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Roller sammying machine with controlled drive of working rollers

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Abstract: The objective of this study is to improve mechanical fluid removal from semi-finished leather products to reduce harmful vapor emissions during drying and enhance moisture uniformity across hide topography. An improved roller machine is proposed, incorporating a combined toothed-chain transmission to synchronize the angular velocities of the driving and driven rollers while adapting to material thickness. A kinematic analysis of the drive system is conducted, and analytical expressions for linear velocity, acceleration and angular velocity of moving links are derived. The analysis confirms equal linear velocities at the roller contact points, ensuring stable compression and uniform fluid extraction. The adaptive drive mechanism maintains consistent roller motion despite variations in hide thickness, promoting more efficient and even moisture removal. The proposed roller machine design enables controlled mechanical dewatering of hides, minimizing reliance on heat drying and thereby reducing the release of hazardous tanning vapors. The results provide a theoretical basis for designing roller systems in fibrous material processing machines, supporting optimized loading modes that achieve reliable fluid removal and improved environmental performance in leather production.
Keywords: *Combined toothed and chain transmission, Control, Fibrous semi-finished product, Roller Drive, Roller pressure, Roller sammying machine, Rotation speed, Working rollers.*

1. Introduction

In the production of leather and fur, various roller machines are used for the mechanical processing of semi-finished products. These machines are designed to operate at a specific speed, and to change the speed of the working rollers, it is necessary to install a gearbox instead of a reducer. This adds extra weight to the technological machines. Advances in science and technology have led to the creation of velocity control of the working bodies of control devices by connecting frequency converters to electric motors. This allows for the regulation of the velocity of the working body in roller technological machines used for mechanical processing, based on the mechanical parameters of leather and fur.

The range of leathers is very diverse, while the technological process for removing fluid remains the same. Currently, the process of removing fluid from semi-finished products in tanneries is carried out using roller sammying machines. In tanneries, different skins require different residual moisture contents depending on their final use. This process is controlled by the pressure of the squeezing rollers. However, it is also possible to regulate the desired residual moisture by adjusting the roller velocity with a frequency controller for the electric motor, specifically a frequency converter, which accurately adjusts the squeezing rate based on the skin type and thickness.

2. Material and Methods

Consider known publications devoted to the development and study of drive devices and

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mechanisms for the working bodies of technological machines.

The authors of reference [1] developed an improved drive design with combined chain and toothed transmissions. Geometric and kinematic calculations of the drive mechanism were performed. The drive design allows it to withstand high loads and has high kinematic accuracy of the links.

In Tupitsyn et al. [2], the authors developed and studied a wave (harmonic) gear transmission, allowing high gear ratios in one stage. The proposed transmission design provided a gear ratio of 6 or higher in one stage. As a result, the efficiency of the drive increased, and wear decreased.

In Lustenkov [3], design options for a combined planetary gear with expanded kinematic capabilities were developed. The mechanism performs mechanical transmissions based on composite intermediate rolling elements, has a high efficiency coefficient, and ensures high gear ratios.

A synthesis of toothed gear and chain gear engagement was performed in Protasov et al. [4]. The method for finding the working profile of the teeth of a gear wheel or a chain gear sprocket was developed. The ability to control the parameters of chain engagement during its synthesis was obtained. The synthesis problem was solved by integrating a differential equation describing the profile of teeth of a gear wheel or sprocket.

In Gonçalves et al. [5], a method was developed that considers angular variables of spatial mechanical systems using mixed coordinates. This method allows for the efficient calculation of the positions of the kinematic chain.

In Anuradha et al. [6] an analysis of the contact of the teeth of spiral bevel gears was performed. a model was developed that allows the profiles of the contact curves of the teeth of spiral bevel gears to be investigated.

The effect of profile modifications on the transmission efficiency in cylindrical gear transmissions was investigated in the reference [7]. An analytical model for estimating the load distribution and instantaneous friction coefficient was improved. It was found that the pressure angle modification has an insignificant effect on power losses at high torques. The results are based on static analysis, but they can be applied to all types of transmissions and load conditions.

In Abraham et al. [8], a mathematical modeling of spherical rotary gear transmissions, allowing variable roller angles from parallel ones to those approaching 90°, was developed. An analysis of the tooth contact without load was performed for several rotation angles. The results showed that the proposed design with a spherical rotary transmission is more appropriate for low-torque systems.

In Yang et al. [9], a mechanism with a spherical gear transmission and a double degree of freedom, featuring teeth in the form of an arc of a circle, was developed and investigated. Mathematical and geometric models of a spherical gear transmission with teeth in the form of an arc of a circle were proposed.

A mathematical model for a spherical gear engagement mechanism was developed in reference [10]. The model enables plotting a computer graph of the gear transmission and performing an analysis of kinematic errors in the contact of the teeth of spherical gear transmissions.

The works Burmistrov [11], Burmistrov [12], Bahadirov et al. [13], and Nabiev et al. [14] are devoted to the study and calculation of technological machines for leather and fur production. The studies Amanov et al. [15]; Bahadirov and Nosirov [16]; Bahadirov et al. [17]; Bahadirov et al. [18]; Amanov et al. [19] and Nabiev et al. [20] are devoted to the development and study of roller machines of various designs (horizontal, vertical, multi-operation).

Experimental studies of the properties of tanning liquid extracted from chrome leathers were carried out in the works [21-24].

The works of Bahadirov et al. [25]; Nabiev et al. [26]; Amanov et al. [27]; Bahadirov and Musirov [28], and Rakhimova et al. [29] are aimed at improving and substantiating the main design parameters of squeezing machines and their actuators. The work of Nabiev et al. [30] investigated the parameters of working knives with wave-shaped blades for breaking fur skins. The work of Wang et al. [31] is used to strengthen the surface layer of metals, and the results can be applied to strengthen the working knives mentioned in the work [30].

Thus, we have studied the known works aimed at improving technological machines of various designs [32-35]. Currently, automatic control of the technological process of raw material processing is also an urgent task. The work we have done is largely related to solving the stated problem.

The improved drive of the roller sammying machine consists of rollers 1, 2, frame 3, leather 4, electric motor 5, frequency converter 6, cable 7, toothed rack 8, movable support 9 of roller 2, and movable support 15 of roller 1, installed in the grooves of frame 3, and gear 10 is installed on frequency converter 6. Squeezing roller 1 is installed on spherical bearings 11 and 13, and squeezing roller 2 is installed on spherical bearings 12, 14. Electric motor 5 is connected to roller 2 with clutch 16. Squeezing roller 1 is covered with felt coating 18, and roller 2 is covered with felt coating 19. Gear 25 is installed on roller 2 in contact with gear 24 on axis 28, which is installed on levers 20 and 26. Moreover, lever 26 is installed on both sides of the roller axes 2 and 28. The other ends of lever 26 are installed on the roller axis 2 on both sides of gear 25. Sprocket 23 is installed on axis 28, and sprocket 22 is installed on the movable axis of roller 1. Chain 21 goes around sprockets 22 and 23. The second end of lever 26 is connected to spring 27, attached with its second end to frame 3. Toothed rack 8 can be made arched if movable supports 9 or 15 do not move vertically up or down (Figure 1).

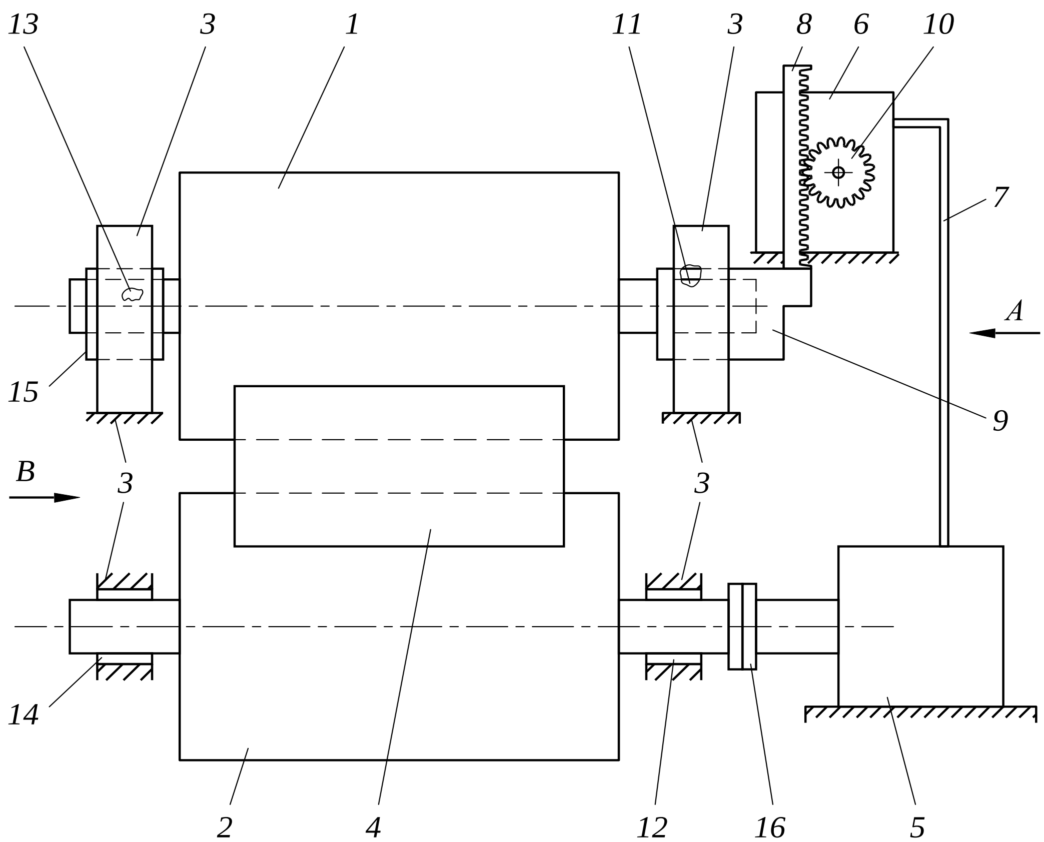

Figure 1.
General scheme of a roller machine with a controlled drive mechanism for the working rollers.

A roller sampling machine with an adjustable drive for the roller working element operates as follows. The change in the velocity of the working element is first determined experimentally, depending on the thickness of the leather semi-finished product during fluid removal. Based on these

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data, the parameters of the toothed rack and the gear in contact with it are selected to determine the optimal rate for squeezing fluid from the leather semi-finished product (Figure 2).

The rotational motion from lower roller 2 is transferred to upper roller 1 as follows. The electric motor 5 drives rotation through the clutch 16 to the lower roller 2. On lower roller 2, gear 2 is mounted, which transfers rotation to gear 24 on axis 28. Sprocket 23, also on axis 28, rotates together with gear 24. Then, via chain 21, rotation from sprocket 23 is transferred to sprocket 22 on roller 1. When feeding material 4 between rollers 1 and 2, the varying thickness of the leather layer 4 allows supports 15 and 17 to move vertically. In this case, lever 26 can pivot up or down along with gear 24 and sprocket 23 relative to the axis of roller 2.

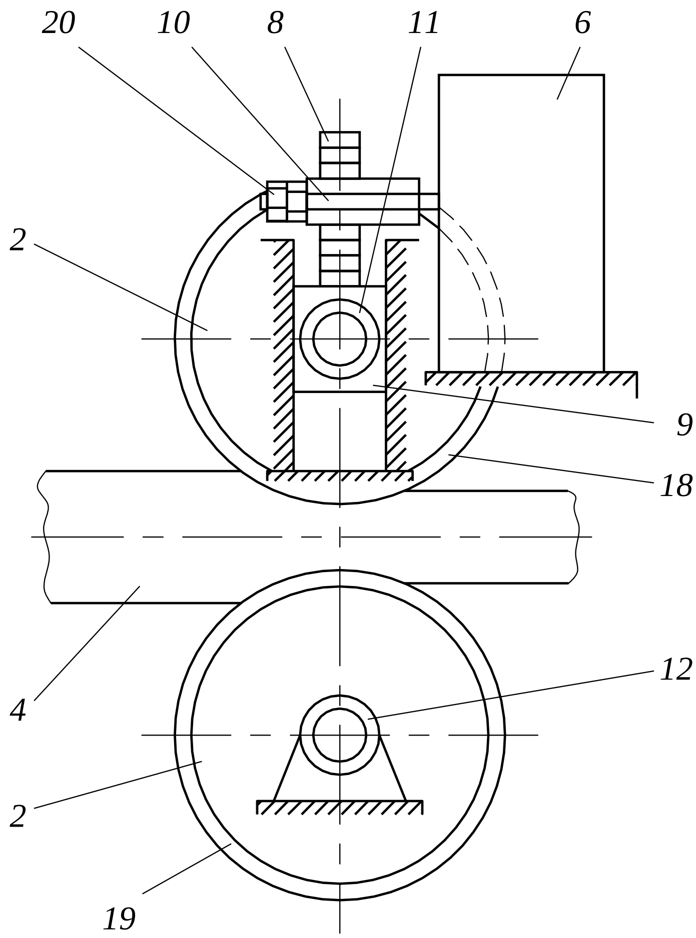

Figure 2.
Side view of the driving and driven working rollers of the machine (View A).

The thickness of the semi-finished leather product 4, depending on the angular velocity of the squeezing roller, changes with the frequency, which can be regulated by the frequency converter 6 through gears 10.

This will ensure better removal of fluid from wet semi-finished leather products and increase productivity with different types and thicknesses of leather.

In this way, an expansion of the various range of raw hides that can be processed on one type of sammying machine is achieved, and the quality and the yield of leather by area are increased.

Preliminarily, the optimal feed rate of different semi-finished leather products is determined experimentally for various thicknesses of leather products.

Then, by adjusting the velocity of frequency converter 6, the parameters of gear 10 and toothed rack 8 are adjusted and selected. In case one support 9 or 15 is rotated, it is possible to mount a toothed rack on movable support 15 with the teeth following an arc-shaped line around the circumference (Figure 3).

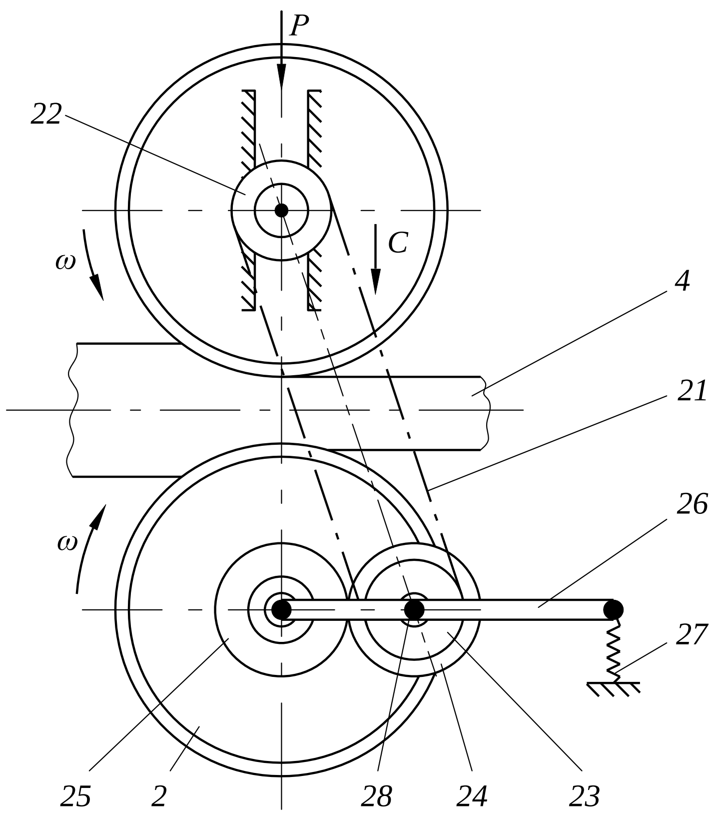

Figure 3.
Scheme of the drive mechanism of the working rollers (View B).

The operation of the roller machine for squeezing fluid from the leather semi-finished product 4 is as follows.

We turn on electric motor 5, and then the rotation is transmitted to lower roller 2 through clutch 16. Then, the rotation from lower roller 2 is transmitted to upper roller 1 from gear 25 on lower roller 2 to gear 24 on axis 28, and then from sprocket 23 on axis 28 by chain 21, the rotation is transmitted to sprocket 22 on the axis of roller 1.
Figure 4 shows (View C) levers 20 and 26, which are mounted on one journal of roller 2.

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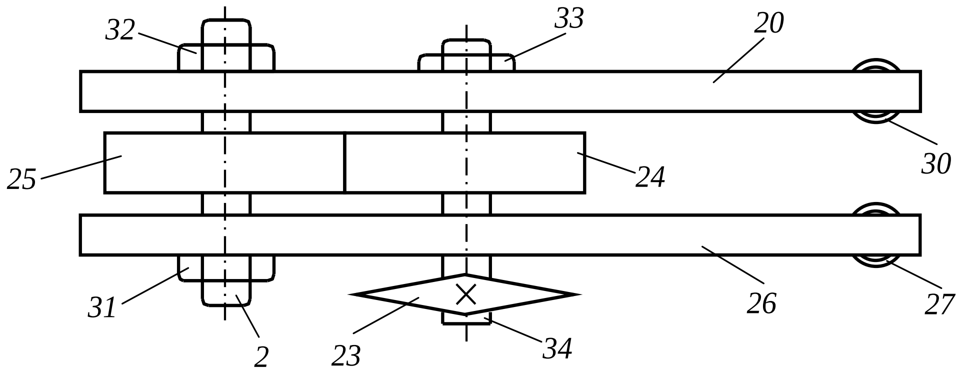


Figure 4.
Scheme of installation of gear pair on levers (View C).

Gear 25 is mounted on the axis of the journal of roller 2, and gear 24 is installed in contact with it, mounted on axis 28. Sprocket 24 is installed on axis 28, which contacts sprocket 23 via chain 21. The end of the journal of lower roller 2 is secured at the ends with nuts 31 and 32. Axle 28 is secured at the ends with nuts 33 and 34. Spring 30 is secured to one end of lever 20, and spring 27 is secured to the other end of the lever. Axle 28 is movable together with gear 24.

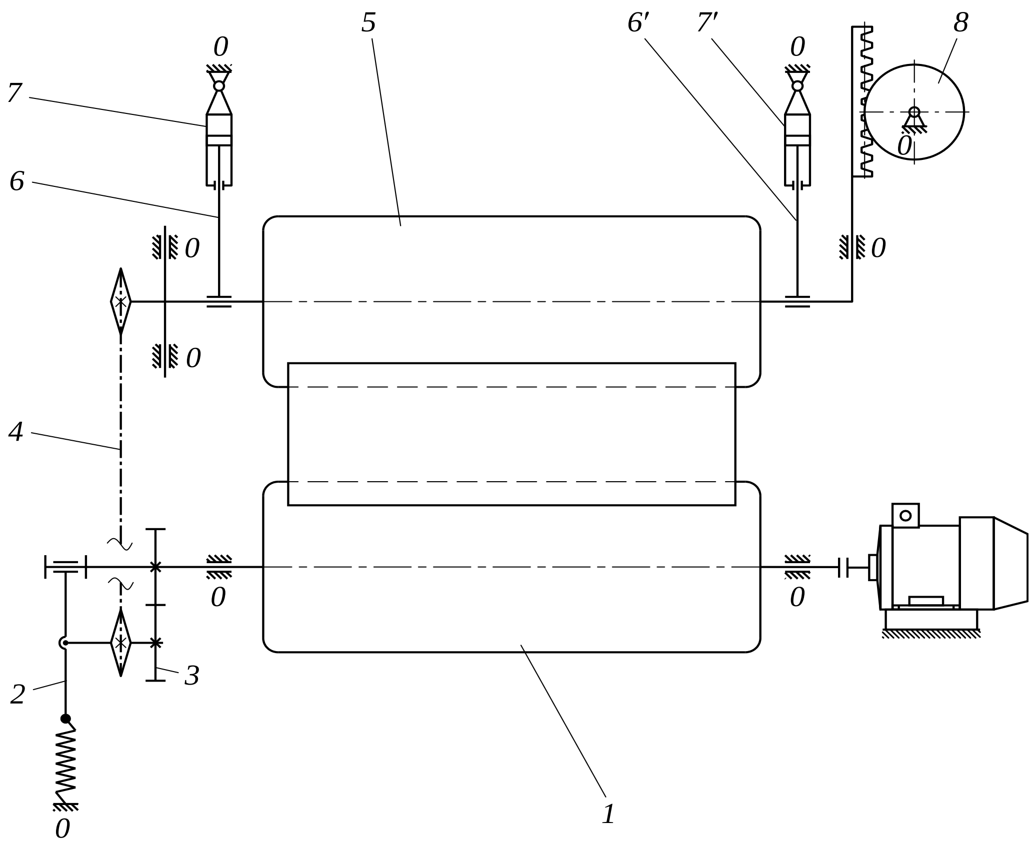


Figure 5.
Scheme of the drive of the roller pair with a movable upper roller.

When the thickness of the fed leather product 4 increases, upper supports 9 and 17 rise up and move the toothed rack 8 upward, which contacts gear 10 and turns it at a certain angle; the frequency meter 6 changes the frequency and reduces the velocity of the electric motor 5.

If the thickness of the feeding leather product 4 decreases, then the toothed rack 8, together with the squeezing roller 1, goes down and turns gear 10 in the opposite direction, and the frequency converter 6 increases the velocity of the electric motor 5.

The result of this technical solution is an increase in the quality of fluid squeezing, and there is no need to install gearboxes, which can incur power losses of 10 to 15%.

Consequently, there are energy savings; large amounts of metal, resources, and production costs are saved.

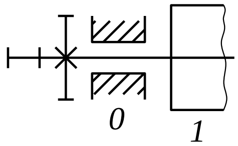
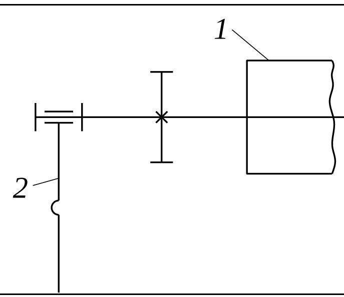
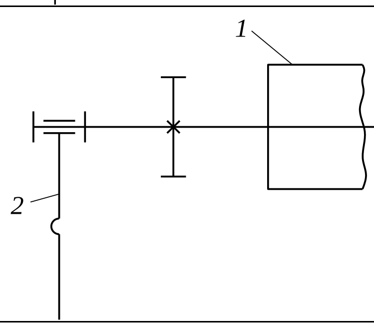
Consider the drive mechanism of the working bodies of the roller machine (Figure 5).

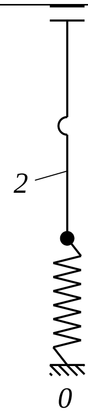
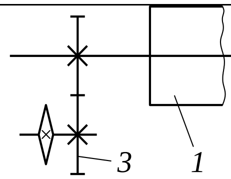
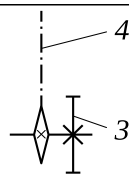
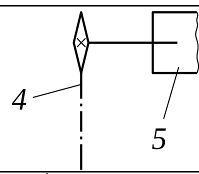
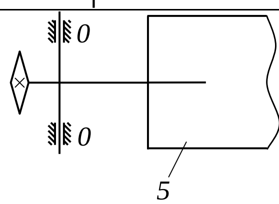
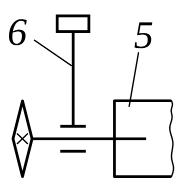
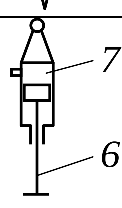
The mechanism consists of 8 movable links located on supports. The degree of freedom of the mechanism is determined by the P.L. Chebyshev formula:

$$W = 3n - 2P_V - P_{IV},$$

here, W is the dependence to determine the number of degrees of freedom of a plane mechanism;
n is the number of movable links;
P_{IV}, P_V are the numbers of kinematic pairs of the 5th and 4th classes, respectively.
We divide the kinematic scheme shown in Figure 5 (Table) into structural groups.

Table 1.
Determining the number of connections of the drive mechanism.

No.	Kinematic pairs	Kinematic pair schemes	Kinematic pair class
1	*0→1*		P_V
2	*0→2*		P_V
3	*1→2*		P_V
4	*3→2*		P_V

			
5	*4⟶2*		P_{IV}
6	*3⟶5*		P_{V}
7	*4⟶5*		P_{V}
8	*5⟶6*		P_{IV}
9	*6⟶7*		P_{V}
10	*7⟶0*		P_{V}

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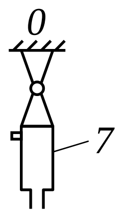
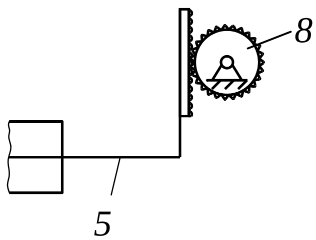
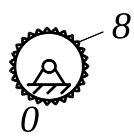
11	5→8		P_V
12	9→8		P_{IV}
13	9→0		P_V

Based on the table data, we determine the number of moving links of the mechanism and their connections.

The mechanism shown in Figure 5 has 8 moving links and 13 lever mechanisms. 10 links belong to the kinematic pair of class V, and 3 kinematic pairs belong to class IV.

$n = 8$,

$P_V = 10$,

$P_{IV} = 3$.

Therefore,

$$W = 3n - 2P_V - P_{IV} = 3\cdot 8 - 2\cdot 10 - 3 = 1. \qquad (1)$$

Thus, the degree of freedom of the mechanism under consideration is 1.

After completing the structural analysis of the mechanism, we proceed to its kinematic analysis.

During the kinematic analysis, the speed, acceleration, and angular velocity and acceleration of the moving links of the mechanism are determined [32-35].

Based on the conditions of the problem, if the system under consideration transmits the motion from the engine to the working roller, then drive roller 1 will rotate n_1 times (Figures 6 and 7).

The angular velocity of the driving working roller is determined as:

$$\omega_1 = \frac{2\pi n_1}{60}. \qquad (2)$$

Hence, we can determine the linear velocity of the surface of the working roller in contact with the surface of the semi-finished product:

$$V_{d_1} = \omega_1 \cdot R_{V_1}, \qquad (3)$$

$$V_{d_1} = \frac{2\pi n_1 \cdot R_{V_1}}{60} = \frac{\pi n_1 \cdot R_{V_1}}{30}.$$

where, R_{V_1} is the radius of the driving working roller.

Gear 3 is rigidly fixed to the outlet end of the axis of the driving working roller. In this case, the angular velocities of the gear and the driving working roller are equal.

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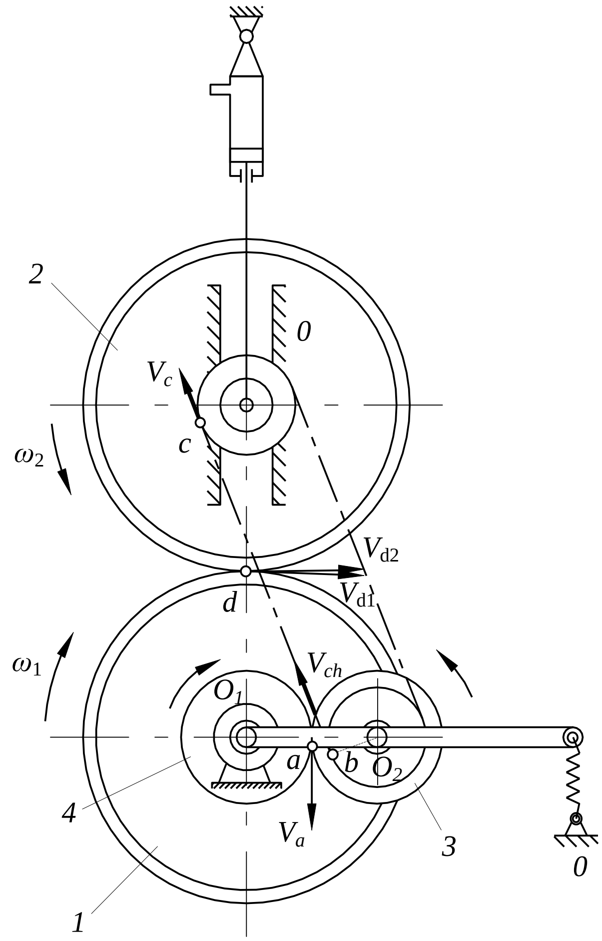

Figure 6.
Kinematic scheme of the roller pair and drive mechanism.

We determine the linear velocity of the toothed gear:

$$V_g = \omega_1 \cdot r_{g_1}, \quad (4)$$

$$V_g = \frac{2\pi n_1 \cdot r_{g_1}}{60} = \frac{\pi n_1 \cdot r_{g_1}}{30}.$$

Since the linear velocities of the contact points of gears 3 and 4 are equal, then on both sides we obtain:

$$V_g = \omega_3 \cdot r_{g_2}, \quad (5)$$

$$\omega_3 = \frac{V_g}{r_{g_2}}, \quad (6)$$

$$\omega_3 = \frac{\pi n_1 \cdot r_{g1}}{30 \cdot r_{g2}}.$$

Having found the linear velocity of link 3, we determine the linear velocity of point *b* on this link. The distance from the center to point *b* is equal to the radius of the sprocket.

$$V_{sp} = \omega_3 \cdot r_{sp1}, \quad (7)$$

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$$V_{sp} = \frac{2\pi n_1 \cdot r_{g_1} \cdot r_{sp_1}}{30 \cdot r_{g2}}.$$

At point *b*, two linear velocities are equal to each other, i.e., this is the linear velocity of the sprocket at point *b* and the linear velocity of the chain at point *b*.

$$V_{ch} = V_{sp} = \frac{\pi n_1 \cdot r_{g_1} \cdot r_{sp_1}}{30 \cdot r_{g_2}}.$$

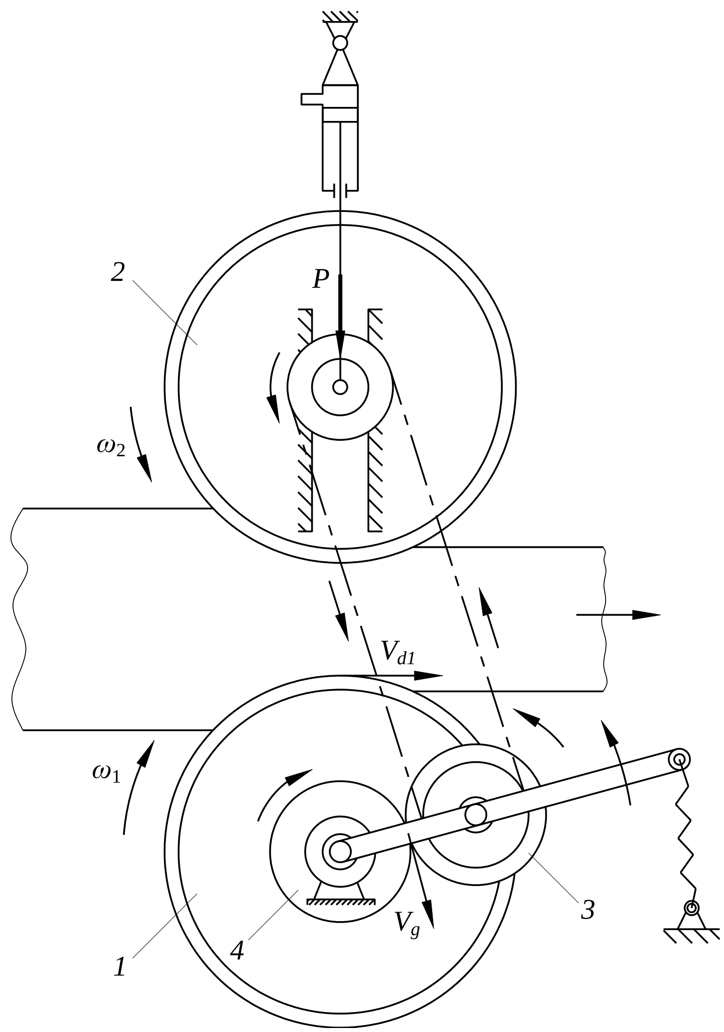

Figure 7.
Scheme of directions of movement of the main links of the rolling machine.

Hence, the linear velocities at arbitrary points of the chain transmission are equal.

$V_c = V_{ch} = V_{sp}$.

If we know the linear velocity of point *c*, then we can determine the angular velocity of the second link.

$V_c = \omega_r \cdot r_{sp_2}$, (8)

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$$\omega_2 = \frac{V_c}{r_{sp_2}}, \tag{9}$$

if we substitute the value of V_c, we have:

$$\omega_2 = \frac{\pi \cdot n_1 \cdot r_{g_1} \cdot r_{sp_1}}{30 \cdot r_{g_2} \cdot r_{sp_2}}.$$

Using the angular velocity of the second link, we can determine the linear velocity of the point of contact of the second working roller with the semi-finished product fed between the rollers.

$$V_{d_2} = \omega_2 \cdot R_{V_2}, \tag{10}$$

$$V_{d_2} = \frac{\pi \cdot n_1 \cdot r_{g_1} \cdot r_{sp_1}}{30 \cdot r_{g_2} \cdot r_{sp_2}} \cdot R_{V_2}.$$

The linear velocity of the lower working roller in contact with the semi-finished product is obtained (Figure 7):

$$V_{d_1} = \frac{\pi n_1}{30} \cdot R_{V1}.$$

Thus, we have examined the drive mechanism of the squeezing machine, the operation of which is based on the automatic control of the technological process of processing fibrous semi-finished products.

3. Results and Discussion

It follows from the solution of the problem that if the diameters of the working rollers are equal, and the diameters of the gear wheels and sprockets of the combined toothed and chain transmission are equal, then the linear velocities of the working rollers at the point of their contact will be equal, regardless of the change in the thickness of the semi-finished product and the distance between the axes of the lower and upper working rollers.

The speed of the upper working roller is determined as follows:

$$V_{d_2} = \frac{\pi n_1 \cdot r_{g_1} \cdot r_{sp_1}}{30 \cdot r_{g_2} \cdot r_{sp_2}} \cdot R_{V_2}.$$

So, if in the drive mechanism r_{g_1} and r_{g_2} ,and r_{sp_1} and r_{sp_2} are equal, and R_{V1} and R_{V_2} are also equal, then consequently $V_{d1} = V_{d2}$ will be equal as well.

$$V_{d_2} = \frac{\pi n_1 \cdot r_{g_1} \cdot r_{sp_1}}{30 \cdot r_{g_2} \cdot r_{sp_2}} \cdot R_{V_2}, \tag{11}$$

$$V_{d_1} = \frac{\pi n_1}{30} \cdot R_{V1}, \tag{12}$$

$$V_{d1} = V_{d2}, \tag{13}$$

$$\frac{\pi n_1}{30} \cdot R_{V_2} = \frac{\pi n_1}{30} \cdot R_{V_1}, \tag{14}$$

$$\frac{\pi n_1}{30} = \frac{\pi n_1}{30} = \omega_1. \tag{15}$$

Thus, by reducing the above formulas (11), (12), (13), (14), (15), the equality of the linear velocities of the contact points of the driving and driven working rollers is stated. The following conclusions can be drawn.

4. Conclusion

1. By ensuring that the linear velocities of the working rollers are equal, surface creasing of the semi-finished product processed between them is prevented, allowing for the uniform removal of excess fluid.

2. The angular velocities of the upper and lower working rollers are automatically adjusted based on the thickness variation of the semi-finished product being processed (using a frequency converter), enabling the handling of different types of semi-finished products in the same manner.

3. By maintaining equal linear velocities at the contact point of the working rollers, slippage during feeding is minimized, resulting in equal friction forces on the front and flesh surfaces of the semi-finished product.

4. When controlling the velocity of the working rollers with a frequency converter through a combined toothed and chain transmission, the process of skin capturing and pulling in is simplified.

5. Ensuring equal linear velocities at contact surfaces during the movement of the semi-finished product leads to a uniform pressure distribution on the working rollers across the topographic sections of the leather product.

6. Adjusting the distance between the axes of the upper and lower working rollers will still ensure equal linear velocities through the drive mechanism, thus improving processing quality.

7. In a combined toothed and chain transmission system, the diameters of the working rollers, gear wheels, and sprockets must be appropriately chosen to maintain equal linear velocities at all transmission points.

8. A rheological model incorporating elastic-viscous elements, which considers the magnitude and rate of deformation, can serve as the basis for describing the process of fluid extraction from fibrous semi-finished products.

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Transparency:
The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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