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Technological parameters of roller machines

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Abstract. The study is devoted to the determination of the technological parameters of roller squeezing machines; these parameters determine the efficiency of the process, product quality, and the environmental situation of production. A mathematical model for the distribution of hydraulic force in roller machines has been obtained. The formulas for calculating the removed and residual moisture of the processed material are determined. It was found that the value of residual moisture depends on the value of the angle where the moisture changes position.

1 Introduction

Roller machines are universal and designed to perform a wide range of technological operations. The basic element of roller machines is a two-roll module used in light, textile, paper-making, mining and metallurgical, and other industries.

One of the technological processes performed in roller machines is the squeezing process, which creates the necessary moisture content for subsequent operations.

The squeezing process is conducted due to the contact interaction of the processed material with pairs of rolls. Here, the processed material is compressed and its moisture content changes. The phenomenon of changes in the moisture content of the processed material is of practical importance for the calculation of such technological parameters as the removed and residual moisture content of the squeezing process. These parameters, in turn, determine the efficiency of the process, product quality and the environmental situation of production.

To determine the change in the moisture content of the processed material, a mathematical model of the distribution of hydraulic pressure is necessary [1].

Studies in [2-19] are devoted to the mathematical modeling of hydraulic pressure. The calculations of the technological parameters of squeezing machines in these publications were conducted using the mathematical models obtained.

The calculation formulas of technological parameters obtained so far are approximate; they do not allow for assessing the technological efficiency of the squeezing process during the operation of squeezing machines.

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2 Materials and methods

Consider the scheme of the squeezing machine [2], shown in Figure 1. In the scheme under consideration, the lower roll is taken to be the first roll, and the upper roll is considered to be the second roll. We assume that in each roll the contact curve consists of compression and recovery zones.

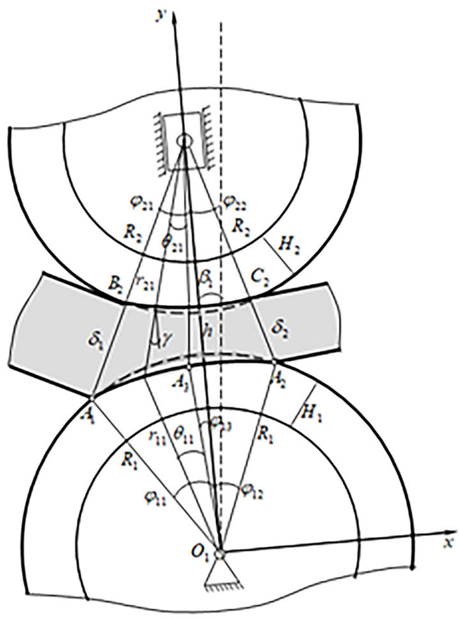

Fig. 1. Scheme of a squeezing machine.

The material being processed at the entrance to the rolls contact zone begins to shrink and fluid is squeezed out from it; this creates hydraulic pressure in the contact zone of the rolls.

The specific pressure acting on each roll is balanced by the equivalent pressure inside the elastic coating, caused by the action of compressive forces to overcome the deformation of the roll coating and hydraulic forces [1]:

$$p_h = p - p_c \,. \tag{1}$$

Due to the small size of the deformation zone, it can be assumed that the compressive load on the roll coating is distributed according to the law of normal stresses. Normal stresses for the compression zone of the lower roll have the following form [3]:

$$n_{11} = \frac{n_{1\max}}{2}\left(1 + \cos\frac{\pi}{\zeta_{11}}\vartheta_{11}\right), \; -\zeta_{11} \le -\vartheta_{11} \le 0 \,, \tag{2}$$

where $\vartheta_{11} = \theta_{11} + \varphi_{13} - \gamma$, $n_{1\max} = B_{11}\left(\frac{\varphi_{11} + \varphi_{21}}{2}\right)^{2s_1}$, $k_{11} = \frac{m_{11} H_1}{m_1^* \delta_1}$, $B_{11} = C_1\left(\frac{R_1}{\delta_1(1 + k_{11}\lambda_{11})}\right)^{s_1}$,

$\vartheta_{11} = \theta_{11} + \varphi_{13} - \gamma$, $\zeta_{12} = \varphi_{12} + \gamma_2$, $m_{11}, m_1^* -$ the hardening coefficients; λ_{11} is the indicator that determines the ratio of the strain rate of the lower roll coating to the strain rate of the material being processed.

From expression (1) for the compression zone of the lower roll, we obtain

$$p_{11h} = p_{11} - n_{11}. \tag{3}$$

There are various approaches to solving the problem related to determining the value of hydraulic pressure.

In [1], the hydraulic pressure model is taken similar to the distribution law of the total pressure, i.e.

$$p_{11h} = \chi_{11} p_{11}$$

or considering expressions (2) and (3)

$$p_{11h} = \frac{\chi_{11} n_{1\max}}{2(1-\chi_{11})}\left(1+\cos\frac{\pi}{\zeta_{11}}\vartheta_{11}\right), \quad -\zeta_{11} \le -\vartheta_{11} \le 0\,. \tag{4}$$

It is evident, that

$$\vartheta_{11} = 0\,, \quad p_{11h}(\vartheta_{11}) = p_{1\max г},\ n_{11h}(\vartheta_{11}) = n_{1\max h}. \tag{5}$$

Taking this condition into account, from equality (4) we obtain

$$\chi_{11} = \frac{p_{1\max г}}{p_{1\max h} + n_{1\max}}\,. \tag{6}$$

To find $p_{1\max h}$, we use the results given in the previous studies [4], according to which the model of hydraulic pressure distribution for the compression zone of the lower roll has the following form:

$$p_{11h} = b_{11}(\zeta_{11}^2 - \vartheta_{11}^2)\cdot\left(2 - \frac{K_{11\max} - K_{11\min}}{K_{11\max}}\cdot(\zeta_{11}^2 + \vartheta_{11}^2)\right), \tag{7}$$

where $b_{11} = \dfrac{\upsilon v_m R_1^2(\varphi_{11}-\gamma_1)^3\cos(\varphi_{11}-\gamma_1)}{12K_{11\min}\delta_1(1+k_{11}\lambda_{11})(1+k_{11}\lambda_{11}\cos(\varphi_{11}-\gamma_1))}$, $v_m -$ is the velocity of the processed material, $K_{11\min} -$ is the minimum filtration coefficient in the direction along the warp threads of the material, $K_{11\max} -$ is the maximum filtration coefficient in the direction across the surface of the material, $\upsilon -$ viscosity coefficient.

From formula (7), taking into account condition (5), we find $p_{1\max h} = 2b_{11}\zeta_{11}^2$ or

$$p_{1\max h} = 2b_{11}(\varphi_{11}-\gamma_1)^2. \tag{8}$$

Then from equality (6), we have

$$\chi_{11} = \frac{2b_{11}(\varphi_{11}-\gamma_1)^2}{2b_{11}(\varphi_{11}-\gamma_1)^2 + n_{1\max}}. \tag{9}$$

The patterns of distribution of hydraulic force in other zones are determined similarly:

$$p_{12h} = \frac{\chi_{12} n_{1\max}}{2(1-\chi_{12})}\left(1+\cos\frac{\pi}{\zeta_{12}}\vartheta_{12}\right), \quad 0 \le \vartheta_{12} \le \zeta_{12}\,, \tag{10}$$

where $\chi_{12} = \dfrac{2b_{12}(\varphi_{12}+\gamma_2)^2}{2b_{12}(\varphi_{12}+\gamma_2)^2 + n_{1\max}}$, $b_{12} = \dfrac{\upsilon v_m R_1^2(\varphi_{12}+\gamma_2)^3\cos(\varphi_{12}+\gamma_2)}{12K_{12\min}\delta_1(1+k_{12}\lambda_{12})(1+k_{12}\lambda_{12}\cos(\varphi_{12}+\gamma_2))}$

$$p_{21h} = \frac{\chi_{21} n_{2\max}}{2(1-\chi_{21})}\left(1+\cos\frac{\pi}{\zeta_{21}}\vartheta_{21}\right), \quad -\zeta_{21} \le -\vartheta_{21} \le 0\,, \tag{11}$$

where $\chi_{21} = \dfrac{2b_{21}\varphi_{21}^2}{2b_{21}\varphi_{21}^2 + n_{2\max}}$, $b_{21} = \dfrac{\upsilon v_m R_2^2\varphi_{21}^3\cos\varphi_{21}}{12K_{21\min}\delta_2(1+k_{21}\lambda_{21})(1+k_{21}\lambda_{21}\cos\varphi_{21})}$,

$$p_{22h} = \frac{\chi_{22} n_{2\max}}{2(1-\chi_{22})}\left(1+\cos\frac{\pi}{\zeta_{22}}\vartheta_{21}\right), \quad 0 \le \vartheta_{22} \le \zeta_{22}, \tag{12}$$

where $\chi_{22} = \dfrac{2b_{22}\varphi_{22}^2}{2b_{22}\varphi_{22}^2 + n_{2\max}}$, $b_{21} = \dfrac{\upsilon v_m R_2^2 \varphi_{22}^3 \cos\varphi_{22}}{12K_{22\min}\delta_2(1+k_{22}\lambda_{22})(1+k_{22}\lambda_{22}\cos\varphi_{22})}$.

According to [1, 3], we have

$$dG = -\frac{B\rho K_t}{\upsilon}\frac{\partial p_h}{\partial \vartheta}\frac{\dfrac{dh}{d\vartheta}}{\dfrac{dn}{d\vartheta}}d\vartheta. \tag{13}$$

As follows from [3], for the compression zone of the lower roll, the following relations hold:

$$\frac{dh_{11}}{d\vartheta_{11}} = -\frac{R_1}{1+k_{11}\lambda_{11}}, \quad \frac{dn_{11}}{d\vartheta_{11}} = \frac{R_1}{1+k_{11}\lambda_{11}}, \quad K_{11t} = \frac{K_{11\max}K_{11\min}}{K_{11\max}-(K_{11\max}-K_{11\min})\vartheta_{11}^2}.$$

Then for the compression zone of the lower roll of the considered two-roll module, we obtain:

$$dG_{11} = \frac{B\rho}{\upsilon}\cdot\frac{K_{11\min}}{1-\dfrac{K_{11\max}-K_{11\min}}{K_{11\max}}\vartheta_{11}^2}\frac{\partial p_{11z}}{\partial \vartheta_{11}}d\vartheta_{11}$$

or taking into account expression (7)

$$dG_{11} = -\frac{B\rho\pi^2\chi_{11}n_{1\max}K_{11\min}}{2\upsilon(1-\chi_{11})\zeta_{11}^2}\cdot\frac{\vartheta_{11}}{1-\dfrac{K_{11\max}-K_{11\min}}{K_{11\max}}\vartheta_{11}^2}d\vartheta_{11}.$$

After integration, we get

$$G_{11} = \frac{B\rho\pi^2\chi_{11}n_{1\max}K_{11\max}K_{11\min}}{4\upsilon(1-\chi_{11})\zeta_{11}^2(K_{11\max}-K_{11\min})}\ln\left(1-\frac{K_{11\max}-K_{11\max}}{K_{11\max}}\vartheta_{11}^2\right)+C_{11}.$$

Expanding the logarithmic function into a series and restricting the terms to the second degree with respect to ϑ_{11}, taking into account condition $G_{11}(-\zeta_{11}^2)=0$, we have

$$G_{11} = \frac{B\rho\pi^2\chi_{11}n_{1\max}K_{11\min}}{4\upsilon(1-\chi_{11})}\left(1-\frac{\vartheta_{11}^2}{\zeta_{11}^2}\right). \tag{14}$$

The amount of water removed that has flowed through the compression zones is determined by the flow rate at the end point of the compression zone, that is, by moisture content $G_{11}(0)$:

$$G_{11}(0) = \frac{B\rho\pi^2\chi_{11}n_{1\max}K_{11\min}}{4\upsilon(1-\chi_{11})}. \tag{15}$$

By analogy with expression (14), we determine the patterns of change in the removed fluid that has flowed through the recovery zones:

$$G_{12} = \frac{B\rho\pi^2 n_{1\max}}{4\upsilon}\left(\frac{\chi_{11}K_{11\min}}{1-\chi_{11}}-\frac{\chi_{12}K_{12\min}}{1-\chi_{12}}\frac{\vartheta_{12}^2}{\zeta_{12}^2}\right). \tag{16}$$

The amount of removed liquid flowing along the contact line of the lower roll is determined by the humidity $G_{12}(\zeta_{14})$:

$$G_{12} = \frac{B\rho\pi^2 n_{1\max}}{4\upsilon}\left(\frac{\chi_{11}K_{11\min}}{1-\chi_{11}} - \frac{\chi_{12}K_{12\min}}{1-\chi_{12}}\frac{\zeta_{14}^2}{\zeta_{12}^2}\right), \quad 0 \le \zeta_{14} \le \zeta_{12}. \tag{17}$$

Similarly, we find:

$$G_{22} = \frac{B\rho\pi^2 n_{2\max}}{4\upsilon}\left(\frac{\chi_{21}K_{21\min}}{1-\chi_{21}} - \frac{\chi_{22}K_{22\min}}{1-\chi_{22}}\frac{\zeta_{24}^2}{\zeta_{22}^2}\right), \quad 0 \le \zeta_{24} \le \zeta_{22}. \tag{18}$$

Therefore, the amount of liquid removed from the material during the wringing process is:

$$G_{rem} = \frac{B\rho\pi^2 n_{1\max}}{4\upsilon}\left(\frac{\chi_{11}K_{11\min}}{1-\chi_{11}} - \frac{\chi_{12}K_{12\min}}{1-\chi_{12}}\frac{\zeta_{14}^2}{\zeta_{12}^2}\right) - \\ - \frac{B\rho\pi^2 n_{2\max}}{4\upsilon}\left(\frac{\chi_{21}K_{21\min}}{1-\chi_{21}} - \frac{\chi_{22}K_{22\min}}{1-\chi_{22}}\frac{\zeta_{24}^2}{\zeta_{22}^2}\right). \tag{19}$$

With a known amount of fluid removed, the water removed from the semi-finished leather product during squeezing is determined by the following expression [3]:

$$W_{rem} = \frac{G_{\text{уд}}}{\rho B v_m}100\%, \tag{20}$$

where v_m – material speed.

In roller squeezing, there is an equality $W_{res} = W_{in} - W_{rem}$, where W_{res}, W_{in} – is the residual and initial moisture content of the pressed material.

From expressions (19) and (20), it follows that the residual moisture content of the processed material is determined by the following expression:

$$W_{res} = W_{in} - \frac{B\rho\pi^2 n_{1\max}}{4\rho B v_{\text{м}}\upsilon}\left(\frac{\chi_{11}K_{11\min}}{1-\chi_{11}} - \frac{\chi_{12}K_{12\min}}{1-\chi_{12}}\frac{\zeta_{14}^2}{(\varphi_{12}+\gamma_2)^2}\right) + \\ + \frac{B\rho\pi^2 n_{2\max}}{4\rho B v_{\text{м}}\upsilon}\left(\frac{\chi_{21}K_{21\min}}{1-\chi_{21}} - \frac{\chi_{22}K_{22\min}}{1-\chi_{22}}\frac{\zeta_{24}^2}{\varphi_{22}^2}\right). \tag{21}$$

3 Results

A mathematical model of the distribution of hydraulic pressure during the squeezing process was developed.

Based on the obtained mathematical model of hydraulic pressure, formulas for calculating the removed and residual moisture content of the processed material were derived.

4 Conclusions

The analysis of the graphs showed that the curves of hydraulic pressure distribution described by models (7), (10), (11), and (12) fully correspond to the experimental hydraulic pressure diagrams.

From the analysis of formula (21) it was revealed that W_o depends on the value of the angles ζ_{14} and ζ_{24}. When $0 < \zeta_{i4} < \zeta_{i2}$, the W_o will be more than its moisture at the end of the compression zone. When $\zeta_{i4} = 0$, the W_o has the smallest value, and when $\zeta_{i4} = \zeta_{i2}$ has the largest value.

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