

Shapes of contact curves of squeezing rolls

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Abstract. Mathematical models of the shape of the contact curves of the squeezing rolls are obtained. Based on the analysis of the phenomenon of interaction and filtration of moisture in the squeezing module, calculation formulas are obtained for determining the ratio of the deformation rates of the contacting bodies. It is revealed that with an increase in the thickness of the material, the ratio of the deformation rates during compression increases. It is established that an increase in the thickness of the roll coating leads to an increase in the ratio of the deformation rates during compression.

1 Introduction

Squeezing pairs are the main working elements of most types of roller technological machines in various industries. They are used in the textile and light industry to remove moisture from various materials, in the pulp and paper industry – to dehydrate paper, etc.

The study of squeezing pairs is directly related to the removal of wastewater and therefore to the environmental safety of the enterprise. Therefore, when creating new and modernizing existing squeezing pairs of technological machines, along with improving the quality of products, it is necessary to pay increased attention to focusing on environmentally friendly production.

The squeezing pair (squeezing rolls) and the wet material to be processed in a two-roll machine form a squeezing module.

Squeezing modules differ from conventional roller modules in the presence of a certain moisture content in the material being processed and elastic coatings made of moisture-permeable material of the rollers of the squeezing rolls [1-3].

Under the action of the pressing force, the elastic coatings of the rolls and the processed material are deformed and form roll contact curves. At each point of the roll contact curves, contact and hydraulic pressures arise, resulting in contact interaction. Therefore, mathematical models of roll contact curves are of great importance in solving applied problems of pressing process parameters.

For the case of a squeezing module with a metal roller and a roller with an elastic coating, one of the contact curves will be part of a circle whose radius is equal to the radius of the metal roller. If both rollers have elastic coatings, then the roll contact curves will have different (complex) shapes, while in a particular case (with the same roll sizes, identical

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by analytical relationships “stress-relative strain”, obtained based on the results of experimental studies.

Under squeezing, moisture is removed from the processed material in the compression zone; therefore, in the compression zone, the moisture content of the processed material and the roller coating changes. A change in moisture content leads to a change in their strain. Based on this, we will characterize the deformation of contacting bodies by analytical dependencies “stress – relative deformation – relative humidity” [11]:

$$\sigma_{1c} = A_1 \varepsilon_{1c}^{a_1} W_{1c}^{c_1}, \quad \sigma_{1m} = B_1 \varepsilon_{1m}^{b_1} W_{1m}^{e_1}, \quad (1)$$

where $\sigma_{1c}, \varepsilon_{1c}$ – are the stress and relative strain of the roller coating under compression, A_1, a_1, c_1 – are the coefficients characterizing the deformation properties of the roller coating under compression, W_{1c} – is the relative moisture content of the roller coating in the compression zone, $\sigma_{1m}, \varepsilon_{1m}$ – are the stress and relative strain of the processed material under compression, B_1, b_1, e_1 – are the coefficients characterizing the deformation properties of the processed material under compression, W_{1m} – is the relative moisture content of the processed material in the compression zone.

In the recovery zone, the processed material may reabsorb some of the water extracted from the roller coatings; therefore, changes in moisture content in the roller coating and the processed material can occur in the recovery zone as well.

In [8] devoted to the study of roller squeezing of wet materials, the hypothesis “on the highest efficiency of roller squeezing” is often used, according to which the residual moisture of the pressing process is the moisture content of the processed material at the end of the compression zone. It is argued that this hypothesis can be realized by choosing the type of roller coatings.

We accept this hypothesis. Then, at the beginning of the recovery zone, the moisture content of the processed material is equal to the residual moisture W_{re} , and the moisture content of the roller coating is equal to $W_{inc} + W_{inn} - W_{re}$, where W_{inc}, W_{inn} – are the initial moisture contents of the roller coating and the processed material, respectively. By the accepted hypothesis, changes in moisture content in the processed material and roller coating in the recovery zone of the squeezing module do not occur. Therefore, the pattern of deformation of the processed material and the roller coating can take the following dependence:

$$\sigma_{2c} = A_2 \varepsilon_{2c}^{a_2} (W_{inc} + W_{inn} - W_{re})^{c_2}, \quad \sigma_{2m} = B_2 \varepsilon_{2m}^{b_2} W_{re}^{e_2}, \quad (2)$$

where $\sigma_{2c}, \varepsilon_{2c}$ – are the stresses and relative strain of the roller coating under recovery, A_2, a_2, c_2 – are the coefficients characterizing the deformation properties of the roller coating under recovery, $\sigma_{2m}, \varepsilon_{2m}$ – are the stresses and relative strain of the processed material under recovery, B_2, b_2, e_2 – are the coefficients characterizing the deformation properties of the processed material under recovery.

3 Results and discussion

According to [1], the mathematical model of the roll contact curves does not depend on the direction of deformation of the contacting bodies. Therefore, we consider the deformation of the contacting bodies in the radial direction to the roll axis. Then their thicknesses at the points of the compression zone are written as shown in Figure 1 and (3):

$$h_{1c} = R - r, \quad h_{1m} = r - R \frac{\cos \varphi_1}{\cos \theta}, \quad -\varphi_1 \leq \theta \leq 0, \quad (3)$$

where r, θ – are the polar coordinates of point M , φ_1 – is the nip angle.

We consider

$$\frac{dh_{1c}}{dt} = k_1 = \text{const.} \quad (4)$$

Hence

$$h_{1c} = k_1 h_{1m} + C$$

or with the boundary conditions $h_{1c} = 0$ and $h_{1m} = 0$, for $\theta = -\varphi_1$

$$h_{1c} = k_1 h_{1m}. \quad (5)$$

After substituting the expression and from equality (3) into equality (5), we obtain

$$r = \frac{R}{1+k_1} \left(1 + k_1 \frac{\cos \varphi_1}{\cos \theta} \right), \quad -\varphi_1 \leq \theta \leq 0. \quad (6)$$

By analogy with (4), we find the equation for the output part of the roll contact curve:

$$r = \frac{R}{1+k_2} \left(1 + k_2 \frac{\cos \varphi_2}{\cos \theta} \right), \quad 0 \leq \theta \leq \varphi_2, \quad (7)$$

where φ_2 – the angle defining the end point of the contact zone, k_2 - is the ratio of the rates of deformation during recovery.

From the generalization of (6) and (7) it follows:

$$r(\theta) = \begin{cases} \frac{R}{1+n_1} \left(1 + k_1 \frac{\cos \varphi_1}{\cos \theta} \right), & -\varphi_1 \leq \theta \leq 0, \\ \frac{R}{1+n_2} \left(1 + k_2 \frac{\cos \varphi_2}{\cos \theta} \right), & 0 \leq \theta \leq \varphi_2. \end{cases} \quad (8)$$

System of equations (8) is a mathematical model of the shape of the roll contact curves of a symmetrical squeezing module.

To match the curves in the compression and recovery zones (system (8)), the following conditions must be observed:

$$\frac{R}{1+k_1} (1 + k_1 \cos \varphi_1) = \frac{R}{1+k_2} (1 + k_2 \cos \varphi_2).$$

Hence, we find the relationship between the values of k_1 and k_2 :

$$k_1 = \frac{k_2 \varphi_2^2}{\varphi_1^2 + k_2 (\varphi_1^2 - \varphi_2^2)}. \quad (9)$$

Values of k_1 and k_2 depend primarily on the deformation properties of the roller coating and the material to be processed.

Deformation properties of the roller coating and the processed material are characterized by relative strains ε_{1c} and ε_{1m} .

Let us determine the rates of relative strains of the roller coating and the processed material under compression:

$$\frac{d\varepsilon_{1c}}{dt} = \frac{1}{H} \frac{dh_{1c}}{dt}, \quad \frac{d\varepsilon_{1m}}{dt} = \frac{2 \cos \varphi_1}{\delta_1} \frac{dh_{1m}}{dt}. \quad (10)$$

Let us introduce the following notation:

$$m_1 = \frac{\frac{d\varepsilon_{1c}}{dt}}{\frac{d\varepsilon_{1m}}{dt}}. \quad (11)$$

From equality (11), considering expressions (4) and (10), we obtain

$$m_1 = \frac{\delta_1}{2H \cos \varphi_1} k_1$$

or

$$m_1 = \frac{\delta_1}{H(2 - \varphi_1^2)} k_1. \quad (12)$$

Similar to (12), we obtain:

$$m_2 = \frac{\delta_2}{H(2 - \varphi_2^2)} k_2, \quad (13)$$

where δ_2 – is the thickness of the processed material at the end of the contact zone.

According to Newton's law, from equality (2) for the recovery zone we obtain

$$A_2 \varepsilon_{2c}^{a_2} (W_{inc} + W_{inm} - W_{re})^{c_2} = B_2 \varepsilon_{2m}^{b_2} W_{re}^{e_2}$$

or

$$A_2 \varepsilon_{2c}^{a_2} = W_2 B_2 \varepsilon_{2m}^{b_2}, \quad (14)$$

where $W_2 = \frac{W_{re}^{e_2}}{(W_{inc} + W_{inm} - W_{re})^{c_2}}$ – is the constant value.

Differentiating (14), we obtain:

$$A_2 a_2 \varepsilon_{2c}^{a_2-1} \frac{d\varepsilon_{2c}}{dt} = W_2 B_2 b_2 \varepsilon_{2m}^{b_2-1} \frac{d\varepsilon_{2m}}{dt}, \quad (15)$$

From equality (13), it follows that $m_2 = const$, since $k_2 = const$.

For $m_2 = const$, the following equality holds:

$$m_2 = \frac{\frac{d\varepsilon_{2c}}{dt}}{\frac{d\varepsilon_{2m}}{dt}} = \frac{\varepsilon_{2c}}{\varepsilon_{2m}}. \quad (16)$$

From equalities (15) considering equalities (14) and (16), it follows that $a_2 = b_2$.

With this in mind, from equality (14) and (16), we obtain:

$$m_2 = a_2 \sqrt{\frac{W_2 B_2}{A_2}}. \quad (17)$$

Then from equality (13), we obtain:

$$k_2 = \frac{H^{a_2} \sqrt{W_2 B_2} (2 - \varphi_2^2)}{\delta_2^{a_2} \sqrt{A_2}}. \quad (18)$$

The value of k_1 is determined from equality (9):

$$k_1 = \frac{2H^{a_2} \sqrt{W_2 B_2} \varphi_2^2}{\delta_2^{a_2} \sqrt{A_2} \varphi_1^2 + 2H^{a_2} \sqrt{W_2 B_2} (\varphi_1^2 - \varphi_2^2)}. \quad (19)$$

From Figure 1, it follows that

$$R \cos \varphi_1 + \frac{\delta_1}{2} = R + \frac{\delta_0}{2}, \quad R \cos \varphi_2 + \frac{\delta_2}{2} = R + \frac{\delta_0}{2},$$

where δ_0 – is the distance between the rollers. Hence

$$\varphi_1 = \sqrt{\frac{\delta_1 - \delta_0}{R}}, \quad \varphi_2 = \sqrt{\frac{\delta_2 - \delta_0}{R}}. \quad (20)$$

Considering expression (20) from equality (18) and (19), we obtain:

$$k_1 = \frac{2H^{a_2} \sqrt{W_2 B_2} (\delta_2 - \delta_0)}{\delta_2^{a_2} \sqrt{A_2} (\delta_1 - \delta_0) + 2H^{a_2} \sqrt{W_2 B_2} (\delta_1 - \delta_2)}, \quad (21)$$

$$k_2 = \frac{H^{a_2} \sqrt{W_2 B_2} (2R + \delta_0 - \delta_2)}{R \delta_2^{a_2} \sqrt{A_2}}. \quad (22)$$

Figure 2 shows the dependence of the ratio of the strain rate of the roller coating to the strain rate of the processed material under compression on the thickness of the contacting bodies.

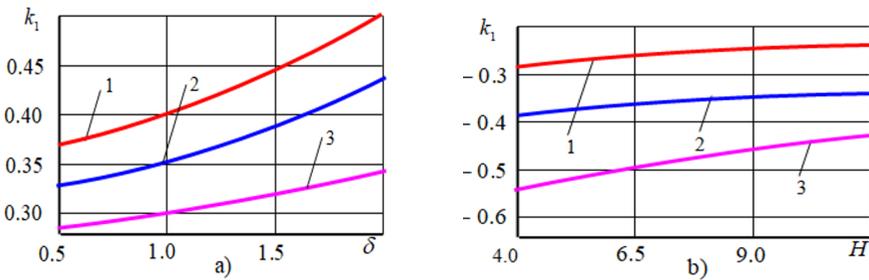


Fig. 2. Dependence of the ratio of the deformation rates of contacting bodies during compression: a) on the thickness of the processed material at different coating thicknesses: 1 – $H = 5\text{mm}$, 2 – 10mm , 3 – 15mm .; b) on the thickness of the roll coating at different material thicknesses: 1- $\delta = 8\text{mm}$, 2- $\delta = 5\text{mm}$, 3- $\delta = 3\text{mm}$.

4 Conclusion

Mathematical models of the shape of the contact curves of the squeezing rolls are obtained.

Based on the analysis of the phenomenon of interaction and filtration of moisture in the squeezing module, calculation formulas are obtained for determining the ratio of the rates of deformation of the contacting bodies.

It is revealed that the ratios of the rates of deformation of the contacting bodies depend on the deformation and geometric parameters, initial and residual moisture of the contacting bodies.

Based on the calculated data according to formulas (21) and (22) and the graphs shown in Figure 2, it is revealed:

- with an increase in the thickness of the material, the ratio of the rates of deformation under compression increases;
- an increase in the thickness of the roll coating leads to an increase in the ratio of the rates of deformation under compression.

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