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Experimental Study of the Technological Process of Pressure and Speed-Based Pressure Compression of Leather Raw Material in a Multi-Operational Shaft Machine

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Abstract: This paper presents experimental studies on a multi-operation shaft machine recommended for use in the leather industry. In experimental studies, taking into account three input factors, the pressure of the working shafts, the rotational speed of the working body, the angle formed by the transmission mechanism with the vertical, and the thickness of the leather raw material, a regression equation was obtained in which the output factor depends on the residual moisture. The solutions of the regression equation were obtained and analyzed graphically.

Keywords: technological machine, transmission mechanism, leather raw material, pressure mechanism, levers, rotational speed, pressure force calculation.

Introduction. The global demand for leather and leather products is growing year by year. China (7977 million feet) in leather production^2), Italy (4357 million feet^2), Brazil (2260 million feet^2), Turkey (4246 million feet^2) Russia (605.7 million feet^2), India (1093 million feet^2), South Korea (1144 million feet^2) United States (7615 million feet^2) are considered leading countries. Today, as in all areas of production, increasing the efficiency of machines and mechanisms and improving quality indicators is one of the pressing issues in the leather industry. Considering that the global mechanical engineering industry accounts for 35% of total industrial production, the continuous and efficient organization of technological processes in this sector is of great importance [1].

An experimental stand for a multi-operation shaft technological machine was built in the mechanical workshop of the Institute of Mechanics and Seismic Strength of Structures of the Academy of Sciences of the Republic of Uzbekistan. An overview of this experimental stand is shown in Figure 1.

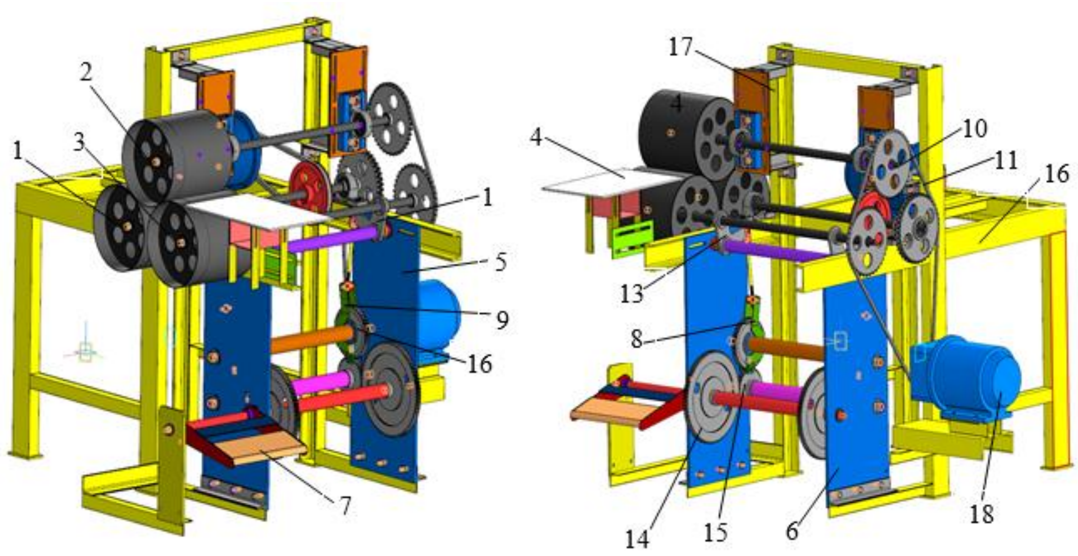

Figure 1 Experimental stand of a multi-operation roller technological machine (Institute of Mechanical Engineering of the Academy of Sciences of the Republic of Uzbekistan)

1– Working shaft, 2,3– Compression shaft, 4– shelf, 5,6– crank, 7– pedal, 8,9– tension levers, 10– pulley, 11– chain, 12,13– lever, 14– gear sector, 15– parasitic gear wheel, 16– frame, 17– bearing housing, 18– electric motor

Figure 4.6 3D view of a multi-operation spindle machine

The multi-operation machine mainly performs the pressing technological process, the planing technological process, and the flattening technological process. The processes performed in this case are carried out due to the cantilevering of the shafts. The working shafts used in the compression technological process are the same length, 250 mm, and the diameter is 190 mm.

Currently, the technological shaft machines used in leather factories for mechanical processing of leather raw materials consist of a pair of compression shafts. Due to the varying topographic structure of leather raw materials, the widely used industrially used roller machines cannot sufficiently squeeze out excess moisture from some surfaces of the leather during the squeezing process [2].

As part of the research conducted to eliminate these shortcomings, patent No. IAP 06847 was obtained by the Intellectual Property Agency under the Ministry of Justice of the Republic of Uzbekistan. This patent relates to the invention of a machine for mechanically processing leather raw materials [3].

The main function of this machine is to qualitatively squeeze excess moisture from leather raw materials and increase machine productivity. The advantage of the new design is that the structural solution of the shafts allows the machine to be used for other technological operations. This helps to increase productivity, save time, and perform multiple leather processing processes (compression, smoothing, sanding) using a single machine [4].

Methods. In this research work, the technological process of covering leather raw materials between compression shafts of different diameters without layers is considered new and relevant. In addition, the process of squeezing moisture from different parts of the leather raw material is also considered. In the first part of the experimental study, the residual moisture in different topographical parts of the leather raw material is determined under the condition of providing the same residual moisture with the required minimum energy consumption [5-8].

The second part of the experimental study is aimed at studying the process of layer-free coating of leather raw materials in a shaft compression machine under experimental conditions, in which the issue of increasing the surface area of leather raw materials is considered. To do this, the initial surface of the samples is first measured, then the surface is measured again with the layer formed, the compression process is performed, and the resulting surface is measured again. In this way, the difference between the initial and output surfaces of the leather raw material determines the amount of elongation (in percent) at various parameters and the amount of flattening (in percent) between the surfaces as a result of layer formation [8-12].

Results and discussion. Before conducting the experiment, the required number of measurements (number of repetitions) was selected using mathematical statistical methods that provided the required accuracy. In the experiment, the factors are equal to the following according to the formula.

$$X_i = \frac{z_i - z_i^0}{\varepsilon_i} \quad (1)$$

here ε_i —interval value of factors.

The general form of the regression equation in the experiment is as follows.

$$y = b_0 + b_1 X_1 + b_2 X_2 + \ldots + b_n X_n + b_{12} X_1 X_2 + \ldots + b_{n-1,n} X_{n-1} X_n \quad (2)$$

here y – the amount of moisture released in coded form; b_0 – free term of the regression equation, $b_n, b_{12} .. b_{n-1,n}, b_{11} .. b_{nn}$ – coefficients of the regression equation; X_n —conditional value of factors.

Table 1. Levels and intervals of variation of the experimental factor

<table>
<tr><th rowspan="2">No</th><th rowspan="2">Factor name</th><th rowspan="2">Unit of measurement</th><th rowspan="2">Character</th><th colspan="3">Factor values</th><th rowspan="2">Variation level</th></tr>
<tr><th>1</th><th>0</th><th>1</th></tr>
<tr><td>1</td><td>Working shaft pressure</td><td>M</td><td>|||UNTRANSLATED_CONTENT_START|||x1|||UNTRANSLATED_CONTENT_END|||</td><td>16</td><td>24</td><td>32</td><td>8</td></tr>
<tr><td>2</td><td>Working body rotation speed</td><td>M, S</td><td>2</td><td>0-17 age:</td><td>25</td><td>34</td><td>0.085</td></tr>
<tr><td>3</td><td>The angle between the transmission mechanism and the vertical</td><td>refusal</td><td>|||UNTRANSLATED_CONTENT_START|||x3|||UNTRANSLATED_CONTENT_END|||</td><td>1.2</td><td>1</td><td>55</td><td>175%</td></tr>
</table>

During the experiment $x_1(P)$ pressure, $x_2(V)$ speed and $x_3(\alpha)$ The compressed and final weights of the leather raw material at different values of the angle formed by the transmission mechanism with the vertical are presented in Table 2. Table 2 shows the size of the input parameter of the experiment. Working matrix TOE $2^3 = 8$.

Table 2. Experimental data on squeezing liquid from wet leather raw materials

<table>
<tr><th>No</th><th>|||UNTRANSLATED_CONTENT_START|||x1|||UNTRANSLATED_CONTENT_END|||</th><th>2</th><th>|||UNTRANSLATED_CONTENT_START|||x3|||UNTRANSLATED_CONTENT_END|||</th><th colspan="2">y_1 , gr</th><th colspan="2">y_2 , gr</th><th colspan="2">y_3 , gr</th></tr>
<tr><td></td><td></td><td></td><td></td><td>y_{b1}</td><td>y_{o1}</td><td>y_{b2}</td><td>y_{o2}</td><td>y_{b3}</td><td>y_{o3}</td></tr>
<tr><td>1</td><td>+</td><td>+</td><td>+</td><td>2</td><td>5</td><td>7</td><td>7</td><td>8</td><td>7</td></tr>
<tr><td>2</td><td>-</td><td>+</td><td>+</td><td>82,8
67.5</td><td>6.</td><td>5</td><td>66.5</td><td>4</td><td>8</td></tr>
</table>

3	+	-	+	90	6.	8	60	3	4
4	-	-	+	1	1	6.	3	5	7
5	+	+	-	4	60	3	5	83.7	3
6.	-	+	-	9	60	1	58.5	7	1
7	+	-	-	3	60	7	5	4	5
8	-	-	-	1	6.	8	5	4	5

here is $_{b}$ –initial weight of the wet leather raw material sample;

y_{oh} – the weight of a wet leather raw material sample after compression.

Using the values in Table 2, an experimental design matrix was constructed. That is, mathematical calculations of the moisture extracted from the leather raw material product (in percentage) are presented in Table 3 [12-17].

In a full factorial experiment, the regression coefficients are determined by the following formulas [84; pp. 65-70]:

$$b_0 = \frac{1}{N}\sum_{j=1}^{N} y_i;\ b_j = \frac{1}{N}\sum_{j=1}^{N} X_{ji} y_j;\ b_{im} = \frac{1}{N}\sum X_{ji} X_{jm} y_i. \quad (3)$$

According to the above results, the regression coefficients are equal to: $b_0 = 24{,}1;\ b_1 = 5{,}1;\ b_2 = 0{,}2;\ b_3 = 0{,}05;\ b_{12} = 4{,}23;\ b_{13} = -1{,}06;$
$b_{23} = -0{,}04;\ b_{123} = -0{,}89.$

Table 3. Experiment planning matrix

<table>
<tr><td rowspan="2">No</td><td colspan="3">Factors</td><td colspan="4"></td><td colspan="3">Experimental results</td><td>Average result</td></tr>
<tr><td>|||UNTRANSLATED_CONTENT_START|||x₁|||UNTRANSLATED_CONTENT_END|||</td><td>2</td><td>|||UNTRANSLATED_CONTENT_START|||x₃|||UNTRANSLATED_CONTENT_END|||</td><td>|||UNTRANSLATED_CONTENT_START|||x₁₂|||UNTRANSLATED_CONTENT_END|||</td><td>|||UNTRANSLATED_CONTENT_START|||x₁₃|||UNTRANSLATED_CONTENT_END|||</td><td>2310</td><td>x 123</td><td>|||UNTRANSLATED_CONTENT_START|||y₁|||UNTRANSLATED_CONTENT_END|||</td><td>2</td><td>y 3</td><td>y place</td></tr>
<tr><td>1</td><td>+</td><td>+</td><td>+</td><td>+</td><td>+</td><td>+</td><td>+</td><td>23</td><td>24.2</td><td>24.9</td><td>24</td></tr>
<tr><td>2</td><td>-</td><td>+</td><td>+</td><td>-</td><td>-</td><td>+</td><td>-</td><td>18</td><td>20.4</td><td>21.2</td><td>19</td></tr>
<tr><td>3</td><td>+</td><td>-</td><td>+</td><td>-</td><td>+</td><td>-</td><td>-</td><td>26.1</td><td>27</td><td>25</td><td>26</td></tr>
<tr><td>4</td><td>-</td><td>-</td><td>+</td><td>+</td><td>-</td><td>-</td><td>+</td><td>22</td><td>23.6</td><td>8</td><td>4</td></tr>
<tr><td>5</td><td>+</td><td>+</td><td>-</td><td>+</td><td>-</td><td>-</td><td>-</td><td>22.8</td><td>25</td><td>26.8</td><td>25</td></tr>
<tr><td>6.</td><td>-</td><td>+</td><td>-</td><td>-</td><td>+</td><td>-</td><td>+</td><td>25</td><td>25</td><td>|||UNTRANSLATED_CONTENT_START|||24,1|||UNTRANSLATED_CONTENT_END|||</td><td>24</td></tr>
<tr><td>7</td><td>+</td><td>-</td><td>-</td><td>-</td><td>-</td><td>+</td><td>+</td><td>29</td><td>30</td><td>29</td><td>8</td></tr>
<tr><td>8</td><td>-</td><td>-</td><td>-</td><td>+</td><td>+</td><td>+</td><td>-</td><td>17.2</td><td>19</td><td>19.8</td><td>18</td></tr>
</table>

Table 4.1 We find the dispersion repeatability:

<table>
<tr><td rowspan="2">Inventory</td><td colspan="4">1</td><td>2</td><td>3</td><td>4</td><td>5 6.</td></tr>
<tr><td>|||UNTRANSLATED_CONTENT_START|||y₁|||UNTRANSLATED_CONTENT_END|||</td><td>2</td><td>y_3</td><td>y_j</td><td>$(y_{j1}-\bar{y})^2$</td><td>$(y_{j2}-\bar{y})^2$</td><td>$(y_{j3}-\bar{y})^2$</td><td>S_j^2</td></tr>
<tr><td>1</td><td>23</td><td>24.2</td><td>24.9</td><td>24</td><td>15</td><td>0,03</td><td>0,3</td><td>16</td></tr>
<tr><td>2</td><td>18</td><td>20.4</td><td>21.2</td><td>19</td><td>3.3</td><td>23</td><td>1</td><td>1</td></tr>
<tr><td>3</td><td>26.1</td><td>27</td><td>25</td><td>26</td><td>13</td><td>1</td><td>76</td><td>81</td></tr>
<tr><td>4</td><td>22</td><td>23.6</td><td>8</td><td>4</td><td>34</td><td>0,04</td><td>14</td><td>0-17 age:</td></tr>
<tr><td>5</td><td>22.8</td><td>25</td><td>26.8</td><td>25</td><td>5.5</td><td>0,59</td><td>49</td><td>2</td></tr>
<tr><td>6.</td><td>25</td><td>25</td><td>|||UNTRANSLATED_CONTENT_START|||24,1|||UNTRANSLATED_CONTENT_END|||</td><td>8</td><td>|||UNTRANSLATED_CONTENT_START|||0,1|||UNTRANSLATED_CONTENT_END|||</td><td>0.12</td><td>45</td><td>23</td></tr>
<tr><td>7</td><td>29</td><td>30</td><td>29</td><td>8</td><td>0.05</td><td>0,3</td><td>0.12</td><td>0-17 age:</td></tr>
<tr><td>8</td><td>17.2</td><td>19</td><td>19.8</td><td>18</td><td>3</td><td>0.9</td><td>65</td><td>1</td></tr>
</table>

We calculate the sum of the elements of the column from Table 4.6.

$$\sum_{j=1}^{8} S_j^2 = 7{,}72 \quad (4)$$

The dispersion repeatability is equal to the following expression:

$$S_{\{y\}}^2 = \frac{1}{8}\sum_{j=1}^{8} S_j^2 = 7{,}72/8 = 0{,}965 \quad (5)$$

We determine the mean square of the coefficient of deviation:

$$S_{\{y\}} = \sqrt{\frac{S_{\{y\}}^2}{n \cdot m}} = \sqrt{\frac{0{,}965}{8 \cdot 3}} = 0{,}2 \quad (6)$$

Only specific coefficients are included in the mathematical model of the process. Thus, as a result of processing the data obtained using the Excel computer program, a regression equation is obtained for the leather raw material product and takes the following form [84]:

$$y = 24{,}1 + 5{,}1x_1 + 0{,}2x_2 + 0{,}05x_3 + 4{,}23x_1x_2 - 1{,}06x_1x_3 - 0{,}04x_2x_3 - 0{,}89x_1x_2x_3. \quad (7)$$

An adequate mathematical calculation of the regression equation shows the similarity, i.e. adequacy, of the experimental results and the mathematical models. In models, the value of the regression coefficients describes the significance of the corresponding factor in the magnitude of the output parameters as the factor moves up or down the level. The importance of a factor on the magnitude of the output factor when moving from a low level to a high level is called the effect of the factor. The larger the regression coefficient, the higher the efficiency of the factor, that is, the greater the impact of the factor on the output parameter. Thus, the order of the factor is carried out in the model according to the magnitude of the regression coefficients, depending on the influence of the factor on "Y". The sign in front of the regression coefficient describes the effect of the factor on "Y".

The level of confidence, based on the hypothesis of the adequacy of the equations from which the results were obtained, $\alpha = 0{,}95$ was checked using Fisher's exact test.

$$F_p = \frac{S^2_{a\partial}}{S^2_{\{y\}}} < F_T \quad (8)$$

Here $S^2_{a\partial}$ –residual variance or adequacy variance; $S_{\{y\}}{}^2$ –repeated variance.

$S^2_{a\partial}$ and $S_{\{y\}}{}^2$ Let's define.

$$S^2_{a\partial} = \frac{3}{8-7}\sum_{j=1}^{8}(\tilde{y}_j - \bar{y}_j)^2 = 20{,}84 \quad (9)$$

Fisher's criterion adequacy model:

$$F_p = \frac{S^2_{a\partial}}{S^2_{\{y\}}} = \frac{20{,}84}{0{,}965} = 21{,}76 > F_T = 21{,}59 \quad (10)$$

$x_1 = \frac{P-24}{8}$, $x_2 = \frac{\alpha - 1{,}375}{0{,}175}$, $x_3 = \frac{V-0{,}25}{0{,}085}$ The equations (7) are put into the regression equation.

Here P – the compressive force of the shafts. V – constant rotation speed of the working body.

α -the angle formed by the transmission mechanism with the vertical.

$$\begin{aligned} y = 24{,}1 + 5{,}1\left(\frac{P-24}{8}\right) + 0{,}2\left(\frac{\alpha-1{,}375}{0{,}175}\right) + 0{,}05\left(\frac{V-0{,}25}{0{,}085}\right) + \\ + 4{,}23\left(\frac{P-24}{8}\right)\left(\frac{\alpha-1{,}375}{0{,}175}\right) - 0{,}04\left(\frac{\alpha-1{,}375}{0{,}175}\right)\left(\frac{V-0{,}25}{0{,}085}\right) - \\ - 1{,}06\left(\frac{P-24}{8}\right)\left(\frac{V-0{,}25}{0{,}085}\right) - 0{,}89\left(\frac{P-24}{8}\right)\left(\frac{V-0{,}25}{0{,}085}\right)\left(\frac{\alpha-1{,}375}{0{,}175}\right). \end{aligned} \quad 11$$

Thus, the regression equation can be considered to be suitable with a 95% confidence level, and we can simplify the derived regression equation (11) and write it in the following form for the leather raw material product [84]:

$$\Delta W = 156{,}75 - 5{,}57P - 202{,}3V - 114{,}6\alpha + 4{,}85P\alpha + 175V\alpha + 8{,}64PV - 7{,}4VPd \quad 12$$

Using the regression equation (12), the angle α formed by the transmission mechanism with the vertical is the pressure of the fluid being squeezed. *ΔW* graphs of dependence on quantity *P=32 kN/m* and rotation of the working body *V* constructed for different values of speed (Fig. 2). The working body rotates *V* velocity of the compressed liquid *ΔW* graphs of dependence on quantity *α=1.55 rad* and working shafts are designed for different values of thrust force (Figure 3). Working body rotation *V* The velocity of the liquid being squeezed out *ΔW* graphs of dependence on quantity *P=32 kN/m* and the vertical axis of the transmission mechanism *α* constructed for different values of the angle) (Figure 4). Analysis of the experimental results shows that when the leather raw material product moves between the pairs of compression shafts, the moisture efficiency of the leather raw material can be increased by reducing the speed of the leather raw material product and increasing the compression force of the compression shafts.

Based on the constructed graphs, the experimental results show that the angle formed by the transmission mechanism with the vertical *α=1.55 rad,* compressive force compressing the shafts

P=32 kN/m and the speed of rotation of the working body *V=0.17 m/s* The amount of liquid squeezed out of the raw material (Δ *W=38 %)* showed the highest result. The angle between the transmission mechanism and the vertical *α=1.55 rad,* compressive force compressing the shafts *P=32 kN/m* and the speed of rotation of the working body *V=0.25 m/s* The amount of liquid squeezed out of the raw material (Δ *W=36 %)* The average result is also the angle formed by the transmission mechanism with the vertical. *α=1.55 rad,* compressive force compressing the shafts *P=32 kN/m* and the speed of rotation of the working body *V=0.34 m/s* The amount of liquid squeezed out of the raw material (Δ *W=31 %)* showed the lowest result.

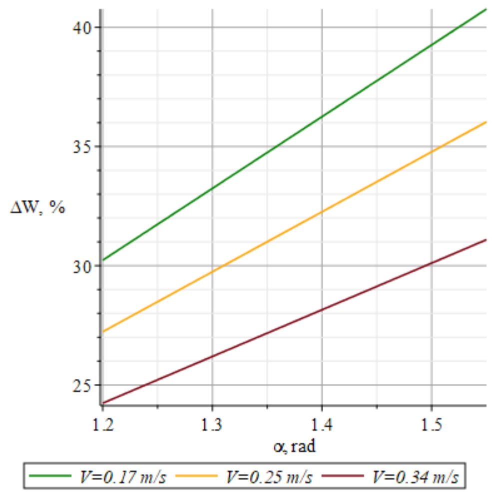

Figure 2 The vertical axis of the transmission mechanism *α* liquid squeezed out of the corner *ΔW* Graphs of dependence of the amount of (P=32 kN/m and different values of the working body rotation speed V

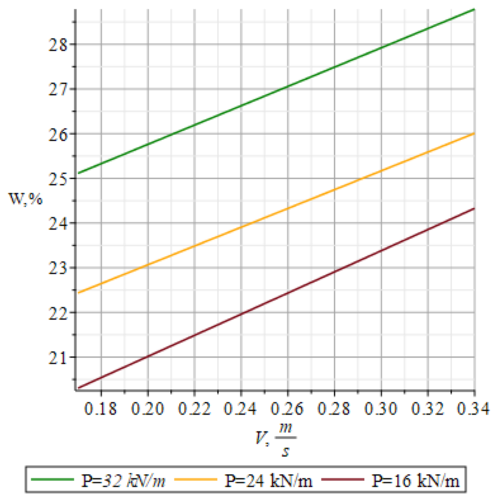

Figure 3. The working body rotates at a speed V, the fluid displaced *ΔW* graphs of dependence on the amount of (α=1.55 rad and working shafts are built for different values of the pressure force)

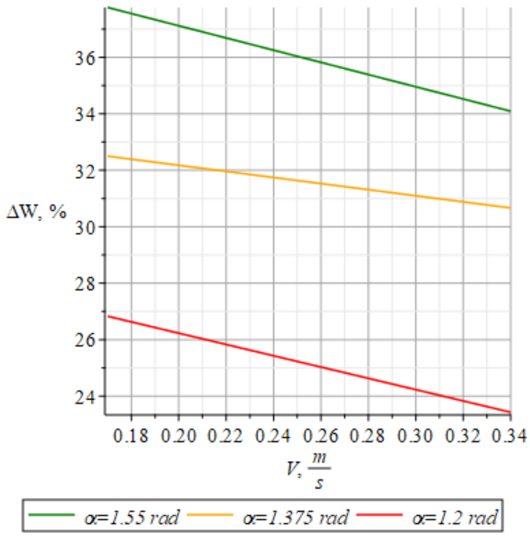

Figure 4. The working body rotates at a speed V, the fluid displaced *ΔW* Graphs of dependence on the amount of (P=32 kN/m and constructed for different values of the angle α formed by the transmission mechanism with the vertical)

Also, based on the constructed graphs, we can say that the angle formed by the transmission mechanism with the vertical *α=1.375 rad,* compressive force that compresses the shafts *P=32* *kN/m* and working body rotation speed *V=0.17* m/s, the amount of liquid squeezed out of the leather raw material product *(ΔW=32 %)* is producing an average result. The angle between the transmission mechanism and the vertical *α=1.2 rad,* compressive force that compresses the shafts *P=32 kN/m* and maximum transition speed *V=0.17 m/s* when the amount of liquid squeezed out of the leather raw material product *(ΔW=27 %)* is producing less results.

Conclusion. In conclusion, it can be said that the angle formed by the transmission mechanism with the vertical *α=1.55 rad,* The compressive force is large. *P=32 kN/m* and the maximum throughput of the leather raw material product is small *V=0.17 m/s* The moisture extracted is highest when. Therefore, the greater the angle formed by the transmission mechanism with the vertical, the maximum speed of passage, and the compressive force, the less liquid is squeezed out of the leather raw material product. The proposed shaft machine design, consisting of a transmission mechanism, compresses the leather raw material product and ensures maximum moisture removal from the leather raw material product. This structure is wet. skin Removing excess moisture from raw materials increases the efficiency of technological operations.

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