentricity.

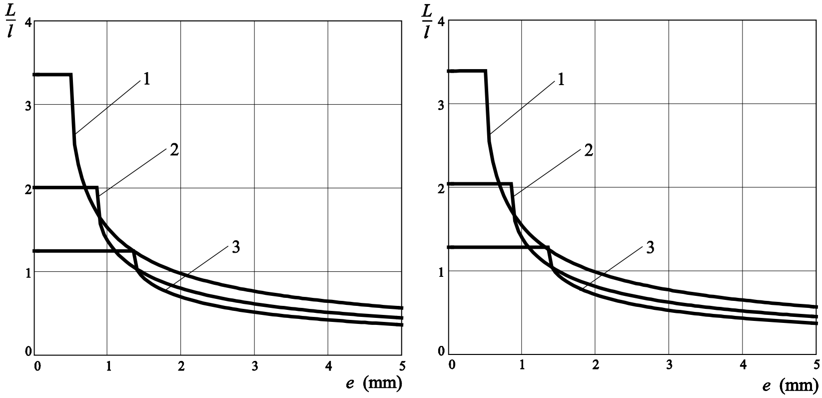

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Fig. 4. Influence of the eccentricity size e on the dimensionless cutting length L / l depending on different values of the feed rate of the v_0
a – Synchronous cutting, b – Anty-synchronous cutting
1– v_0=150mm/s, 2 – v_0=250mm/s, 3 – v_0=400mm/s
Parameters: a=70mm, b=10mm, R=100mm, n=2000 obr/min.

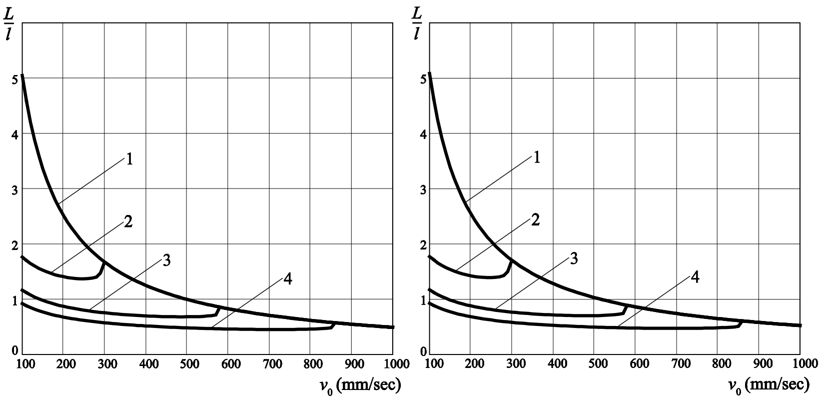

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Fig. 5. Influence of the feed rate of the insert v_0 on the dimensionless cutting length L / l depending on the eccentricity size e
a – Synchronous cutting, b – Anty-synchronous cutting
1 – e=0мм, 2 – e=1мм, 3 – e=2мм, 4 – e=3мм
Parameters: a=70mm, b=10mm, R=100mm, n=2000 obr/min, changes in diagrams 2, 3, 4 indicate the transition from intermittent to continuous cutting.

Simulations of cutting processes with a circular, positioned eccentrically knife with (without an eccentricity) showed that the cutting length (cutting marks) in intermittent mode is smaller than the cutting length in continuous mode and significantly depends on the size of the eccentric – e. The difference in the cutting lengths in between continuous cutting *and* intermittent cutting is not significant. During intermittent cutting, not all sectors of the knife blade participate in cutting the book block. With the proper choice of intermittent process parameters, when the total size of the cutting sector is around 180°, only half of the blade of the circular knife will be used (only if cutting is in contact with the paper of the book insert). After blunting this part of the knife blade, it is possible to invert the circular knife by about 180° what makes further cutting with a sharp part of the blade possible. This phenomenon extends the life of the cutting tool what makes the hole process more effective and profitable.

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