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Study of the drive mechanism of the working bodies of a roller machine

Auezhan T. Amanov[1], Gayrat A. Bahadirov[2], Ayder M. Nabiev[3]*, Gerasim N. Tsoy[4], Asrorbek A. Abdullajanov[5]
[1]Faculty of engineering and natural sciences, Tampere University, Finland; auezhan.amanov@tuni.fi (A.T.A.)
[2,3,4]Institute of Mechanics and Seismic Stability of Structures named after M.T. Urazbaev of the Uzbekistan Academy of Sciences, Uzbekistan; instmech@rambler.ru (G.A.B.) a.nabiev@mail.ru (A.M.N.) tsoygeran@mail.ru (G.N.T.)
[5]Namangan Engineering Construction Institute, Uzbekistan; asrorabdullajanov@gmail.com (A.A.A.)

Abstract: A design of a roller machine with an improved drive mechanism of working bodies is developed in the article. The roller machine has expanded functionality when performing technological operations of dehydrating moisture-saturated fiber materials. The developed mechanism ensures stable and reliable operation of the drive of working bodies, regardless of the unevenness and variations in the parameters of the processed moisture-saturated fibrous materials, achieving synchronicity of the working body operation. The study aims to expand the functionality of the roller machine, ensure stable and reliable operation of working roller drives regardless of the unevenness and changes in the parameters of the processed moisture-saturated fibrous materials, and ensure synchronicity of the working rollers.

Keywords: *Drive mechanism, Fibrous material, Mechanism structure, Roller machine, Working bodies, Working body clearance.*

1. Introduction

We consider the current trends, innovations, and methods in the design and modeling of drive systems used in engineering, in various machines and production.

The creation of new designs and the improvement of existing designs of technological machines that meet modern requirements of high efficiency, environmental safety, accuracy, reliability, and economy are based on innovative achievements of fundamental and applied sciences [1].

Today, numerous publications are devoted to developing and studying promising roller devices that ensure high-quality processing of fibrous materials [2–7].

In [8], the parameters of the lever device were studied and a model describing the force load exerted on the elements of the lever device of mining transportation facilities was developed.

The authors of [9] developed a new method for synthesizing planetary mechanisms with one and several degrees of freedom. This method of synthesizing mechanisms is effective for designing automatic transmission mechanisms.

In [10], a new model of the gear system was developed that accounts for the gears' engagement and their reactions to torsion. The friction characteristics between gear wheels are investigated.

The study in [11] is devoted to developing a new compact drive with adjustable stiffness. The transmission accuracy of this drive is based on a planetary gear transmission with a rocker connection. A prototype drive was built and its performance and the developed algorithm for stiffness identification were experimentally validated.

In [11], a new type of drive was developed that increases the energy efficiency of a technical system due to the variability of torque and compensation for gravity. This drive will be effective when used in the design of robotic systems.

The authors of [12] solved the problem of the permissible position of the working element of serial mechanisms with low mobility using the inverse kinematic modeling method.

* Correspondence: a.nabiev@mail.ru

In [13], the balancing of the gear mechanism of the cardan drive was considered and investigated. It was theoretically determined that the mechanism could be balanced using springs. Robot manipulators were experimentally tested on the prototype of the developed balancer with one degree of freedom.

Reference [14] is devoted to gear contacts considering their transmission efficiency. For this purpose, a method of gear surface treatment was developed. The study results showed improved gear transmission characteristics achieved by gear surface treatment.

The dynamic performance of planetary gears is studied in [15]. For this purpose, the authors developed a matrix method for searching for planetary gear configurations. As a result of this method, it is possible to provide the required gear ratios of the planetary mechanism.

The authors of article [16] proposed a new graphical method for analyzing the gear transmission to construct a geometric model and determine the rotation speed of the planetary drive elements. This graphical method simplifies the stages of designing planetary gears.

Based on the analysis of modern studies [8–16], it was determined that, when designing and calculating a differential transmission mechanism for a roller technological machine, it is necessary to account for the gear ratios, the torque of the working elements, the balance of the generated power, the losses in the engagement of the gear wheels and the efficiency of the transmission. These values will facilitate the design and calculation of strength characteristics of the gear-lever differential transmission mechanism without losing the generated and transmitted power.

In designing drives for roller pairs, when the rollers are located along a horizontal line, using gear-lever transmission mechanisms is not appropriate from the point of material consumption. Therefore, the authors propose a drive mechanism for working rollers, which operates in a combination of gear and chain transmission [18, 19]. This design of the drive mechanism for a roller pair is convenient and appropriate when transmitting rotary motion, where the diameters of the working rollers are the same. This drive mechanism ensures synchronicity of rotation of the working rollers when processing flat materials and materials with uneven surfaces (fibrous and textile materials). That is, the technological requirement such as the constancy of the rotational motion of rollers is met at a constant change in the center distance of the working rollers. The drive mechanism needs minimal costs for installation, dismantling, and maintenance.

Numerous roller machines are implemented in production, in particular, the VOPM-1800-K squeezing roller machine; its squeezing rollers are equipped with inter-roller drives that consist of two contacting gears with elongated teeth, rigidly installed one above the other at the ends of the axes of the working rollers [20].

The VOPM-1800-K roller machine contains an electric motor, a gearbox, a chain, toothed sprockets, gears, hydraulic cylinders, and two working rollers installed one above the other.

Between two working rollers located one above the other, two endless conveyors made of monchon (water-permeable cloth) are installed. One monchon covers the lower working roller, and the other – the top working roller.

The working rollers are driven by an electric motor through a gearbox. On the shaft of the gearbox, there is a sprocket in contact with a chain with a sprocket located on the axis of one end of the lower working roller. At the other end of the lower working roller, there is a gear in contact with another gear of the top working roller.

The working rollers are driven as follows:

The rotation is transmitted from the electric motor to the gearbox. From the gearbox, through the sprockets and chains, rotation is transmitted to the top working roller. Hydraulic cylinders are installed at the ends of the rollers on the frame and press the top+ working roller against the lower one.

The disadvantages include inadequate squeezing of leather semi-finished products, low machine reliability, and difficulty using different thicknesses of monchons and leather semi-finished products. These shortcomings may be attributed to the imperfect design of the roller machine

When squeezing wet semi-finished leather products in roller pressing machines, the center distance of the working rollers changes arbitrarily depending on the thickness of the semi-finished leather being pressed. As a result, the gear wheels are in an inconstant engagement and often disengage, which leads to geometric sliding between the pressing rollers and the processed material, accompanied by intensive wear of monchons and rims of the gear wheels, deteriorating the quality of the semi-finished leather product.

In addition, it is often necessary to use monchons of different thicknesses, which cannot be done without replacing the gear wheels to increase or decrease the center distance of the working rollers.

Another design disadvantage of the roller machine VOPM-1800-K is the impossibility of copying the topography of leather product along the feed width, since the design of the roller machine does not provide for the rotation of one working roller relative to the second working roller at a certain angle, ensuring reliable drive. Copying the topography of the leather semi-finished product improves the quality of its processing.

In the method for squeezing moisture from the leather semi-finished product presented in [21], the range of the inter-roller distance is quite large since the thickness of the package of leather semi-finished product with the base plate can be different, depending on the quality of the simultaneously processed leather product [22-40].

Rotational motion in a roller machine is transmitted by friction, toothed, belt, and chain transmission. We will conventionally call the pair that performs rotational motion a gear or sprocket. The gear or sprocket from which rotation is transmitted is usually called the driving one, and the gear or sprocket that receives motion is called the driven one. Belts and chains are conventionally called flexible elements.

2. Material and Methods

The technical result of using the drive mechanism is that the functionality of the roller machine is widened; it ensures the processing of sheet materials of different thicknesses and can process sheet materials more efficiently due to symmetrically rotating working rollers relative to each other at a certain angle, depending on the change in the thickness of the sheet material along the width of its feed for processing; it ensures synchronicity of rotation of the working rollers, reduces wear of the coatings of the working rollers, and increases the productivity of the roller machine.

The technical result is achieved by the fact that the roller machine with a frame, on which four levers are installed on the rollers, has rotational mobility; on the upper part of the levers cups with a lid are fixed, inside which bushings with two projections are installed; spherical rolling bearings are seated in the bushings, on which the axes of the working rollers are seated. Due to the installation of spherical bearings and bushings with projections, the working rollers can symmetrically rotate relative to each other, forming acute angles. This ensures the copyability of wedge-shaped thicknesses of sheet material along the feed width during its processing. The drive of the working rollers is transmitted from the electric motor to the reducer, through the clutch the rotation is transmitted to the roller installed on the frame, and a gear and sprocket are installed on the roller.

Figure 1 shows a side view of the roller machine; Fig. 2 shows a top view of the roller machine; Fig. 3 shows section A–A – a view of the working roller supports; and Fig. 4 shows a drive of a base plate.

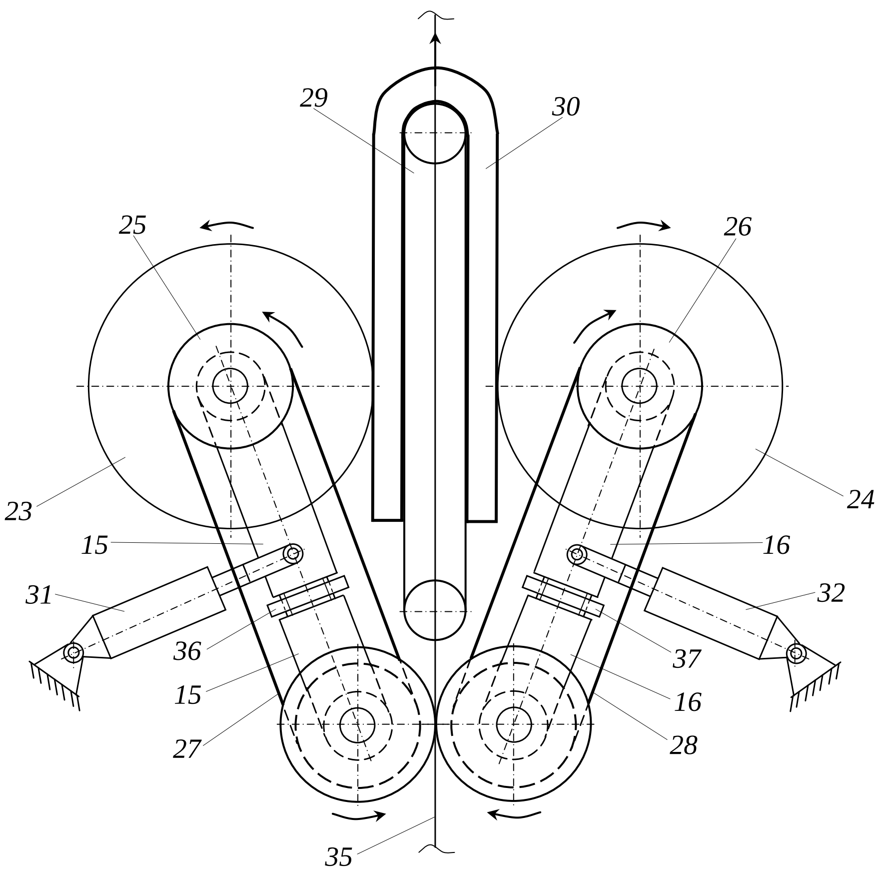


Figure 1.
Scheme of a roller machine with a combined mechanism for driving the working bodies.

The roller machine consists of electric motor *1* connected to gearbox *2*, which in turn is connected via clutch *3* to roller *5* mounted on frame *4*, on which gear *6* and sprocket *7* are mounted. Roller *8* is mounted parallel to roller *5*, on which gear *9* and sprocket *10* are mounted, with *6* and *7*, *9* and *10* opposite each other. On the extension of the axes of rollers *5*, *8*, rollers *11*, *12*, *13*, *14* are mounted, on which levers *15*, *16*, *17*, and *18* are mounted with rotational mobility around their axes. At the other ends of levers *15*, *16*, *17*, and *18*, cups *19* are installed and secured, with lid *20*, bushing *21* is installed inside with two cylindrical projections *38*, the lower of which is inserted into the opening at the bottom of cup *19*, and the upper projection is inserted into lid *20*, screwed into cup *19* with a thread. Spherical rolling bearing *22* is installed in bushing *21*, on which the axes of working rollers *23*, *24* are installed. From the drive side, wheels *25*, *26* are installed on working rollers *23*, *24*.

Sprocket *25* is connected by flexible element *27* to sprocket *7*, and sprocket *26* is connected by flexible element *28* to sprocket *10*. Gears *6* and *9* are in constant engagement with each other. There are sprockets *43*, *44*, *45*, *46*, *48*, *49*, *51*, *52*, *53*, *54*, chains *47*, *55*, axle *50*. Between working rollers *23*, *24*, base plate *29* with processed sheet material *30* (preferably, wet leather semi-finished product) is pulled in. Flexible elements *27*, *28* are made in the form of cardan chains.

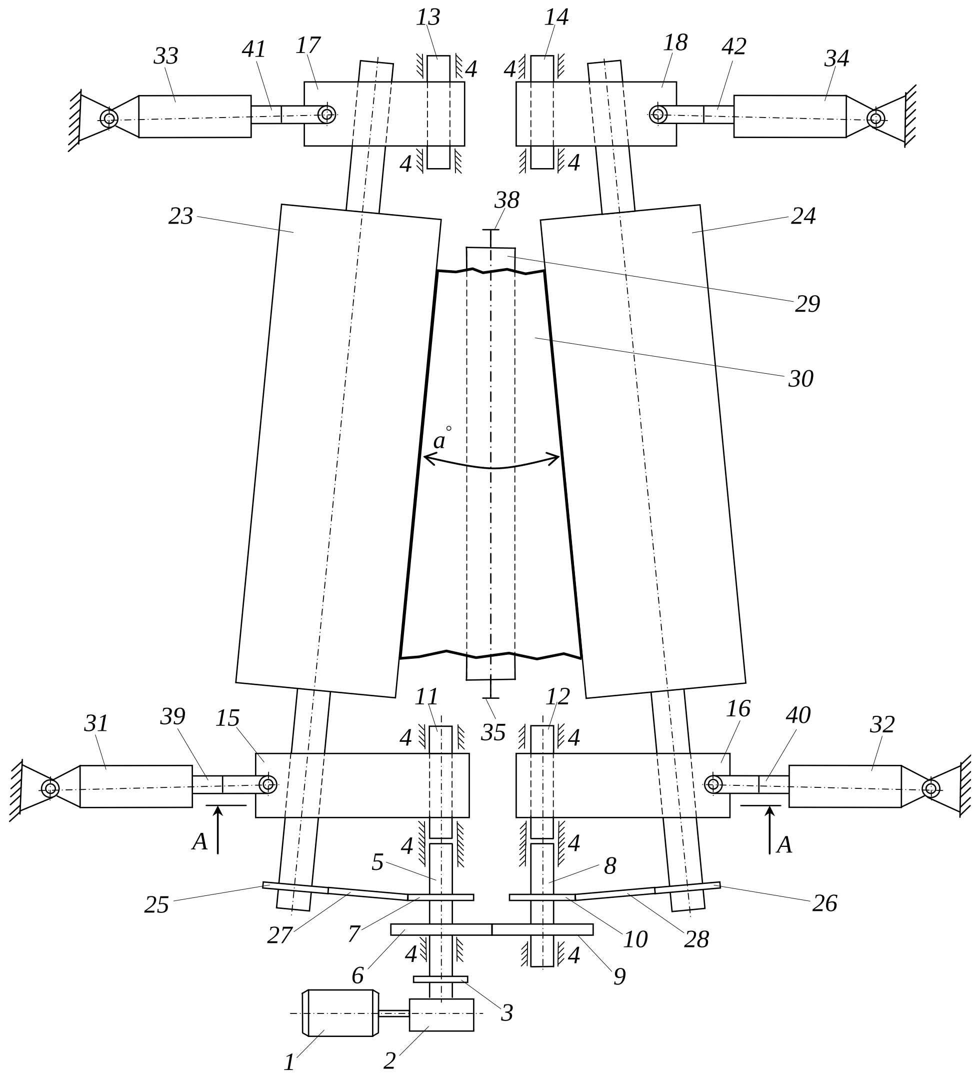


Figure 2.
Layout of working elements in contact with wedge-shaped processed material.

To press the working rollers *23*, *24*, hydraulic cylinders *31*, *32*, *33*, *34* are installed and attached to frame *4*, installed rods *39*, *40*, *41*, *42* are connected to levers *15*, *16*, *17*, *18*, respectively. Tensioning of flexible elements *27*, *28* is ensured by rotating the adapter with right and left screw threads *36*, *37* relative to levers *15*, *16*, respectively.

The roller machine operates by supplying base plate *29* with sheet material *30* using chains *35*, *38* installed parallel to each other. For this purpose, electric motor *1* is switched on, the rotation is transmitted to gearbox *2*, then through clutch *3* to roller *5*. From roller *5* through sprocket *7*, the rotation is transmitted by flexible element *27* to sprocket *25*, which rotates working roller *23*. From gear *6*, the rotation is transmitted to gear *9*, then through roller *8* with sprocket *10* through flexible element *28*, the rotation is transmitted to wheel *26*, which rotates working roller *24*.

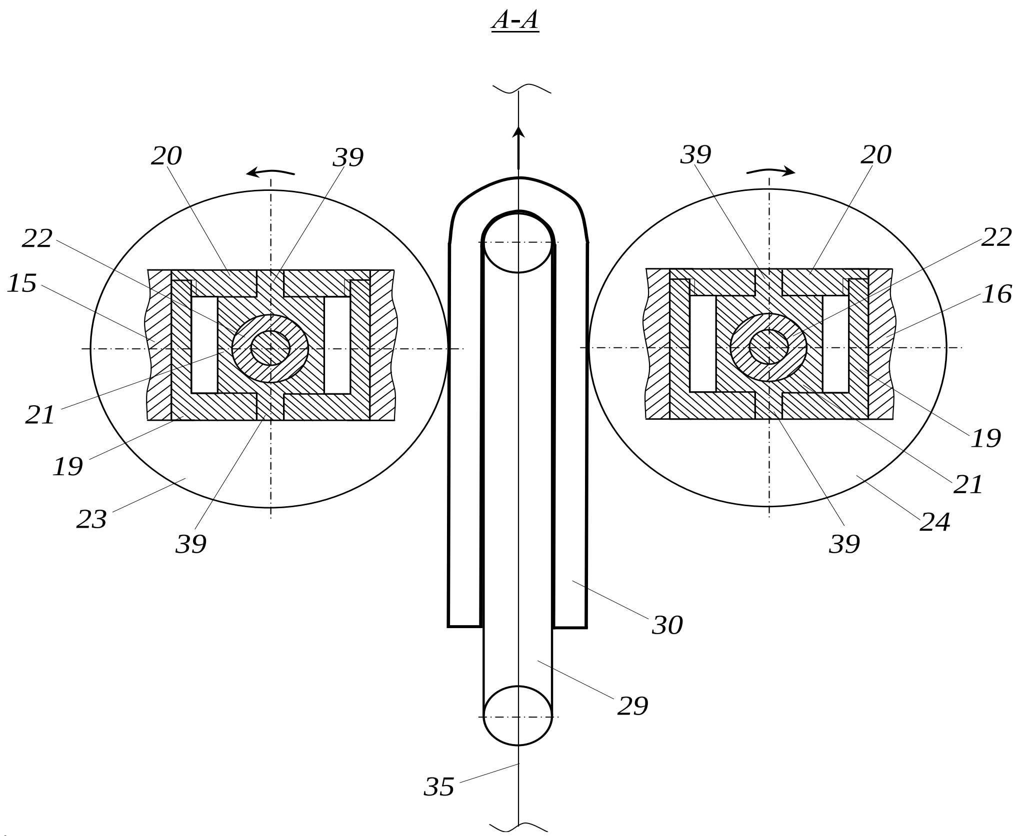


Figure 3.
Scheme of installation of axes of working bodies in supports.

Base plate *29* with skin *30* moves as follows. Rotation from roller *5*, gearbox *2* through sprockets *49*, and chains *47* is transmitted to sprocket *48*, mounted on axle *50*, from which rotation is transmitted to sprocket *43*, which rotates chains *35*, *55* mounted on sprockets *43*, *44*, *45*, *46*, *51*, *52*, *53*, *54*. Chains *35*, *55* pull base plate *29* with sheet material *30* for squeezing between working rollers *23*, *24*. Rotation synchronism is ensured due to symmetrical rotation feed to working rollers *23*, *24*. The installation of spherical roller bearings *22* on the supports of the working rollers *23*, *24* ensures their angle of rotation up to *5*°. The installation of bushing *21* with the possibility of their rotation around the cylindrical projections allows for significantly increasing the angle of rotation of working rollers *23*, *24*. This ensures the copyability of the topography of sheet material *30* with the wedge-shaped thickness along the feed width, which ultimately increases the pressing quality of processed sheet material *30*.

Implementation of the proposed roller machine expands the functional capability, allows for the significant expansion of the range of thicknesses of processed sheet materials, improves the quality of processing due to synchronous operation of working rollers, reduces wear of coatings of working rollers, increases the productivity of the roller machine, ensures reliability of operation of the drive of working rollers, and the possibility of using coatings for different thicknesses.

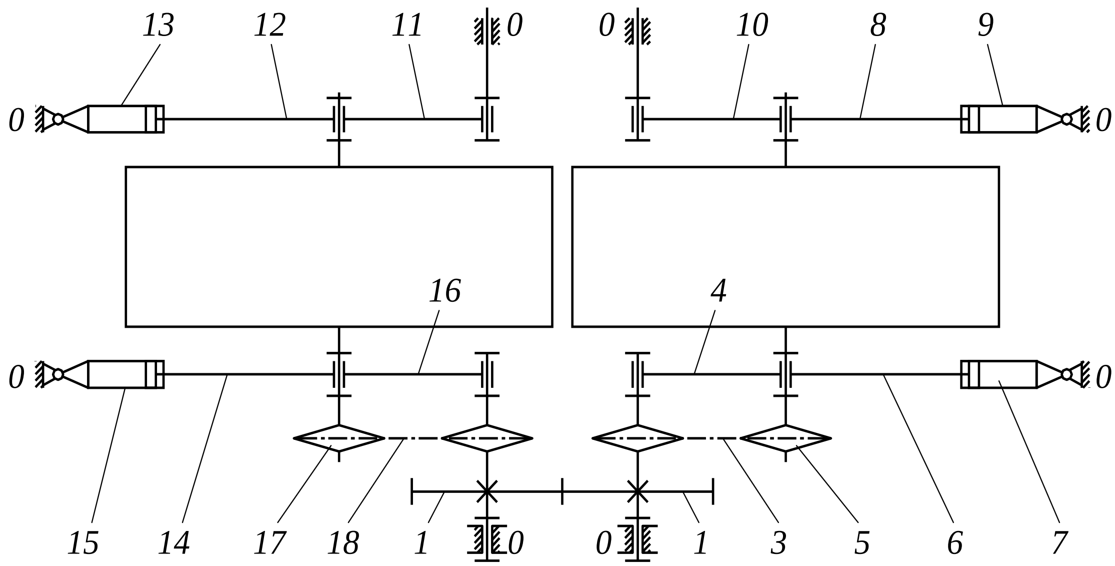


Figure 4.
Structural scheme of the drive mechanism of working bodies.

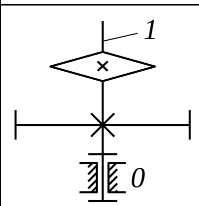
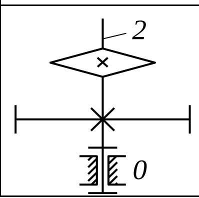
Consider the drive mechanism of working bodies of the roller machine shown in Fig. 4. The mechanism consists of 18 movable units located on the support. The degree of freedom of the mechanism is determined by the P.L. Chebyshev formula.

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

Here,
W is the dependence for determining the number of degrees of freedom of a plane mechanism;
n is the number of movable units;
P_{IV}, P_V are the numbers of kinematic pairs of the 5th and 4th classes, respectively.

We determine the number of units of the mechanism shown in scheme figure 4 (see Table).

Table 1.
Determination of the number of units of the drive mechanism.

No.	Kinematic pairs	Schemes of a kinematic pair	Class of a kinematic pair
1	*0→1*		P_V
2	*0→2*		P_V

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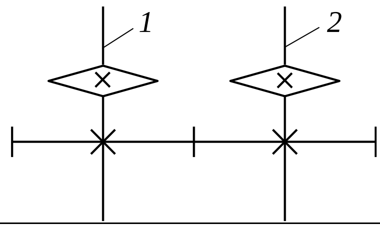
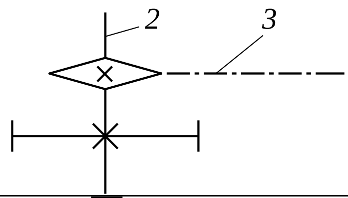
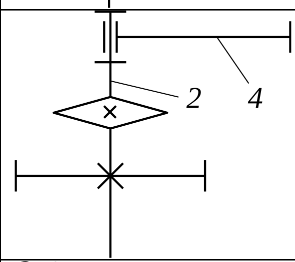
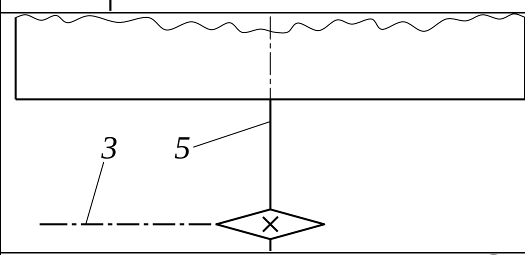
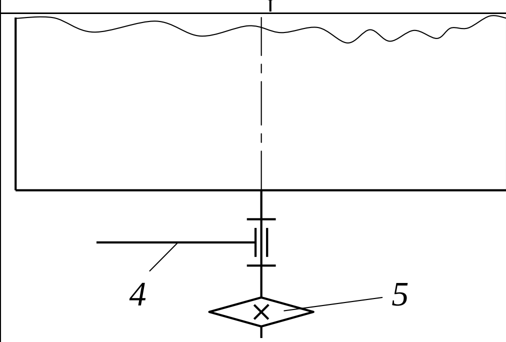
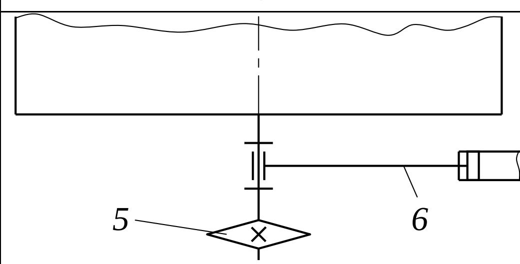
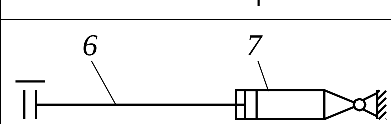
3	*1⟶2*		P_{IV}
4	*3⟶2*		P_{V}
5	*4⟶2*		P_{V}
6	*3⟶5*		P_{V}
7	*4⟶5*		P_{IV}
8	*5⟶6*		P_{V}
9	*6⟶7*		P_{V}

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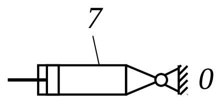
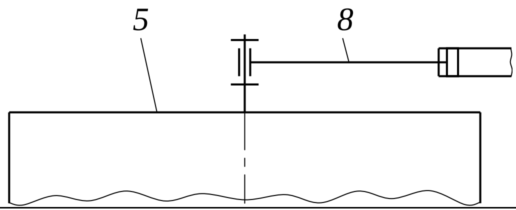
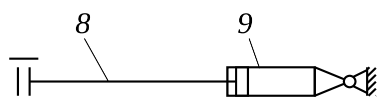
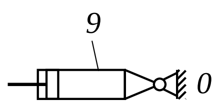
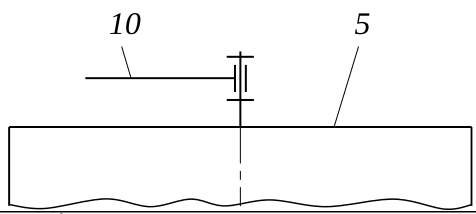
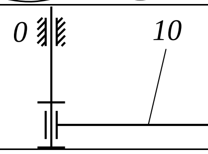
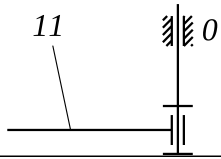
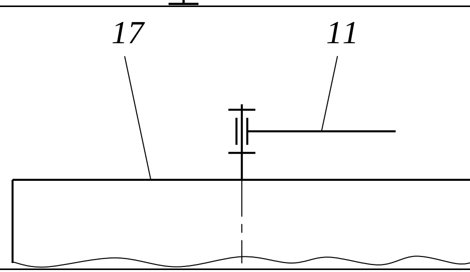
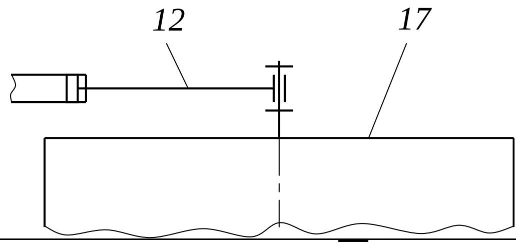
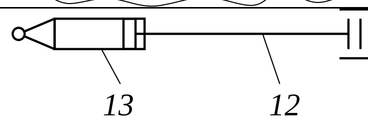
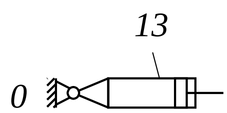
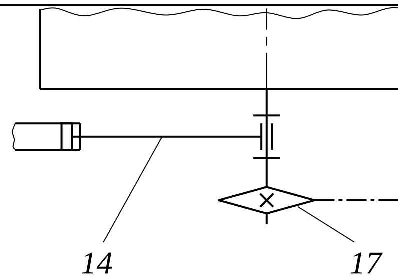
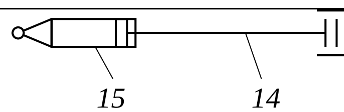
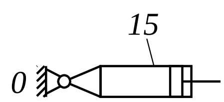
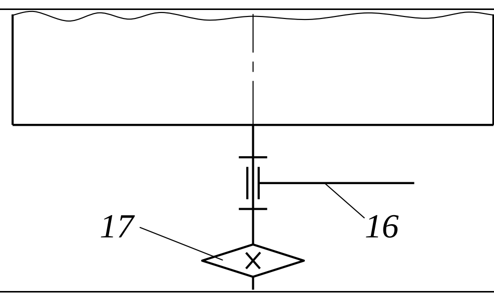
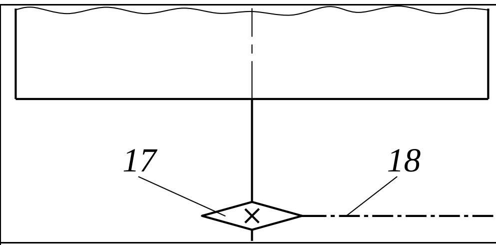
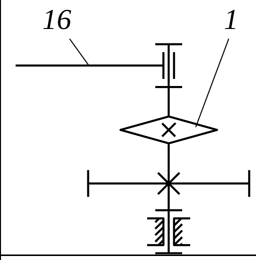
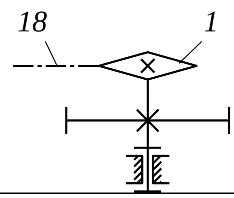
10	*7⟶0*		P_V
11	*5⟶8*		P_V
12	*9⟶8*		P_V
13	*9⟶0*		P_V
14	*10⟶5*		P_V
15	*10⟶0*		P_V
16	*11⟶0*		P_V
17	*17⟶11*		P_V

18	*12⟶17*		P_V
19	*12⟶13*		P_V
20	*0⟶13*		P_V
21	*14⟶17*		P_V
22	*15⟶14*		P_V
23	*0⟶15*		P_V
24	*17⟶16*		P_V

25	*17→18*		P_V
26	*16→1*		P_V
27	*18→1*		P_V

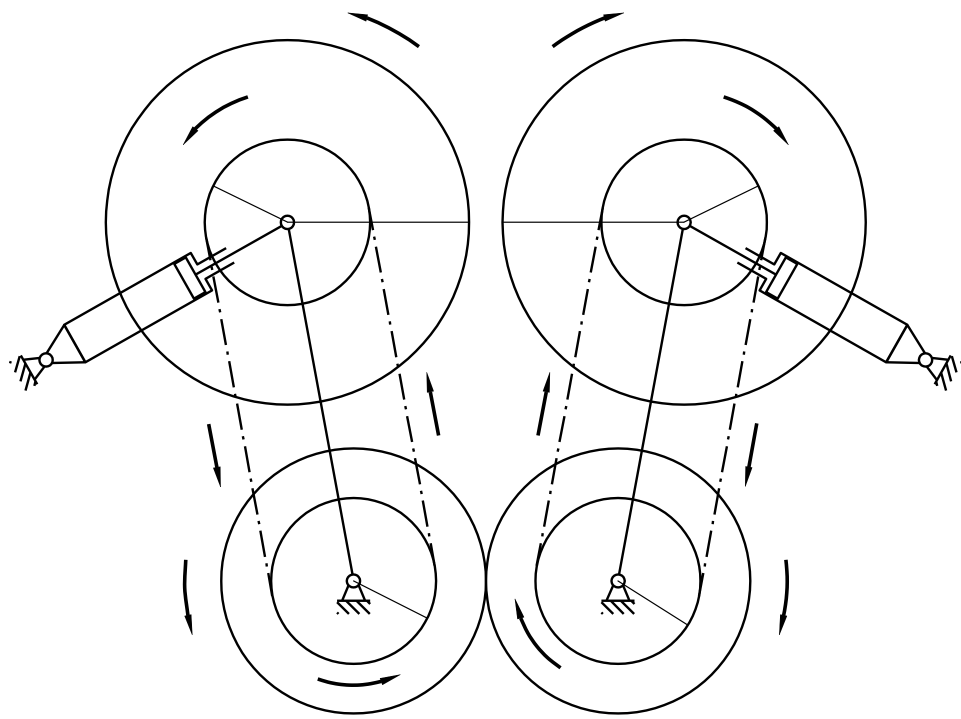


Figure 5.
Scheme of the direction of the main unit motion of the roller machine.

3. Results and Discussion

The mechanism shown in Fig. 4 has 18 movable units and 27 lever mechanisms. 26 units belong to the kinematic pair of class V and 1 kinematic pair to class IV.

$n = 18$

$P_V = 26$
$P_{IV} = 1$,
therefore,

$$W = 3n - 2P_V - P_{IV} = 3 \cdot 18 - 2 \cdot 26 - 1 = 1 \quad (1)$$

$$W = 1.$$

The operation principle of the drive mechanism of the working bodies is as follows.

The first gear 9 rotates counterclockwise at an angle of ω_9. The second gear 10 rotates clockwise with an angular velocity of ω_{10} when attached to the first gear. Sprockets 3, 9, 4, 10 are fixed to the gears. Symmetrically moving working rollers 1, 2 are driven by chain drives 7, 8. The working rollers are pulled to the base by levers. When the semi-finished product moves between the working rollers, it is compressed by hydraulic cylinders.

The roller machine is used to remove moisture from semi-finished products. The semi-finished product is taken out from the drum and undergoes the first processing operation in a roller press. The semi-finished product is attached to a special device and moves between the working rollers from the bottom to the top. The working rollers are pressed by hydraulic cylinders and excess moisture is removed from the leather semi-finished product. The linear velocities at the contact points of the working rollers and the semi-finished product are the same and their values are determined based on the initial settings established by the gears.

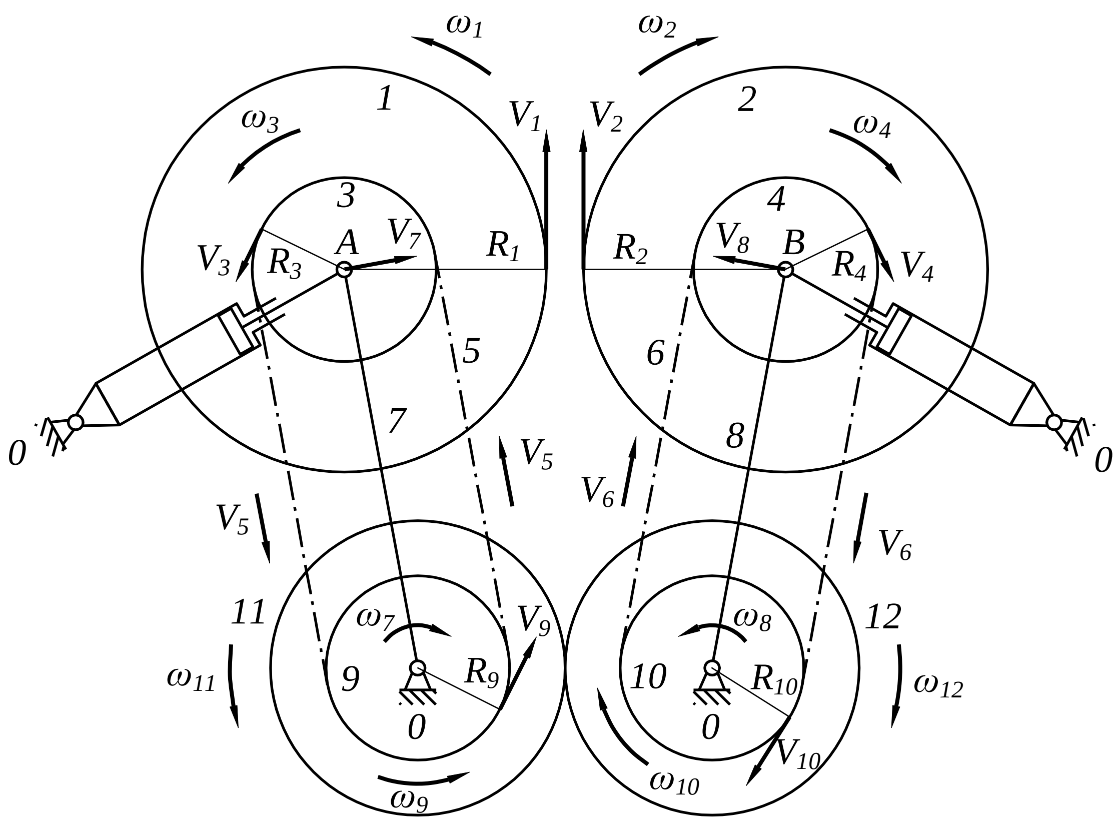


Figure 6.
Kinematic scheme of the drive mechanism.

Let us calculate the linear velocities of the first and second working bodies as they rotate around their axes.

$$V_1 = \omega_1 R_1 \quad (2)$$

$$V_2 = \omega_2 R_2 \quad . \tag{3}$$

We determine the linear velocities of the sprockets fixed at the output ends of the axes of the working bodies.

$$V_3 = \omega_3 R_3 \tag{4}$$

$$V_4 = \omega_4 * R_4 \quad . \tag{5}$$

Since the diameters of the sprockets are the same, the following velocities are also equal.

$$V_5 = V_3 = V_9 \tag{6}$$

$$V_6 = V_4 = V_{10} \quad . \tag{7}$$

We determine the linear velocities at points *A* and *B* of the seventh and eighth levers, respectively

$$V_7 = \omega_7 R_7 \tag{8}$$

$$V_8 = \omega_8 R_8 \quad . \tag{9}$$

We determine the linear velocities of the sprockets installed above the gears.

$$V_9 = \omega_9 R_9 \tag{10}$$

$$V_{10} = \omega_{10} R_{10} \quad . \tag{11}$$

We determine the linear velocities of the gears.

$$V_{11} = \omega_{11} R_{11} \tag{12}$$

$$V_{12} = \omega_{12} R_{12} \tag{13}$$

The angular velocities of the sprocket and the working body are $\omega_1 = \omega_3$ since they are fixed at a single end of the rotating axis.

$$\omega_1 = \omega_3 = \frac{V_3}{R_3}; \tag{14}$$

Since the radii of sprockets of the chain drive are equal, their linear velocities $V_3 = V_9$ will also be equal.
Therefore, formula (14) will have the following form:

$$\omega_1 = \frac{V_9}{R_3}; \tag{15}$$

according to formulas (10) and (15), the expression has the following form:

$$\omega_1 = \frac{\omega_9 R_9}{R_3} . \tag{16}$$

As follows from formula (15), since the radii of sprockets 3 and 9 are the sam1e, their peripheral velocities are $\omega_3 = \omega_9$ and, accordingly, considering that sprocket 9 is fixed above gear 11, we have the following expression:

$$\omega_9 = \omega_{11} . \tag{17}$$

As a result, we obtain the linear velocity of the contact points of the working bodies.

$$V_1 = \omega_1 R_1 .$$

$$\omega_1 = \omega_{11} .$$

$$V_1 = \omega_{11} R_1 \quad . \tag{18}$$

The linear velocities $V_1^{/}$ and $V_2^{/}$ are determined as:

$$V_1^{/} = V_1 \cdot \cos\alpha. \tag{19}$$

Substituting the values from (18) into (19), we obtain the following expressions:

$$V_1^{/} = \omega_{11} \cdot R_1 \cdot \cos\alpha \tag{20}$$

$$V_2^{/} = \omega_{12} \cdot R_2 \cdot \cos\alpha \quad . \tag{21}$$

An experimental prototype (Figure 7) was made according to the developed mechanism for driving the working bodies of a roller machine (of vertical type).

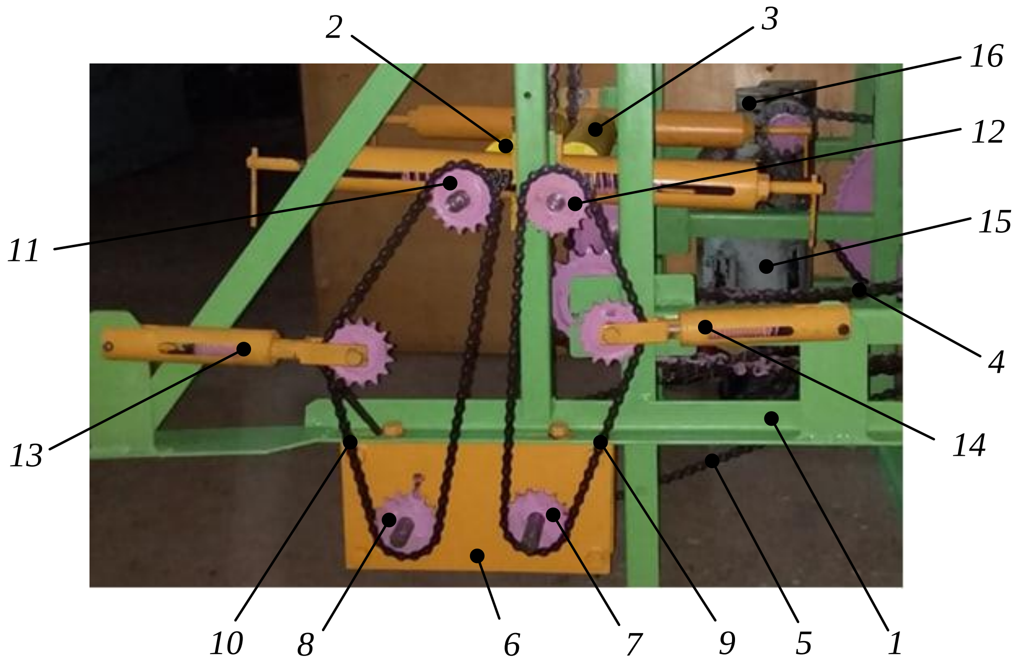


Figure 7.
View of the experimental prototype of the drive mechanism for the working bodies of the roller machine.

The setup shown in Figure 7 consists of frame 1, on which working rollers 2, 3 are installed, sprockets 11, 12 are rigidly fixed at the output ends of their axes. Chain conveyor 4 is driven by engine 15 and gearbox 16. The sprockets are fixed to the drive axle (not shown in the figure 7), from which the rotation is transmitted via chain 5 to the sprocket, by which the first gear and the second gear mounted in housing 6 are in constant engagement (not shown in the figure 7). The gears rotate in opposite directions. From each pinion axis, the rotation is transmitted first to sprocket 7, and then to sprocket 8. Then, the steady rotational motion is transmitted via chains 9, 10 to sprockets 11, 12 and they rotate working rollers 2, 3 in opposite directions, as seen in Figures 5 and 6. Figure 8 shows a graph of the dependence of the contact point velocities V on the angle α.

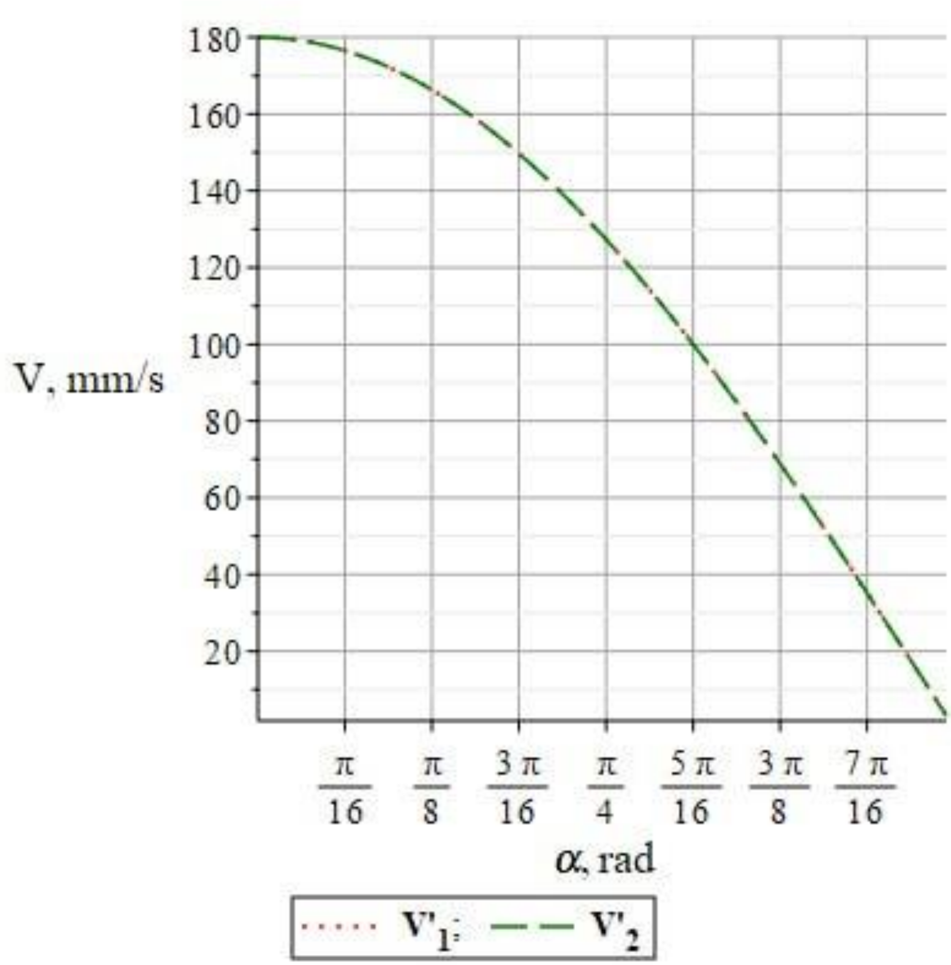


Figure 8.
Graph of the dependence of the contact point velocity V on angle α.

4. Conclusion

It has been established that the speed between the working elements and the processed fibrous material will change depending on the angular velocities of the gears, the diameters of the working elements.

It was determined that the velocities of the working units and the processed fibrous material change depending on the angular velocities of gears and the diameters of working units.

It was stated that the velocity between the working shafts and the semi-finished product changes depending on the angular velocities of the gear wheels, the diameters of the working shafts, and the cosine of the angle between the projections of their velocities V_1 and V_2 onto the axis. Since the angular velocities of the gear wheels are equal, $\omega_1=\omega_2$, the linear velocities of the contact points of the working shafts with the semi-finished product will also be equal, $V_1^{/}=V_2^{/}$.

The feed rate of the conveying device is important here. In this case, the quality of the processed raw material is improved, i.e., no excessive braking or other undesirable effects occur when raw material is conveyed between the rotating working shafts during its processing.

According to formulas (20) and (21), obtained from the above-mentioned theoretical studies, the velocities of the transmission mechanism's characteristic points were determined by numerical solutions, and a graph was plotted (Figure 8).

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