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MATHEMATICAL STUDY OF THE INFLUENCE OF KNIFE GEOMETRY WITH ARC-LIKE CROSS-SECTIONAL SHAPE ON THE PROCESS OF LONGITUDINAL FELT CUTTING

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A promising study is the design and improvement of machines for longitudinal cutting of materials with minimal energy costs to perform the technological process of cutting due to the geometry of the cutting tool. The article considers the issues of reducing energy costs for the process of longitudinal cutting when using a knife blade with an arcuate cross-section. The analysis is carried out, the effective method of the analysis of influence of size of a backlash between generators of transporting rollers and size of distance from a vertical axis of rotation of transporting rollers to an edge of a knife blade with an arc-shaped cross section on the total size to determine the necessary settings in the machine of longitudinal cutting for felt, as well as to verify the reliability of analytical and experimental models of the process of longitudinal cutting with a knife with an arcuate cross-sectional shape. To determine the total amount of losses during longitudinal cutting of the material and the number of losses due to friction of the material on the face of a fixed knife with an arcuate cross-sectional shape, as well as linear cutting force, a two-factor experiment was conducted for the study model. The obtained regression equations describe the total amount of losses during longitudinal cutting of the material and the number of losses due to friction of the material on the face of a stationary knife with an arcuate cross-section, suggest the adequacy of analytical and experimental models made earlier. Also make the necessary adjustments, namely, to adjust the degree of compression of the material and set the edge of the knife blade relative to the vertical axis of the transport rollers to reduce friction losses on the edge of the knife, which in turn reduces energy costs for longitudinal cutting. Comparing the total values of losses in the longitudinal cutting of the material of a knife with one-sided sharpening and a knife with an arcuate cross-section, allows you to talk about the feasibility of using a knife with an arcuate cross-section, which will reduce energy costs for the process.

Key words: *running force, the total amount of losses, losses due to friction of the material, transporting rollers, knife blade, longitudinal cutting.*

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Introduction

Today, energy-saving technologies, reduction of energy costs for production processes in general, as well as at individual levels are of great interest at the state level, which is further aimed at reducing production costs and thus stimulating its demand. This position of enterprises at the state level contributes to the formation of energy-saving resources and the formation of an efficient energy market. The main goal of the development of mechanical engineering in Ukraine is machine-building products with minimal energy costs for the implementation of technological processes. Therefore, a promising study is the design and improvement of machines for longitudinal cutting of materials with minimal energy costs to perform the technological process of cutting due to the geometry of the cutting tool.

The formation of energy efficiency policy is a necessary condition for the revival of national production, increasing innovation attractiveness, sustainable development, as well as achieving European energy security standards. The development of mechanical engineering based on energy efficiency policy with the use of energy efficient technologies will create advantages for domestic enterprises in a competitive environment (Mykoliuk and Bobrovnyk, 2019). In (Sevastianov, 2016) the author noted that increasing the energy efficiency of an industrial enterprise determines the economic development of the enterprise and its survival in competitive markets. The author of (Polishchuk, 2019) experimentally studied the process of cutting materials in static and dynamic modes, namely the technological process of felling.

Longitudinal cutting machines are used for leveling or doubling materials. The main part of the technological process of longitudinal cutting in thickness is the interaction of the working parts of the machine, namely the transport rollers and various in shape knife blade (various in cross section, sharpening angles, etc.) with the material of the part that affects energy costs (Makatora and Panasiuk, 2014a, 2014b, 2014c, 2014d; Makatora, 2010a, 2010b; Makatora, 2013; Makatora, 2014; Makatora and Kniaziev, 2004a, 2004b; Cherno-Ivanov, 1998), and their authors investigated the process of longitudinal cutting and regression equations describing the total amount of losses when cutting material and the amount of loss of friction material on the face of a stationary knife, and determined the driving force of different materials (microporous and monolithic rubber, felt) different forms of the knife (Makatora and Panasiuk, 2014a, 2014b, 2014c, 2014d; Makatora, 2010a, 2010b; Makatora, 2013; Makatora, 2014; Cherno-Ivanov, 1998), and the authors of (Makatora and Kniaziev, 2004a, 2004b) conducted analytical studies to talk about the feasibility of using a knife with an arcuate cross-section, which will reduce the spacing force when performing a technological operation by reducing the tension of the material between the conveying roller and the surface of the knife, thereby reduce friction losses of the material that occur during the technological operation of longitudinal cutting, thereby reducing energy costs for the process.

The aim of this study is to develop an effective method for analyzing the effect of the gap between the generators of the conveyor rollers h and the distance from the vertical axis of rotation of the conveyor rollers to the edge of the knife blade a with an arcuate cross-section, by using regression equations, as well as verifying the validity of previously obtained models (Makatora and Panasiuk, 2014a, 2014b, 2014c, 2014d; Makatora, 2010a; Makatora, 2013; Makatora, 2014; Makatora and Kniaziev, 2004a, 2004b; Cherno-Ivanov, 1998).

Materials and Methods

This study is devoted to the longitudinal cutting of felt with a knife with an arcuate cross-section, determining the dependence of the value describing the total amount of losses in longitudinal cutting of felt and the number of losses due to friction of the felt on the face of the knife. The task of the research is to experimentally determine the linear force of felt cutting, to determine the total values of losses during longitudinal cutting of material and the values of friction losses of material on the face of a stationary knife with an arcuate sharpening shape. The influence of such factors as the distance between the edge of the knife blade and the axes of the conveying rollers (a) and the distance between the conveying rollers (h) (Makatora and Panasiuk, 2014a, 2014b, 2014c, 2014d; Makatora, 2010a, 2010b; Makatora, 2013; Makatora, 2014; Makatora and Kniaziev, 2004a, 2004b; Cherno-Ivanov, 1998) on the process of performing the technological operation of felt doubling is studied.

Longitudinal cutting of felt with a stationary knife is characterized by a complex process of deformation of the material. The scheme of the process itself (for its quantitative analysis) should be based on the influence of complex stress shear, which is destroyed during processing of the material from external forces – the force of resistance to movement of the material acting on the knife blade (Makatora and Kniaziev, 2004a, 2004b; Cherno-Ivanov, 1998).

The choice and characterization of research relationships is important. As a material for the experiment, an artificial material was chosen – felt. This is due to the fact that natural materials, which are widely used for the manufacture of materials, are not homogeneous in composition and for research (determination of linear cutting force), they cannot be objective samples for comparison, as their thickness is not uniform.

Experimental samples (details) (Fig. 1) with a width of B = 35 mm (radius of curvature R = 17.5 mm) and a length of L = 140 mm were obtained from the plates of the material with a cutter.

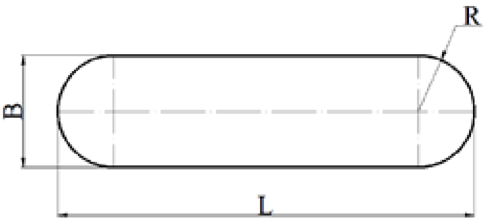

Fig. 1. Sample part used in the experiment

Experimental studies were conducted on an experimental setup that simulates the process of longitudinal cutting (Fig. 2).

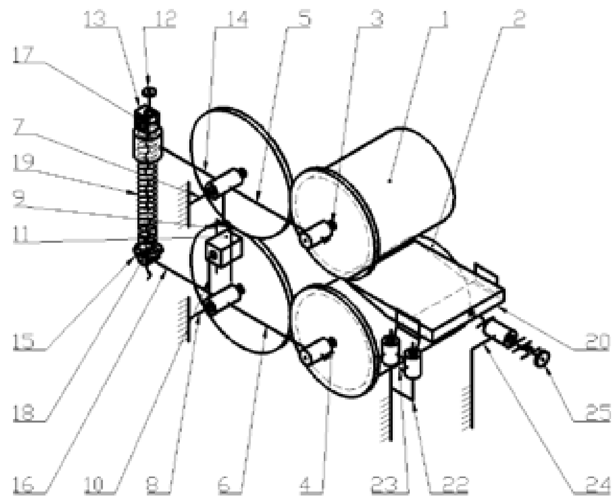

Fig. 2. Kinematic scheme of the experimental installation

The design of the experimental installation consists of a rocker-rocker transport mechanism (Cherno-Ivanov, 1998), which allows the simultaneous expansion of the transport rollers (the same amount) as the part is transported to the knife and cut depending on the geometric parameters of the part. The unit contains the upper 1 and lower 2 conveying rollers fig. 2, mounted respectively on the axes 3 and 4, fixed at the ends of the shoulders of the upper 5 and lower 6 of the three-shoulder rockers, which in turn are mounted on the axes 7 and 8, fixed on the frame. The second arm of the rocker arm 5 is made in the form of a rocker arm 9 and is kinematically connected to the second arm 10 of the rocker arm 6 by means of a slider 11. At the ends of the third arms of the rocker arm 5 and 6 with the mechanism of adjustment of effort of compression of a detail by rollers. Device for adjusting the gap between the generators of the conveying rollers, comprising adjusting rod 12 with right and left threads, kinematically connected to the upper locking nut 13 and mounted in the third arm 14 of the rocker arm 5, and the lower nut 15 mounted in the third arm 16 of the rocker arm 6. adjusting the compression force of the part between the conveying rollers 1 and 2, includes the installation between the arms 14 and 16 of the rockers 5 and 6 and the threaded rod 12, a pair of nuts 17 and 18, between which in turn is installed an elastic element 19. Between the conveying rollers 1 and 2 installed a knife device comprising a knife blade 20 with an arcuate sharpening shape, installed with the possibility of reciprocating movement in the holder 21, which, in turn, is installed with adjustable height in the guide 22 by a pair of adjusting screws 23. The device for adjusting the position of the edge of the blade 20 of the knife relative to the axes of the transporting rollers 1 and 2 contains an elastic beam 24 with adjusters' screw 25, mounted on the frame of the installation.

The experimental setup used a scheme of measuring the parameters of the linear cutting force of microporous and monolithic rubber, felt, which causes deformation of the blade of the knife 20 in accordance with the recommendations (Cherno-Ivanov, 1998). Therefore, on opposite sides of the elastic beam 24 (Fig. 3) glued two strain gages 26 and 27 (RTD1 = RTD2 = 400 Ohms), which were included in the bridge measuring circuit, which was connected to an 8-bit WAD-AIK-BUS controller with analog-to-digital converter (not shown), which, in turn, was connected to a personal computer 28, which allowed to record in real time the results of changes in the deformation of the blade of the knife 20 with an arcuate sharpening shape.

To construct a working planning matrix (Table 1), a staging experiment was conducted, during which the limit parameters of the process (values a and h) were determined, during which the part was cut longitudinally, with an error not exceeding the allowable (Cherno-Ivanov, 1998), with a thickness the details obtained were measured using a thickness gauge TR-25-1. For these parameters, Johanson's test tiles (measuring the size of the gap between the generators of the conveyor rollers 1 and 2 – h) and a template for measuring the distance from the edge of the blade 20 to the axis of the conveyor rollers 1 and 2 (value a), similarly (Cherno-Ivanov, 1998), with measuring indicator with an accuracy of 0.01 mm. To do this, the rollers in three different imposed textolite, bored in diameter rollers, template. According to the indicator, the probe of which rests on the edge of the knife blade, set the value of the distance a.

Experimental studies were conducted in the mode of doubling, when the part is cut longitudinally into two levels along the thickness of the part. The following relationship was observed (Fig. 4): $h_1 = h_2$, ie the distance between the plane edge of the blade of the knife 20 and the generators of the transport rollers 1 and 2 must be equal.

Why the holder 22 (Fig. 2) with loose screws 23 and nuts 24 screw 25 sets the knife in between the transport rollers 1 and 2, when the gap between them is already installed and controlled by Johanson's tiles, after which the holder 22 is fixed in the guide frame. not shown). Then the motor is turned on, and the part is fed between the conveying rollers 1 and 2.

After cutting it, with the help of a thickness gauge TR-25-1, the obtained parts were measured and in case of their inconsistency in thickness, the position of the knife holder between the transporting rollers 1 and 2 was adjusted.

The next step was the control calibration of strain gauges on the beam 24, by suspending the control loads from 100 to 1200 N, using a special rod with a suspension unit.

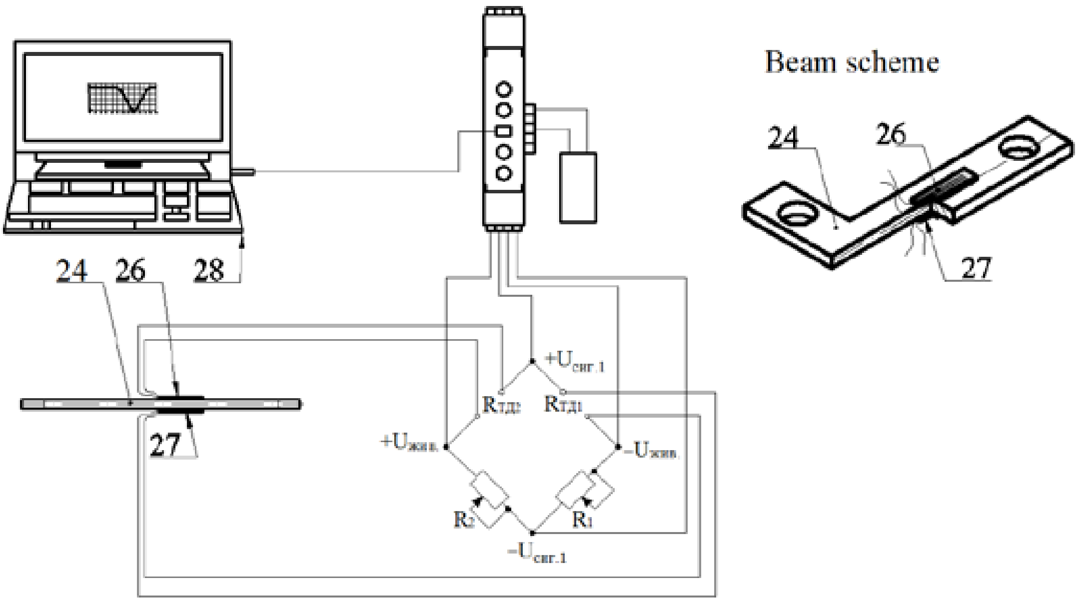

Fig. 3. Block diagram of the connection of the WAD-AIK-BUS module, bridge measuring circuit with a beam with strain gauges to the personal computer

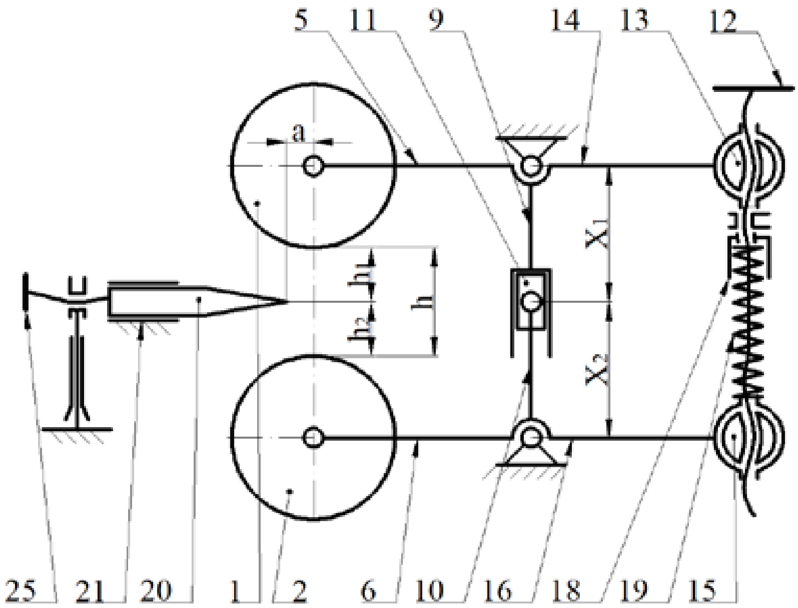

Fig. 4. Geometric scheme of the experiment

Calibration was performed before each series of experiments and every three hours of continuous operation. Then the calibration graphs were constructed: the values of the load were plotted on the ordinate axis, and on the abscissa axis the values of the deviation from the zero position, then the points were connected by a smooth curve, resulting in the desired graph. At the first run of the part (its cutting) determined the total amount of costs for longitudinal cutting of the material of the part. Then the two separated parts were folded together and fed again between the transport rollers 1 and 2 to the edge of the blade of the knife 20 already in the separated state and repeated the measurements. When re-running the part in the separated state was determined by the amount of friction costs. Each experiment was repeated at least five times.

For subsequent experiments, the installation was adjusted according to the data of the working planning matrix. After conducting all the tests, with the help of calibration graphs deciphered the value of total costs and friction costs, when performing longitudinal cutting with a knife blade 20, each measurement. The calculated average values of these values were entered in the corresponding columns of the tables.

Results

To determine the total amount of losses during longitudinal cutting of the material and the number of losses due to friction of the material on the face of a stationary knife with an arcuate cross-section, as well as linear cutting force, a two-factor experiment was conducted for the study model:

$$y = F(x_1,\ x_2)$$

where y – optimization criteria, which determine q_p; x_1 i x_2 – controlled parameters (factors) that characterize the size of the gap between the generating transport rollers *h* and the value of the distance from the vertical axis of rotation of the rollers to the edge of the blade ***a***.

When determining q_p, it is necessary to carry out double machining of the part, during which the total value of machining costs P is determined during its cutting, and then after cutting the material is folded together and passed through the plane through the knife, and the amount of friction costs is determined. values related to the value of the width of the part, gives the true value of the running force of cutting felt (Makatora and Panasiuk, 2014a, 2014b, 2014c, 2014d; Makatora, 2010a, 2010b; Makatora, 2013; Makatora, 2014; Cherno-Ivanov, 1998; Patent № 70012 Ukraina, 2004; Tikhomirov, 1974):

$$q_p = \frac{P - F}{B}. \tag{1}$$

The experiment was planned to use a rotatable Box plan for a two-factor experiment ($k_{1,2} = 2$), which is recommended when $k_{1,2} \le 5$ (Tikhomirov, 1974).

The total number of experiments is determined by the formula (Tikhomirov, 1974):

$$N_{1,2} = 2^2 + 2 \cdot 2 + 5 = 13$$

Coding, naming the values of factors and intervals of their variation are given in table. 1, the values of which were determined using ratios:

$$x_1 = \frac{x_1 - 4{,}35}{1}; \quad x_2 = \frac{x_j - 5}{0{,}5}. \tag{2}$$

We will process the experimental data to determine the total amount of losses during longitudinal cutting of the material. The planning matrix of the two-factor experiment is presented in table. 2. When determining the number of measurements for each experiment, five repeated measurements were performed at zero level (experiments 9–13) and the approximate value of the standard error of the equation was determined (Tikhomirov, 1974): $S_p = 1{,}118$.

Table 1

Table of levels and intervals of variation of the current factors to be studied

Factors	Measurement levels					Measurement intervals
	-1,414	-1	0	+1	+1,414	
h – distance between transporting rollers, mm (x_1)	2,95	3,35	4,35	5,35	5,75	1
a – the distance between the vertical axis of rotation of the conveying rollers and the edge of the knife blade, mm (x_2)	4,3	4,5	5	5,5	5,7	0,5

The estimated value of the Student's criterion in this case: $i_{расч(P)} = 4{,}0001$.

Tabular value of Student's criterion for $a_B = 0{,}95$ i $n_1 = 5$ (Tikhomirov, 1974). That is, the condition is met: $t_{estimated\,(P)} \geq t_{tabular}$.

Therefore, the number of measurements $n_1 = 5$ is sufficient for each experiment. After conducting the experiment and decoding the records using a calibration graph, the average value of five repeated measurements of the optimization criterion for each experiment was determined and the data were entered into the working matrix of planning (Table 2).

In this case, it is necessary to find the values of the regression coefficients of the equation (Tikhomirov, 1974):

$$y_u = b_0 + b_1 x_1 + b_2 x_2 + b_{12} x_1 x_2 + b_{11} x_1^2 + b_{22} x_2^2 . \quad (3)$$

To determine these coefficients, the equations for the two-factor experiment proposed by the author were used (Tikhomirov, 1974):

$$a_1 = 0{,}2;\ a_2 = 0{,}1;\ a_3 = 0{,}125;\ a_4 = 0{,}25;$$
$$a_5 = 0{,}125;\ a_6 = 0{,}187;\ a_7 = 0{,}1.$$

Therefore: $b_0 = 285{,}67;\ b_1 = -18{,}545;\ b_2 = -30{,}7;$
$b_{12} = -1{,}5;\ b_{11} = 3{,}53;\ b_{22} = 1{,}54.$

Thus, equation (3) takes the form:

$$y_u = 285{,}67 - 18{,}545 x_1 - 30{,}7 x_2 - 1{,}5 x_1 x_2 + 3{,}53 x_1^2 + 1{,}54 x_2^2 . \quad (4)$$

The hypothesis about the adequacy of equation (4) is tested in the following sequence.

Since the experiments were duplicated only at the zero point, the variance of adequacy according to the equation (Tikhomirov, 1974):

$$S^2_{ад} = \frac{16{,}9 - 11{,}225}{3} = 1{,}892 .$$

The reproducibility variance for this case is determined by the formula (Tikhomirov, 1974):

$$S^2_{\{y\}} = \frac{11{,}225}{4} = 2{,}81 .$$

Table 2

Planning matrix of a two-factor experiment to determine the total amount of losses during longitudinal cutting of the material

Research number	Planning matrix		Working matrix			Calculation data	
№	x_1	x_2	h	a	y_u	y_u	$(y_u - y_u)^2$
1	1	1	5,35	5,5	241	240,00	1,0098
2	-1	1	3,35	5,5	280	280,08	0,0071
3	1	-1	5,35	4,5	306	304,40	2,5724
4	-1	-1	3,35	4,5	339	338,49	0,2651
5	-1,414	0	2,95	5	320	318,96	1,0830
6	1,414	0	5,75	5	266	266,52	0,2657
7	0	-1,414	4,35	4,3	332	332,15	0,0226
8	0	1,414	4,35	5,7	246	245,33	0,4498
9	0	0	4,35	5	288	285,67	5,4275
10	0	0	4,35	5	286	285,67	0,1087
11	0	0	4,35	5	286	285,67	0,1087
12	0	0	4,35	5	284	285,67	2,7899
13	0	0	4,35	5	284	285,67	2,7899
$\sum_1^{13} = 3758 \quad \sum_1^{13} \left(y_u - \bar{y}_u \right)^2 = 16{,}9$							

Knowing the number of degrees of freedom for greater ($f_{adequately} = 3$) and lower ($f_e = 4$) dispersion (Tikhomirov, 1974), table value of Fisher's criterion 95% confidence:

$$F_{tabl} = 6{,}59.$$

Estimated value of Fisher's criterion according to the formula (Tikhomirov, 1974):

$$F_{calc\,(P)} = \frac{1{,}892}{2{,}81} = 0{,}67.$$

Comparison of tabular and calculated values of Fisher's test showed that equation (4) can be considered adequate with confidence $a_B = 0{,}95$, since the condition is met: $F_{tabl} \geq F_{calc(P)}$.

The significance of the regression coefficients in equation (4) is checked taking into account the equations for the case when $k_1 = 2$ (Tikhomirov, 1974). In this case:

$$a_8 = 0{,}2 ;\ a_9 = 0{,}125 ;\ a_{10} = 0{,}1438 ;\ a_{11} = 0{,}25 .$$

Therefore:

$$S^2_{\{b_0\}} = 0,2 \cdot 2,81 = 0,562 \, i \, S_{\{b_0\}} = 0,75;$$
$$S^2_{\{b_i\}} = 0,125 \cdot 2,81 = 0,35 \;\; i \;\; S_{\{b_i\}} = 0,59;$$
$$S^2_{\{b_{ii}\}} = 0,1438 \cdot 2,81 = 0,4 \, i \, S_{\{b_{ii}\}} = 0,63;$$
$$S^2_{\{b_{ij}\}} = 0,25 \cdot 2,81 = 0,7025 \, i \, S_{\{b_{ij}\}} = 0,84.$$

Hence the ratios (Tikhomirov, 1974):

$$\Delta b_0 = \pm 2 \cdot 0,75 = \pm 1,5;$$
$$\Delta b_i = \pm 2 \cdot 0,59 = \pm 1,18;$$
$$\Delta b_{ii} = \pm 2 \cdot 0,63 = \pm 1,26;$$
$$\Delta b_{ij} = \pm 2 \cdot 0,84 = \pm 1,68.$$

A comparison of the absolute values of the regression coefficients of equation (4) and the corresponding errors in their estimation shows that with a confidence level of 0.95 can be considered significant all coefficients except b_{12}, then we get:

$$y_u = 285,67 - 18,545x_1 - 30,7x_2 + 3,53x_1^2 + 1,54x_2^2 \quad (5)$$

Equation (5) is a regression equation that describes the total amount of losses when performing longitudinal cutting of the material with a stationary knife depending on the distance between the conveying rollers (x_1), and the distance between the vertical axis of rotation of the conveying rollers and the edge of the knife blade (x_2).

Given expressions (2), we turn to the named values:

$$P = 285,67 - 18,545(h - 4,35) - 30,7\left(\frac{a-5}{0,5}\right) + 3,53(h-4,35)^2 + 1,54\left(\frac{a-5}{0,5}\right)^2 \quad (5)$$

After simplifying the equation takes the form:

$$P = 817,14 + 3,53h^2 - 49,26h + 3,08a^2 - 92,2a \quad (6)$$

The obtained expression (6) is an experimental mathematical model of the dependence of the value of total losses when performing longitudinal cutting on the size of the gap between the rollers and the distance from the vertical axis of rotation of the rollers to the edge of the knife blade.

Fig. 5-6 presents graphs of the total cost *P* when performing the operation of longitudinal cutting of felt with a knife with an arcuate cross-sectional shape, respectively, from the distance *a* from the vertical axis of the conveying rollers to the edge of the knife blade and the distance *h* between the conveying rollers.

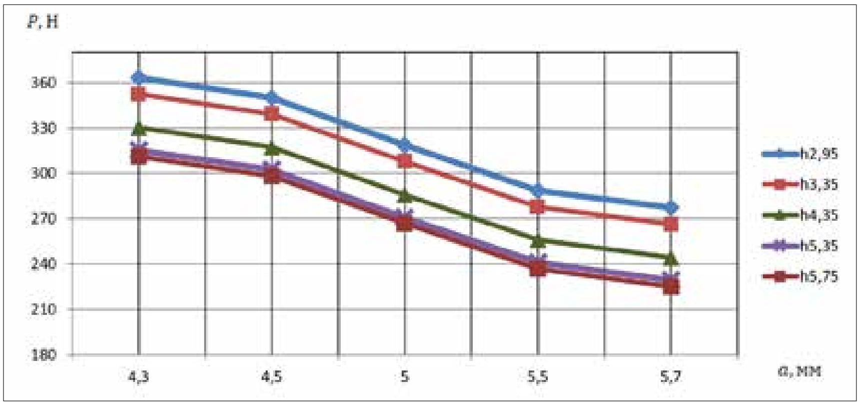

Fig. 5. Graph of the dependence of the total cost *P* when cutting felt with a knife with an arcuate cross-section, from the value of the distance *a* from the vertical axis of the conveying rollers to the edge of the knife blade: When $a = const$, in the range $a_{min} = 4,3$ – $a_{max} = 5,7$.

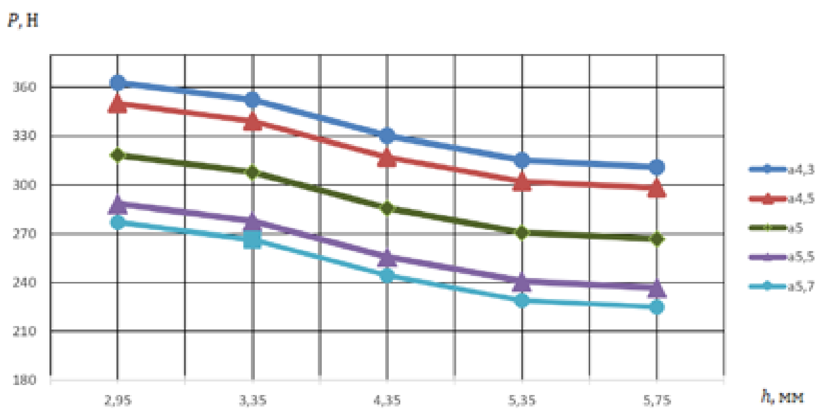

Fig. 6. Graph of the dependence of the total cost *P* when performing felt cutting with a knife with an arcuate cross-section, from the distance *h* between the transport rollers: when $h = const$, in the range $h_{min} = 2,95$ – $h_{max} = 5,75$.

Table 3

Planning matrix of a two-factor experiment to determine the amount of loss due to friction of the material on the face of a fixed knife

Research number	Planning matrix		Working matrix			Calculation data	
	x_1	x_2	h	a	y_u	y_u	$(y_u-y_u)^2$
1	1	1	5,35	5,5	198	197,29	0,5079
2	-1	1	3,35	5,5	230	229,13	0,7494
3	1	-1	5,35	4,5	248	248,03	0,0010
4	-1	-1	3,35	4,5	276	275,88	0,0146
5	-1,414	0	2,95	5	260	259,68	0,1000
6	1,414	0	5,75	5	218	217,48	0,2702
7	0	-1,414	4,35	4,3	272	271,05	0,9102
8	0	1,414	4,35	5,7	202	202,12	0,0145
9	0	0	4,35	5	236	235,26	0,5513
10	0	0	4,35	5	236	235,26	0,5513
11	0	0	4,35	5	234	235,26	1,5813
12	0	0	4,35	5	234	235,26	1,5813
13	0	0	4,35	5	236	235,26	0,5513
$\sum_{1}^{13} = 3080 \sum_{1}^{13}\left(y_u - \bar{y}_u\right)^2 = 7,3844$							

We will process the experimental data to determine the amount of friction losses on the face of a stationary knife. The planning matrix of the two-factor experiment is presented in table 3.

After conducting the experiment and decoding the records using a calibration graph, the average value of five repeated measurements of the optimization criterion for each experiment was determined and the data were entered into the working matrix of planning (Table 3).

In this case, it is necessary to find the values of the regression coefficients of the equation for a two-factor experiment proposed by the author (Tikhomirov, 1974):

$$b_0 = 235,26;\ \ b_1 = -14,92;\ \ b_2 = -24,37;$$
$$b_{12} = -1;\ \ b_{11} = 1,66;\ \ b_{22} = 0,66.$$

Thus, equation (3) takes the form:

$$y_u = 235,26 - 14,92x_1 - 24,37x_2 - \\ -x_1x_2 + 1,66x_1^2 + 0,66x_2^2. \quad (7)$$

The hypothesis about the adequacy of equation (7) is tested in the above method.

Dispersion of adequacy:

$$S_{a\partial}^2 = \frac{7,3844 - 4,8165}{3} = 0,856.$$

Reproducibility disperses for this case:

$$S_{\{y\}}^2 = \frac{4,8165}{4} = 1,2.$$

Estimated value of Fisher's test:

$$F_{calc(F)} = \frac{0,856}{1,2} = 0,47.$$

Comparison of tabular and calculated values of Fisher's test showed that equation (7) can be considered adequate with confidence $a_B = 0,95$, since the condition is met: $F_{tabl} \geq F_{\text{tabl(P)}}$.

The significance of the regression coefficients in equation (7) was tested in the same way as in the above procedure.

Therefore:

$$S_{\{b_0\}}^2 = 0,2 \cdot 1,2 = 0,24\ \ i\ \ S_{\{b_0\}} = 0,49;$$
$$S_{\{b_i\}}^2 = 0,125 \cdot 1,2 = 0,15\ \ i\ \ S_{\{b_i\}} = 0,0225;$$
$$S_{\{b_{ii}\}}^2 = 0,1438 \cdot 1,2 = 0,173\ \ i\ \ S_{\{b_{ii}\}} = 0,42;$$
$$S_{\{b_{ij}\}}^2 = 0,25 \cdot 1,2 = 0,3\ \ i\ \ S_{\{b_{ij}\}} = 0,55.$$

Hence the ratios (Tikhomirov, 1974):

$$\Delta b_0 = \pm 2 \cdot 0,49 = \pm 0,98;$$
$$\Delta b_i = \pm 2 \cdot 0,0225 = \pm 0,045;$$
$$\Delta b_{ii} = \pm 2 \cdot 0,42 = \pm 0,84;$$
$$\Delta b_{ij} = \pm 2 \cdot 0,55 = \pm 1,1.$$

A comparison of the absolute values of the regression coefficients of equation (7) and the corresponding errors in their estimation shows that with a confidence level of 0,95 can be considered significant all coefficients except b_{12} *and* b_{22} , then we get:

$$y_u = 235,26 - 14,92x_1 - 24,37x_2 + 1,66x_1^2. \quad (8)$$

Equation (8) is a regression equation that describes the total amount of losses when performing longitudinal cutting of the material with a stationary knife depending on the distance between the conveying rollers (x_1), and the distance between the vertical axis of rotation of the conveying rollers and the edge of the knife blade (x_2).

Given expressions (2), we turn to the named values:

$$F = 235{,}26 - 14{,}92\left(h - 4{,}35\right) -$$
$$-24{,}37\left(\frac{a-5}{0{,}5}\right) + 1{,}66\,(h - 4{,}35)^2$$

After simplifying the equation takes the form:

$$F = 575{,}27 + 1.66h^2 - 29{,}36h - 48.74a \qquad (9)$$

The obtained expression (9) is an experimental mathematical model of the dependence of the amount of material friction losses on the face of a stationary knife when performing longitudinal cutting with a stationary knife, from the gap between the rollers and the distance from the vertical axis of rotation to the edge of the knife blade.

Fig. 7-8 are graphs of the dependence of total friction costs *F* when performing the operation of longitudinal cutting of felt with a knife with an arcuate cross-sectional shape, respectively, from the distance *a* from the vertical axis of the conveying rollers to the edge of the knife blade and the distance *h*.

The obtained experimental models, namely the determination of the total value of losses *P* (6) and the amount of friction losses of material *F* (9) substituting in condition (1) will determine the running force of cutting felt with a knife with an arcuate cross-sectional shape:

$$q_p = \frac{1}{B}\left(241{,}87 + 1{,}87h^2 - 19{,}9h + 3{,}08a^2 - 43{,}46a\right)$$

Discussion

Substituting the value in equation (1) we obtain the average value of the running force felt: $q_p = 1{,}44\frac{H}{MM}$.

Deviations from the previously obtained values of robots (Makatora and Panasiuk, 2014d) and (Makatora, 2014)

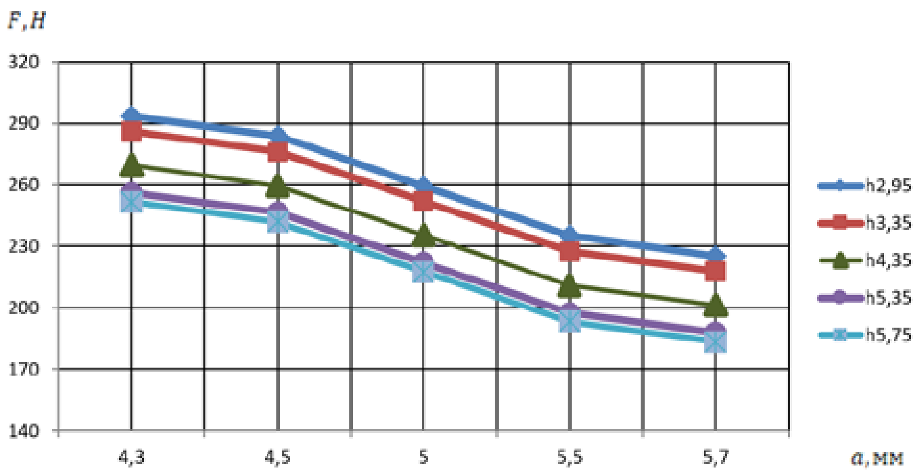

Fig.7. Dependency graph of total costs *F* during cutting the felt with the grooved knife with one-sided cross-section on the gap size *h* = *const*, between transport rollers: while *a* = *const*, in the range $a_{min} = 4{,}3$ – $a_{max} = 5{,}7$

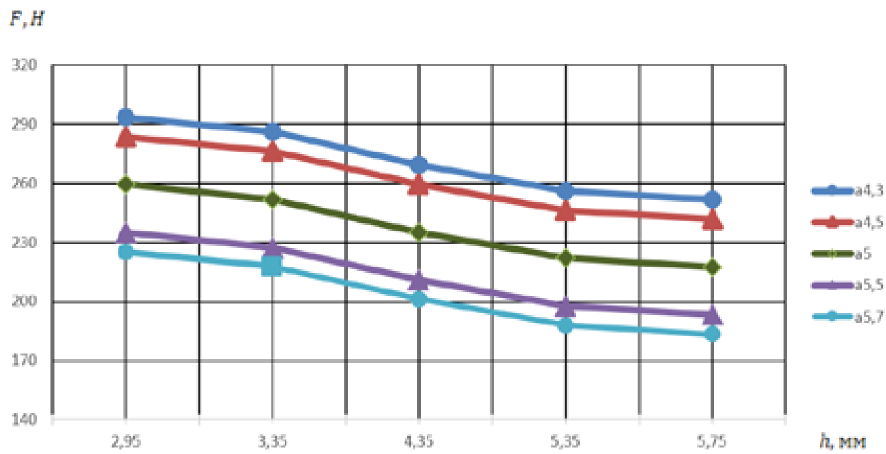

Fig. 8. Dependency graph of total costs F during slitting cutting with the grooved knife with one-sided cross-section on the gap size *a* from the vertical axis of transport rollers to the knife edge: while $h = const$, in the range $h_{min} = 2{,}95$ – $h_{max} = 5{,}75$.

are respectively $\Delta = 5{,}1\ \%$ and $\Delta = 10{,}3\ \%$ indicating the adequacy of the experimental study.

Comparing the total values of losses in the longitudinal cutting of felt when using a knife with one-sided sharpening and a knife with an arcuate cross-sectional shape (obtained by the author in (Makatora, 2014)), we obtain:

$$\Delta P = \frac{314{,}88 - 285{,}67}{314{,}88} \cdot 100\% = 9{,}3\%.$$

The determined deviation of the total amount of losses during longitudinal cutting of the material confirms the mathematical model developed by the author in (Makatora and Kniaziev, 2004a) and shows that the operation of longitudinal cutting of felt it is advisable to use a knife blade with an arcuate cross-section, which in turn will reduce energy costs for the process.

Conclusions

The obtained regression equations describe the total amount of losses during longitudinal cutting of the material and the number of losses due to friction of the material on the face of a fixed knife with an arcuate cross-sectional shape, allow to speak about the adequacy of analytical model (Makatora and Kniaziev, 2004a) and experimental models (Makatora and Panasiuk, 2014d; Makatora, 2014). Also make the necessary adjustments, namely, to adjust the degree of compression of the material and the distance from the edge of the knife blade relative to the vertical axis of the conveyor rollers to reduce friction losses on the edge of the knife, which in turn reduces energy costs for longitudinal cutting. Comparing the total values of losses during longitudinal cutting of the material of a knife with one-sided sharpening and a knife with an arcuate cross-section, allows you to talk about the feasibility of using a knife with an arcuate cross-section, which will reduce energy costs for the process.

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Математичне дослідження впливу геометрії ножа з дугоподібною формою поперечного перерізу на процес поздовжнього різання повсті

Перспективним дослідженням є проектування та вдосконалення машин поздовжнього різання матеріалів з мінімальними енергетичними витратами на виконання технологічного процесу різання за рахунок геометрії ріжучого інструменту. У статті розглянуті питання щодо зниження енергетичних витрат на процес поздовжнього різання при використанні леза ножа з дугоподібною формою поперечного перерізу. Проведений аналіз, розроблений ефективний метод аналізу впливу величини зазору між твірними транспортуючих валиків і величини відстані від вертикальної осі обертання транспортуючих валиків до кромки леза ножа з дугоподібною формою поперечного перерізу на сумарну величину втрат при поздовжньому різані та величину втрат на тертя матеріалу, шляхом використання рівнянь регресії для визначення необхідних налаштувань в машині поздовжнього різання при повсті, а також зробити перевірку достовірності аналітичної та експериментальних моделей процесу поздовжнього різання ножом з дугоподібною формою поперечного перерізу. Для визначення сумарної величини втрат при поздовжньому різані матеріалу та величини втрат на тертя матеріалу о грані нерухомого ножа з дугоподібною формою поперечного перерізу, а також погонного зусилля різання був проведений двох факторний експеримент для моделі дослідження. Отриманні рівняння регресії описують сумарну величину втрат при поздовжньому різані матеріалу та величину втрат на тертя матеріалу о грані нерухомого ножа з дугоподібною формою поперечного перерізу, дозволяють говорити про адекватність аналітичної та експериментальних моделях зроблених раніше. Також зробити необхідні налаштування, а саме підібрати ступінь стиснення матеріалу та встановити кромку леза ножа щодо вертикальної вісі транспортуючих валиків з метою зменшення величини втрат на тертя матеріалу о грані ножа, що в свою чергу зменшить енергетичні витрати на процес поздовжнього різання. Порівняння сумарних величин втрат при поздовжньому різані матеріалу ножа з односторонньою заточкою та ножа з дугоподібною формою поперечного перерізу, дозволяє говорити про доцільність використання ножа з дугоподібною формою поперечного перерізу, що дозволить зменшити енергетичні витрати на технологічний процес, ти самим зробити конкурентнішу продукцію.

Ключові слова: *погонне зусилля, сумарна величина втрат, втрати на тертя матеріалу, транспортуючи валики, лезо ножа, поздовжнє різання.*