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Experimental Study of the Squeezing of a Leather Semi-Finished Product by Roller Pairs of Different Diameters

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Abstract: The article presents experimental studies of roll pairs of different diameters of the squeezing machine, proposed for use in the leather industry. In the course of experimental studies, a regression equation was derived, and the dependence of the straightening coefficient of the output surface was determined, taking into account five input factors: linear velocity at the points of contact of the rolls, the pressing force of the rolls, the angle of feed of the processed material to the squeezing zone, the diameters of the rolls and the thickness of the leather semi-finished product. Solutions to the regression equations were obtained and analyzed graphically.

Keywords: linear velocities of the contact points of the rolls, squeezing, pressing forces of the rolls, feed angle, roll diameters, semi-finished leather product thickness.

INTRODUCTION

The semi-finished leather product obtained by processing the skins of various animal species is used in the production of shoes, clothing and other leather accessories, as well as for furniture and car interiors. In this regard, in the production of high-quality leather goods, it is important to use high-performance methods for processing semi-finished leather products and modern roller technological machines. At present, large-scale measures are being taken to reduce the labor intensity and energy consumption of processing raw hides, to develop techniques and methods that increase the efficiency of technological processes during treatment. In the implementation of these tasks, along with the high-quality processing of raw hides for leather goods, a special place is occupied by the development of technically and technologically modernized machines that meet modern technological requirements.

Since drying raw materials in tanneries is one of the most energy-intensive processes, it is appropriate to reduce moisture mechanically. Numerous scientific studies were conducted in this area [1-17]. Scientists of our republic T.Yu. Amanov [2, 5, 10], G.A. Bahadirov [1, 7, 14], A. Abdukarimov [6], Sh. Khurramov [8], K. Khusanov [17], G.N. Tsoi [3], A. Nabiev [4] and others made a great contribution to the development of this branch of science. In these works, the problem of determining the motion of a moisture-saturated flat material between roll pairs is considered.

In particular, T. Yu. Amanov, G. N. Tsoi, A. Nabiev, Z. Rakhimova [2-5, 10, 12-13] studied the process of vertical feed of semi-finished leather products to the gripping zone by roll pairs; improved vertical roll machines; data about the principle of operation and functions of units. Scientific studies of experimental and mechanical properties of the processing of multi-layer tanned leather products by a roller machine were conducted and the results were implemented into practice. The results of these studies refer only to roll pairs with equal radii and vertical machines with base plates.

The research conducted by Abdukarimov A., Saidakulov I. [6] focused only on the transmission mechanisms of roller machines and kinematic analysis of the mechanisms. This analysis was performed to determine the angular and linear velocities and accelerations of the links of the mechanism, depending on the angular velocity of the guide link (gear) and the linear velocities and accelerations of the center of rotation of the free working roll. The kinematic analysis was conducted according to the centroid theory by the method of the instantaneous center of rotation of the links [6]. Such works are focused only on transmission mechanisms, and not on the velocity of movement of the working bodies.

Sh. Khurramov, F. Kholturaev, F. Kurbanova [8-9, 11, 15-16] focused their studies on the issues of compression of a pair of rolls and presented various mathematical models of the process of passing a semi-finished leather product between the rolls. The resulting equations for the contact curves of rolls are general in the sense that they are applicable to special cases of contact interaction in two-roll modules [11].

This study is devoted to the optimization of the parameters of the squeezing zones. Regression models of the residual moisture of the skin and the intensity of the pressing process, which depends on the intensity of the load, radius and velocity of the rolls, were developed. A number of patterns were established that make it possible to increase the pressing efficiency of the skin with rollers. An extreme problem was solved to determine the diameter of the rolls, which ensured the minimum deflection of their working part [20, 26]. The forms of the contact curves of the rolls in the two-roll module considered in the article are described for the case when the material layer is deformed in the vertical direction during the interaction.

The theoretical studies obtained are reflected in experimental works. The articles present the results of experimental studies to substantiate the efficiency of the method for the simultaneous removal of excess moisture from wet semi-finished leather products. The experiment was conducted using a moisture-removal cloth - monshon of BM brand laid on a guide bar, on which two or more layers of wet leather semi-finished product were previously folded. Monshon of LASCH brand was folded between layers of semi-finished leather. Due to the elasticity of the monshon, the displacement of the path of movement of leather product along the transporting device is reduced. In the experiment, the influence of the feed rate, and the pressing force of the squeezing rollers on the amount of moisture extracted from two and five layers of the semi-finished leather product after their squeezing was determined [2-5, 12-14].

As mentioned above, a lot of research was done in this area. In general, most of these works were conducted for symmetrical horizontal and vertical squeezing machines with roll pairs of the same diameter and the influence of the determined parameters on the amount of moisture removed from the semi-finished leather product or on the residual moisture was studied. However, another factor in increasing the useful output area during the processing of semi-finished products was not given much attention. Considering that 60-70 percent of the main costs in leather production are the costs of raw materials and the price of the finished product is determined by the surface area, it is necessary to investigate the dependence of the determined processing parameters on the straightening factor and the output surface of the tanned semi-finished product.

MATERIALS AND METHODS

As a result of scientific research, it was established that the diameter of the rolls has a great influence on the gripping of a leather semi-finished product without wrinkles between the roller pairs, prevents a decrease in the output surface, and improves the surface quality of the processed material. Experimental studies were aimed at determining the effect of roll diameters on the increase in the output surface of the semi-finished product.

To conduct the tests, an experimental bench of a squeezing machine with roller pairs of different diameters was developed, with all the necessary factors for the mechanical processing of raw hides.

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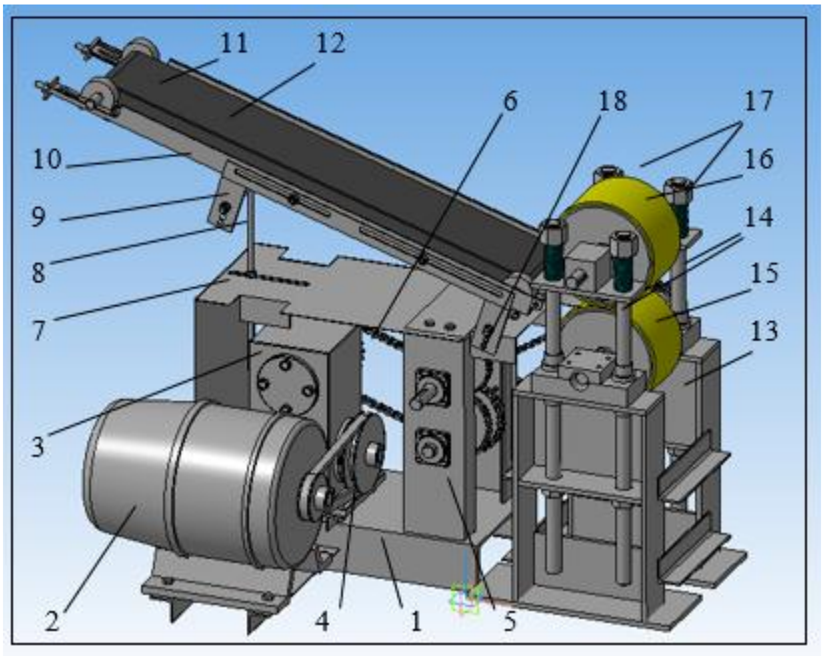
This device was designed; technical documentation and drawings were developed to enable the management of experimental tests and obtain the necessary results by changing the diameters, coatings, rotation velocities of working rollers, the compression force between the rollers and the angle of feed (conveyor inclination) of the processed material into the pressing zone. The experimental squeezing device (ESD), designed for the tests, consists of a drive part (1), a part that conveys the processed material to the squeezing zone, that is, a conveyor part (2), and a working part (3), where the sample is squeezed out between roll pairs.



1- base of the drive part, 2- electric motor, 3- gearbox, 4- belt drive, 5- parasitic mechanism, 6- sprocket, 7- base of the conveyor, 8- threaded stud, 9- lower part of the conveyor, 10- upper part of the conveyor.

Figure 1: The arrangement of the compression device developed for the tests

Samples of the processed material for testing were selected and cut in accordance with the recommendations of ISO 2588-85.

The purpose of the experiment is to determine the output surface of the leather raw material after pressing by pairs of rolls and to substantiate the geometric parameters of the roller machine. For the experiment, the method of planning 2^5 complete factorial experiments was chosen [18]. All identified main factors varied at two levels (+1 and -1), and the number of experiments was 2^5=32. After determining the five factors and the levels of their variation, the process of determining the output surface of the rawhide was studied. The following factors were chosen: $x_1(V)$ - the linear velocity of the squeezing rollers at the points of contact, $x_2(t_0)$ - the thickness of the leather raw material, $x_3(P)$ - the squeezing pressure, $x_4(\tau)$ - the material feed angle, and $x_5(D)$- the diameter of the squeezing rolls.

The general form of the regression equation in the method of planning complete factorial experiments is [18]:

$$y = b_0 + b_1x_1 + b_2x_2 + ... + b_nx_n + ... + b_{12}x_1x_2 + ... + b_{n-1}x_{n-1}x_n \quad (1)$$

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here y is the amount of residual moisture extracted in coded form; $b_0 -$ is the free term of the regression equation; $b_n, b_{12}...b_{n-1,n}, b_{11}...b_{nn} -$ are the regression equation coefficients; $x_n -$ is the conditional value of factors.

Table 1. Levels and intervals of variation of experimental factors

Factor			Levels of variation of factors			Interval of variation	Factor calculation
Name	Designation						
	natural	coded	+1	0	-1		
Linear velocity of the contact point of the rolls (m/s)	V	x_1	0.28	0.3	0.32	0.02	x_1=(V–0.3)/0.02
Thickness of processed material (m)	t_0	x_2	0.001	0.003	0.005	0.002	x_2=(t_0–0.003)/0.002
Stress at the contact point of the rolls (N/m)	P	x_3	32000	40000	48000	8000	x_3=(P–40000)/8000
Angle of feeding of the processed material into the pressing zone (rad)	τ	x_4	-0.2618	0	0.2618	0.2618	x_4=(τ–0)/0.2618
Upper roll diameter (m) (lower roll 0.32 m)	D	x_5	0.125	0.2225	0.32	0.0975	x_5=(D–0.125)/0.2225

The accuracy of experimental results largely depends on the level of accuracy of all input and output parameters and their constancy. Therefore, multiple control of input and output parameters during roll pressing helps in carrying out each experiment. Using Table 1, an experiment design matrix was constructed.

Table 2. Experiment planning matrix

№	Matrix					Natural values of variables				
	x_1	x_2	x_3	x_4	x_5	V	t_0	P	τ	D
1	-1	-1	-1	-1	-1	0.28	0.001	32000	-0.262	0.125
2	1	-1	-1	-1	-1	0.32	0.001	32000	-0.262	0.125
3	-1	1	-1	-1	-1	0.28	0.005	32000	-0.262	0.125
4	1	1	-1	-1	-1	0.32	0.005	32000	-0.262	0.125
5	-1	-1	1	-1	-1	0.28	0.001	48000	-0.262	0.125
6	1	-1	1	-1	-1	0.32	0.001	48000	-0.262	0.125
7	-1	1	1	-1	-1	0.28	0.005	48000	-0.262	0.125

8	1	1	1	-1	-1	0.32	0.005	48000	-0.262	0.125
9	-1	-1	-1	1	-1	0.28	0.001	32000	0.2618	0.125
30	1	-1	1	1	1	0.32	0.001	48000	0.2618	0.32
31	-1	1	1	1	1	0.28	0.005	48000	0.2618	0.32
32	1	1	1	1	1	0.32	0.005	48000	0.2618	0.32

Table 3. Finding the reproducibility of the variance:

№	x_1	x_2	x_3	x_4	x_5	Y_{21}	Y_{22}	Y_{23}	$\overline{Y}$ ўр	$S^2\{Y\}$
1	-1	-1	-1	-1	-1	56.7	56.4	56.2	94.6	0.063
2	1	-1	-1	-1	-1	58.3	58.8	58.6	92.2	0.063
3	-1	1	-1	-1	-1	58.2	57.9	57.7	95.8	0.063
4	1	1	-1	-1	-1	61.1	62.2	61.9	94.4	0.323
5	-1	-1	1	-1	-1	45.7	45.4	45.2	95.2	0.063
6	1	-1	1	-1	-1	47.3	47.8	47.6	92.8	0.063
7	-1	1	1	-1	-1	49.7	49.4	49.2	97.4	0.063
8	1	1	1	-1	-1	52.8	52.6	53.7	95	0.343
9	-1	-1	-1	1	-1	56.7	56.4	56.2	97.6	0.063
10	1	-1	-1	1	-1	58.3	58.8	58.6	95.2	0.063
30	1	-1	1	1	1	50.7	50.4	50.2	92.7	0.063
31	-1	1	1	1	1	51.3	51.1	52.2	95.6	0.343
32	1	1	1	1	1	54.7	54.4	54.2	95.4	0.063
Σ									3032.20	4.47

The output factor variance values are calculated using the following formulas:

$$S_1{}^2\{Y\} = \frac{\sum_{i=1}^{3}\left(Y_i - \overline{Y}\right)^2}{n-1} = 0{,}063; \qquad S_4{}^2\{Y\} = \frac{\sum_{i=1}^{3}\left(Y_i - \overline{Y}\right)^2}{n-1} = 0{,}323;$$

$$S_{31}{}^2\{Y\} = \frac{\sum_{i=1}^{3}\left(Y_i - \overline{Y}\right)^2}{n-1} = 0{,}343; \quad S_{32}{}^2\{Y\} = \frac{\sum_{i=1}^{3}\left(Y_i - \overline{Y}\right)^2}{n-1} = 0{,}063\,. \qquad (2)$$

The homogeneity of regression values was checked using the Cochran test [18].

1. $$G_x = \frac{S_i^2\{Y\}_{\max}}{\sum_{i=1}^{N} S_i^2\{Y\}} = \frac{0,343}{4,47} = 0,076$$ (3)

where Gx —is the calculated value of the Cochran test; $S_i^2\{Y\}$ - is the largest value of the dispersion of test results; $\sum_{i=1}^{N} S_i^2\{Y\}$ is the sum of the variance values.

The calculated value of the Cochran test is compared with the value selected from the table. In this case, condition $G_x \langle G_{жсад}$ must be satisfied. The value of the Cochran test selected from the table at the level of 0.5% is:

$$G_{жсад} = \{ f_1 = N = 32, \quad f_2 = m - 1 = 2 \}$$ (4)

So, in the case under consideration, the dispersions are homogeneous. Since 0.08<0.16, the condition is met.

In the next step, we build a regression equation and determine the regression coefficients.

The regression equation has the following form:

$$Y = 94,75 - 1x_1 + 0,8875x_2 + 0,1625x_3 + 1,3625x_4 - 0,2688 + \\ + 0,1813x_1x_2 + 0,044x_1x_3 + \ldots + 0,031x_1x_2x_3x_4x_5.$$ (5)

Table 4. Table to determine coefficients b_0 and b_i

№	x_1	x_2	x_3	x_4	x_5	x_1	x_2	x_3	x_4	x_5	x_1x_2	…	$x_1x_2x_3x_4x_5$	Y'
1	-1	-1	-1	-1	-1	-94.6	-94.6	-94.6	-94.6	-94.6	94.6	94.6	-94.6	94.6125
2	1	-1	-1	-1	-1	92.2	-92.2	-92.2	-92.2	-92.2	-92.2	-92.2	92.2	92.6125
3	-1	1	-1	-1	-1	-95.8	95.8	-95.8	-95.8	-95.8	-95.8	95.8	95.8	96.3875
4	1	1	-1	-1	-1	94.4	94.4	-94.4	-94.4	-94.4	94.4	-94.4	-94.4	94.3875
5	-1	-1	1	-1	-1	-95.2	-95.2	95.2	-95.2	-95.2	95.2	-95.2	95.2	94.9375
6	1	-1	1	-1	-1	92.8	-92.8	92.8	-92.8	-92.8	-92.8	92.8	-92.8	92.9375
7	-1	1	1	-1	-1	-97.4	97.4	97.4	-97.4	-97.4	-97.4	-97.4	-97.4	96.7125
8	1	1	1	-1	-1	95	95	95	-95	-95	95	95	95	94.7125
31	-1	1	1	1	1	-95.6	95.6	95.6	95.6	95.6	-95.6	-95.6	-95.6	96.9
32	1	1	1	1	1	95.4	95.4	95.4	95.4	95.4	95.4	95.4	95.4	94.9
Σ	0	0	0	0	0									3032.20

$$b_0 = \frac{1}{N} \sum_{i=1}^{N} \overline{Y}_i ,$$ (6)

Here N is the number of experiments [18].

$$b_i = \frac{1}{N} \sum_{i=1}^{N} x_{ji} x_{ij} \overline{Y}_i , \qquad b_{ji} = \frac{1}{N} \sum_{i=j=1}^{N} x_{ij} \overline{Y}_i ,$$ (7)

here i - is the test procedure; j - is the order of factors [18].

At the next step, we check the significance of the regression coefficients using Student's t-test [18]:

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$$t_R = \frac{(b_i)}{S(b_i)}, \qquad S^2(b_i) = \frac{S_Y^2}{N \cdot n} \tag{8}$$

Here, S_Y^2 - is linear dispersion, determined by the following expression:

$$S_Y^2 = \frac{1}{N}\sum_{i=1}^{N} S_i^2\{Y\}. \tag{9}$$

Let us calculate the numerical value of serial dispersion [18]:

$$S_Y^2 = \frac{1}{N}\sum_{i=1}^{N} S_i^2\{Y\} = \frac{4{,}47}{32} = 0{,}14.$$

After that, we calculate the numerical value of the dispersion coefficient:

$$S^2(b_i) = \frac{S_Y^2}{N \cdot n} = \frac{0{,}14}{32 \cdot 3} = 0{,}001458\,(3)$$

$$S(b_i) = \sqrt{0{,}001458(3)} = 0{,}0381881307\!9$$

Let us determine the calculated value of Student's test [18] for the regression coefficients

$$t_{xb_0} = \frac{|94{,}75625|}{0{,}038} = 2485{,}002, \qquad t_{xb_1} = \frac{|-1|}{0{,}038} = 26{,}5222, \qquad t_{xb_2} = \frac{|0{,}8875|}{0{,}038} = 23{,}27487,$$

$$t_{xb_3} = \frac{|0{,}1625|}{0{,}038} = 4{,}261595, \qquad t_{xb_{1235}} = \frac{0{,}003125}{0{,}038} = 0{,}819538\ .$$

Student's test is selected from the table according to the calculated value:

$$t_{жад} = [P_D = 0{,}95;\ f_2 = 32] = 1{,}998\ .$$

The following condition must be met:

$$t_x > t_{жад}$$

When the above condition is met, the calculated regression coefficients are considered significant, and if the condition is not met, then the same regression coefficients are considered insignificant and eliminated from further calculations. Then we write the regression equation as follows:

$$\begin{aligned} Y = 94{,}75 - 1x_1 + 0{,}8875x_2 + 0{,}1625x_3 + 1{,}3625x_4 - 0{,}2688x_5 + \\ + 0{,}1813x_1x_2 - 0{,}2438x_3x_4 + \ldots + 4{,}753318x_1x_2x_3x_4. \end{aligned} \tag{10}$$

After that, the regression equation was checked for adequacy based on the Fisher criterion. The calculated value of the Fisher criterion is given [18]:

$$F_x = \frac{S_{ад}^2}{S_Y^2}, \tag{11}$$

here $N - M > 0$ when $S_{ад}^2$ - is the difference in adequacy; M is the number of significant coefficients.

$$S_{a\partial}^2 = \frac{1}{N-k-1} \cdot \sum_{i=1}^{N} (\overline{Y_i} - Y_{Ri})^2 . \qquad (12)$$

The calculation results are given in Table 5. Table 5

№	$\overline{Y_i}$	Y_{Ri}	$\overline{Y_i} - Y_{Ri}$	$(\overline{Y_i} - Y_{Ri})^2$
1.	94.6	94.7438	-0.1438	0,0002
2.	92.2	92.4188	-0.2188	0,1702
3.	95.8	95.3688	0.4313	0,3452
4.	94.4	94.4938	-0.0938	0,0002
5.	95.2	95.1688	0.0313	0,0689
6.	92.8	92.7688	0.0313	0,0189
7.	97.4	97.3688	0.0313	0,4727
8.	95	94.9688	0.0313	0,0827
31.	95.6	95.8813	-0.2812	1,6900
32.	95.4	95.0063	0.3938	0,2500
Total				1.14

Determine the numerical value of the difference in adequacy

$$S_{a\partial}^2(Y) = \frac{3}{32-11-1} 1{,}14 = \frac{3{,}42}{20} = 0{,}171.$$

Determine the estimated value of the Fisher criterion

$$F_x = \frac{0{,}171}{0{,}14} = 1{,}229 .$$

When comparing the tabular value of the Fisher criterion $F_{жс}$ with the real value F_x, condition $F_{жс} \rangle F_x$ was fulfilled and the adequacy of the model was determined [18].

Each regression coefficient in the regression equation is important in describing the output factor.

If the value of the regression coefficient before the input factor participating in the regression model is large, then the influence of this factor on the output factor is large, if vice versa, then the influence is small. The signs in front of the coefficients indicate how they affect them, that is, if the sign is positive (+), then the effect of the output factor is positive, if it is negative (-), then the effect of the output factor is negative.

Only important coefficients are introduced into the mathematical model of the process. Experiments were conducted on leather raw materials. The system of equations obtained by processing data using the Excel program has the following form:

$$Y = 94{,}75 - 1x_1 + 0{,}8875x_2 + 0{,}1625x_3 + 1{,}3625x_4 - 0{,}2688x_5 +$$
$$+ 0{,}1813x_1x_2 - 0{,}2438x_3x_4 + ... + 4{,}753318x_1x_2x_3x_4.$$

RESULTS

The mathematical calculation of the model and the results of experiments showed that the resulting equation (10) is true.

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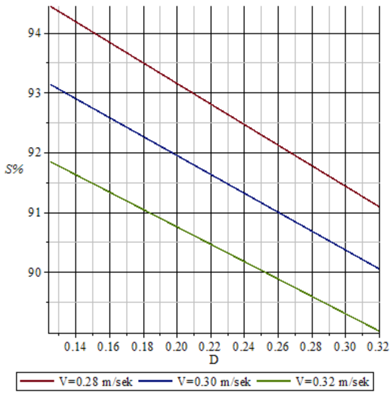

Figure 2. Graph of dependence of the diameter of the pressing rolls on the output surface of the raw hide (built for different numerical values of the linear velocity at the points of contact)

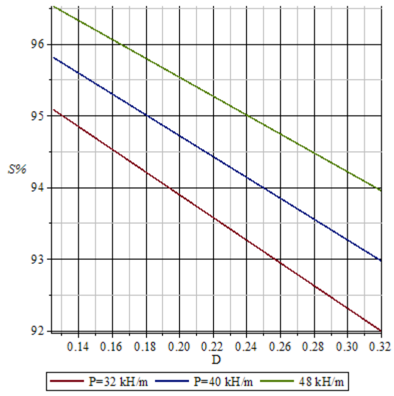

Figure 3. Graph of dependence of the diameter of the pressing rolls on the output surface of the raw hide (built for various numerical values of compression force)

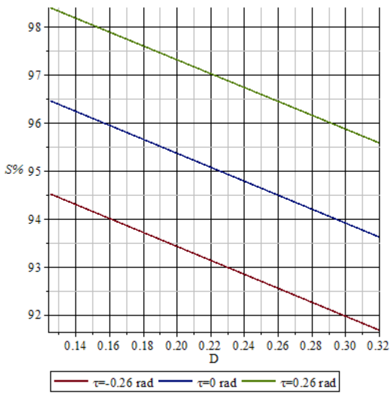

Figure 4. Graph of dependence of the diameter of the pressing rolls on the output surface of the raw hide (built for different numerical values of the angle of feed of the raw hide between the pair of rolls)

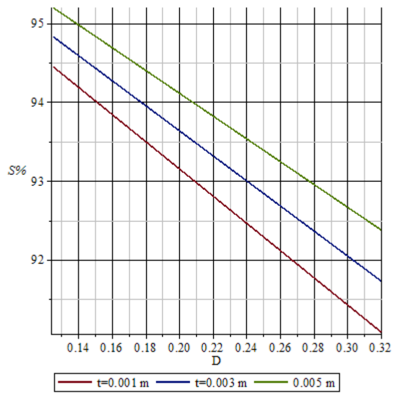

Figure 5. Graph of dependence of the diameter of the pressing rolls on the output surface of the raw hide (built for various numerical values of the thickness of the hide)

Based on the regression equation (10), obtained in experimental studies, the following graphs were plotted and analyzed. The graph of dependence of the diameters of the squeezing rolls on the area of the output surface of leather raw material is plotted for different numerical values of the linear velocity of the squeezing rolls at the points of contact, i.e. V=0.28 m/s, V=0.30 m/s, V=0.32 m/s (Fig. 2). Analyzing the output area of the leather raw material, it can be seen from the graph that the smaller the diameter of the rolls and the linear velocity at the points of contact of the squeezing rollers, the more the useful area of the output surface of leather material. The graph of dependence of the diameter of the squeezing rolls on the useful surface area of the raw hide is built for different numerical values of the linear velocities at the point of contact of the rolls, i.e. V=0.28 m/s, V=0.30 m/s, V=0.32 m/s (Fig. 2). When analyzing the graph of the useful surface of the hide, it can be seen that as the diameter of the squeezing roll increases, the useful surface area of the hide decreases. In this case, for the diameters of the squeezing roll D=0.125 m, V=0.28 m/s, P=32 kN, t0=1 mm, t=-0.2618 rad, the useful area of the hide is S=94-94.5 %; for D=0.125 m, V=0.30 m/s, P=32 kN, t0=1 mm, t=-0.2618, the useful surface area of raw leather is S=93-93.5%; for D=0.125 m, V=0.32 m/s, P=32 kN, t0=1 mm, t=-0.2618, the useful surface of the hide is S=91.5-92%. The graph of dependence of the diameter of the squeezing rolls on the useful surface area of the raw hide is built for various numerical values of the pressing force R=32 kN, P=40 kN, P= 48 kN (Fig. 3). On the basis of the plotted graph, the following results can be obtained: for D=0.125 m, V=0.30 m/s, P=32 kN, t0=1 mm, t=0 rad, the useful area of the raw hide is S=95-95.5 %; for D=0.125 m, V=0.30 m/s, P=40 kN, t0=1 mm, t=0, the useful surface of the hide is S=95.5-96%; for D=0.125 m, V=0.30 m/s, P=48 kN, t0=1 mm, t=0 rad, the useful area of the raw hide is S=96.5-97%. A graph of dependence of the diameter of the squeezing rolls on the usable area of the output surface of leather raw materials is plotted for various numerical values of the angle of feed of the semi-finished product between the roll pairs at t=-0.2618 rad, t=0 rad, t=0.2618 rad (Fig. 4). It can be seen from this graph that with an increase in the feed angle of the semi-finished leather product between the roll pairs, the useful surface area of the raw leather increases. A graph of dependence of the diameter of the squeezing rolls on the usable area of the hide is built for various numerical values of the thickness of hides, i.e. t0=1 mm, t0=3 mm, t0=5 mm (Fig. 5). In this graph, as the thickness of the leather semi-finished product increases and the diameter of the squeezing rolls decreases, the useful surface area of the leather semi-finished product increases.

CONCLUSIONS

A regression model of the area of rawhide straightening was experimentally obtained, depending on the parameters of the pressing force of the rolls, the feed rate, the diameters of the pressing rolls, and the angle of inclination of the feed. As a result of the analysis of the obtained regression model, the following conclusion can be drawn: with the smallest diameter of the squeezing roll d=125 mm and velocity V=0.28 m/s, the largest value of the squeezing force is equal to pressure P=48 kN, while the output useful area of the raw hide has the largest value, at the largest diameter of the squeezing rolls d=320 mm, velocity V=0.32 m/s, and at the lowest value of the squeezing force P=32 kN, the output of the usable area of the raw leather is small. That is, the increase in the usable area of the raw hide is greatly influenced by the thickness of the hide, the pressing force of the rolls, the feed angle and the decrease in the values of the diameter of the rolls and the linear velocity at the point of contact. At a diameter of squeezing rolls of 0.125 m, a feed rate of 0.28 m/s, and a pressing force of 48 kN/m, the increase in area due to straightening is 6%. At a diameter of squeezing rolls of 0.32 m, a feed rate of 0.32 m/s and a pressing force of 32 kN/m, the increase in the area due to straightening is 2%.

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