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Investigation of the process of squeezing a wet leather semi-finished product between a roller pair

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ABSTRACT: The motion of a wet leather semi-finished product hung over the bendon the base plates, vertically fed into the squeezing zone by means of drag-chains, is considered and mathematically described in the paper. The influence of the working shaft radius on the angle of capture of a leather semi-finished product by a roller pair is determined. The influence of the working shafts torque on technological process of water squeezing from a leather semi-finished product between the roller pair is determined.

KEYWORDS: Roller pair, leather semi-finished product, base plate, feed mechanism, vertical feed, water squeezing.

I.INTRODUCTION

After liquid-based procedures, the leather semi-finished products contain more than 70% of water. To carry out further mechanical operations and reduce energy consumption the water squeezing is done by mechanical means. For the normal conduct of mechanical operations, it has been experimentally determined [1] that the moisture content should be about 45-60% depending on the type of the leather semi-finished product. Keeping the moisture content at 45-60% is carried out mechanically, in particular, by roller squeezing. In [2], many shortcomings are listed that lead to the defects in the leather semi-finished product during mechanical processing at uneven moisture content more or less within 55-60% in all its topographic sites.

Previously, we have developed a technological line for the transportation and mechanical processing of flat material, in particular, of a wet leather semi-finished product [3]. In order to ensure smooth and stable operation of this process line, in this study we have reviewed and mathematically described the motion of a wet leather semi-finished product hung to the base plates, fed into the machining zone by means of drag-chains [4, 5, 6].

II. LITERATURESURVEY

In [7], the process of pressing a fibrous material in a roller device was studied; it was considered as a dynamic oscillatory system “roller pair - fibrous material - fluid”. The author has developed a mathematical model of the transition state of the process of mass transfer during the squeezing of fibrous material in the roller device; it allowed getting a scientifically based forecast of the parameters of the technological process. A technique has been developed for determining the stable operation of a roller device in the mode of dynamic loading. The development of the process of leather dehydration and the study to improve the properties of fur semi-finished product are given in [8, 9].

In [10], a method was developed where the processed raw material was fed into the clearance between the driven roller and the fixed cheek. The authors of this method state that the energy consumed per unit of product when using a single-roll crusher is two times less as compared to a two-roll crusher due to the torsional strains and shear stresses acting on the material being processed. The processed leather semi-finished product due to the bending in the base plate, forms two separate pieces, each of which is in contact with a separate working shaft and a fixed rigid base plate. So, it can be assumed that in that case, in total counting it will be possible to achieve about 4 times saving ofenergy, due to the simultaneous processing of the two halves of the leather half-finished product.

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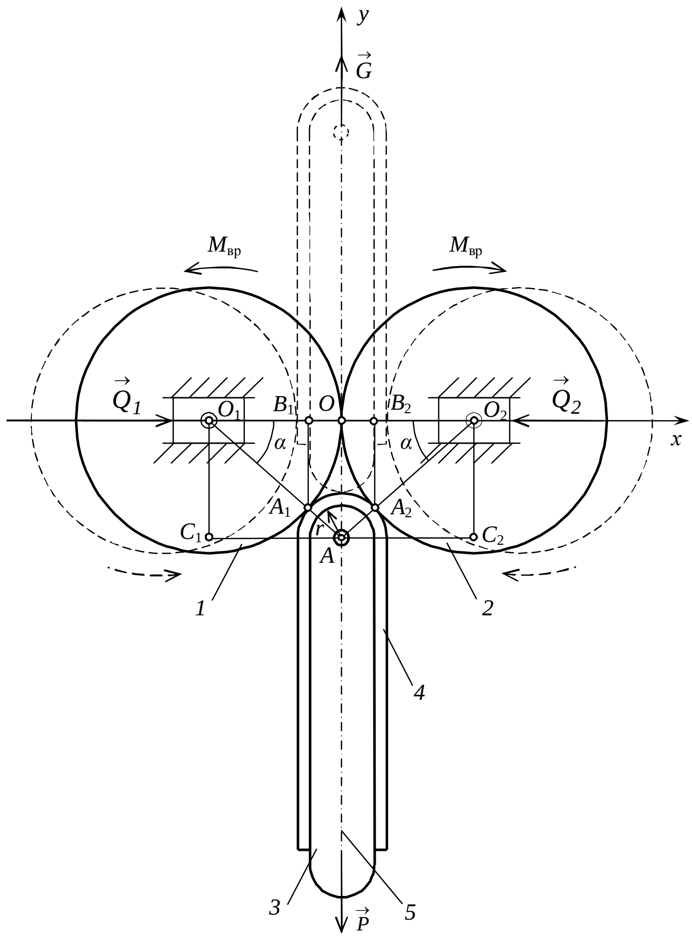
III. METHODOLOGY

Consider the problem for the vertical position of the base plate with rounded-off ends, on which the wet leather half-finished product is hung. In this case, an equation of motion is derived for a wet leather semi-finished product4, hung over thebend on the base plate3and fed vertically by means of drag-chains5between the working shafts 1 and 2using the Lagrange equation of the second kind. Next, using the generalized coordinate, consider the angle α (formed between the segment AO_1 and the horizontal line connecting the centers of the working shafts) (Fig. 1). To derive the equation of motion, the kinetic energy of the base plate and the working shafts is calculated. Fig. 1 shows that the wet leather semi-finished product, hung over the bend on the base plate, will make translational motion in the vertical direction. In this case, the kinetic energy of the base plate is as follows:

$$T_1 = \frac{1}{2} m_1 \dot{y}^2, \; T_2 = \frac{1}{2} m_2 \dot{y}^2, \; T_3 = \frac{1}{2} m_3 \dot{y}^2 \quad (1)$$

where, T_1 is thekinetic energy of the drag-chain;
T_2 is the kinetic energy of the leather semi-finished product;
T_3 is the kinetic energy of the base plate;
$m_1$is the mass of the drag-chain;
m_2 is the mass of the leather semi-finished product;
m_3 is the mass of the base plate.



1, 2 – working shafts,3 – base plate,4 – leather semi-finished product,5 –drag-chain
Fig. 1. Scheme for calculating the process of feeding leather semi-finished product on the base plate between the roller pair

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Next, equation (1) is written as

$$T_{123} = \frac{1}{2}(m_1 + m_2 + m_3)\dot{y}^2 \qquad (2)$$

Since, the working shafts move symmetrically to each other, and make a plane-parallel motion in a horizontal plane, their kinetic energy is:

$$T_4 = T_5 = \frac{1}{2}m_4\dot{x}^2 + \frac{1}{2}J_{O_1}\omega_1^2 ,$$

whereT_4, $T_5$are thekinetic energies of the working shafts, $T_4 = T_5$; m_4, m_5 are the masses of the working shafts, $m_4 = m_5$; J_{O_1} is the moment of inertia of the working shaft, the center of which is located at the point O_1; ω_1 is the angular velocity of the working shaft.

In this problem, the moment of inertia of the right working shaft equals to:

$$J_{O_1} = \frac{m_4 R^2}{2} .$$

R is the radius of the rotating working shaft.

In this case, the following equations are relevant

$$O_1O = (O_1A_1 + A_1A)\cos\alpha = (R + r)\cos\alpha ,$$

$$O_1C_1 = (O_1A_1 + A_1A)\sin\alpha = (R + r)\sin\alpha .$$

Here$O_1A_1 = R$,$AA_1 = r$, $r$is theroundingoff radius of the nose of the base plate. Substituting the O_1Osegment on the x-axis and, accordingly, the O_1C_1 segment on the y-axis, the following expressions related to the angle α are obtained:

$$\begin{cases} x = (R + r)\cos\alpha \\ y = (R + r)\sin\alpha \end{cases}$$

Differentiating these expressions, we get the following expressions

$$\begin{cases} \dot{x} = -(R + r)\dot{\alpha}\sin\alpha \\ \dot{y} = (R + r)\dot{\alpha}\cos\alpha \end{cases} \qquad (3)$$

To derive the equation of motion of the working roller pair, the Lagrange equation of the second kind is used:

$$\frac{d}{dt}\frac{\partial T}{\partial \dot{\alpha}} - \frac{\partial T}{\partial \alpha} = Q_\alpha , \qquad (4)$$

here,$T$is thekinetic energy, Q_α is the generalized force.

Now calculate the total kinetic energy.

$$T = T_{123} + T_4 + T_5 = \frac{1}{2}(m_1 + m_2 + m_3)\dot{y}^2 + 2\left(\frac{1}{2}m_4\dot{x}^2 + \frac{1}{2}J_{O_1}\omega_1^2\right) =$$

$$\frac{1}{2}(m_1 + m_2 + m_3)\dot{\alpha}^2(R + r)^2\cos^2\alpha + m_4\dot{\alpha}^2(R + r)^2\sin^2\alpha + J_{O_1}\omega_1^2$$

Next, calculate complete and partial derivatives of kinetic energy

$$\frac{\partial T}{\partial \dot{\alpha}} = (m_1 + m_2 + m_3)\dot{\alpha}(R + r)^2\cos^2\alpha + 2m_4\dot{\alpha}(R + r)^2\sin^2\alpha ,$$

$$\frac{d}{dt}\frac{\partial T}{\partial \dot{\alpha}} = (m_1 + m_2 + m_3)(R + r)^2\ddot{\alpha}\cos^2\alpha - 2(m_1 + m_2 + m_3)(R + r)^2\dot{\alpha}^2\sin\alpha\cos\alpha +$$

$$+ 2m_4(R + r)^2\ddot{\alpha}\sin^2\alpha + 4m_4(R + r)^2\dot{\alpha}\sin\alpha\cos\alpha \qquad (5)$$

$$\frac{\partial T}{\partial \alpha} = -(m_1 + m_2 + m_3)(R + r)^2\dot{\alpha}^2\cos\alpha\sin\alpha + 2m_4(R + r)^2\dot{\alpha}^2\sin\alpha\cos\alpha \qquad (6)$$

To calculate the generalized force, the principle of possible displacements is used and the work done is determined.

$$\delta A_\alpha = Q_\alpha\delta_\alpha ,$$

$$\delta A_\alpha = 2M_{вр}\delta\alpha + 2Q\delta x + G\delta y - P\delta y , \qquad (7)$$

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Here G isthe dragging force of the chain;
P is the force of gravity of the drag-chain, the leather semi-finished product and the base plate;
$Q=Q_2=Q_3$ is the pressing force of the working shafts,$M_{вр}$ is the torque of the working shaft.
Displacements and δy in expression (7) equal to

$$\begin{cases} \delta x = -(R+r)\sin\alpha\delta\alpha \\ \delta y = (R+r)\cos\alpha\delta\alpha \end{cases} \quad (8)$$

Calculating the generalized force, expression (8) is substituted into (7) and the following value is obtained:

$$Q_\alpha = 2M_{вр} + (G-P)(R+r)\cos\alpha - 2Q(R+r)\sin\alpha \ . \quad (9)$$

Substituting expressions (5), (6) and (9) into equation (1), the equation of motion of the working roller pair is derived:

$$\left((m_1+m_2+m_3)\cos^2\alpha + 2m_4\sin^2\alpha\right)(R+r)^2\ddot{\alpha} + \left(m_4 - \frac{m_1+m_2+m_3}{2}\right)\cdot(R+r)^2\cdot\omega^2\sin 2\alpha = \\ = 2M_{вр} + (G-P)(R+r)\cos\alpha - 2Q(R+r)\sin\alpha. \quad (10)$$

In this problem, the considered base plate and working shafts will move at a constant velocity. Hence, equality $\dot{y} = (R+r)\dot{\alpha}\cos\alpha = (R+r)\omega\cos\alpha = const$ is appropriate here and equality $\dot{\alpha} = \omega = const$ is fulfilled. Considering that $\dot{\alpha}$ is constant, we get equality $\ddot{\alpha} = 0$.
In the first approximation, let $M_{вр}$ = 0, i.e. consider the case when external forces will not act on the leather semi-finished product and working shafts (Fig. 2). In this case, equation (10) takes the following form:

$$m(R+r)^2\omega^2\sin 2\alpha = (G-P)(R+r)\cos\alpha - 2Q(R+r)\sin\alpha \ , \quad (11)$$

here, $m = m_4 - \dfrac{m_1+m_2+m_3}{2}$.
The solution of equation (11) is found taking into account $R+r$.

$$(m\omega^2\sin 2\alpha)(R+r)^2 - ((G-P)\cos\alpha - 2Q\sin\alpha)(R+r) = 0 \quad (12)$$

Equation (12) is transformed to the following form:

$$R+r = \frac{(G-P)\cos\alpha - 2Q\sin\alpha}{m\omega^2\sin 2\alpha} \quad (13)$$

For equation (13) to be appropriate, the following conditions must be met:

$$R+r = \frac{(G-P)\cos\alpha - 2Q\sin\alpha}{m\omega^2\sin 2\alpha} \geq 0,$$

$$tg\alpha \leq \frac{G-P}{2Q},$$

$$-\frac{\pi}{2} + \pi n \leq 0 \leq arctg\left(\frac{G-P}{2Q}\right).$$

In this problem, the angle α could not be less than zero.

$$0 < \alpha \leq arctg\left(\frac{G-P}{2Q}\right) \quad (14)$$

Equation (13) is written in the form,

$$R = \frac{(G-P)\cos\alpha - 2Q\sin\alpha}{m\omega^2\sin 2\alpha} - r \ . \quad (15)$$

Equation (15) expresses the change in the working shaft radius depending on the angle α.

IV. RESULTS

To solve this problem, the Maple computer program for Windows was used and graphical solutions for changing the working shaft radius were obtained depending on the angle α for given values at Q = 20 N, $M_{вр}$ = 20 N·m(Fig. 2).It should be noted that condition (14) is not always met. The explanation for this is the strength and durability of the drag-chains on which the base plates are mounted. If the dragging force G does not reach the required value, then this leads

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to the non-fulfilment of condition (14). To solve this problem, it is necessary to take into account the torques of the working shafts (Fig. 3).

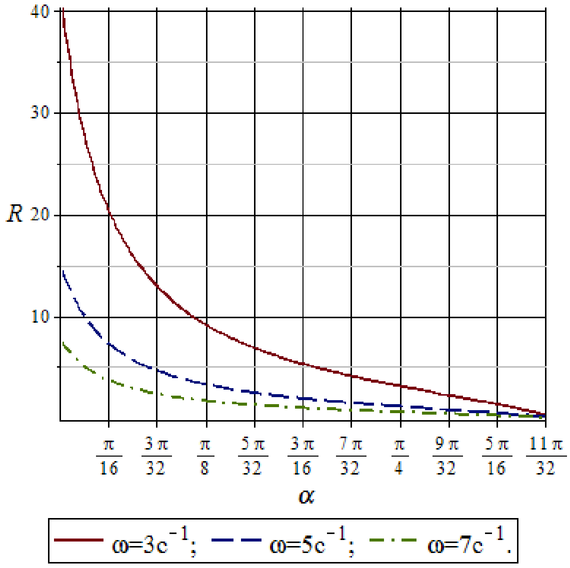

Fig. 2. Change in the working shaft radius R depending on the angle α for given values at Q=20 N, $M_{вр}$=0

$$m(R+r)^2\omega^2 \sin 2\alpha = 2M_{вр} + (G-P)(R+r)\cos\alpha - 2Q(R+r)\sin\alpha \,,$$

$$(m\omega^2 \sin 2\alpha)(R+r)^2 - ((G-P)\cos\alpha - 2Q\sin\alpha)(R+r) - 2M_{вр} = 0 \,,$$

$$a(R+r)^2 + b(R+r) + c = 0 \,,$$

here, $a = m\omega^2 \sin 2\alpha$, $b = -((G-P)\cos\alpha - 2Q\sin\alpha)$, $c = -2M_{вр}$.

$$(R+r)_{1,2} = \frac{-b \pm \sqrt{D}}{2\alpha} \,,$$

here, $D = b^2 - 4ac$

$$R_{1,2} = \left(\frac{-b \pm \sqrt{D}}{2\alpha}\right) - r \,. \tag{16}$$

The resulting equation (16) expresses changes in the working shaft radius depending on the angle α, taking into account the torques.

Construct the graphs of changes in the working shaft radius as a function of the angle α for given values at$Q$ = 20 N (Fig. 3) taking into account the torque of the working shaft $M_{вр}$=20 N·m.

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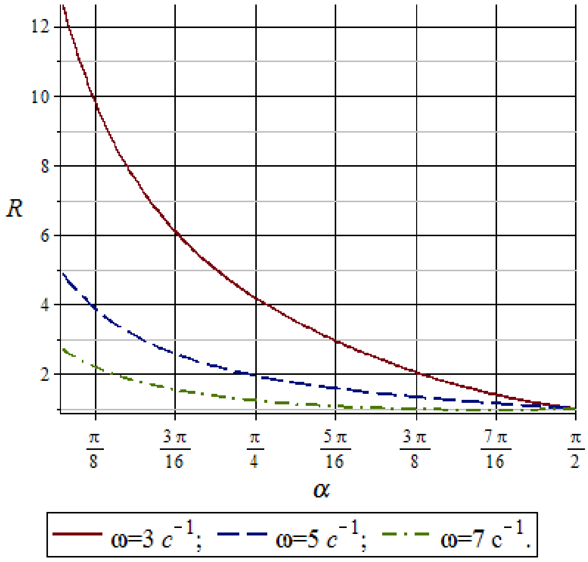
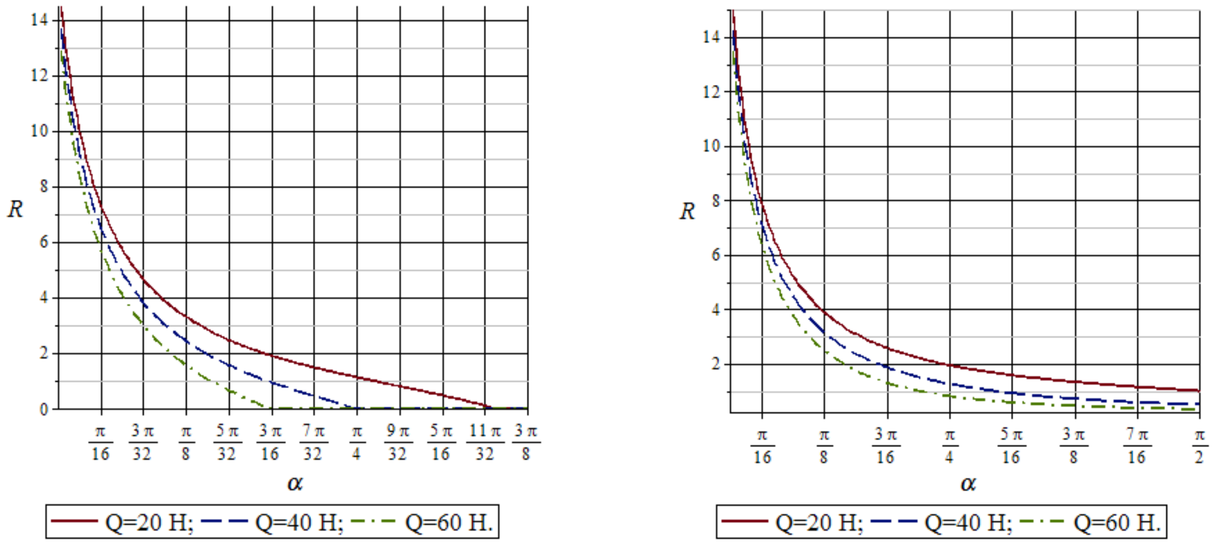


Fig. 3. Change in the working shaft radius *R* depending on the angle *α* for the given values at *Q*=20 N, $M_{\text{вр}}$=20 N·m

To compare the cases of forced and free capture of a leather semi-finished product by a working roller pair, construct the graphs of changes in the radius of the working shaft depending on the angle *α* for given values, at average value ofω = 5 s^{-1} for cases at*a*) $M_{\text{вр}}$ = 0 and *b*) $M_{\text{вр}}$ = 20 N·m(Fig. 4).

The obtained theoretical calculations give a clearer presentation of the technological process of feeding and machining of wet leather semi-finished products, namely, the vertical motion of the product on a base plate between the roller pair. Equations of motion of a wet leather semi-finished product fed vertically on a base plate between a roller pair are derived and graphical solutions are obtained for changing the radius of the working shaft depending on the angle of capture of the leather semi-finished product by a working roller pair (Figs. 2, 3, 4).



a) *b*)

a) $M_{\text{вр}}$=0, *b*) $M_{\text{вр}}$=20 N·m

Fig. 4. Change in the working shaft radius *R* depending on the angle *α* at an average value of ω =5 s^{-1}

V. CONCLUSION

From the obtained graphs, it can be concluded that at the presence of the torque of the working shafts, the angle of capture of the roller pairs may increase to a certain extent, taking into account the value of the radius of rounding-off the nose of the base plate of the roller machine (Fig. 2, 3, 4*a*, 4*b*).

It is determined that in the technological operation of water squeezing from wet leather semi-finished products between a roller pair, the forced rotation of the working rolls will contribute to a smoother process, which will directly affect the increase in the service life of the drag-chains of the roller machine with a vertical feed of the processed material (Fig. 3).

It is recommended to select the designs of the baseplate with minimum material consumption and maximum strength, and also to manufacture them of lighter, moisture-resistant and durable materials, such as plastic, rubber, aluminium or other composites [6].

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