# INVESTIGATIONS ON BOOK CUTTING BY CIRCULAR KNIFE WITH ECCENTRIC BLADE MOVEMENT

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**Abstract:** The paper describes investigations on new method of the book cutting by using special circular knife with eccentric blade movement. 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 interrupted cutting process - with the impulse cutting knife action to treated material. The results of the conducted experimental studies confirm the kinematic analysis of the cutting process.

Key words: book cutting, circular knife, eccentric blade movement, kinematic analysis

#### 1. PREFACE

Paper cutting operations are widely applied in the implementation of the printing process: before printing - to trim the stacks to the desired format by single-knife cutting machines, as well as the treatment of the final book blocks - by three-knife trimmers. Until recently, cutting the paper was to be regarded as secondary operation and auxiliary. But today, applied to the much more attention, as it is proven that the correct cutting largely influences on the smooth running of other technological operations, which has a large impact on the quality of the final product and the cost of production.

Development of modern three-knife trimmers goes towards the maximum automation of auxiliary processes, while the principle of work practically unchanged for over more than 170 years. The most part of the modern trimmers realized a knife cutting movement as a combined motion (saber movement). However, this cutting process is characterized by relatively large values of cutting force, repeatedly increasing when it working with blunt knives, makes cutting quality worse and reduces the processing speed. However, the modern bookbinding automatic lines works much faster. There is a need to look for the possibility of using other cutting methods enabling the implementation of streamline processing.

### 2. BACKGROUNDS

Most of the research on paper cutting processes is devoted to single-knife cutting process (Dittrich, 1965; Ginzburg, 1957; Mordowin, 1962; Neumann et al, 2012; Rusin and Petriaszwili, 2013). The process of cutting paper stacks and books with a circular knife is relatively poorly researched. Krabisch (1962) (Krabisch, 1962) found that the strength and quality of the trimming of brochures largely depend on the thickness of the block, the feed rate, and the rotary speed and direction of rotation of the circular knife. The main obstacle in using this method for processing thick book blocks is a significant increase in trimming forces and the phenomenon of excessive heating of the knife as a result of rubbing against the paper, which causes local "burns" and deterioration of the cutting quality. Research conducted by Grushevski (1963) (Gruszewski, 1963) confirmed the limitation of the possibility of qualitative trimming of books.

There is intensive research into the practical use of vibration of cutting tools in the machining of various materials (Kumabe, 1985; Markov, 1966; Podurajev, 1970). The results of these tests show a significant reduction in cutting forces and an improvement in the quality of the treatment with lower energy consumption. The performed studies also indicated the possibility of vibration trimming of paper stacks (Komarov and Petriaszwili, 1989). These studies showed a significant reduction in the cutting forces of paper stacks and an improvement in the quality of cutting. However, for the implementation of vibratory cutting it is necessary to use special vibrators to drive the knife. In order to reduce the cutting forces, without using vibrators, an eccentric setting of the rotary knife was proposed (Petriaszwili et al, 2019; Petriaszwili and Janicki, 2017).

The purpose of this work is to analyze the possibility of the streamline book cutting using special circular knife with eccentric blade movement and to test the possibility of new method of book cutting.

#### 3. KINEMATICS OF CIRCULAR BOOK CUTTING

During the process of cutting using circular knife, a kinematic transformation of the cutting angle occurs – the mentioned transformation depends on kinematic and geometrical parameters of the cutting process as: cutter angular speed and rotation direction, feed rate, knife diameter and book thickness. The kinematics of the cutting process with a circular knife differs from the kinematics of cutting with a straight knife. The effective cutting angle value (the kinematic one) becomes smaller, than actual sharpened edge angle. It also causes a significant decreasing of cutting forces (Figure 1):



Figure 1: Transformation of real cutting angle  $lpha_T$  of circular knife during cutting process

When cutting with the circular knife cutter (Figure 1), the real cutting angle  $\alpha_T$  is calculated with the following formula [11]:

$$\alpha_T = \arctan\left[\tan(\alpha_0) \frac{v_0 \cos(\varphi)}{\sqrt{\left[v_R \sin(\varphi) - v_0\right]^2 + \left[v_R \cos(\varphi)\right]^2}}\right]$$
(1)

where: v - actual cutting speed,  $v_0$  - feed speed,  $v_R$  - linear speed of the circular knife,  $\alpha_0$  - angle of sharpened edge,  $\varphi$  - rotating angle of knife at the point of cutting.



Figure 2: Scheme of book cutting with eccentric circular knife: a - forward cutting, b - reverse cutting  $v_0$ -feed speed,  $v_R$  - linear speed of the circular knife,  $\omega$  - rotating speed of the knife, e - value of eccentric, R - radius of circular knife

The kinematic analysis has been carried out for two rotation directions of the circular knife (figure 2): forward cutting – takes place when the cutter rotation direction is synchronous to the movement direction of the book and reverse cutting – takes place when the cutter rotation direction is anti-synchronous to the feed direction of book.

Figure 3 shows the calculated graphs of changes of the actual cutting angle in the cycle of one full rotation of the circular knife set with the eccentricity e for various ratios  $v_R/v_0$ . The value 20° of the knife sharpening angle was used in the calculations. The vertical dashed lines in both graphs indicate the knife position when the cutting process interrupted.



Figure 3: Changes of real cutting angle  $\alpha_T$  in the cycle of full rotation of circular knife with eccentric blade movement e for different ratios  $v_R/v_0$ a - forward cutting, b - reverse cutting  $1 - v_R/v_0=5$ ;  $2 - v_R/v_0=8$ ;  $3 - v_R/v_0=20$ ;  $4 - v_R/v_0=80$ 

Analysis of kinematic parameters of book cutting shows, that by using eccentric circular knife the cutting process may be realized in two different modes:

- continuous cutting when the knife's blade is in constant contact with the book during the processing, and
- interrupted (impulse) cutting when the knife's blade comes out of contact with the book paper in a certain phase of the knife rotation cycle - at this point, the cutting process is interrupted, and the edge of cutting knife does not touch the part of the book during this time.

Continuous cutting is performed under the condition that the horizontal component of the linear cutting speed is  $\geq 0$ . The condition of cutting in the interrupted mode is that the horizontal cutting speed has the direction opposite to the feed speed and its absolute value is greater than the value of the feed speed. During the investigation, mathematical description of the interrupted and contiguous cutting was established. The equations allow calculating of the needed kinematic parameters for the interrupted cutting mode (Petriaszwili and Janicki, 2017). The equations are transcendental, so all calculations and graphs were made using Mathcad. It was found that the greatest influence on the characteristics of the process and the value of cutting angle 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 path of knife blade inside the paper of the book during cutting with the circular knife, in order to minimize the blade wear (Petriaszwili et al, 2019). By analyzing the charts, it can be concluded that for the reverse cutting mode, the real cutting angle is smaller than for the forward cutting. This means that in the case of using a reverse cutting with an eccentric knife, lower forces of books cutting can be expected.

#### 4. EXPERIMENTAL RESEARCH

In order to verify the formulated scientific hypothesis about two modes of cutting: continuous and interrupted cutting, a special laboratory stand was designed and built with a drive unit for transport books with different speed and a rotary cutting unit equipped with circular knives.

The special laboratory stand with mounted circular knives enables research on the processes of streamline cutting of books both with one circular knife and with several sets of circular knives at the same time. Laboratory stand makes possible to test the cutting process of clamped books with cutting length – up to 240 mm and thickness – up to 30 mm with the book feed speed – up to 3 m/s.

A National Instruments (USA) data acquisition system was used to register and analyze fast-changing signals. Enhanced data acquisition system enables simultaneous recording the process of cutting books of the following parameters: three components of cutting force, clamping force, three components of knives vibrations together with spectral analysis and measurement of knife blade wear. The measuring path of the acquisition system consists of three basic blocks: measuring, signal processing and analyzing block. Registration and analysis of signals takes place in a PC computer using specialized programs LabVIEW SignalExpress and DIAdem (National Instruments).

Figure 4 shows the distribution of force components that act on the transport carriage registered during cutting. The cutting force can be presented in the form of three components: horizontal Fx - operating in the cutting plane in the direction of transport of the book, Fz component - perpendicular to the transport direction in the cutting plane, and vertical component Fy - perpendicular to the cutting plane.

As a result of the research, it was found that in the cutting process (continuous and interrupted) of books, the components of the forces Fx and Fz are the most significant, the size of which depends on the appropriate selection of the parameters of the cutting process.



Figure 4: Three components of the force acting on the transport carriage when cutting books with a circular knife

Figure 5 presents the experimental plots of recording the component Fx of cutting force during the revers cutting of books with an eccentric circular knife:



Figure 5: Changes of Fx component of cutting force during cutting the book with an eccentric circular knife (e = 1 mm) a –continuous cutting, b – interrupted cutting

In the interrupted (pulse) cutting mode, the force on the knife drops practically to zero when the blade is detached from the paper and increases again from the moment the knife's cutting edge comes into

contact with the book's paper (Figure 5a). Cyclical fluctuations and a decrease in the average values of the actual knife cutting angle as well as the dynamic nature of the interaction between the knife blade and the paper result in a reduction of the processing forces. The intermittent nature of the cutting also increases the efficiency of the processing with the circular knife by reducing the temperature in the cutting zone, due to the periodic lack of contact between the cutter blade and the paper being cut.

In the continuous cutting mode (Figure 5b), cyclic fluctuations in the value of the Fx component of the cutting force with an eccentric knife are noted. However, due to the higher feed speed of the book, the knife blade cannot keep up with the contact with the paper being cut and the nature of the cutting force changes on the experimental plot is different than in the case of interrupted cutting.

## 5. CONCLUSIONS

The conducted experimental studies confirm the analytical conclusions of the performed kinematic analysis of the cutting process on the implementation of two cutting modes: continuous cutting – with the constant contact between cutting edge and cut material, and interrupted cutting process - with the impulse action on paper block. The choice of cutting mode can be determined depending on the selected parameters of the machining process. Using the special circular knife with eccentric blade movement it becomes possible to implement book-flow-cutting in automatic lines for producing books.

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