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# Optimizing the parameters of leather pressing machines

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**Abstract.** The work is devoted to the optimization of the parameters of leather pressing machines. Regression models of the residual moisture content of leather and the intensity of the pressing process are developed. which depend on the intensity of the load. the radius and the speed of the rollers. A number of patterns were established that allow increasing the efficiency of leather pressing by rollers. An extremum problem was solved to determine the diameter of the rollers that provide the minimum deflection of their working part. the content of residual moisture required during the pressing process and the minimum power required to conduct the pressing process.

## 1. Introduction

The efficiency of the roll pressing of wet materials is determined by the amount of residual moisture. Therefore one of the main tasks of roller pressing of wet materials is the description of the residual moisture content of the pressed material [1]. The description of the residual moisture of the pressed material can be conducted either theoretically using mathematical modeling or experimentally as a result of studying the influence of the main parameters of the two-roll module on it.

In [2-6] on the basis of solving contact and hydraulic problems analytical expressions were found for the residual moisture content of wet material during roller pressing.

Articles [7-8] are devoted to the experimental study and description by a regression model of the residual moisture content of a semi-finished leather product at a vertical feed.

This study is devoted to experimental research of the effect of the parameters of leather squeezing machines on the residual moisture of leather. The aim of the study is to obtain the dependence of residual moisture content on the main parameters which could be used to select the optimal technological and design parameters for leather squeezing machines.

The choice of optimal parameters for leather squeezing machines depends on the setting of an extremum problem. An extreme task to determine the diameter of the rollers providing a minimum deflection of their working part the content of residual moisture required during the pressing process and the least power required to perform the pressing process is set in the article. To solve this problem. regression dependences of the residual moisture content of leather and the intensity of the squeezing process on the main parameters of pressing machines are required.

## 2. Analytical solutions of the problems posed

The experiments were conducted on a setup (figure 1) consisting of the following main units: a frame, working rollers, a spring-screw system, and a drive. The design of the setup allows the replacement of the rollers, changing the speed of the rollers and the force of their pressing. A set of rollers with diameters of 0.100, 0.210 and 0.320 m was provided (after winding the cloth. their radii were 0.058. 0.114 and 0.170 m. respectively) the required pressing force was applied by a spring-screw system. the speed of the rollers was regulated by a rheostat. The length of the rollers in all cases was 0.12 m.

The study was conducted on semi-finished leather samples cut from bovine hide. after chrome tanning (of leather). The samples were cut out with a width of 0.06 m and the required length. depending on the type of experiment. after that. they were assembled into groups.

Power consumption was determined by the formula $N = \omega M$. In this case. the torque $M$ was measured by the strain gauge method [9].

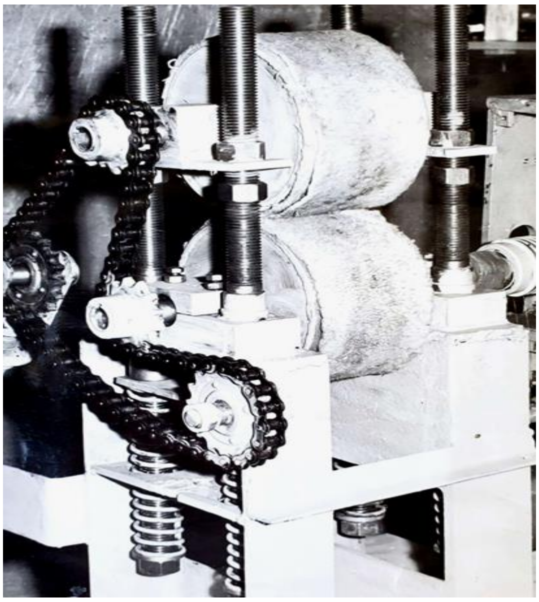

**Figure 1.** Experimental setup.

Experimental studies were conducted by methods of experiment planning. On the basis of search experiments. It was decided to conduct experiments by the second-order D optimal planning methods using the K. Kano design matrix for a three-factor experiment [9].

As a result of research in the field of the contact area of the rollers [10-11] and the experience of operating leather squeezing machines. It was found that the main parameters affecting the residual moisture content of leather are the load intensity, the diameters of the rollers and the speed of the rollers. Therefore the residual moisture content $W$ and power $N$ were taken as response functions, and as factors of load intensity $Q$ roller radius $R$ and roller speed $V$ , respectively.

Levels and intervals of factor variations are given in table 1.

**Table 1.** Levels and intervals of factor variations.

| **Factor** | **Variation Level** | | | **Variation Interval** |
|---|---|---|---|---|
| | - | 0 | + | |
| $Q$ , *kH/m* | 15 | 40 | 65 | 25 |
| *R, m* | 0.058 | 0.114 | 0.170 | 0.056 |
| *V, m/s* | 0.10 | 0.22 | 0.34 | 0.12 |

Target function is approximated by a polynomial

$$y_0 = b_0 + \sum_{i=1}^{k} b_i x_i + \sum_{i,j=1}^{k} b_{ij} x_i x_j + \sum_{i=1}^{k} b_{ii} x_i^2, \qquad (1)$$

where $b_0$, $b_i$, $b_{ij}$, $b_{ii}$ – are the regression coefficients.

After the implementation of the working matrix the arithmetic mean values $\overline{W}_{\text{ост}}$ and $\overline{N}$ were obtained (table 2).

**Table 2.** The arithmetic mean values $\overline{W}_{\text{ост}}$ and $\overline{N}$

| Working matrix | | | Residual moisture content, % | | Power, W | |
|---|---|---|---|---|---|---|
| $Q$ | $R$ | $V$ | $\overline{W}$ | $\hat{W}$ | $\overline{N}$ | $\hat{N}$ |
| 40 | 0.114 | 0.22 | 57.93 | 58.03 | 65.8 | 63.4 |
| 65 | 0.170 | 0.34 | 58.64 | 59.23 | 126.6 | 124.3 |
| 65 | 0.058 | 0.34 | 56.32 | 54.01 | 119.0 | 118.5 |
| 15 | 0.058 | 0.34 | 60.59 | 59.58 | 99.7 | 98.3 |
| 15 | 0.170 | 0.34 | 62.2 | 60.57 | 104.4 | 104.1 |
| 65 | 0.170 | 0.10 | 52.31 | 50.86 | 35.2 | 35.4 |
| 65 | 0.058 | 0.10 | 43.51 | 45.64 | 34.1 | 33.8 |
| 15 | 0.058 | 0.10 | 58.47 | 58.03 | 24.8 | 24.5 |
| 15 | 0.170 | 0.10 | 60.24 | 59.02 | 26.7 | 26.1 |
| 65 | 0.114 | 0.34 | 57.18 | 56.62 | 112.4 | 115.2 |
| 40 | 0.058 | 0.34 | 59.63 | 57.51 | 107.9 | 108.4 |
| 15 | 0.114 | 0.34 | 59.8 | 60.08 | 92.2 | 95.0 |
| 65 | 0.058 | 0.22 | 54.13 | 51.27 | 73.6 | 75.1 |
| 15 | 0.058 | 0.22 | 62.1 | 60.25 | 59.2 | 60.2 |
| 15 | 0.170 | 0.22 | 61.17 | 61.24 | 63.2 | 64.1 |
| 65 | 0.170 | 0.22 | 58.43 | 56.49 | 77.8 | 78.8 |
| 40 | 0.170 | 0.34 | 59.38 | 60.62 | 113.8 | 114.2 |
| 65 | 0.114 | 0.10 | 51.06 | 48.25 | 29.9 | 28.4 |
| 40 | 0.058 | 0.10 | 53.52 | 52.55 | 27.4 | 29.1 |
| 15 | 0.114 | 0.10 | 59.31 | 58.52 | 18.8 | 19.1 |
| 40 | 0.170 | 0.10 | 57.26 | 55.56 | 29.2 | 30.8 |

The homogeneity of variances was estimated by the Fisher criterion [9] at confidence level $\alpha = 0{,}95$. The tabular values of the Fisher criterion for $f_{\max} = 5$ and $f_{\min} = 4$ are $f_{\text{табл}} = 6.26$ [13]. Thus, all dispersions for $W$ and $N$ at $\alpha = 0.95$ can be considered homogeneous since $f_{\text{расч}} < f_{табл}$.

After determining the regression coefficients of the K. Kano plan [9], the following equations were obtained:

$$\hat{W} = 58.03 - 0.718x_1^2 - 0.113x_2^2 - 1.442x_3^2 + 1.058x_1x_2 + \\ + 1.705x_1x_3 - 0.762x_2x_3 - 3.431x_1 + 1.553x_2 + 2.481x_3, \qquad (2)$$

$$\hat{N} = 63.4 - 0.073x_1^2 + 6.176x_2^2 + 1.051x_3^2 + 0.119x_1x_2 + \\ + 2.716x_1x_3 + 1.035x_2x_3 + 7.377x_1 + 1.859x_2 + 40.68x_3. \qquad (3)$$

The hypothesis on the adequacy of the found equations was checked using the Fisher criterion [9] at confidence level $\alpha = 0{,}95$. The tabular values of the Fisher criterion for $f_{\max} = 90$ and $f_{\min} = 91$ and $f_{\min} = 11$ are $F_{\text{табл}} = 1{,}85$ [9]. Thus, equations (2) and (3) can be considered suitable with 95% confidence probability ($F_{\text{расч}} < F_{\text{табл}}$).

Eliminating insignificant coefficients, equations (2) and (3) are written in the following form

$$\hat{W} = 58.03 - 0.718x_1^2 - 1.442x_3^2 + 1.058x_1x_2 + 1.705x_1x_3 - 3.431x_1 + 1.553x_2 + 2.481x_3, \quad (4)$$

$$\hat{N} = 63.4 + 6.176x_2^2 + 1.051x_3^2 + 2.716x_1x_3 + 1.035x_2x_3 + 7.377x_1 + 1.859x_2 + 40.68x_3. \quad (5)$$

After decoding equations (4) and (5), we obtain

$$W = 57.57 - 0.0011Q^2 - 100.4V^2 + 0.754QR + 0.568QV - 0.256Q + 25R + 42V, \quad (6)$$

$$N = 14.19 + 1959.4R^2 + 73V^2 + 0.905QV + 154.02RV + 0.96Q + 449.7R + 253.11V. \quad (7)$$

Figures 2 – 4 show graphical interpretations of dependences (6), (7).

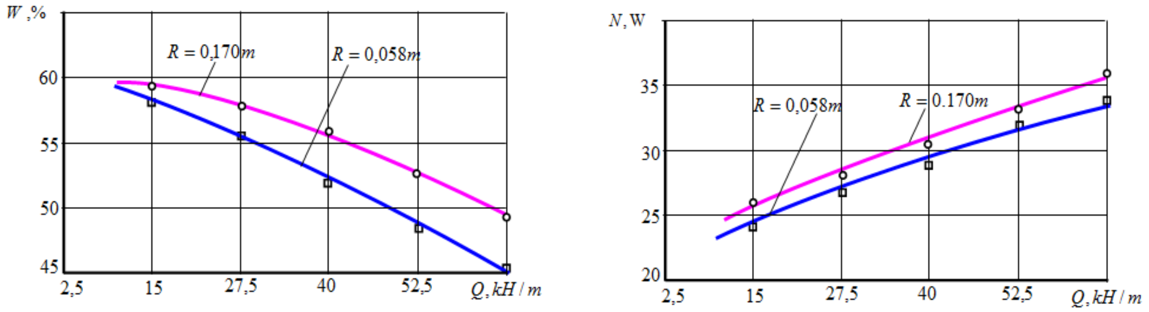

**Figure 2.** Dependence of the change in residual moisture content and power on the intensity of the load $Q$, *kN/m* for $V = 0{,}10$ *m/s.*

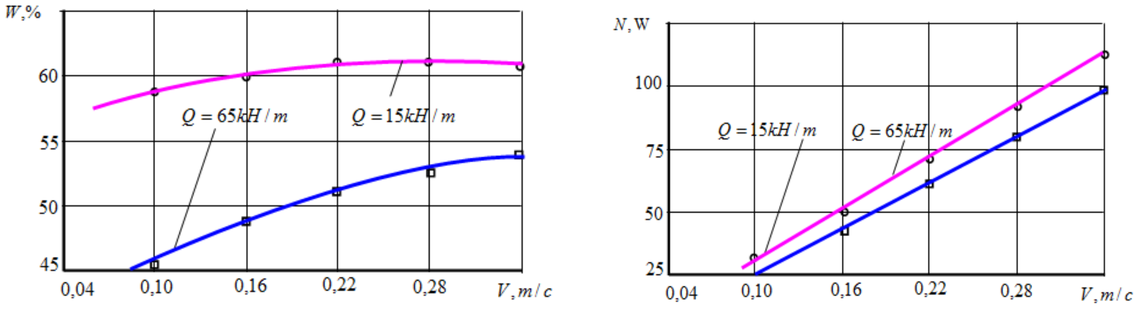

**Figure 3.** Dependence of the change in residual moisture content and power on roller speed $V$, *m/s* for $R = 0.058m$.

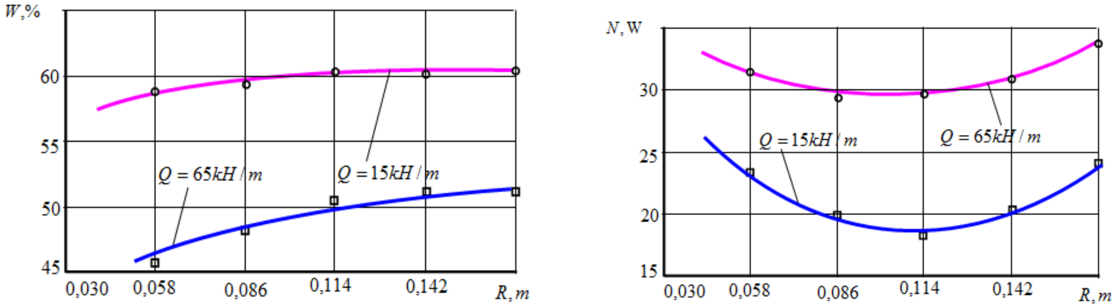

**Figure 4**. Dependence of change of residual moisture content and power from the roller radii $R$, m for $V=0.10$, m/s .

Now we will solve the formulated extremum problem. When calculating the optimal diameter of the rollers, we will take into account the conditions for the minimum deflection of their working part $D \geq 0.1B$ [12] or:

$$x_2 \geq \frac{0.05B+\lambda-0.114}{0.056}, \tag{8}$$

where $\lambda -$ is the thickness of the elastic coating of the roller.

We solve the extremum problem by the Maple system of mathematical packages according to the following calculation scheme:

1) change $x_3$ with step $0.0625$, within $-1 \div 1$;

2) change $x_1$ with step $0.05$, within $-1 \div 1$;

3) for each combination of $x_1$ and $x_3$ with the accepted values $W_{\text{ост}}$ $(W_{\text{ост}}=58.59,\ 60\ \%)$ according to expression (6) $x_2$ is calculated;

If for values $B=1.8m$ and $\lambda=0.016m$ factor $x_2$ satisfies condition (8), then $N$ is calculated by expression (7);

4) the following arrays of values $N$ are calculated for different values:

for values of $W_{\text{ост}}=58,\ B=1.8$ and $x_3=-1$;
for values of $W_{\text{ост}}=58,\ B=1.8$ and $x_3=-0.9375$;
$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$
for values of $W_{\text{ост}}=58,\ B=1.8$ and $x_3=1$;
for values of $W_{\text{ост}}=59,\ B=1.8$ and $x_3=-0.9375$;
$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$
for values of $W_{\text{ост}}=60,\ B=1.8$ and $x_3=1$;

5) the minimum value of $N_0$ is selected from each array;

6) factors $x_1,\ x_2,\ x_3$ at given value of $N_0=N_{\min}$ provide for set values of $W_{\text{ост}}$ and $B$, and decode the natural $Q,\ R,\ V$ values;

7) $W_{\text{ост}},\ B,\ N,\ Q,\ R,\ V$ are printed.

As a result of solving the extremum problem, it was revealed that, at values of m/s to press the $B=1.8$ m, $V=0.16\div0.22$ m/s moisture to $W_{\text{ост}}=58\div60\ \%$, the lowest power is achieved for $R=0.101\div0.111\ m$.

Roller squeezing machines used in the tannery are equipped with conveying mechanisms for feeding leather into the working area of the squeezing rollers. The speed of the conveying mechanism is determined based on the capabilities of an operator who feeds and straightens the leather folds on the conveying mechanism. Considering this, and the effect of the roller speed on the productivity and energy costs of the machine, $B = 1.8$ m - $V = 0.190$ m/s are taken as the rational speed of the rollers.

The intensity of the load $Q$ is determined from formula (6) at known values of $W_{\text{ост}}, B, R$ and $V$. The calculation results show that at the values of $B = 1.8$ m, $R = 0.110$ m and $V = 0.190$ m/s , the residual moisture content decreases by $58\ \%$ at $Q = 35.58$ kN/m.

The power of the setup $N_0$ required for pressing the leather semi-finished product is determined from equation (7). The power of the roller feed-through machine with the width of the working pass $B$, taking into account losses in transmission gears, is calculated by formula [12]

$$N = (1.15 \div 1.25)\frac{2N_0 B}{\eta i b},$$

where $i -$ is the total gear ratio of the drive mechanism; $\eta -$ is the overall efficiency of the drive mechanism. Then for $B = 1.8$ $m$ and gear transmission we have

$$N = \frac{1.25 \cdot 2 \cdot 52.02 \cdot 1.8}{1 \cdot 0.95 \cdot 0.06} = 4107W = 4.11kW.$$

Thus, in order to achieve the residual moisture content of leather $58 \div 60\ \%$, the roller feed-through machine must have the following parameters: width of working pass – 1800 mm; roller speed – 0.190 m/s; roller diameter (with coating) – 0.22 m; electric motor power (for gear transmission) – 4.11 kW; load intensity – 35.58 kH/m.

## 3. Results

Using the methods of planning the experiment, regression formulas were found that describe the residual moisture content of leather and power on the intensity of the load, speeds and radii of the rollers.

An extremum problem was solved to determine the diameter of the rollers that provide the minimum deflection of their working part, the content of residual moisture required during the pressing process and the least power required to realize the pressing process.

## 4. Conclusions

An experimental study stated that:

- with a decrease in the radius, speed of the rollers, and with an increase in the intensity of the load, the quality of the roller pressing of leather improves;
- all other conditions being equal, the function of residual moisture content on the radius of the roller $W_{\text{ост}}(R)$ can be considered a linearly increasing one;
- the pattern of change in residual moisture content from the speed of the roller $W_{\text{ост}}(V)$ does not depend on the radius of the rollers;
- the graph of power dependence on the radius of the roller $N = N(R)$ has an extremum point, that is, there is such a radius of the rollers in which $N$ is minimal.

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