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Modeling roll contact curves of a squeezing machine

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Abstract. Mathematical models of roll contact curves of leather squeezing machines were developed. The phenomenon of contact interaction of leather with working rolls is considered taking into account the water filtration during the squeezing process and the strain properties of leather and cloth. Analysis of the obtained models showed that the contact curves of the rolls depend on the thickness, humidity and deformation properties of the leather, the radii of the rolls and the deformation properties of the cloth, as well as on the forces acting on their supports.

1 Introduction

Roll mechanisms are an integral part of many machines. They are especially widespread in the leather industry. They operate in squeezing, spreading, rolling, and other machines for the mechanical processing of semi-finished leather products.

In leather production, product quality is associated with environmental safety, since the squeezing process is associated with the problem of wastewater disposal.

In the theory of leather roller pressing, a coupled solution to two types of problems is necessary - contact interaction of leather with working rolls (contact problem) and water filtration (hydraulic problem).

References [1-5] are devoted to solving contact and hydraulic problems of roller pressing of wet materials.

During the squeezing process, the cloth (an elastic covering of rolls) and the leather are deformed under the influence of pressure, transmitted to the skin along the roll contact curves.

In [6,7], the shapes of roll contact curves, which do not take into account the phenomenon of water filtration during the squeezing process, are analytically described.

The article is devoted to modeling the contact curves of the rollers of leather squeezing machines. This takes into account changes in moisture during the spin process and the deformation properties of leather and cloth.

2 Materials and metods

Figure 1 shows a diagram of a roller squeezing mechanism, in which rolls with radii R have covering of cloth with a thickness of H, and the leather has an initial of δ_1. This scheme is

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most typical for leather squeezing machines and has advantages over other options in terms of size, metal consumption, simpleness, and quality of processing [7].

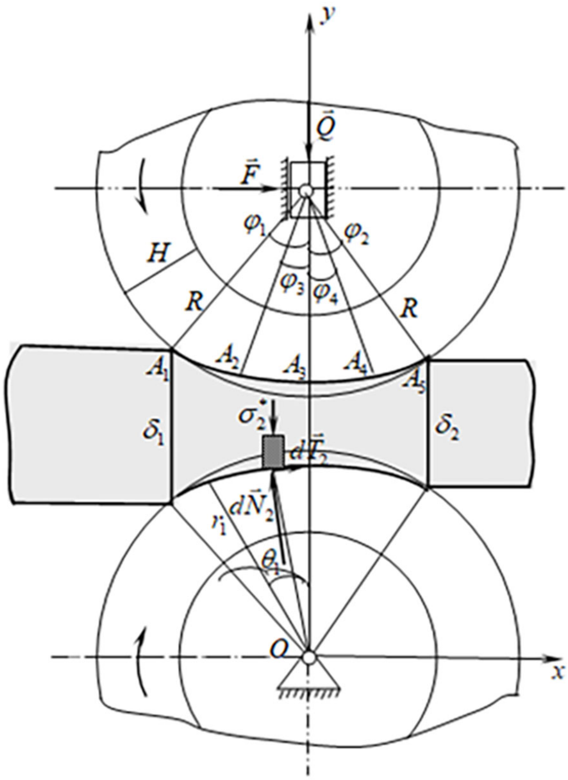

Fig. 1. Scheme of the roller squeezing mechanism.

The skin deformation zone is divided relative to the line of centers into zones of compression I and deformation recovery II. Here, zone I is not equal to zone II, since the skin deformation does not obey Hooke's law [8,9]; therefore, the symmetry of the roll contact curves relative to the line of centers is not observed.

According to [7], in the roll contact curves, there are zones of lag, sticking, and advance. The sticking zone is divided into two parts. The first refers to the compression zone and the second - to the deformation recovery zone. In this regard, the contact curves of each roll have sections 1, 2, 3, and 4, corresponding to segments A_1A_2, A_2A_3, A_3A_4, and A_4A_5 (Fig. 1).

Let the equation of the contact curve of each roll be given in polar coordinates $r_i = r_i(\theta_i)$, $i = \overline{1,4}$, $i -$ is the index standing for the number of the section.

According to Figure 1:

$$-\varphi_1 \le \theta_1 \le -\varphi_3, \quad -\varphi_3 \le \theta_2 \le 0, \quad 0 \le \theta_3 \le \varphi_4, \ \varphi_4 \le \theta_4 \le \varphi_2,$$

where $\varphi_1, \varphi_2 -$ are the contact angles, φ_3, $\varphi_4 -$ angles separating the sliding and sticking zones.

According to [6], the dependence between contact voltages is written like this:

$$t_i = \frac{\sin(\theta_i + \xi) r_i - \cos(\theta_i + \xi) r_i'}{\cos(\theta_i + \xi) r_i + \sin(\theta_i + \xi) r_i'} n_i, \tag{1}$$

where $\xi = arctg\frac{F}{Q}$; Q, $F-$ are the pressure force of the clamping devices and the horizontal response of the roll supports, t_i, n_i- are the shear and normal stresses distributed over the roll sections.

From equality (1), it follows:

$$\frac{r_i'}{r_i} = \frac{\sin(\theta_i + \xi)n_i - \cos(\theta_i + \xi)t_i}{\cos(\theta_i + \xi)n_i + \sin(\theta_i + \xi)t_i}. \quad (2)$$

By research conducted in [6,7], it was established that in the lag sliding zone, the Amonton law is observed $t_1 = f_1 n_1 = tg\nu_1$, where $f_1, \nu_1 -$ are the coefficient and angle of friction of the skin on the surface of the cloth under compression.

Then from equality (2), for the lag sliding zone, that is, for the 1st section of the roll, we have:

$$\frac{r_1'}{r_1} = \frac{\sin(\theta_1 + \xi) - \cos(\theta_1 + \xi)tg\,\nu_1}{\cos(\theta_1 + \xi) + \sin(\theta_i + \xi)tg\,\nu_1}$$

or

$$\frac{r_1'}{r_1} = tg(\theta_1 + \xi - \nu_1).$$

Having integrated the latter and conducting some transformations taking into account the initial condition $r_1 = R$ for $\theta_1 = -\varphi_1$, we obtain the equations for the contact curve of the 1st section of the roll:

$$r_1 = \frac{\cos(\varphi_1 - \xi + \nu_1)}{\cos(\theta_1 + \nu_1 - \xi)}R, \;\; -\varphi_1 \le \theta_1 \le -\varphi_3. \quad (3)$$

From Figure 1, it follows that the relative deformation of skin in the compression zone has the following form:

$$\varepsilon_i = \frac{2}{\delta_1}\left(r_i \cos\theta_i - R\cos\varphi_1\right), \qquad i = 1,2. \quad (4)$$

The leather is pressed after chrome tanning. It has been established [8,9] that the nature of skin deformation is described by empirical dependencies of the form:

$$\sigma_i^* = A_1 \varepsilon_i^{m_1}\left(\frac{W_{in}}{W_i}\right)^{s_1}, \quad (5)$$

where $\sigma_i^* -$ is the compression stress, $A_1, m_1, s_1 -$ are the coefficients characterizing the properties of leather under compression, $W_i -$ is the skin moisture content, $W_{in} -$ is the initial skin moisture content, that is, skin moisture before squeezing.

Substituting the expression for relative deformation into equation (5), for the 2nd section from equation (4), we obtain:

$$\sigma_2^* = A_1\left(\frac{2}{\delta_1}(r_2\cos\theta_2 - R\cos\varphi_1\right)^{m_1}\left(\frac{W_{in}}{W_2}\right)^{s_1}. \quad (6)$$

In the 2nd section, we select an element with length dl_2 directed along the normal of the curved contact (Fig. 1). The selected element of the skin is acted upon by forces dN_2 and dT_2 and the reaction of the cut off parts of the skin.

The components of force dN_2 and dT_2 are balanced by force $\sigma_2^* dx_2$ (Fig. 1):

$$\sigma_2^* dx_2 - dN_2\cos 0^o - dT_2 \sin 0^0 = 0,$$

or

$$n_2^* = \sigma_2^* \cos(\theta_2 - \psi_2), \tag{7}$$

where $\psi_2 -$ is the angle between dN_2 and r_2.

Taking into account expression (6), from (7), we obtain:

$$n_2^* = A_1\left(\frac{2}{\delta_1}(r_2 \cos\theta_2 - R\cos\varphi_1)\right)^{m_1}\left(\frac{W_{in}}{W_2}\right)^{s_1} \cos(\theta_2 - \psi_2). \tag{8}$$

An analysis of literature sources [6,8] showed that the strain properties of cloth are also described by a power law. Using the power law for cloth, we obtain:

$$n_2 = B_1\left(\frac{1}{H}(r_2 - R)\right)^{u_1} \cos\psi_2, \tag{9}$$

where $B_1, u_1 -$ are the coefficients characterizing the properties of cloth under ompression.

At the points of the curved contact the condition is satisfied $n_2^* = n_2$ (Newton's law).

Then, according to expressions (8) and (9), we obtain:

$$A_1\left(\frac{2}{\delta_1}(r_2 \cos\theta_2 - R\cos\varphi_1)\right)^{m_1}\left(\frac{W_{in}}{W_i}\right)^{s_1} \cos(\theta_2 - \psi_2) = B_1\left(\frac{1}{H}(R - r_2\right)^{u_1} \cos\psi_2,$$

or assuming that $tg\psi_2 \sin\theta_2 \approx 0$

$$A_1\left(1 - \frac{\delta_1 - 2(r_2\cos\theta_2 - R\cos\varphi_1)}{\delta_1}\right)^{m_1} W_{in}^S \cos\theta_2 = B_1\left(1 - \frac{H + r_2 - R}{H}\right)^{u_1} W_2^{s_1}. \tag{10}$$

Expanding the binomials in brackets into power series, and limiting ourselves to the first terms of the series since $\frac{\delta_1 + 2R\cos\varphi_1 - 2r_2\cos\theta_2}{\delta_1} < 1$ and $\frac{H + r_2 - R}{H} < 1$, after transformations we obtain the equations for the contact curve of the 2[nd] section of the roll:

$$r_2 = \frac{B_1\delta_1(H + u_1(R - H))W_2^{s_1} + A_1H(m_1\Delta - \delta_1)W_{in}^{s_1}\cos\theta_2}{B_1\delta_1 u_1 W_2^{s_1} + 2A_1Hm_1W_{in}^{s_1}\cos^2\theta_2}, \quad -\varphi_3 \le \theta_2 \le 0. \tag{11}$$

Similarly to (11) and (3), we find the equations for the contact curves of the 2[nd] and 4[th] sections of the roll:

$$r_3 = \frac{B_2\delta_2(H + u_2(R - H))W_3^{s_2} + A_2H(m_2\Delta - \delta_2)W_r^{s_2}\cos\theta_3}{B_2\delta_2 u_2 W_3^{s_1} + 2A_2Hm_2W_r^{s_1}\cos^2\theta_3}, \quad 0 \le \theta_3 \le \varphi_4, \tag{12}$$

$$r_4 = \frac{\cos(\varphi_2 + \xi - \nu_2)}{\cos(\theta_4 - \nu_1 + \xi)} R, \quad \varphi_4 \le \theta_4 \le \varphi_2, \tag{13}$$

where $A_2, m_2, s_2 -$ are the coefficients characterizing the properties of leather during deformation recovery, $B_2, u_2 -$ are the coefficients characterizing the properties of cloth during deformation recovery, $W_r -$ is the residual moisture of the skin, that is, skin moisture after squeezing, $\delta_2 -$ is the final thickness of the leather layer, $\nu_2 -$ is the angle of friction of the skin on the surface of the cloth during deformation recovery.

3 Results

Mathematical models of the roll contact curves of leather squeezing machines were developed. At that, the phenomenon of contact interaction of leather with working rolls was considered taking into account the phenomenon of water filtration during the squeezing process and the strain properties of leather and cloth. The study of the squeezing process based on these models made it possible to find with sufficient accuracy the appropriate parameters for roller squeezing of leather, necessary for the rational design and operation of squeezing machines.

4 Conclusions

Analysis of the obtained models showed that the contact curves of the rolls depend on the thickness, humidity and deformation properties of the leather, the radii of the rolls, the thickness and deformation properties of the cloth, as well as on the forces acting on their supports.

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