Study on the conditions of material capture by pairs of rolls of squeezing machines

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Abstract. This paper is devoted to the analysis of the condition for material capture with pairs of rolls of squeezing machines. Calculation formulas for the parameters of roll pairs of squeezing machines are given, such as: contact angles, minimum distance between the rolls, the thickness of the processed material after squeezing. It has been established that the capture of material in the roll pairs of squeezing machines is determined by the center distance between the rolls, the thickness of the processed material and the coefficients of friction of the rolls on the processed material. It was determined that the displacement of the upper roll relative to the lower roll does not affect the values the nip angles.

1. Introduction

One of the most economical and versatile types of machines used in many industries, including construction, when performing various technological processes, are roller machines.

Compliance of roller machines with certain technological requirements involves the use of various designs of both working bodies (pairs of rolls) and auxiliary mechanisms.

A special group in the technology of mechanical processing of materials in roller machines is the process of roller squeezing of wet materials.

Based on the analysis of the design of roller wringers of the textile, light and pulp and paper industries [1-3] and the features of the roll wringing of wet materials, we select the scheme of the studied roll pair of squeezing machines. (Fig. 1), in which the upper roll is mixed relative to the lower roll towards the movement of the processed material to a distance Δ , which is determined by the angle β . Rolls with different diameters are coated with materials with different stiffnesses. The upper roll is free, and the lower one is driven. The layer of material is fed in such a way that the line, which is a continuation of its front end, passes through the axis of rotation of the upper roll since no additional external forces are required to conduct the gripping [4].

In mathematical modeling of the squeezing process, it is required to solve the problems of contact interaction and moisture filtration.

In works [5-19], the problems of contact interaction and moisture filtration during the pressing process were solved.

The boundary conditions of these problems are determined by the condition of material capture by pairs of rolls [20].

The conditions for capturing the material by pairs of rolls, in turn, depend on the deformation properties of the processed material [19, 20].

There are quite a lot of works devoted to the analysis of the conditions of capture in symmetric [21] and asymmetric [22-27] roll pairs of squeezing machines.

For further development of theoretical concepts, let us analyze the conditions for the capture of material in the investigated roll pair of squeezing machines.

2. Resultative Methods

Let the material layer touch the rolls in section A_1A_2 (Fig. 1). We derive a formula for determining the nip angles of the lower roll α_1 and the upper roll α_2.

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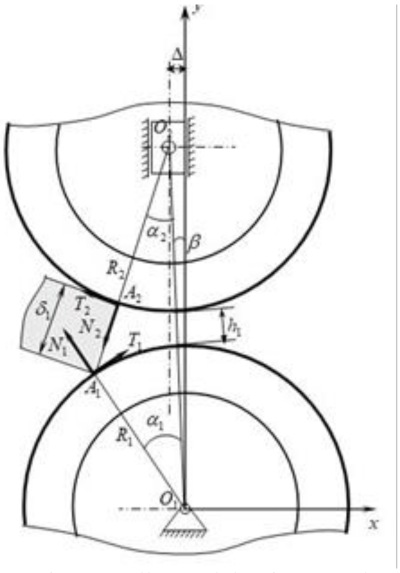

Fig. 1. Scheme of a two-roller module of a squeezing machine

According to [28], in triangle $O_1A_1O_2$ we obtain

$$\sin\frac{A}{2} = \sqrt{\frac{(p-b)(p-c)}{bc}}, \quad (1)$$

where $p = \frac{1}{2}(a+b+c)$.

Here, $A = \alpha_1$, $a = O_2A_1 = R_2 + \delta_1$, $b = O_1A_1 = R_1$, $c = O_1O_2 = R_1 + R_2 + h_1$.

Substituting the values of the sides of triangle $O_1A_1O_2$ into formula (1), after simple transformations, we obtain

$$\sin\frac{\alpha_1}{2} = \frac{1}{2}\sqrt{\frac{(2R_2 + \delta_1 + h_1)(\delta_1 - h_1)}{R_1(R_1 + R_2 + h_1)}}. \quad (2)$$

If we accept assumption $\sin\frac{\alpha_1}{2} \approx \frac{\alpha_1}{2}$, then we obtain an approximate formula to calculate the angle α_1

$$\alpha_1 = \sqrt{\frac{(2R_2 + \delta_1 + h_1)(\delta_1 - h_1)}{R_1(R_1 + R_2 + h_1)}}. \quad (3)$$

The accuracy of the approximate formula (3) is sufficient. Comparative calculations using formulas (2) and (3) show that, for values of $R_1 = 50 \div 150mm$, $R_2 = 50 \div 150mm$, $\delta_1 = 5 \div 15mm$, and $h_1 = 0 \div 8mm$ the calculation error using formula (3) does not exceed $1.0 - 1.3\%$.

Similar to formula (3), we find the formula for calculating the angle α_2

$$\alpha_2 = \sqrt{\frac{(2R_1 - \delta_1 + h_1)(\delta_1 - h_1)}{(R_2 + \delta_1)(R_1 + R_2 + h_1)}}. \quad (4)$$

Formulas (3) and (4) are used to calculate the angles of capture at the moment of contact between the processed material and pairs of rolls.

Next, we evaluate the capture angles α_1 and α_2 taking into account the forces acting on the material.

At the points of contact from the side of the rolls, normal pressure forces and friction forces Q_1, Q_2 act F_1, F_2 on the material (Fig. 1).

The capture conditions depend on the ratio of the retracting and retracting forces, as well as the equation for the balance of forces along the ordinate axis [23]:

$$Q_{1x} + Q_{2x} + F_{2x} - F_{1x} \leq 0, \tag{5}$$

$$Q_{1y} - Q_{2y} + F_{1y} + F_{2y} = 0. \tag{6}$$

From the force diagram in Fig. 1, we find

$$Q_{1x} = Q_1 \sin(\alpha_1 + \beta), \quad F_{1x} = F_1 \cos(\alpha_1 + \beta), \quad Q_{1y} = Q_1 \cos(\alpha_1 + \beta),$$
$$F_{1y} = F_1 \sin(\alpha_1 + \beta), \quad Q_{2x} = Q_2 \sin(\alpha_2 - \beta), \quad F_{2x} = F_2 \cos(\alpha_2 - \beta),$$
$$Q_{2y} = Q_2 \cos(\alpha_2 - \beta), \quad F_{2y} = F_2 \sin(\alpha_2 - \beta). \tag{7}$$

For the friction force T_1, we apply the Amonton-Coulomb friction law $T_1 = f_1 N_1 = N_1 tg\nu_1$, where f_1, ν_1 – are the coefficient and angle of friction of the lower roll during gripping, and for the friction force T_2 – we apply expression $T_2 = f_2 N_2 = tg\nu_2 N_2 = tg\left(\nu_ш \frac{r_ш}{R_2}\right) N_2$ [2], where f_2, ν_2 – are the coefficient and angle of friction of the upper roll during gripping; $r_ш$ – is the upper roll neck radius; $T_ш$ – is the resultant of friction forces in the neck of the upper roll.

Let us substitute the values of F_1 and T_2 into inequality (8) and equality (9), taking into account expression (7), we have

$$Q_1 \frac{\sin(\alpha_1 + \beta - \nu_1)}{\cos\nu_1} + Q_2 \frac{\sin(\alpha_2 - \beta + \nu_2)}{\cos\nu_2} \leq 0, \tag{8}$$

$$Q_1 \frac{\cos(\alpha_1 + \beta - \nu_1)}{\cos\nu_1} - Q_2 \frac{\cos(\alpha_2 - \beta + \nu_2)}{\cos\nu_2} = 0. \tag{9}$$

From equality (11), we determine Q_2 and substitute it into inequality (10). After transformations, we find the capture condition for the considered roll pair:

$$\sin(\alpha_1 + \alpha_2 - \nu_1 + \nu_2) \leq 0.$$

or

$$\alpha_1 + \alpha_2 \leq \nu_1 - \nu_2. \tag{10}$$

Using formula (1), from triangle $O_1 A_1 O_2$ we find

$$\sin(\alpha_1 + \alpha_2) = \frac{1}{2}\sqrt{\frac{(2(R_1 + R_2) + \delta_1 + h_1)(\delta_1 - h_1)}{R_1(R_2 + \delta_1)}}$$

or

$$\alpha_1 + \alpha_2 \approx \sqrt{\frac{(2(R_1 + R_2) + \delta_1 + h_1)(\delta_1 - h_1)}{R_1(R_2 + \delta_1)}}. \tag{11}$$

For $R_1 = 50 \div 150mm$, $R_2 = 50 \div 150mm$ $\delta_1 = 5 \div 15mm$, and $h_1 = 0 \div 8mm$ the calculation error according to formula (11) is $0.1 - 2.7\%$.

With expressions (11), from inequality (10) we obtain

$$\sqrt{\frac{(2(R_1 + R_2) + \delta_1 + h_1)(\delta_1 - h_1)}{R_1(R_2 + \delta_1)}} \leq \nu_1 - \nu_2. \tag{12}$$

In most cases, the rollers on roller machines are mounted in ball bearings, where the amount of friction is small. As a result, the friction force F_2 can be ignored in comparison with other forces acting on the roll [23].
Then the gripping condition is

$$\alpha_1 + \alpha_2 \le \nu_1 \tag{13}$$

or

$$\sqrt{\frac{(2(R_1+R_2)+\delta_1+h_1)(\delta_1-h_1)}{R_1(R_2+\delta_1)}} \le \nu_1 \tag{14}$$

Transforming inequality (14) and assuming that $h_1^2 \approx 0$, we have

$$h_1 \ge \frac{(2(R_1+R_2)+\delta_1)\delta_1 - R_1(R_2+\delta_1)\nu_1^2}{2(R_1+R_2)}. \tag{15}$$

By condition (17), knowing the radii and friction angles of the rolls, it is possible to determine the minimum distance (a gap) between the rolls to be set to grip a layer of material of a given thickness:

$$h_{1\min} = \frac{(2(R_1+R_2)+\delta_1)\delta_1 - R_1(R_2+\delta_1)\nu_1^2}{2(R_1+R_2)}. \tag{16}$$

At the balance of the indicated forces, the process of contact interaction in the two-roll module passes into a steady-state process.
Now let us analyze the contact angles for a steady-state process. Let the layer of material in the steady process pass from section B_1B_2 to section C_1C_2 (Fig. 2); this is accompanied by the rise of the upper roll to distance $\Delta_1 = h - h_1$, where $h -$ is the distance between the rolls in the steady process.

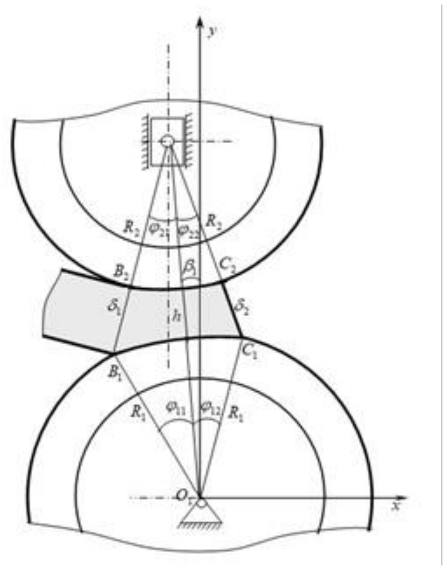

Fig. 2. Scheme of a two-roll module in a steady state

Let, under a steady process, the nip angles (in section B_1B_2) be determined by angles φ_{11} and φ_{21}, and the exit angles (in section B_1B_2) – by angles φ_{12} and φ_{22}.
By analogy with formula (11), we have

$$\varphi_{11} + \varphi_{21} = \nu_1', \tag{17}$$

where $\nu_1' -$ is the friction angle of the lower roll at point B_1.
With (17), we obtain

$$\sqrt{\frac{(2(R_1+R_2)+\delta_1+h)(\delta_1-h)}{R_1(R_2+\delta_1)}}=\nu_1'. \tag{18}$$

Similarly to formulas (3), (4), and (17), we obtain

$$\varphi_{11}=\sqrt{\frac{(2R_2+\delta_1+h)(\delta_1-h)}{R_1(R_1+R_2+h)}},\qquad \varphi_{21}=\sqrt{\frac{(2R_1-\delta_1+h)(\delta_1-h)}{(R_2+\delta_1)(R_1+R_2+h)}},$$

$$\varphi_{12}=\sqrt{\frac{(2R_2+\delta_2+h)(\delta_2-h)}{R_1(R_1+R_2+h)}},\qquad \varphi_{22}=\sqrt{\frac{(2R_1-\delta_2+h)(\delta_2-h)}{(R_2+\delta_2)(R_1+R_2+h)}}, \tag{19}$$

$$\varphi_{21}+\varphi_{22}=\nu_1'', \tag{20}$$

where $\nu_1''-$ is the friction angle of the lower roll at point C_1.
Formulas (19) are used to calculate the grip and exit angles for a steady-state process.
From expression (18), we find expressions for calculating the distance between the rolls

$$h=\frac{(2(R_1+R_2)+\delta_1)\delta_1-R_1(R_2+\delta_1)\nu_1'^2}{2(R_1+R_2)}. \tag{21}$$

Taking into account expressions (16) and (21), we find the value of the upper roll lift:

$$\Delta_1=\frac{R_1(R_2+\delta_1)(\nu_1^2-\nu_1'^2)}{2(R_1+R_2)}. \tag{22}$$

Taking into account equality (20), by analogy with formula (21), we have

$$h=\frac{(2(R_1+R_2)+\delta_2)\delta_2-R_1(R_2+\delta_2)\nu_1''^2}{2(R_1+R_2)}. \tag{23}$$

Equating the right-hand sides of formulas (22) and (23), we find expressions for calculating the thickness of the processed material after pressing:

$$\delta_2=\frac{(2(R_1+R_2)-R_1\nu_1'^2)\delta_1-R_1R_2(\nu_1'^2-\nu_1''^2)}{2(R_1+R_2)-R_1\nu_1''^2}. \tag{24}$$

3. Conclusions

1.The formulas for calculating the parameters of the roll of squeezing machines, such as contact angles and minimum distances between the rolls during gripping and in a steady-state process, and the thickness of the processed material after squeezing, were determined.
2. In most cases, the rollers on roller machines are mounted in ball bearings, where the amount of friction is small. As a result, the friction force can be ignored in comparison with other forces acting on the roll.
3. It has been established that the capture of material in the roll pairs of squeezing machines is determined by the center distance between the rolls, the thickness of the processed material and the coefficients of friction of the rolls on the processed material.
The results of calculations using formulas (3) and (4) made it possible to reveal the following:
− with an increase in R_2, δ_1 and a decrease in R_1, h_1, the angle α_1 increases;
−an increase in R_1, δ_1 and a decrease in R_1, δ_1 lead to an increase in the angle α_2;
− the displacement of the upper roll relative to the lower roll does not affect the values of the nip angles.

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