AIP Conference Proceedings

RESEARCH ARTICLE | JANUARY 12 2024

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AIP Conf. Proc. 2969, 060036 (2024)
https://doi.org/10.1063/5.0182655

Contact Angles with a Free Upper Roll of Roll Machines

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Abstract. In the work the expressions of the contact angles of the roller machine with the upper free roller are found. These formulas determine the contact angles for all cases of material interaction with rolls of technological machines. It has been established that the maximum thickness of the material layer that can be captured by the rolls of a two-roll module is almost four times less with a free upper roll than with a drive roll.

INTRODUCTION

The problems of improving existing and developing new technological processes for the mechanical processing of materials are closely related to the phenomena of contact interaction between a layer of material and pairs of rolls.

In works [1-12], the contact problems of roll technological machines are solved. It follows from these works that contact problems are primarily determined by contact angles [13].

Despite numerous works [14–17] devoted to determining the contact angles of roller machines, there are currently no generally accepted models of contact angles in asymmetric roller pairs.

The contact angles of roller machines depend on the type and location of the guiding movable roll, which can be designed mainly according to two schemes [18]:

1. The sliding roll is guided by a slider that moves with roll along the guide relative to the bed;
2. The guide of the movable roll is a lever that connects the axis of the movable roll with bed.

In works [19, 20], contact angles were determined in roller machines, where the slider of the movable roll moves along a vertical line.

The paper deals with the definition and evaluation of contact angles, where the slider of the movable roll moves along the line of centers.

ANALYTICAL SOLUTIONS OF THE PROBLEMS POSED

We consider the windrow pair shown in Fig. 1 etween the rollers is h_1

According to [20], the angles of capture and their sum for the considered roll pair have the form:

$$\phi_{11} = \sqrt{\frac{2R_2(\delta_1-h_1)}{R_1(R_1+R_2)}} + \frac{\delta_1\gamma_1}{R_1+R_2}, \tag{1}$$

$$\phi_{21} = \sqrt{\frac{2R_1(\delta_1-h_1)}{R_2(R_1+R_2)}} - \frac{\delta_1\gamma_1}{R_1+R_2}, \tag{2}$$

Proceedings of the III International Conference on Advances in Science, Engineering, and Digital Education
AIP Conf. Proc. 2969, 060036-1–060036-5; https://doi.org/10.1063/5.0182655
Published by AIP Publishing. 978-0-7354-4795-0/$30.00

$$\phi_{11} + \phi_{21} = \sqrt{\frac{2(R_1+R_2)(\delta_1-h_1)}{R_1 R_2}}. \tag{3}$$

Let the considered two-roll module have one (upper) free roll.

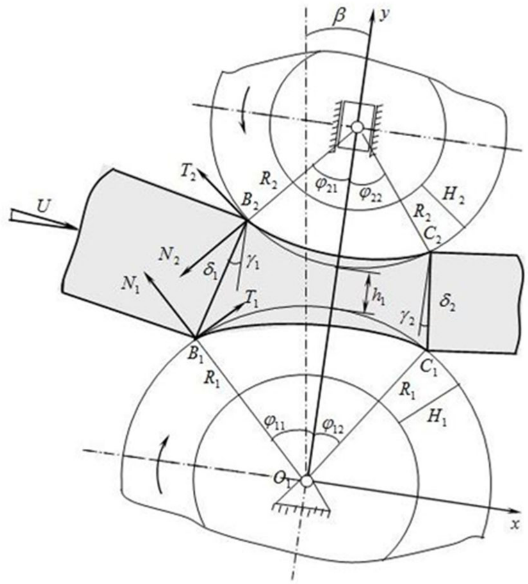

FIGURE 1. Scheme of interaction of two-roll module with one driven roller.

Let us compose the force balance equations for the layer of material at the contact with the rollers in the steady-state process according to Fig. 1:

$$\begin{cases} \sum X = -N_{1x} - N_{2x} + T_{1x} - T_{2x} = 0, \\ \sum Y = \quad N_{1y} - N_{2y} + T_{1y} + T_{2y} = 0. \end{cases} \tag{4}$$

From the diagram of forces in Fig. 1, we find

$$N_{1x} = N_1 \sin\phi_{11}, T_{1x} = T_1 \cos\phi_{11}, \; N_{1y} = N_1 \cos\phi_{11}, \;\; T_{1y} = T_1 \sin\phi_{11},$$

$$N_{2x} = N_2 \sin\alpha_{21}, \;\; T_{2x} = T_2 \cos\alpha_{21}, \; N_{2y} = N_2 \cos\alpha_{21}, \;\; T_{2y} = T_2 \sin\alpha_{21}. \tag{5}$$

Taking these expressions into account, system (4) has the form

$$\begin{cases} N_1 \sin\phi_{11} - T_1 \cos\phi_{11} = -(N_2 \sin\phi_{21} + T_2 \cos\phi_{21}), \\ N_1 \cos\phi_{11} + T_1 \sin\phi_{11} = \quad N_2 \cos\phi_{21} - T_2 \sin\phi_{21}. \end{cases} \tag{6}$$

The value of the friction force T_2 can be determined from equation [20]:

$$M_ш = T_ш r_ш = N_2 f_ш r_ш = T_2 R_2,$$

where $M_ш$ -is the moment created by friction forces in the necks of a free roller; $T_ш$-is the resultant force of friction in the necks; $r_ш$-is the neck radius of the free roller; $f_ш$-is the coefficient of friction in the necks.

We determine $T_2 = N_2 f_ш \frac{r_ш}{R_2}$. After substituting the values of T_2 and $T_1 = f_1 N_1$ into system (6) and jointly solving this equation, we obtain:

$$tg(\phi_{11} + \phi_{21}) = \frac{f_1 - f_ш \frac{r_ш}{R_2}}{1 + f_1 f_ш \frac{r_ш}{R_2}}.$$

We assume that $\frac{r_ш}{R_2} f_ш = \frac{r_ш}{R_2} tg\nu_ш = tg\left(\nu_ш \frac{r_ш}{R_2}\right)$, where $\nu_ш$-is the angle of friction in the necks.

Then we write:

$$\frac{f_1 - f_ш \frac{r_ш}{R_2}}{1 + f_1 f_ш \frac{r_ш}{R_2}} == \frac{tg\nu_1 - tg\left(\nu_ш \frac{r_ш}{R_2}\right)}{1 + tg\nu_1 tg\left(\nu_ш \frac{r_ш}{R_2}\right)} = tg\left(\nu_1 - \nu_ш \frac{r_ш}{R_2}\right),$$

where ν_{11}-is the friction angle of the lower drive roll along the material layer.

So,

$$\phi_{11} + \phi_{21} = \nu_1 - \nu_ш \frac{r_ш}{R_2}. \quad (7)$$

Taking into account equality (7) of the equalities (1), (2) and (3), we have

$$\phi_{11} = \frac{1}{R_1+R_2}\left(R_2\left(\nu_{11} - \nu_ш \frac{r_ш}{R_2}\right) + \delta_1\gamma_1\right), \quad \phi_{21} = \frac{1}{R_1+R_2}\left(R_1\left(\nu_{11} - \nu_ш \frac{r_ш}{R_2}\right) - \delta_1\gamma_1\right), \quad (8)$$

Likewise, we have

$$\phi_{12} = \frac{1}{R_1+R_2}\left(R_2\left(\nu_{12} - \nu_ш \frac{r_ш}{R_2}\right) + m_1\delta_1\gamma_1\right), \quad \phi_{22} = \frac{1}{R_1+R_2}\left(R_1\left(\nu_{12} - \nu_ш \frac{r_ш}{R_2}\right) - m_1\delta_1\gamma_1\right). \quad (9)$$

At the moment of initial contact of the material, the free roll does not exert a retracting effect on the material, but to some extent counteracts the retraction of the material due to the resistance to rotation in its supports.

Let us formulate the free capture condition in the form

$$\boldsymbol{N_{1x}} + \boldsymbol{N_{2x}} + \boldsymbol{T_{2x}} \le \boldsymbol{T_{1x}}. \quad (10)$$

Solving inequalities (10) together with the second equation of system (6), we find the condition of gripping in a steady process of a two-roll module with one driven roller

$$\phi_{11} + \phi_{21} \le \nu_{11} - \nu_ш \frac{r_ш}{R_2}. \quad (11)$$

Based on dependencies (8) and (9), we find expressions for evaluating the angles of contact in the steady-state process of a two-roll module with one driven roller:

$$\phi_{11} \le \frac{1}{R_1+R_2}\left(R_2\left(\nu_{11} - \nu_ш \frac{r_ш}{R_2}\right) + \delta_1\gamma_1\right), \quad \phi_{21} \le \frac{1}{R_1+R_2}\left(R_1\left(\nu_{11} - \nu_ш \frac{r_ш}{R_2}\right) - \delta_1\gamma_1\right). \quad (12)$$

Since in most cases, in two-roll modules, the rolls are installed in rolling bearings, where the amount of friction is small. As a result, the friction force T_2 can be ignored in comparison with other forces acting on the roller [20].

Then the gripping condition is

$$\phi_{11} + \phi_{21} \le \nu_{11}. \quad (13)$$

Thus, if we assume that there is no resistance to rotation in the necks of a free roller, then the sum of the maximum nip angles in two-roll modules with one driven roller is two times less than with two driven rollers.

Let us compare the maximum thickness of the layer that can be gripped by the rollers of a two-roll module in the presence of a driven and free upper roller. We assume that the rollers of the two-roll module at the moment of gripping are located without a gap, that is $h_1 = 0$.

From equality (3) for $h_1 = 0$ and $\nu_{21} = 0$, we have

$$\sqrt{2(\delta_1 - h_1)} = \sqrt{\frac{R_1 R_2}{R_1 + R_2}}\nu_{11}.$$

It follows from here

$$\delta^c \frac{R_1 R_2}{2(R_1 + R_2)}{}^2_{11_{1max}}$$

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Such a dependence for a two-roll module with two drive rolls has the form [20]:

$$\delta^{n}{}_{1\max} = \frac{R_1 R_2}{2(R_1 + R_2)}(v_{11} + v_{21})^2.$$

Determine the relation

$$\frac{\delta^{n}{}_{1max}}{\delta^{c}{}_{1\max}\frac{(v_{11} + v_{21})^2}{v_{11}^2}}$$

Hence, for $v_{11} = v_{21}$, we have:

$$\frac{\delta^{n}{}_{1max}}{\delta^{c}{}_{1\max}}$$

Thus, the maximum thickness of a layer of material that can be gripped by the rollers of the two-roll module is almost four times less with a free upper roller than with a driven roller.

When the coefficient of friction in the necks of the free roller is zero for the free roller to rotate with a layer of material, the line, which is a continuation of the front end of the layer of material must pass through the axis of rotation of the free roller. For gripping at such an arrangement of the layer and the absence of friction in the necks, no additional external pushing forces are required [20].

Let the line, which is a continuation of the front end of the layer of material, pass through the axis of rotation of the free roller. In this case, the angle of inclination of the layer of material to the O_1x axis is critical $\gamma_{\text{кр}}$.

Let the line, which is a continuation of the front end of the material, pass through the axis of rotation of the free roll. In this case, the angle of inclination of the material to the O_1x axis is equal to the critical one $\gamma_{\text{кр}}$.

The critical angle of inclination of the material in the considered roll pair has an angle $\gamma_{\text{кр y}} = \phi_{21}$, i.e.

$$\gamma_{\text{кру}} = \sqrt{\frac{2R_1(\delta_1 - h_1)}{R_2(R_1 + R_2)}} - \frac{\delta_1 \gamma_1}{R_1 + R_2}. \tag{14}$$

In the critical inclination of the layer of material, the nip angle of the lower roller in a steady-state process has the following form:

$$\phi_{11\kappa p} = \frac{\delta_1 + R_2}{\delta_1 + R_1 + R_2}\sqrt{\frac{2(\delta_1 - h_1)(R_1 + R_2)}{R_1 R_2}}. \tag{15}$$

Analysis of the graphs obtained on the basis of calculations of the critical angle of inclination according to formula (14), indicates that:

- with a decrease in the radius of the lower roll and the initial thickness of the material, the critical angle of inclination decreases;
- the critical angle of inclination decreases with increasing radius of the upper roll;
- the greater R_2 and the less R_1, the greater $\gamma_{1\kappa p}$.

In the presence of friction in the necks of the free roll or with an arbitrary inclination of the material relative to the O_1x axis, the conditions for rotation of the material of the free upper roll will not be fulfilled, and therefore, an external pushing force is necessarily required for the capture.

CONCLUSION

Thus, the angles of contact in the steady-state process of a two-roll module with one driven roller were obtained, which were determined by formulas (8) and (9). They are evaluated by conditions (12). These formulas are general since they determine the contact angles of all particular cases of material interaction with pairs of rolls in roll machines with one free roll.

The paper defines contact angles and conditions for their evaluation in a generalized roll pair, which takes into account all kinds of asymmetries in the interaction of the material with the rolls of technological machines.

It has been established that the maximum thickness of the material layer that can be captured by the rolls of a two-roll module is almost four times less with a free upper roll than with a drive roll.

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