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REDUCTION OF ELECTRICITY EXPENDITURE OF THE ROLLER DEVICE FOR THE RECYCLING OF POLYMERIC MATERIALS BY OPTIMIZATION OF PARAMETERS

Summary: The dynamic calculation of the loads arising during the recycling of polymeric material in a roller device, carried out in the work, allowed to determine the main technological and structural parameters that affect the power consumed by this device. The analytical expressions, which connected the basic parameters of the roller device with the stress-strain state created in the polymeric material, were obtained. For the first time, for such devices, the physical and mechanical characteristics of the polymer were taken into account.
The mathematical model of the process of polymer material recycling in a roller device, which takes into account the dynamics of the interaction of toothed rollers and the physical and mechanical properties of the polymeric material that was developed, allowed us to determine the optimal technological and structural parameters of the roller device, in which the electrical energy consumption would be minimal.
The method of optimization of technological and structural parameters of a roller device, which provided the minimum power consumption, was proposed. Using the obtained laws, it was possible to determine the basic technological and structural parameters of rollers, which with minimal electric energy consumption create a deformation in which the spheruline structure of the polymeric material is oriented and the connections between the conglomerate oriented spherulites are destroyed.

Key words: polymer waste, tension, deformation, fracture, roller device, power.

1. THE RESEARCH TASKS AND URGENCY

In previous works [3-5] the process of transformation of the spheruline structure into the oriented structure of the conglomerates of the extracted spherulites was studied, dependences between the relative deformations of the polymer material and the spherulites were obtained [3].

In the work [6], there was proposed a prototype of equipment for recycling of polymer waste, consisting of: a toothed roller that provides stretching of the polymeric material in the direction of its feed and compression in the transverse direction to the feed; From rollers made of the Relo profile, which provide stretching and shear of the polymeric material in the direction of its feed and

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compression in the transverse direction to the feed; The needle-cutter, which provides shredding of a polymeric material, in which the connections between the conglomerate of the spherulites are destroyed as a result of material processing by the two previous nodes. In the work [6], the basic structural parameters of the gear rollers, which are created in the processed polymeric material, deformation of stretching and compression, which destroy its structure, were calculated.

Nowadays in the world there is an acute problem of saving energy resources, in particular electricity. In this regard, when designing equipment for the recycling of polymer waste, attention should be paid to optimizing its parameters that affect the consumption of electrical energy.

In order to reduce the cost of electricity we will solve the problem, which is that, given the productivity of the roller device, it is necessary to optimize its basic technological and structural parameters, in which the power used for deformation, in which the spheruline structure is drawn, and the connections between the conglomerates of oriented spherulites are destroyed, would be minimal.

In this work, we will consider a node consisting of toothed rollers, between which a polymeric material passes. The toothed rollers, scrolling, create a tensile stress in the polymeric material, under the influence of which the structure of the polymer is strongly oriented, and compression tensions that destroy the bonds between the conglomerates of the elongated spherulites.

Thus, the purpose of this study is to analyze the influence of the main technological and structural parameters of the roller device on the power consumed by it, and, on the basis of the obtained dependencies, the development of a method for optimizing the technological and structural parameters of the roller device to reduce the cost of electric energy.

2. THE RESEARCH METHODOLOGY

During the passage of the polymeric material between the toothed rollers, it is subjected to deformations of tension and compression along the entire thickness. The calculation scheme of polymer processing is presented in Figure 1.

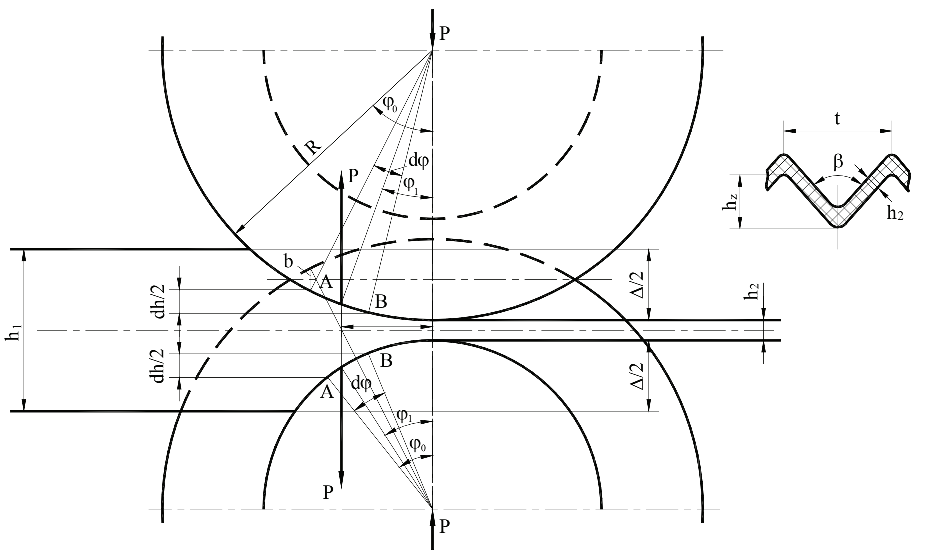

Fig. 1. Scheme of deformation of polymeric material in toothed rollers

The polymeric material with an initial thickness h_1 enters the zone of action of the toothed rollers, and proceeds out of it with a thickness h_2 (Fig. 1). Before calculating this device, it is necessary to determine the deformation of the polymeric material, which must be ensured to obtain the oriented structure [3, 4].

We accept the following assumptions:

– there is no strain relaxation;
– the area of influence on the polymer is only in the plane of the toothed rolls axes.

In the process of action on the polymeric material of the toothed rolls it undergoes: stretching, compression and bending [6]. The inner layer of the polymeric material at the vertex of the teeth will be taken out under the action of tensile stresses and compressed under the action of bending stresses (Fig. 2).

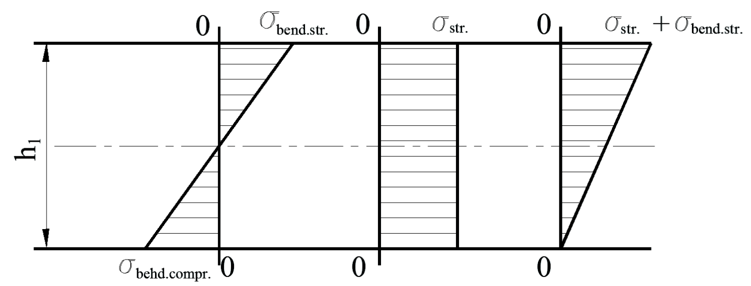

Fig. 2. Diagrams of internal tensions arising in a polymeric material

Thus, the tensile deformation of the inner layer is compensated by its compression deformation, and the deformation of the outer layer of polymeric material increases due to tension that occurs during bending. As a result of the fact that tops of the teeth and cavities have different radii of rotation, there is a tangential tension caused by friction.

Consequently, when recycling the polymeric material in the toothed rollers, the power will be spent on deformation of the tensile material, deformation of compression and overcoming frictional forces.

In view of the foregoing, complete torque can be represented as follows:

$$T = T_{str} + T_{cmp} + T_{fr} \tag{1}$$

where: T_{str} – the moment of force causing the stretching of the polymeric material,
T_{cmp} – the moment of force causing the compression of the polymeric material,
T_{fr} – the moment of friction.

Let us consider the stresses in the interaction zone of the polymeric material with the roller teeth. The whole process of this interaction will be divided into two stages.

At the first stage, the stretching of the polymeric material takes place (Fig. 1). Bending and stretching forces create forces acting on the toothed rollers:

$$P_1 = 2P_{def} \cos\frac{\beta}{2} \tag{2}$$

where: P_{def} – the force causing deformation in the zone of interaction of the polymer with the teeth of the rolls,
β – the angle of teeth profile.

The stretching area of a polymeric material that is limited to the curve $R \cdot d\varphi$ and thickness of the material dh is determined from the equation:

$$dS_1 = R \cdot d\varphi \cdot dh \tag{3}$$

where: $d\varphi$ – the change in the angle of rotation of the toothed rollers,
dh – the change in the thickness of the polymeric material, which decreases as a result of the previous drawing.

The thickness of the polymeric material h_2 after passing between the toothed rollers is determined from the following equation:

$$h_2 = h_1(1 - \nu\varepsilon_1) \tag{4}$$

where: ν – Poisson's coefficient for a particular polymeric material (selected from reference books [2]),
ε_1 – tensile strain, which provides drawing and orientation of spherulites in the polymeric material.

The force acting on an area dS_1 of polymeric material can be determined from the following equation:

$$dP_{def} = \sigma_{str} \cdot R \cdot d\varphi \cdot dh \tag{5}$$

where: σ_{str} – tensile strain.

This force has the same values on both sides of the teeth and creates a force of resistance that prevents the rotation of the toothed rollers:

$$dP_1 = 2\sigma_{str} \cdot R \cdot \cos\frac{\beta}{2} d\varphi \cdot dh \tag{6}$$

The moment created by force dP_1, a shall be defined as follows:

$$dM_{def} = 2\sigma_{str} \cdot R^2 \cdot \cos\frac{\beta}{2} \sin\varphi \cdot d\varphi \cdot dh \tag{7}$$

Turning to the angle φ_1, toothed rollers compress previously stretched polymeric material. Compression of the polymeric material in order to destroy the bonds between the elongate conglomerate of the spherulites occurs at the second stage of the interaction of the polymer material with the toothed rollers (Fig. 1).

The compression area of the polymeric material, which is limited by the curve and the length of the surface of the contact between the polymer and the tooth, can be determined from the following equation:

$$dS = R \cdot d\varphi \cdot dl \tag{8}$$

where: dl – The length of the arc on which the polymer material contacts the lateral surface of the tooth, which varies from 0 to l_1,
t – step between the teeth.

From Figure 1 we define l_1 as follows:

$$l_1 = -\frac{t}{2\sin\frac{\beta}{2}} \tag{9}$$

The force acting on an area dS_2 perpendicular to the side surface of the teeth, thereby compressing the polymeric material, is determined from the following equation:

$$dP_p = \sigma_{cmp} \cdot R \cdot d\varphi \cdot dl \tag{10}$$

The force dP_p creates a force of resistance to the rotation of the toothed roll dP_{rot} and axial force dP_{ax}, oriented along the axis of rotation of the roller. Axial force acts on the lateral surfaces of the teeth, that is, its components, acting on opposite surfaces in one direction, are mutually offset, so it will not create moment.

The resistance force to rotation of the toothed roller dP_{rot} from compression of polymeric material on the sides of teeth is determined from the following equation:

$$dP_{rot} = 2\sigma_{cmp} \cdot R \cdot \sin\frac{\beta}{2} d\varphi\, dl \tag{11}$$

where: σ_{cmp} – compression tension.

Compressive moment, created by the force of resistance dP_{rot}, according to Figure 1 we define as follows:

$$dM_{cmp} = 2\sigma_{cmp} \cdot R^2 \cdot \sin\frac{\beta}{2} \sin\varphi\, d\varphi\, dl \tag{12}$$

In practice, the moment arms acting on the toothed rollers may differ, for example, at different diameters of rollers. Experimental studies of the deformation of the polymeric material as a result of its passage between the toothed rollers carried out within the framework of this work, showed that to obtain the desired structure of the polymeric material at a minimal cost of electricity, rollers of the same diameter should be used.

Thus, the full moment of resistance to the rotation of one of the teeth can be determined by the following formula:

$$\begin{aligned} dM = dM_{def} + dM_{cmp} = 2\sigma_{str} \cdot R^2 \cdot \cos\frac{\beta}{2} \sin\varphi \cdot d\varphi \cdot dh + \\ + 2\sigma_{cmp} \cdot R^2 \cdot \sin\frac{\beta}{2} \sin\varphi\, d\varphi\, dl \end{aligned} \tag{13}$$

We integrate the equation (13) by φ for an interval from φ_0 to φ_1 (stretching) and for an interval from φ_1 to 0 (compression); by h for an interval from h_1 to h_2; by l for an interval from 0 to l_1:

$$\begin{aligned} M &= \int_{\varphi_0}^{\varphi_1}\int_{h_1}^{h_2} dM_{def} + \int_{\varphi_1}^{0}\int_{0_1}^{l_1} dM_{cmp} = \\ &= \int_{\varphi_0}^{\varphi_1}\int_{h_1}^{h_2} 2\sigma_{str} \cdot R^2 \cdot \cos\frac{\beta}{2} \sin\varphi\, d\varphi\, dh + \int_{\varphi_1}^{0}\int_{0_1}^{l_1} \sigma_{cmp} \cdot R^2 \cdot \sin\frac{\beta}{2} \sin\varphi\, d\varphi\, dl = \\ &= 2\sigma_{str} \cdot R^2 \cdot \cos\frac{\beta}{2}\left(\cos\varphi_0 - \cos\varphi_1\right) \cdot \left(h_2 - h_1\right) + \\ &\quad + 2\sigma_{cmp} \cdot R^2 \cdot \sin\frac{\beta}{2}\left(1 - \cos\varphi_1\right) \cdot l_1 \end{aligned} \tag{14}$$

Taking into account the expressions (4) and (9) and Hooke's law, let us rewrite equation (14) as follows:

$$M = 2R^2 \cdot \left(E_1 \cdot \varepsilon_1{}^2 \cdot \nu \cdot \cos\frac{\beta}{2}\left(\cos\varphi_1 - \cos\varphi_0\right) \cdot h_1 + \frac{t}{2} \cdot E_2 \cdot \varepsilon_2 \cdot \left(1 - \cos\varphi_1\right) \right) \quad (15)$$

where: E_1, E_2 – modulus of elasticity, respectively, along and across the orientation of the spherulite conglomerates,

ε_1 – tensile strain at which the orientation of the spherulites occurs,

ε_2 – deformation of compression, in which the destruction of bonds between oriented conglomerate spherulites occurs. Deformations ε_1, ε_2 are determined by the equations given in the works [3-5].

The cosines of the angles φ_0 and φ_1 we express through the structural parameters of the roller device (Fig. 1) in this way [4]:

$$\cos\varphi_0 = \frac{2R - h_z - \varepsilon_2 h_1}{2R}$$
$$\cos\varphi_1 = \frac{\left(2R - h_z\right)\sin\frac{\beta}{2} - h_2}{\left(2R - h_z\right)\sin\frac{\beta}{2}} \quad (16)$$

where: h_z – the height of the teeth on both rollers.

Thus, using equation (15), one can determine the total moment of resistance to the rotation of one tooth.

In addition to the full moment of resistance to the rotation M, which can be called the moment of useful resistance, the moment of harmful resistance M_{tr} to the frictional forces that arise between the polymer material and the teeth due to the difference in the radii of vertices and dentures of the teeth is applied to the toothed rollers. As a result, the polymer material slides on the lateral surfaces of the teeth (Fig. 3).

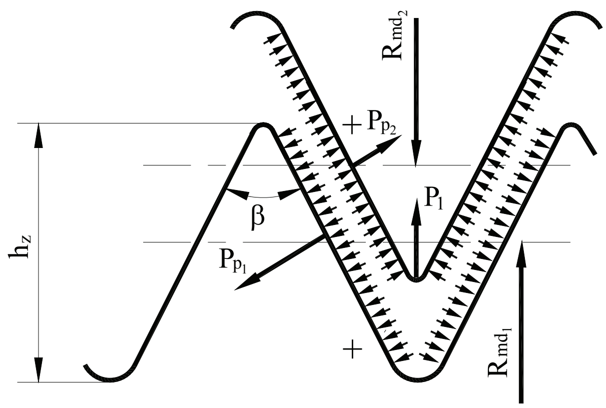

Fig. 3. Scheme of forces that arise between the polymeric material and the lateral surfaces of the teeth

At the point where joints and cavities are combined, the circular velocities are equal $(\omega_1 R_1 = \omega_2 R_2)$. Since the radii of the toothed rollers of this device must be the same, the angular velocity of their rotation must also be the same $(\omega_1 = \omega_2)$. If the thickness of the polymer material is equal to zero, in the middle of the lateral surface of the tooth of one roll, which coincides with the middle of the lateral surface of the cavity of another roller, there would be no slip. Since the polymer products recycled on this equipment always have a thickness, the circles of the average radii of the teeth of the rollers are in contact with each other (Fig. 3), which causes the difference in speeds over the thickness of the polymeric material from the tooth of one roller to the tooth of the other that leads to slipping.

To destroy the bonds between the oriented conglomerates of the spherulites in a transversely elongated polymeric material, it is necessary to compress it to the deformation ε_2, which can be calculated from the equations obtained in the work [3]. By the defined compression deformation ε_2, the gap between the toothed rollers is set.

As a result of compression of the polymeric material located between the teeth of the rollers by the force P_1 (Fig. 3) in the material arises effort P_p trying to stretch it in the transverse direction, thereby destroying connections between oriented conglomerates of spherulites.

The slip caused by the difference in speed over the thickness of the polymer material, and the normal pressure created by the effort, results in the appearance of dry sliding friction between the polymer material and the toothed roller. The resulting friction force is proportional to the normal pressure and is directed in the opposite direction to the slip speed.

As can be seen from Fig. 3, the frictional forces on the outer side of the polymer material at the point of contact with the lateral surfaces of the tooth on both rollers are directed in opposite directions, therefore, in the polymeric material there will be strain of displacement that will cause the corresponding deformation. These deformations will contribute to the destruction of the oriented structure of the polymeric material.

The shear deformation significantly depends on the technological (rotational speed of the toothed rollers) and structural (tine height, profile angle, gap between the rollers, roller diameter) parameters of the processing equipment, thickness and physical and mechanical characteristics of the polymeric material.

As it was noted earlier, in the proposed device the speed of rotation of the toothed rollers is equal to $(\omega_1 = \omega_2)$. Therefore, in the case of small thickness of the polymeric material $(h = (1...4) \cdot 10^{-3}$ m$)$ there appears insignificant shear deformation, whichcan be neglected due to the fact that the coefficients of friction, such as polyethylene and polyethylene terephthalate and polyimide film on steel lies in the range $f = 0{,}2...0{,}6$.

Investigation of the recycling of polymeric materials with a thickness greater than indicated above, requires determination of shear strain and consideration when calculating its technological and structural parameters of recycling equipment.

The friction between the polymeric material and toothed rollerappears at the time of touching the top of a tooth by apolymer. In order to reduce slippage of polymeric material, on the tops of teeth there are cut notches that hook the material and drag it into the space between the rollers.

While stretching a polymeric material between the teeth of one roller, on the side surfaces of tooth there is friction that is different from the friction force of the compression of a polymer. The forces of friction on the sides of teeth caused by tension and compression polymeric material are defined in the following expressions:

– stretching of the polymer:

$$dF_1 = 2\,f\,\sigma_{str}\,R\cos\frac{\beta}{2}d\varphi\,dh \tag{17}$$

– compression of the polymer:

$$dF_2 = 2\,f\,\sigma_{cmp}\,R\;d\varphi\,dl \tag{18}$$

where: f – coefficient of friction of polymeric material on steel.

The moment of friction dF_1, dF_2, which is created on the lateral surfaces of the tooth, we define from the following equation:

$$dM_{fr} = 2\,f\,\sigma_{str}\,R^2\cos\frac{\beta}{2}d\varphi\,dh + 2\,f\,\sigma_{cmp}\,R\left(R-\frac{h_z}{2}\right)d\varphi\,dl \tag{19}$$

We integrate the equation (19) by φ on the interval from φ_0 to φ_1 (stretching) on the interval from φ_1 to 0 (compression); by h on the interval from h_1 to h_2; by l on the interval from 0 to l_1:

$$\begin{aligned} M_{fr} &= \int_{\varphi_0}^{\varphi_1}\int_{h_1}^{h_2} 2\,f\,\sigma_{str}\,R^2\cos\frac{\beta}{2}d\varphi\,dh + \int_{\varphi_1}^{0}\int_{0_1}^{l_1} 2\,f\,\sigma_{cmp}\,R\left(R-\frac{h_z}{2}\right)d\varphi\,dl = \\ &= 2\,f\,\sigma_{str}\cdot R^2\cdot\cos\frac{\beta}{2}(\varphi_0-\varphi_1)\cdot(h_2-h_1) + 2\,f\,\sigma_{cmp}\cdot R^2\cdot\left(1-\frac{h_z}{2R}\right)(0-\varphi_1)\cdot l_1 \end{aligned} \tag{20}$$

Taking into account the expressions (4) and (9) and Hooke's law from equation (20), we obtain the expression for the moment of friction on one tooth:

$$M_{fr} = 2\,f\,R^2\left(E_1\cdot\varepsilon_1^{\;2}\,\nu\cdot\cos\frac{\beta}{2}(\varphi_0-\varphi_1)\cdot h_1 + \frac{E_2\,\varepsilon_2\,t}{2\sin\frac{\beta}{2}}\cdot\left(1-\frac{h_z}{2R}\right)\varphi_1\right) \tag{21}$$

The total moment of useful and harmful resistances on one tooth of each roller is determined from the equation (19), taking into account the expressions (15) and (21), and is written as follows:

$$M_{sum} = 2R^2 \cdot \left\{ E_1 \varepsilon_1^2 \nu h_1 \cdot \cos\frac{\beta}{2}\left(\left(\cos\varphi_1 - \cos\varphi_0\right) + f \cdot \left(\varphi_0 - \varphi_1\right)\right) + \right.$$
$$\left. + \frac{E_2 \varepsilon_2 t}{2}\left(\left(1 - \cos\varphi_1\right) + f\left(1 - \frac{h_z}{2R}\right)\frac{\varphi_1}{\sin\frac{\beta}{2}}\right)\right\} \tag{22}$$

The total torque is determined from the following expression:

$$T = M_{sum} \cdot z \tag{23}$$

where: z – number of teeth on each roll.

Then the power that is consumed to create a torque at a uniform motion is equal to:

$$N = \frac{T \cdot \omega}{\eta} \tag{24}$$

where: η – the coefficient of performance of the device (experimentally substantiated meaning $\eta = 0{,}65$),

$\omega = \frac{\pi n}{30}$ – angular speed of rotation of toothed rollers, rad^{-1},

n – frequency of rotation of toothed rollers, min^{-1}.

Substituting expression (22) into equation (24), taking into account (23), we obtain the power that should be spent on the drawing of the spherulites and the destruction of the bonds between the conglomerate-oriented spherulites in the polymeric material:

$$N = \frac{z \pi n R^2}{15 \cdot \eta} \cdot \left\{ E_1 \varepsilon_1^2 \nu h_1 \cdot \cos\frac{\beta}{2}\left(\left(\cos\varphi_1 - \cos\varphi_0\right) + f \cdot \left(\varphi_0 - \varphi_1\right)\right) + \right.$$
$$\left. + \frac{E_2 \varepsilon_2 t}{2}\left(\left(1 - \cos\varphi_1\right) + f\left(1 - \frac{h_z}{2R}\right)\frac{\varphi_1}{\sin\frac{\beta}{2}}\right)\right\} \tag{25}$$

As can be seen from equation (25), for optimizing energy expenditures for obtaining the oriented structure of polymeric material and breaking the bond between conglomerate-oriented spherulites, it is necessary to optimize the technological (rotational speed of the toothed rollers) and structural (number and height of the teeth, profile angle, roller diameter, gap between rollers) parameters of the recyclingdevice.

3. THE RESULTS OF THE RESEARCH

Output parameters for calculation: speed of rollers: n = 1000 min^{-1}; the diameter of the toothed rollers: D = 0,1 m; number of teeth: z = 25; the step of teeth: t = 1 mm; the angle of the teeth profile: β = 60°; initial thickness of the polymeric material: h_1 = 4 mm.

The polymeric material:
- Polyethylene film (E_1 = 1020 MPa, E_2 = 770 MPa, ν = 0,37),
- Polyimide film (E_1 = 5500 MPa, E_2 = 3400 MPa, ν = 0,35),
- Polyethylene terephthalate (E_1 = 8239 MPa, E_2 = 2000 MPa, ν = 0,32) [1, 2].

Figure 4 shows the dependence of the power consumed on the rotation of the toothed rollers, on the deformation of the polymeric material.

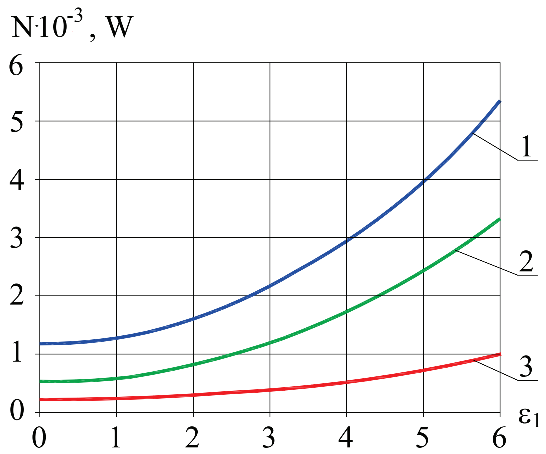

Fig. 4. Dependence of power on the relative deformation of polymeric materials:
1 – polyethylene terephthalate; 2 – polyimide film; 3 – polyethylene film

The graph shows that for the deformation of the material $\varepsilon_1 = 0{,}8$ in which it spheruline structure becomes a structure of oriented conglomerates of elongated spherulites with broken bonds [4, 5] there is a need to spend, for example for polyimide film, 800 $W{\cdot}h$ the electric power.

In order to reduce energy consumption, it is necessary to optimize the parameters of the roller device. To do this, we analyze the influence of technological (rotational speed of toothed rollers) and structural (diameter of rollers, profile angle and step of teeth) on the power used to create a given deformation of the polymeric material as a result of passing it between the toothed rollers.

Figures 5-8 show the power dependence on the rotation frequency and the diameter of the toothed rollers, the profile angle and the step of the teeth.

Structural parameters such as the profile angle and the step of the teeth are not included in equation (1), so changing them can optimize the consumption of electrical energy without affecting the performance of the device.

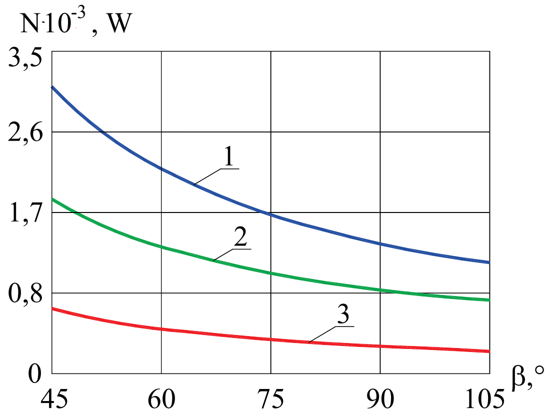

Fig. 5. Dependence of power from the angle of the teeth profile:
1 – polyethylene terephthalate; 2 – polyimide film; 3 – polyethylene film

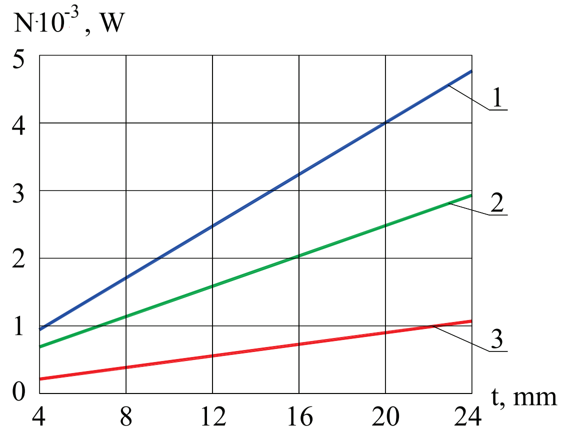

Fig. 6. Dependence of power from the step of the teeth:
1 – polyethylene terephthalate; 2 – polyimide film; 3 – polyethylene film

As can be seen from Figure 5, the greater is the meaning of the angle of the teeth profile, the less power the device consumes. However, according to [6] the profile angle may increase to a meaning of 78°. A further increase in the angle may lead to the fact that the device cannot provide the required deformation, i.e. spheruline structure in which the polymeric material is destroyed and the links between conglomerates of oriented spherulites are destroyed.

Figure 6 shows that an increase in the step between the teeth leads to an increase in power consumption. According to [6] a known angle of tooth profile at which the required deformation is provided and minimum power isconsumed, let is define thestep between the teeth as $t = 4$ mm.

In Figures 7, 8 there are given dependencies on the power consumed by a roller device, the diameter of the toothed rolls and frequency of their rotation.

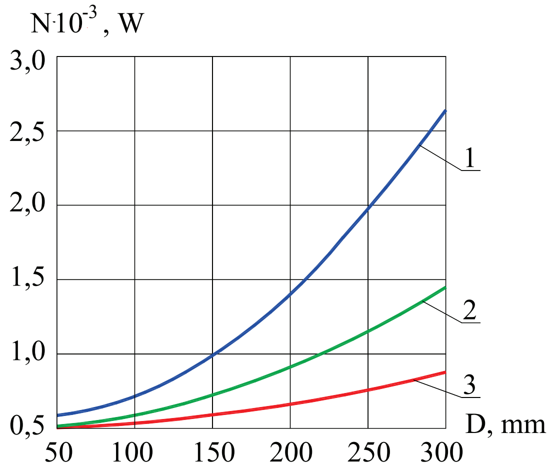

Fig. 7. Dependence of power on the diameter of the toothed rollers:
1 – polyethylene terephthalate; 2 – polyimide film; 3 – polyethylene film

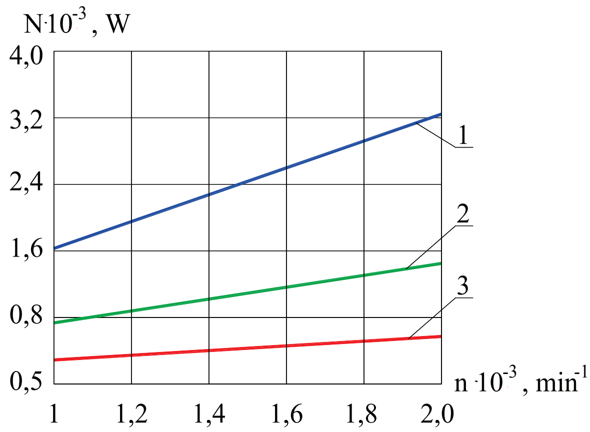

Fig. 8. Dependence of power on the rotational speed of the toothed rollers:
1 – polyethylene terephthalate; 2 – polyimide film; 3 – polyethylene film

As it can be seen from shown in Figures 7-8 dependencies of increasing of the diameter of rollers and their rotational speed lead to an increase in electric energy consumption. This is due to an increase in the inertial forces that arise during the rotation of the rollers and their interaction with the polymeric material.

Reducing the diameter and rotation speed of the toothed rollers will reduce the power consumption, but this will reduce the performance of this device.

Therefore, in our opinion, it is worth investigating which of these two parameters has the greatest impact on power consumption.

A similar analysis was performed for polyethylene film and polyethylene terephthalate.

4. CONCLUSIONS AND RECOMMENDATIONS

The material loading scheme was determined and analytical dependencies were obtained that relatethe basic technological and structural parameters of a roller device with a stress-strain state in a polymeric material.

The basic technological and structural parameters of the roller device were determined, by optimizing which it can be achieved reducing the amount of power consumed by the device, namely the radius of the toothed rollers, the angle of the profile and the step of the teeth, the speed of the rollers.

The method of optimization of technological (speed of rotation of toothed rollers) and structural (diameter of toothed rollers, profile angle and step of the teeth) parameters, at which the minimum power consumption for certain polymeric materials is provided, was proposed. Using the obtained laws, it is possible to determine the basic technological and structural parameters of rollers that, with minimal electric energy consumption, create a deformation in which the spheruline structure of the polymeric material is oriented and the bonds between the conglomerates of the oriented spherulites are partially destroyed.

Using the proposed method, analytical studies of the influence of the technological and structural parameters of the roller device on the power expended on the destruction of the structure of the polymeric material were carried out. As a result, it was found that in the recycling of polymer waste, the lowest electricity consumption will be at the following parameters of the device:

– recycling of polyethylene terephthalate: the diameter of the toothed rollers was from 50 to 80 mm, the angle of the profile of the teeth – 90 ... 100°, the step between the teeth – 5…8 mm, the frequency of rotation of the rollers – 1000…1100 min^{-1};
– recycling of polyimide film: the diameter of the toothed rollers was from 100 to 120 mm, the angle of the profile of the teeth – 75 ... 90°, the step between the teeth – 6…8 mm, the frequency of rotation of the rollers – 1400…1600 min^{-1};
– recycling of polyethylene film: the diameter of the toothed rollers was from 110 to 140 mm, the angle of the profile of the teeth – 60 ... 80°, the step between the teeth – 6…10 mm, the frequency of rotation of the rollers – 1700…2000 min^{-1}.

Thus, for the energy-saving recycling of the polymer materials mentioned above, it is necessary to design a device with rotating toothed rollers with the following parameters: diameter $D = 120$ mm, $\beta = 80°$, $t = 8$ mm; $n = 1200$ min^{-1}.

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ZMNIEJSZENIE WYDATKÓW ENERGII ELEKTRYCZNEJ URZĄDZENIA ROLKOWEGO DO RECYKLINGU MATERIAŁÓW POLIMEROWYCH PRZEZ OPTYMALIZACJĘ PARAMETRÓW

Streszczenie: Dynamiczne obliczenia obciążeń powstających podczas recyklingu materiału polimerowego w urządzeniu rolkowym, przeprowadzone w pracy, pozwoliły określić główne parametry technologiczne i konstrukcyjne, które wpływają na moc zużywaną przez to urządzenie. Przeprowadzone zagadnienie analityczne pozwoliło na połączenie podstawowych parametrów urządzenia rolkowego ze stanem naprężenie-odkształcenie wytworzonym w materiale polimerowym. Po raz pierwszy w przypadku takich urządzeń wzięto pod uwagę właściwości fizyczne i mechaniczne polimeru.

W pracy przedstawiono model matematyczny procesu recyklingu materiału polimerowego w urządzeniu rolkowym, który uwzględnia dynamikę oddziaływania uzębionych wałków oraz właściwości fizyczne i mechaniczne materiału polimerowego.

Zaproponowano metodę optymalizacji parametrów technologicznych i strukturalnych urządzenia rolkowego zapewniającego minimalne zużycie energii. Pozwoliło to na określenie podstawowych parametry technologicznych i strukturalnych walców, które przy minimalnym zużyciu energii elektrycznej powodują odkształcenie, w którym struktura sferoidalna materiału polimerowego jest zorientowana, a połączenia między sferolitami zorientowanymi na konglomerat są niszczone.

Słowa kluczowe: odpady polimerowe, wytrzymałość na rozciąganie, odkształcenie, pękanie, urządzenie rolkowe, moc