Design and methods for calculating the parameters of a machine for cleaning wool from vegetable impurities

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Abstract. The article presents an effective scheme and principle of operation of the device, working bodies, drive mechanisms of machines for cleaning wool from vegetable impurities. Theory - experimental studies have obtained the laws of motion of the peg feeder, saw cylinder, impact roller, take-off drum, motor shaft, the main parameters of the device for cleaning wool from plant impurities are substantiated. Based on the results of comparative production tests, recommendations were developed for introducing the developed machine into production.

1. Introduction

In the world, much attention is paid to improving the quality of the production of wool and products from it, knitted materials, fabrics through the use of new technologies in their production [1]. At the same time, it is possible to include countries where the textile industry is intensively developing, including South Asia, East Asia, the CIS, the USA and European countries.

In animal husbandry from farmed sheep and goat wool, wool processing and production has an important place in the country's economy. It is important to improve the technique and technology for obtaining high-quality wool, by ensuring their purification from plant impurities. The full use of the created opportunities for the implementation of measures for the production of high-quality, import-substituting wool products, the satisfaction of everyday needs for consumer goods, the production of form- stable products, and an increase in their range are one of the urgent modern problems.

To improve the technique and technology for processing wool and conducting research while preserving the natural properties of wool, the world's leading scientists S.S.Diwan, J.F.Morrison [2], A.A.Ugryumov [3], V.K.Afanasiev [4], L.S.Gorbunova, Ya.Ya.Lipenkov [5], A.M.Domashinko, V.I.Bezrukov, N.I.Shleudyakov, YE.V.Gryaznova, YE.V.Kolpakov [6], M.Kulmetov [7], A.Dzhuraev [8,9] and others.

Existing studies were mainly aimed at studying the specific features of wool, improving the processes of washing, combing, chemical treatment in wool processing technology. At the same time, studies on the development of new technologies and the creation of resource-saving, effective designs of wool cleaners from prickly vegetable impurities are not sufficiently given. Therefore, the improvement of the design of machines for cleaning wool from plant impurities is the basis for conducting research to justify the parameters and modes of operation, taking into account the characteristics of wool.

2. Methods

Based on the analysis of the state of the issue, new resource-saving design schemes of the machine for cleaning wool from plant impurities, an effective design of the removable drum of a bundle of wool fibers from the teeth of the saw cylinder of the cleaning machine were developed, and new schemes and principles of operation of belt drives with composite pulleys that provide variable modes of motion were developed. working bodies. On fig. 1 shows a diagram of the recommended machine for cleaning wool from vegetable impurities.

Wool with rubbish is fed to the feed hopper 6. As a result of the rotation of the peg feed roller 2, part of the wool is fed evenly to the serrated cylinder 9. In this case, the wool is fed to the serrated cylinder 3 with the help of a stringing brush 7. Part of the wool is hooked by the teeth 3 of the serrated cylinder 9, weed impurities are partially separated when

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interacting with the grate 8, the remaining litter is separated from the wool with the help of a breaker roller 5. Part of the woolen fibers captured by the teeth 3 of the saw is removed from the teeth of the saws with the help of a separating brush drum 4. The introduction of the proposed design into production increases the efficiency of cleaning wool from plant impurities, and also reduces the consumption of metal and energy.

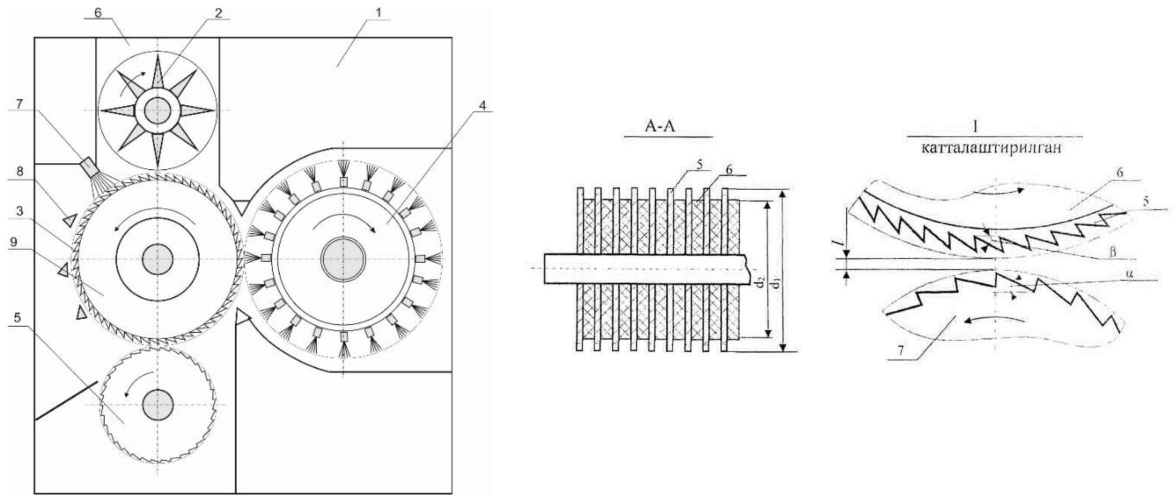


Fig. 1. Installation for cleaning wool from vegetable impurities

If the composition of wool contains a large amount of plant impurities with hornheads and burdocks, a new scheme for the design of a wool cleaner has been developed to clean wool from them (Fig. 2). During operation, the fibrous material with vegetable impurities enter the ring drum 4 with the help of a conveyor 2 and a feed roller 3.

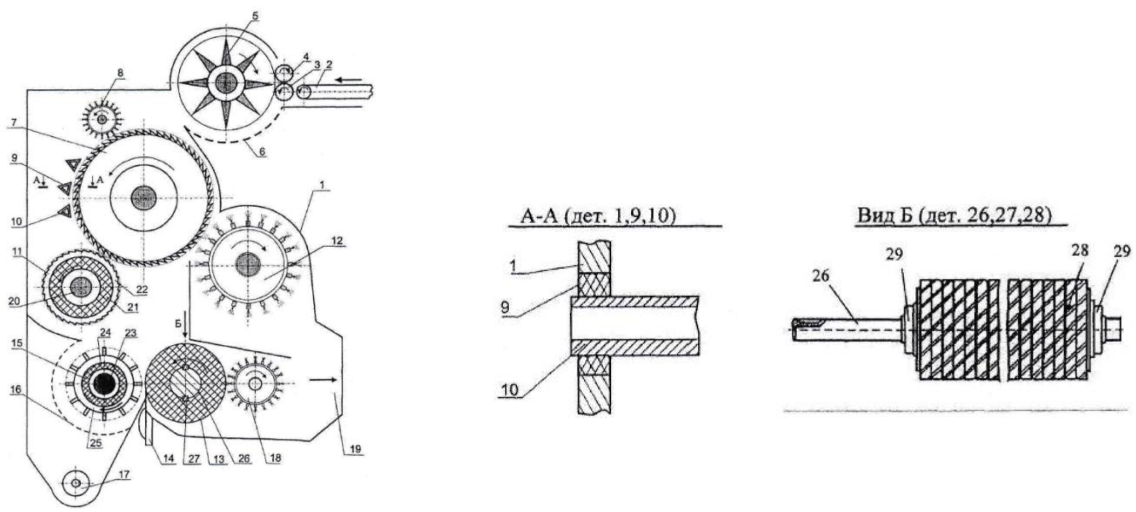


Fig. 2. Machine for cleaning wool from vegetable impurities

The ring drum 4 drags the wool fibers over the mesh surface 6. At the same time, various small litters fall out through the holes of the mesh 6. Then the loosened wool descends to the surface of the saw cylinder 7. The brush roller 8 provides a uniform supply of wool and hooks them to the teeth of the saw cylinder 7. Wool fibers, captured by the teeth of the saw cylinder 7, hitting and passing through the grate 9 oscillating due to the elastic element 10. This allows you to intensively release weed impurities from the wool. However, coarse vegetable matter remains with the wool fibers and continues to move with the serrate cylinder 7. These coarse vegetable mixtures are contacted by the impact roller 11 and separated from the wool. Woolen fibers captured by the teeth of the serrated cylinder 7 are removed by the brush drum 12. Part of the wool fibers enter the working drum 13, the surface of which is made of rubber -leather material. The woolen fiber hooked to the surface of the working drum 13 passes behind the fixed knife 14 and large plant impurities are separated by a 25 impact roller and descend to the 17 weed auger. zone. Woolen fibers from the surface of the working roller 13 are removed with a brush roller 18.

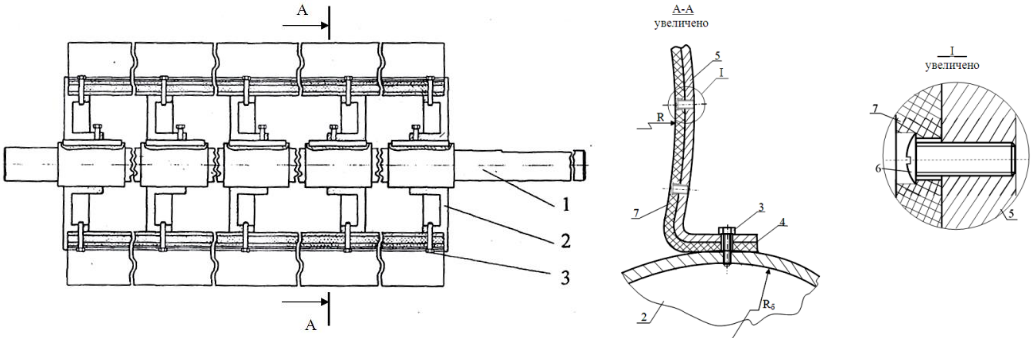
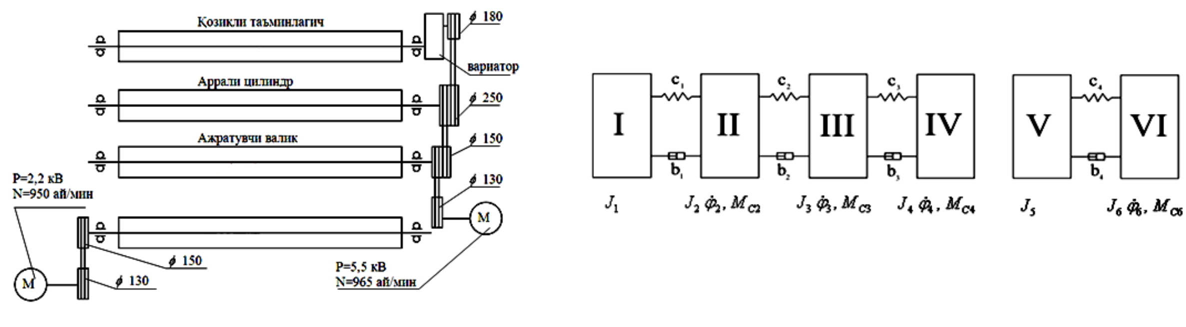


Fig.3. Removable drum

During the operation of the machine, it is important to effectively separate the cleaned wool fibers from the saw teeth. For this, a new design (Fig. 3) is recommended instead of a removable brush roller. The design consists of a disk 2 fixed to the shaft 1. A strip 4 is fixed to the disk 2 with the help of a bolt 3. The strip 4 consists of concave elastic plates 5 and plates 7 glued and additionally fixed with a screw 6 to it with a rubber -fabric gasket. The protruding part of the plate 5 and the rubber -fabric gasket 4 are additionally bent along the radius R_0(here $R=R_b$, R_b=drum radius).

To determine the patterns of movement of the working bodies, peg feeder, serrated removable drum, as well as the rotor of the electric motor, according to the kinematic diagram of machines for cleaning wool from plant impurities (Fig. 4a), a design scheme of the system presented in Fig. 4a was compiled 4b.



a) *b)*

Fig. 4. Kinematic scheme of the cleaning machine (a) and design schemes of machine units (b): *I is the mass of the rotor of the engine and the drive pulley; II - the mass of the impact roller; III - mass of the saw cylinder; IV - weight of the peg feeder; V is the mass of the motor shaft; VI is the mass of the slatted drum*

Using the Lagrange equations of the II -kind, a system of differential equations for the movement of working bodies is derived for a four- mass system:

$$
\begin{aligned}
&M_g = f(\dot{\varphi}_1); J_1\ddot{\varphi}_1 = M_g - b_1\Delta\dot{\varphi}_1 - c_1\Delta\varphi_1; \; J_2\ddot{\varphi}_2 = U_{12}(b_1\Delta\dot{\varphi}_1 + c_1\Delta\varphi_1) - b_2\Delta\dot{\varphi}_2 - c_2\Delta\varphi_2 - M_{c2};\\
&J_3\ddot{\varphi}_3 = U_{23}(b_2\Delta\dot{\varphi}_2 + c_2\Delta\varphi_2) - b_3\Delta\dot{\varphi}_3 - c_3\Delta\varphi_3 - M_{c3};\\
&J_4\ddot{\varphi}_4 = U_{34}(b_3\Delta\dot{\varphi}_3 + c_3\Delta\varphi_3) - M_{c4}
\end{aligned}
\tag{1}
$$

here $\Delta\varphi_1 = \varphi_1 - U_{12}\varphi_2;\; \Delta\dot{\varphi}_1 = \dot{\varphi}_1 - U_{12}\dot{\varphi}_2;$

$\Delta\varphi_2 = \varphi_2 - U_{23}\varphi_3;\; \Delta\dot{\varphi}_2 = \dot{\varphi}_2 - U_{13}\dot{\varphi}_3;\quad \Delta\varphi_3 = \varphi_3 - U_{34}\varphi_4;\; \Delta\dot{\varphi}_3 = \dot{\varphi}_3 - U_{34}\dot{\varphi}_4;$

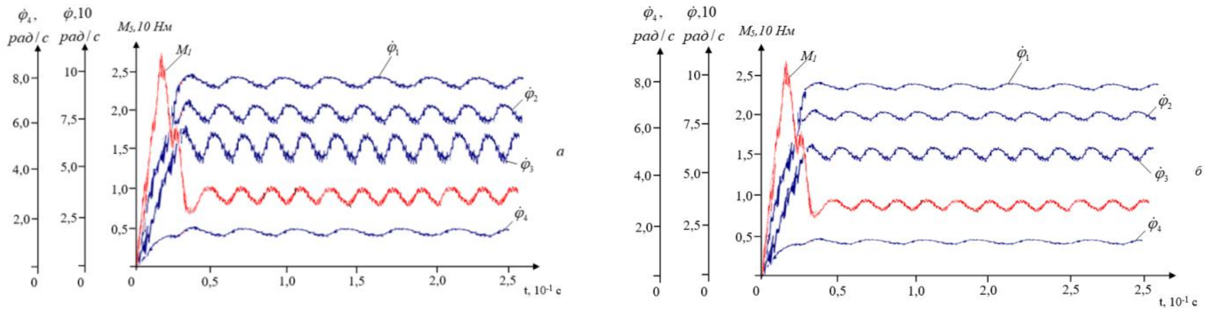
For the movement system of the removable wool drum

$$
\begin{aligned}
&M_g = f(\dot{\varphi}_5); J_5\ddot{\varphi}_5 = M_g - b_4\Delta\dot{\varphi}_4 - c_4\Delta\varphi_4;\\
&J_6\ddot{\varphi}_6 = U_{56}(b_4\Delta\dot{\varphi}_4 + c_4\Delta\varphi_4) - M_{c6};\\
&\Delta\varphi_4 = \varphi_4 - U_{45}\varphi_5;\; \Delta\dot{\varphi}_4 = \dot{\varphi}_4 - U_{45}\dot{\varphi}_5;
\end{aligned}
\tag{2}
$$

where, M_g, $\dot{\varphi}_1$, $\dot{\varphi}_5$ - drive moments and angular velocities in the shafts of electric motors; $\dot{\varphi}_2$, $\dot{\varphi}_3$, $\dot{\varphi}_4$, $\dot{\varphi}_6$ - angular velocities of the shaft of the breaker drum of the wool cleaner; saw cylinder of a ring feeder and a drum that hooks the wool; b_1, b_2, b_3, b_4 - respectively, the coefficients of dissipation of belt drives; c_1, c_2, c_3, c_4 - respectively, the coefficients of rigidity of the belt drive; $U_{12}, U_{23}, U_{34}, U_{56}$ - gear ratios of belt drives; $M_{c2}, M_{c3}, M_{c4}, M_{c6}$ - moments of resistance on the shafts.

3. Results

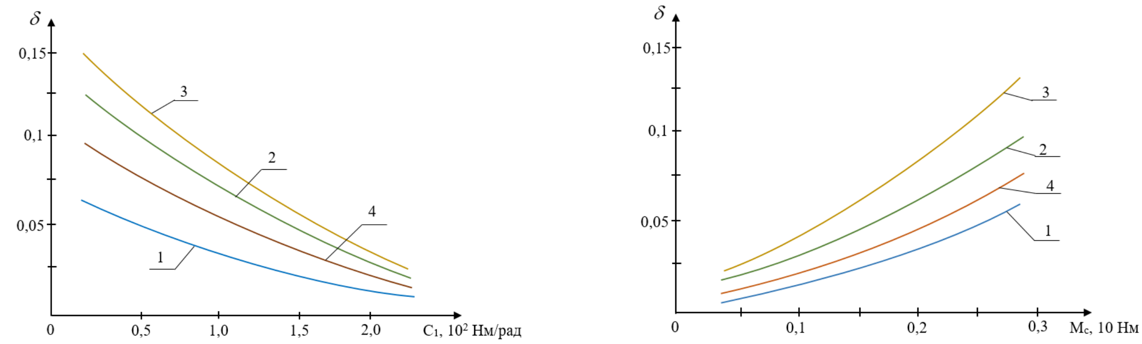
As a result of the numerical solution of differential equations (1) and (2), the laws of motion of the working bodies (Fig. 5) and graphic dependencies (Fig. 6 and 7) were determined.



a-at $\dot{\varphi}_{4mi} = 1{,}67 rad/c$; $c_1 = 210\frac{H \cdot m}{rad}$; $c_2 = 180\frac{H \cdot m}{рад}$; $c_3 = 150\frac{H \cdot m}{рад}$; $J_2 = 0{,}141\ kg \cdot m^2$; $J_3 = 0{,}21 kg \cdot m^2$; $J_4 = 0{,}064 kg \cdot m^2$; $M_{C2} = 14{,}8 H \cdot m$; $M_{C3} = 21 H \cdot m$; $M_{C4} = 28 H \cdot m$

b-at $\dot{\varphi}_{4mi} = 1{,}67 rad/s$; $c_1 = 250\frac{N \cdot m}{rad}$; $c_2 = 205\frac{N \cdot m}{rad}$; $c_3 = 175\frac{N \cdot m}{rad}$; $J_2 = 0{,}16 kg \cdot m^2$; $J_3 = 0{,}25 kg \cdot m^2$; $J_4 = 0{,}11 kg \cdot m^2$; $M_{C2} = 14{,}8 N \cdot m$; $M_{C3} = 21 N \cdot m$; $M_{C4} = 28 N \cdot m$

Fig. 5. Patterns of change in the angular velocities of the drive shafts, the breaking drum, the saw cylinder and the peg feeder of the machine unit of the wool cleaner from vegetable impurities, as well as the law of change in the torque of the drive shaft



1 - $\delta_1 = f(C_1)$; 2 - $\delta_2 = f(C_1)$; 3 - $\delta_3 = f(C_1)$; 4 - $\delta_4 = f(C_1)$;

a) graphical dependences of the coefficients of unevenness of the angular velocities of the shafts of the machine unit, depending on the change in the stiffness coefficient of the belt drive from the engine to the shaft of the doffing drum

1 - $\delta_1 = f(M_4)$; 2 - $\delta_2 = f(M_4)$; 3 - $\delta_3 = f(M_4)$; 4 - $\delta_4 = f(M_4)$;

b) graphical dependences of the coefficients of unevenness of the angular velocities of the shafts of the machine unit, depending on the change in the moment of resistance on the shaft of the peg feeder

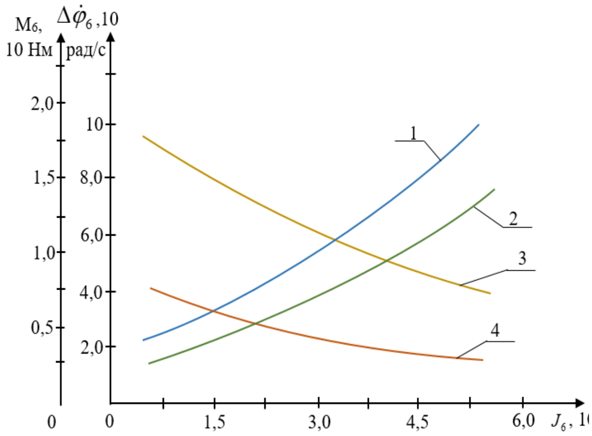
Fig. 6. Graphic dependences of the change in the unevenness of the angular velocities of the drive shafts, the breaking drum, the saw cylinder and the peg feeder of the machine unit of the wool cleaner from vegetable impurities from the change in the moment of resistance from wool

From the laws of motion of the working bodies shown in Fig. 5, it can be seen that when the resistance from the wool being cleaned to the ring feeder is 28Nm , the amplitude of fluctuations of its angular velocity $\dot{\varphi}_4 = 1{,}9\, rad/s$ and $A_{\dot{\varphi}4} = (5{,}0 \div 8{,}0)\cdot 10^{-2} rad/s$. Also, with an average angular speed of the saw cylinder $\dot{\varphi}_3 = 52{,}3 \quad rad/s$ and, accordingly, with a load on the shaft of the breaking drum of 14.8 Nm , the amplitude of the angular velocity fluctuations will change within (1.8÷2.1)·10 $^{-2}$ rad/s. If the random component of the resistance changes within ±(6.0÷8.0)%, then its influence on the nature of the oscillations of the angular velocity is not significant. It should be noted that the torque on the motor shaft varies within (4.5÷9.7) Nm , with an increase (Fig. 5) of the circular stiffness of the belt transmission of the transmitting movement from the engine to the shaft of the removable drum. When changing the circular stiffness of the belt drive from 0.21·10^{2}Nm/rad up to 2.26·10 ^{2} Nm / rad, the coefficient of unevenness of the angular speed of the saw cylinder decreases according to a non-linear law from 0.15 to 0.026 (Fig. 6).

Based on the analysis of the graphs (Fig. 6 and Fig. 7), also taking into account the results of experiments to ensure the necessary fluctuations in the angular velocities of the shafts, the following parameters of machine units are recommended: $J_1=0.018\ kgm^2$; $J_2=(0.15\div0.16)\ kgm^2$; $J_3=(0.22\div0.24)\ kgm^2$; $J_4=(0.06\div0.08)\ kgm^2$; $c_1=(230\div250)$ Nm/rad; $c_2=(180\div200)$ Nm/rad; $c_3=(160\div170)$ Nm/rad, while providing $\delta_3\leq(0.1\div0.12)$; $\delta_2\leq(0.08\div0.09)$.

In a machine for cleaning wool from vegetable impurities, a drum with elastic plates and rubber -fabric pads is recommended for removing a bundle of cleaned wool captured by a saw cylinder. The nature of the movement of the drum is determined on the basis of solving the problem of two mass machine units. Based on the solution of the problem, the nature of the change in $\dot{\varphi}_5$, $\dot{\varphi}_6$ M$_5$. The analyzes obtained graphs of the change in the range of oscillations of the angular velocities of the shaft of the electric motor and the impact drum of the wool and the change in the average values of torques depending on the moments of inertia of the masses (Fig. 7). An increase in the moments of inertia reduces the range of speed fluctuations, leads to an increase in loading (Fig. 7). Based on the analysis, the following parameters of the machine unit are recommended: $J_5=(0.0134\div0.014)kg\cdot m^2$; $J_6=(0.018\div0.026)kg\cdot m^2$; $c=(240\div260)N\cdot m/rad$; $M_{C6}=(3.8\div5.2)\sin 23.1t$.

The radial plane of the removable drum of the machine for cleaning wool from vegetable impurities, the force of removal of wool fibers will be different. Also, the acting force on the fibers will be different and the time of movement of the wool on the surface of the plates will be different. Therefore, the movement of a bundle of wool fibers is analyzed when the inclination of the plates changes.



$1{,}2 - M_6 = f(J_6)$; $3{,}4 - \Delta\dot{\varphi}_6 = f(J_6)$;
$1{,}3 - M_{C6} = 30 \pm 2{,}5\ N\cdot m$;
$2{,}4 - M_{C6} = 20 \pm 1{,}6\ N\cdot m$;

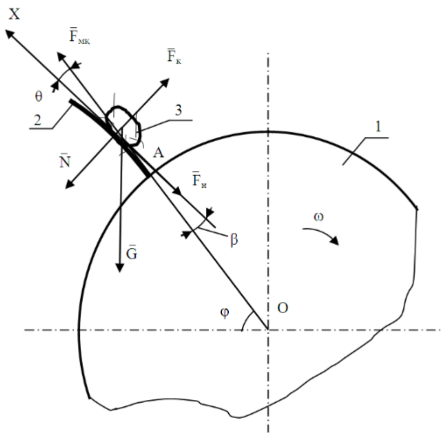
Fig. 7. Dependences of the change in the range of oscillations of the angular velocity and the loading of the removable wool drum depending on its moment of inertia

At different angles of deviation of the elastic plates relative to the surface of the plate, the following forces act on the bundle of wool fibers: F_c - centrifugal force, F_{cor} - Coriolis force, G_x - weight force of the bundle of wool fibers, F_{tr}- friction force of the bundle of wool fibers on the surface plates (Fig. 8a).

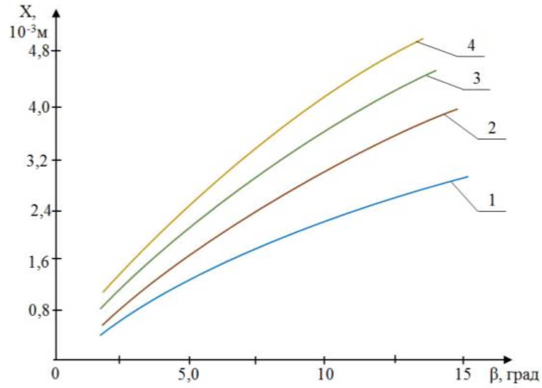
According to the Dalembert principle, an equation was obtained for the relative motion of a bundle of wool fibers on the surface of the plate:

$$m\ddot{x} = -G - F_u + F_{мк} \qquad (3)$$

Wherein: $$F = fmg\cos(\theta - \varphi) - fmg\sin\theta;$$ $G = mg\cos(\pi/2+\theta-\varphi)$; $F_{TP} = mV^2/R + x\cos\theta$. Here: m- is the mass of a bundle of wool fibers, 0.2-0.25·10^{-6} kg; g - free fall acceleration, 9.8 m/s^2; φ - angular displacement of the drum plate; *V* is the portable speed of the bundle of wool fibers; *X* -is the displacement of a bundle of wool fibers relative to the surface of the plate. Initial values of parameters: *m=0.2-0.35·10* $^{-6}$ *kg; g=9.81 m/s*^{2}*; R=0.16 m; ω=87.1 rad/s*, coefficient of friction of wool on the splitter f=0.3-0.45. As a result of the analysis of the solution of the problem, the nature of the movement of a bundle of woolen fibers was obtained from a change in the angular velocity of the drum and the values of the angle of inclination of the plate.



1-drum, 2-elastic plate, 3-bundle of wool fibers.
a-scheme of the removable drum of the wool cleaner from vegetable impurities



1-ω=70 rad/s; 2- ω=78 rad/s; ω=87.1 rad/s; 4- ω=93 rad/s;
b-graphs of the dependence of the change in the displacement of a bundle of wool fibers on the surface of an elastic plate on the angle of its inclination

Fig. 8. Calculation scheme and graphic dependences of parameters

Based on the analysis of the graphs (Fig. 8b), it should be noted that an increase in the angle of inclination of the plates will lead to an increase in the travel distance. At the same time, with an increase in the angle of inclination from 2.5^0 to 13^0 at *ω*=70 rad/s, the displacement of the bundle of woolen fibers increases from 0.9·10^{-3} m to 2.6·10^{-3} m according to a non-linear law. At*ω*=90 rad/s, the travel distance increases according to a non-linear law from 1.1·10^{-3} m to 5.05·10^{-3} m.

Therefore, to remove a bundle of wool fibers from the teeth of saw cylinders, the following values of parameters are recommended: At the same time, the movement of the bundle of wool fibers does not exceed (2.2÷2.6)·10^{-6} m and the necessary removal of the bundle of fibers by an elastic plate and is transferred to the aerodynamic transport zone.

The results of experimental studies of a wool cleaning machine from plant impurities were given experiments to determine the force of separation of plant impurities from wool fibers, to obtain the nature of the load change in the drive shaft of the machine's belt drive, and to substantiate the parameters based on full- factor experiments and production tests. The force of separation of wool from plant impurities was measured on a special modernized measuring unit. The measurement results are shown in Table 1.

Table 1. Breaking strength and elongation of wool when separated from vegetable impurities

t/r	Group of wool fibers by its thickness	Breaking force (N)	Elongation at break (10^{-2} m)	Wool fiber quantity (pcs)
	With a full girth of wool fibers and burdock			
1.	Fine-fiber	8.3	1.5	twenty
2.	Fine-fiber	60	3	160
3.	coarse fibrous	22	1.6	80
4.	coarse fibrous	nine	0.7	40
	With a half girth of burdocks with woolen fibers			
1.	Fine-fiber	2.42	2	120
2.	coarse fibrous	1.2	0.8	80

With an increase in the amount of fine-fibered wool from 18 to 156, the tear-off force from the burdock increases from 4.2 N to 21.3 N; the wool completely embraces the burdock; with fine-fibered wool, the separation force increases from

7.1 N to 42.2 N; with coarse-fibered wool, this figure increases from 12.4 N to 158 N. At the same time, the elongation of fine-fibered wool at break reaches up to 3.0sm, then for coarse wool it reaches up to 1.6 sm.

Designs of belt drives are recommended for use in the drive of a machine for cleaning wool from vegetable impurities. At the same time, due to the elastic element of the drive pulley, the maximum amplitude of load oscillations on the shaft decreases. As a result, uniform operation of the working bodies of the machine is ensured. In experiments, the loading of the saw cylinder shaft was measured at various capacities using the recommended belt drive.

An analysis of the obtained oscillograms showed that the torque fluctuations directly depend on the circular stiffness of the rubber bushing of the composite pulley. When the rubber bushing is made of rubber grade 1338, the amplitude of torque fluctuations is within (8.2÷9.3) Nm, and with rubber grade 1338 it is within (6.1÷7.0) Nm. Therefore, in the drive pulley of the recommended belt drive, it is advisable to use rubber grade 3820 MVS S, which has a circular stiffness of (230÷280) Nm/rad.

On the basis of full- factorial experiments, a regression equation was obtained:

$$Y_1 = 81.487 - 0.104x_1 + 0.954x_2 - 0.02x_3 - 0.246x_1x_2 + 0.237x_1x_3 + 0.046x_2x_3 - 0.012x_1x_2x_3 \quad (4)$$

Rational input parameters were determined: productivity 70 kg/h, rigidity of the elastic support $2.8 \cdot 10^{-3}$ N/m, distance between the saw cylinder and the grate $-7 \cdot 10^{-3}$ m. With these values of the factors, the efficiency of cleaning wool from plant impurities on the machine will be higher than 82% -83%.

The recommended machine for cleaning wool from vegetable impurities has been tested under production conditions. In the process of testing, the recommended machine for cleaning wool from vegetable impurities showed high reliability and the necessary cleaning effect. The cleaning effect relative to the existing structure increased on average by 17.2%, the mechanical damage to the wool fiber decreased by 4.2%, and the fiber in weed impurities decreased to 8.5-10.5%.

4. Conclusions

Efficient resource-saving designs of machines for cleaning wool from vegetable impurities have been developed. The design of the drum for separating the bundle of wool fibers from the teeth of the saw cylinder of the cleaning machine is recommended. The nature of the movement of the saw cylinder, the breaking drum, which separates the wool from the teeth of the saw cylinder and motor shafts, is determined. Graphs of the dependence of the range of oscillations of the angular velocities of the shafts of the machine unit on the change in the moments of inertia of the impact shaft and the saw cylinder are obtained. The problem of fluctuations of the grate is solved by the analytical method, taking into account various forms of load: uniform, impulsive and in the form of a portion acting when cleaning wool. Graphs of the dependences of the change in the maximum displacement of the trihedral grate on the increase in the technological resistance of the cleaned wool are constructed. To ensure the amplitude of oscillations within $(1.1\text{-}1.5)10^{-3}$m, a rubber support with a stiffness coefficient of $C=(2.5 \ldots 4.5)10^{-3}$ N/m is recommended and mass m=(0.25...0.3)kg. Based on the analysis, the condition of uniform supply of wool to the cleaning zone, $F(t) \leq [(5.5\div6.0)\pm(0.55\div0.6)]$N was determined. The dependences of the change in the force of separation of wool fibers from plant impurities were determined, in particular from spines, taking into account the number of fibers. To reduce the amplitude of torque oscillations on the saw cylinder shaft, rubber grade 3820 MVS S with circular stiffness (230÷280) Nm/rad is recommended. On the basis of full- factorial experiments, the following values of the parameters are substantiated: productivity -70 kg/h; rigidity of the elastic support $2.8 \cdot 10^{-3}$ N/m; distance between saw cylinder and grate, 7 mm. At the same time, the efficiency of cleaning wool from vegetable impurities is 81% -83%.

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