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Parameters of contact lines of rolls

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Abstract. The article defines the parameters of the contact lines of the rolls. Calculation formulas are found for determining such parameters as the ratio of strain rates in roll pairs when the deformation of the semi-finished leather product and the coating of are given by rheological models. It was revealed that the forms of contact lines in roll pairs do not depend on the methods of specifying the deformation of the leather material and the coating of the rolls.

1. Introduction

One of the main tasks of the theory of contact interaction in roll pairs is the modeling of contact lines of rolls. The shape of these lines primarily depends on the deformation properties of the leather material and the coating of the rolls.

In [1-14], the main problems of contact interaction in roll pairs were solved, including the modeling of contact lines of rolls. In these works, for the deformation properties of the leather material and the coating of the rolls, empirical dependences of the power-law type were used. However, these dependences have a number of disadvantages [15, 16]. In addition, as the analysis of studies [17-20] showed, the deformation of most materials processed in roller machines, and materials used as a coating of rolls of these machines, are characterized by rheological models.

In this regard, this work is devoted to modeling the contact lines of rolls, when the deformation of the leather material and the coating of the rolls are given by rheological models.

2. Analytical solutions of the problems posed

Let the deformation properties of the leather material and the coating of the lower roll be given by rheological models

$$\sigma_{11} = E_{11}\varepsilon_{11} + \mu_{11}\frac{d\varepsilon_{11}}{dt}, \quad \sigma_{11}^* = E_1\varepsilon_{11}^* + \mu_1\frac{d\varepsilon_{11}^*}{dt}, \quad (1)$$

where $\sigma_{11}, \varepsilon_{11}, E_{11}, \mu_{11}, \sigma_{11}^*, \varepsilon_{11}^*, E_1, \mu_1$ – deformation characteristics of the coating of the lower roll and the leather material during compression.



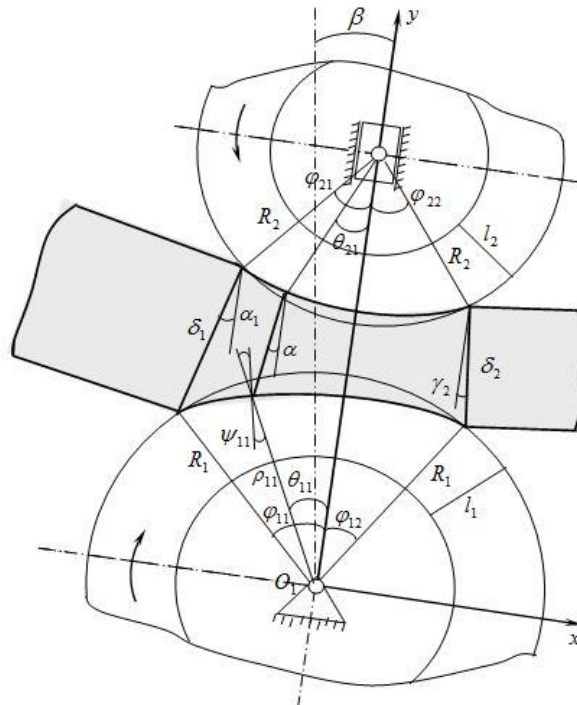


Figure 1. The scheme of interaction of the leather material and the coating of the rolls.

As in the wheel theory [21, 22], we assume that

$$\frac{\varepsilon_{11}}{\varepsilon_{11}^*} = \frac{d\varepsilon_{11}}{d\varepsilon_{11}^*} = A_{11}. \tag{2}$$

where A_{11} – the ratio of the deformation rates of the coating of the lower roll and the leathers material during compression.

We find relative deformations (Fig. 1)

$$\varepsilon_{11} = \frac{R_1 - \rho_{11}}{l_1}, \quad \varepsilon_{11}^* = \frac{\rho_{11} - R_1 \frac{\cos(\varphi_{11} + \alpha_1)}{\cos(\theta_{11} + \alpha)}}{B_{11}^0}, \tag{3}$$

where $B_{11}^0 = \delta_1 \frac{\sin(\varphi_{21} - \alpha_1)}{\sin(\varphi_{11} + \varphi_{21})}$, l_1 – is the thickness of the elastic coating of the lower roll.

After substituting the expression ε_{11} and ε_{11}^* from equality (3) to equality (2), after transformations, we find

$$\rho_{11} = \frac{R_1}{1 + C_{11}A_{11}} \left(1 + C_{11}A_{11} \frac{\cos(\varphi_{11} + \alpha_1)}{\cos(\theta_{11} + \alpha)} \right), \quad -(\varphi_{11} + \alpha_1) \leq \theta_{11} + \alpha \leq 0, \tag{4}$$

where $C_{11} = \frac{l_1 \sin(\varphi_{11} + \varphi_{21})}{\delta_1 \sin(\varphi_{21} - \alpha_1)}$.

We define ρ_{12} , ρ_{21} and ρ_{22} in the same way ρ_{11} .

Then we have

$$\begin{cases} \rho_{11} = \frac{R_1}{1 + C_{11}A_{11}} \left(1 + C_{11}A_{11} \frac{\cos(\varphi_{11} + \alpha_1)}{\cos(\theta_{11} + \alpha)} \right), & -(\varphi_{11} + \alpha_1) \leq \theta_{11} + \alpha \leq 0, \\ \rho_{12} = \frac{R_1}{1 + C_{12}A_{12}} \left(1 + C_{12}A_{12} \frac{\cos(\varphi_{12} + \alpha_2)}{\cos(\theta_{12} + \alpha)} \right), & 0 \leq \theta_{12} + \alpha \leq \varphi_{12} + \alpha_2, \end{cases} \quad (5)$$

$$\begin{cases} \rho_{21} = \frac{R_2}{1 + C_{21}A_{21}} \left(1 + C_{21}A_{21} \frac{\cos(\varphi_{21} - \alpha_1)}{\cos(\theta_{21} - \alpha)} \right), & -(\varphi_{21} - \alpha_1) \leq \theta_{21} - \alpha \leq 0, \\ \rho_{22} = \frac{R_2}{1 + C_{22}A_{22}} \left(1 + C_{22}A_{22} \frac{\cos(\varphi_{22} - \alpha_2)}{\cos(\theta_{22} - \alpha)} \right), & 0 \leq \theta_{22} - \alpha \leq \varphi_{22} - \alpha_2, \end{cases} \quad (6)$$

where $C_{12} = \frac{l_1 \sin(\varphi_{12} + \varphi_{22})}{\delta_2 \sin(\varphi_{22}\alpha_2)}$, A_{12} – the ratio of the deformation rates of the elastic coating of the

lower roll and the leathers material during recovery; $C_{21} = \frac{l_2 \sin(\varphi_{11} + \varphi_{21})}{\delta_1 \sin(\varphi_{11} + \alpha_1)}$, $C_{22} = \frac{l_2 \sin(\varphi_{12} + \varphi_{22})}{\delta_2 \sin(\varphi_{12} + \alpha_2)}$,

l_2 – is the thickness of the elastic coating of the upper roll, A_{21}, A_{22} – the ratio of the strain rates of the elastic coating of the upper roll and the material being leathers during compression and recovery.

The systems of equations (5) and (6) describe the forms of the contact lines of the rolls of a roll pair when the deformations of the leather material and the coating of the rolls are given by rheological models.

For the compression zone of the coating of the lower roll, we have:

$$\Delta r_{11} + \Delta h_{11} = \Delta l_{11}, \quad (7)$$

$$E_{11}\varepsilon_{11} + \mu_{11} \frac{d\varepsilon_{11}}{dt} = E_1 \varepsilon_{11}^* + \mu_1 \frac{d\varepsilon_{11}^*}{dt}, \quad (8)$$

where $\varepsilon_{11} = \frac{\Delta r_{11}}{l_1}$, $\varepsilon_{11}^* = \frac{\Delta h_{11}}{B_{11}^0}$, $\frac{d\varepsilon_{11}}{dt} = \frac{1}{l_1} \frac{dr_{11}}{dt}$, $\frac{d\varepsilon_{11}^*}{dt} = \frac{1}{B_{11}^0} \frac{dh_{11}}{dt}$.

From equation (7), with expressions (3) and (7), we determine

$$\Delta l_{11} = R_1 \cdot \left(1 - \frac{\cos(\varphi_{11} + \alpha_1)}{\cos(\theta_{11} + \alpha)} \right). \quad (9)$$

Taking into account equation (3), from (8), with equations (9), we obtain

$$A_{11} = \frac{E_1 \Delta l_{11} + \mu_1 \frac{dl_{11}}{dt}}{E_{11} \Delta l_{11} + \mu_{11} \frac{dl_{11}}{dt}}, \quad (10)$$

where Δl_{11} and $\frac{dl_{11}}{dt}$ are determined by equation (9).

Calculation of A_{11} by formula (10) can simplify expressions Δl_{11} and $\frac{dl_{11}}{dt}$ by replacing the mean value:

$$(\Delta l_{11})_{av} = \frac{1}{\varphi_{11} + \alpha_1} \int_{-(\varphi_{11} + \alpha_1)}^0 R_1 \cdot \left(1 - \frac{\cos(\varphi_{11} + \alpha_1)}{\cos(\theta_{11} + \alpha)} \right) d(\theta_{11} + \alpha),$$

$$\left(\frac{dl_{11}}{dt} \right)_{av} = \frac{R_1 \omega_1}{\varphi_{11} + \alpha_1} \cdot \int_{-(\varphi_{11} + \alpha_1)}^0 \left(- \frac{\cos(\varphi_{11} + \alpha_1) \sin(\theta_{11} + \alpha)}{\cos^2(\theta_{11} + \alpha)} \right) d(\theta_{11} + \alpha)$$

or after integration

$$(\Delta l_{11})_{av} = R_1 \cdot \left(1 - \frac{\cos(\varphi_{11} + \alpha_1)}{2(\varphi_{11} + \alpha_1)} \ln \left| \frac{1 + \sin(\varphi_{11} + \alpha_1)}{1 - \sin(\varphi_{11} + \alpha_1)} \right| \right),$$

$$\left(\frac{dl_{11}}{dt} \right)_{av} = \frac{R_1 \omega_1}{\varphi_{11} + \alpha_1} (1 - \cos(\varphi_{11} + \alpha_1)).$$

Expanding the logarithmic function into a series, we have

$$(\Delta l_{11})_{av} = R_1 \cdot \left(1 - \frac{\sin 2(\varphi_{11} + \alpha_1)}{2(\varphi_{11} + \alpha_1)} \right), \quad \left(\frac{dl_{11}}{dt} \right)_{av} = \frac{2R_1 \omega_1}{\varphi_{11} + \alpha_1} \sin^2 \left(\frac{\varphi_{11} + \alpha_1}{2} \right).$$

Thus, we have

$$A_{11} = \frac{E_1 (\Delta l_{11})_{av} + \mu_1 \left(\frac{dl_{11}}{dt} \right)_{av}}{E_{11} (\Delta l_{11})_{av} + \mu_1 \left(\frac{dl_{11}}{dt} \right)_{av}}, \tag{11}$$

where $(\Delta l_{11})_{av} = R_1 \cdot \left(1 - \frac{\sin 2(\varphi_{11} + \alpha_1)}{2(\varphi_{11} + \alpha_1)} \right), \quad \left(\frac{dl_{11}}{dt} \right)_{av} = \frac{2R_1 \omega_1}{\varphi_{11} + \alpha_1} \sin^2 \left(\frac{\varphi_{11} + \alpha_1}{2} \right).$

Likewise:

$$A_{12} = \frac{E_2 (\Delta l_{12})_{av} + \mu_2 \left(\frac{dl_{12}}{dt} \right)_{av}}{E_{12} (\Delta l_{12})_{av} + \mu_2 \left(\frac{dl_{12}}{dt} \right)_{av}}, \tag{12}$$

where $(\Delta l_{12})_{av} = R_1 \cdot \left(1 - \frac{\sin 2(\varphi_{12} + \alpha_2)}{2(\varphi_{12} + \alpha_2)} \right), \quad \left(\frac{dl_{12}}{dt} \right)_{av} = \frac{2R_1 \omega_1}{\varphi_{12} + \alpha_2} \sin^2 \left(\frac{\varphi_{12} + \alpha_2}{2} \right);$

$$A_{21} = \frac{E_1 (\Delta l_{21})_{av} + \mu_1 \left(\frac{dl_{21}}{dt} \right)_{av}}{E_{21} (\Delta l_{21})_{av} + \mu_{21} \left(\frac{dl_{21}}{dt} \right)_{av}}, \tag{13}$$

where $(\Delta l_{21})_{av} = R_2 \cdot \left(1 - \frac{\sin 2(\varphi_{21} - \alpha_1)}{2(\varphi_{21} - \alpha_1)} \right)$, $\left(\frac{dl_{11}}{dt} \right)_{av} = \frac{2R_2 \omega_2}{\varphi_{21} - \alpha_1} \sin^2 \left(\frac{\varphi_{21} + \alpha_1}{2} \right)$.

$$\lambda_{22} = \frac{E_2 (\Delta l_{22})_{av} + \mu_2 \left(\frac{dl_{22}}{dt} \right)_{av}}{E_{22} (\Delta l_{22})_{av} + \mu_{22} \left(\frac{dl_{22}}{dt} \right)_{av}}, \tag{14}$$

where $(\Delta l_{21})_{av} = R_2 \cdot \left(1 - \frac{\sin 2(\varphi_{22} - \alpha_2)}{2(\varphi_{22} - \alpha_2)} \right)$, $\left(\frac{dl_{11}}{dt} \right)_{av} = \frac{2R_2 \omega_2}{\varphi_{22} - \alpha_2} \sin^2 \left(\frac{\varphi_{22} + \alpha_2}{2} \right)$.

Figure 2 shows graphs of the contact lines of the rolls with various changing parameters.

3. Results

Calculation formulas are found for determining such parameters as the ratio of strain rates in roll pairs, when the deformation of the leather material and the coating of the rolls are given by rheological models.

It was revealed that the forms of contact lines in roll pairs do not depend on the methods of specifying the deformation of the leather material and the coating of the rolls.

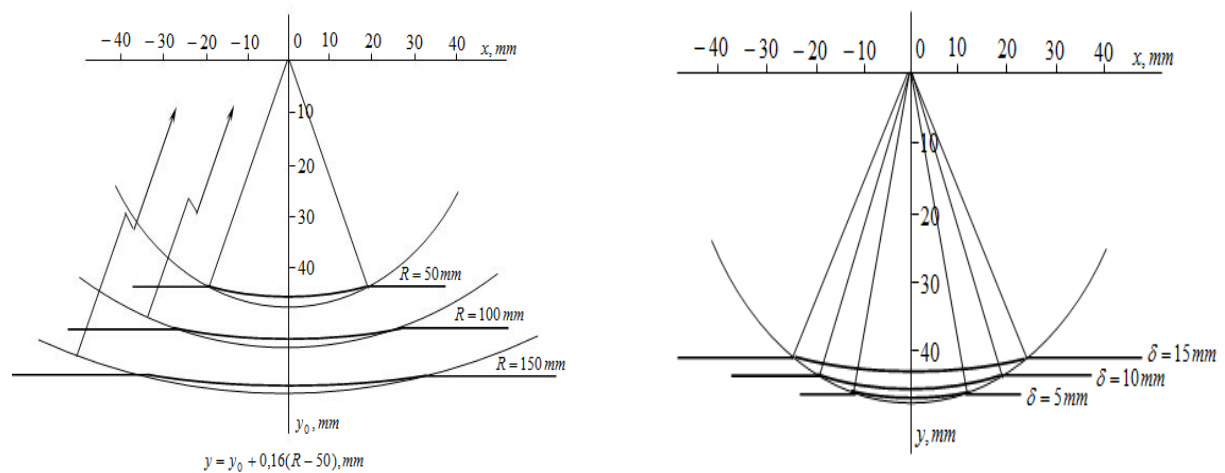


Figure 2. The nature of the influence of the roll radii and the initial thickness of the leather material on the shape of the contact line of the roll.

4. Conclusions

Analysis of calculation of λ_{ij} using formulas (11) - (14) showed that:

- λ_{ij} increases linearly with E_j and μ_j ;
- λ_{ij} decreases asymptotically to zero with an increase in E_{ij} and μ_{ij} ;
- the change in λ_{ij} from the angular velocity of the rolls depends on the relationships $\alpha = \frac{E_j}{E_{ij}}$ and

$\beta = \frac{\mu_j}{\mu_{ij}}$: for $\alpha > 1$ and $\beta > 1$, λ_{ij} decreases asymptotically to zero with an increase in ω_i ; for $\alpha < 1$

and $\beta < 1$, λ_{ij} increases asymptotically to a certain value with an increase in ω_i .

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