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Study of forming conditions of technogenic materials in the unit with elastic forming elements

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Abstract. The article presents scientific and technical developments and analytical studies of the process of forming technogenic materials in a press-roller extruder equipped with pressing bodies — rollers with elastic forming elements. Technical solutions implemented in the design of the unit provide reliable capture of the charge by the forming rolls, uniform distribution of stresses along the material compression arc, as well as increasing the operational reliability of the machine. This is important when forming technogenic materials with different physical-mechanical and rheological characteristics.

1. Introduction

One of the directions of development technological systems for the extruded materials production is a constructive and technological improvement of press-roller extruders (PRE) [1, 2]. The wide area of using PRE in the public and private sectors of the economy (the production of thermal insulation materials and products, recycling of technogenic materials, production of porous granules with special acoustic properties, etc.) predetermines the requirements for the possibility of varying the conditions of forming materials [3-6].

The press roller extruders developed by us contain various mechanical and technological functions:

- uniform feed of the pressed material and its effective preliminary compaction;
- thermal heating of the material to be compacted and the infeeding of various plasticizers into it;
- reliable capture of the material to be compacted by pressing bodies (rollers);

Time of the charge pressure hold is an important condition for forming materials. Using elastic forming elements in PRE makes it possible to set. The purpose of this work is the development of the elastic forming elements design and study of the technogenic materials forming process.

2. Development of the elastic forming elements designs

The important factor determining the quality characteristics of extruded granules is to ensure reliable capture of the charge by the forming rollers, uniform distribution of stresses along the material compression arc, as well as increased operational reliability (exclusion of unit breakage when metal objects enter the press plane) and durability of PRE working bodies.

The use of pneumatic-elastic or elastic forming elements (EFE) in the PRE construction contributes to the solution of the above problems [7]. The eccentrically set (figure 1) EFEs (rolls) provide more favorable conditions for the capture and forming (standing of the charge under pressure for a certain time τ) of the material.



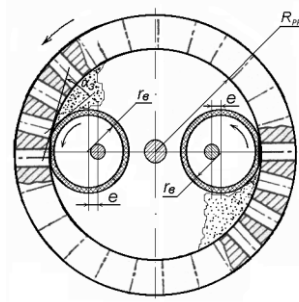


Figure 1. The scheme of the press-plane with elastic forming elements.

The presence of a contact area (figure 2) between the EFE and the press plane contributes to the stabilization of stresses in the layer of a forming material, as well as the subsequent relaxation of stresses σ (figure 2). It is important during forming a charge with different rheological characteristics.

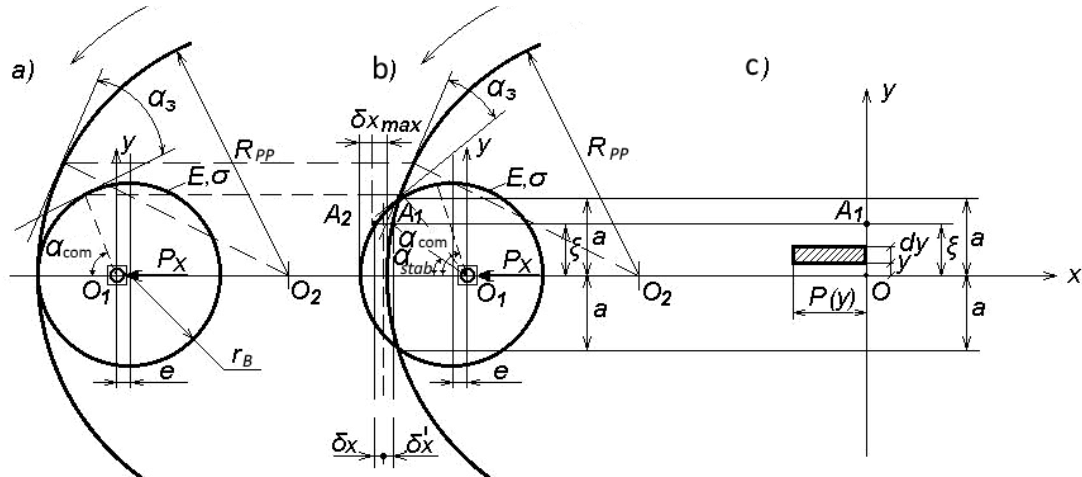


Figure 2. Scheme for calculating the conditions of extrusion of materials by elastic forming elements: (a) before pressing of the roll; (b) during tense condition of the roll; (c) scheme for determining the length of the deformation stage.

3. Analytical studies of the forming process

Let us take into account the forming conditions of the charge in a PRE equipped with an EFE. The stress state of two contiguous elements (a press plane and a roll), having parallel axes, is caused by pressing the latter against the inner surface of the press plane with the intensity of distributed force P_x . We take two points A_1 and A_2 , located at a distance of ξ from the axial plane on the contact surfaces.

Let us assume that the width of the contact plane of the elastic forming element is small compared to its radius. Also we consider each EFE as an elastic half-plane. Using the Flamann formula [8, 9], we can determine the amount of movement of the EFE points during its elastic deformation (the contact of the elastic roll with the press plane).

$$U_{X(y, 0)} = -\frac{2(1-\mu^2)}{\pi E} P \ln \frac{y}{r_B} - \frac{(1+\mu)P}{\pi E} \ln |y| + C \quad (1)$$

where μ – Poisson's ratio, for rubber $\mu = 0.4 \dots 0.5$; E – modulus of elasticity of the material EFE, for rubber $E = (10 \dots 100) \times 10^5$, N/m²; P – compressive forces, N/m; r_B – radius of the forming element (roll), m.

Under the action of a compressive force $P(y)$ acting on a strip of dy width, the magnitude of the displacement of the point A_1 is:

$$dU_X^{(1)} = -\frac{2(1-\mu^2)}{\pi E} P(y) dy \ln \frac{|\xi-y|}{r_B} - \frac{1+\mu}{\pi E_1} P(y) dy = -\frac{2(1-\mu^2)}{\pi E_1} \left[\ln |\xi-y| + \frac{1}{2(1-\mu)} - \ln r_B \right] P(y) dy. \quad (2)$$

Or the projection of the full movement of the point A_1 will be equal to:

$$U_X^{(1)} = -\frac{2(1-\mu^2)}{\pi E_1} \left\{ \int_{-a}^{+a} P(y) \ln |\xi - y| dy + \left[\frac{1}{2(1-\mu)} - \ln r_B \right] P(y) \right\}. \quad (3)$$

Similarly, the amount of movement of the point A_2 will be equal to:

$$U_X^{(2)} = -\frac{2(1-\mu^2)}{\pi E_2} \left\{ \int_{-a}^{+a} P(y) \ln |\xi - y| dy + \left[\frac{1}{2(1-\mu)} - \ln r_B \right] P(y) \right\}. \quad (4)$$

The relationship between the length of the straight section (a), the roll radius (r_B), the compressive force (P) and the elastic modulus (E) is determined by the Hertz formula [8]:

$$a = 2 \sqrt{\frac{P r_B (1-\mu^2)}{\pi E}}. \quad (5)$$

From figure 2a, 2b it is possible to determine the value of the stresses stabilization angle:

$$\alpha_{stab} = \alpha_{ay} = \arcsin \frac{a_y}{r_B} = \arcsin 2 \sqrt{\frac{P_y (1-\mu^2)}{\pi E r_B}}. \quad (6)$$

In this case, we shall comply with the following condition:

$$\alpha_{ay} \leq \alpha_{com},$$

where α_{com} – charge reduction angle; α_{ay} – the time of stabilization of the stresses in the charge layer at the circumferential speed of rotation of the press plane $\vartheta_{pp} = \omega R_{pp}$ is equal to:

$$\tau_{stab} = \frac{2a_y}{\vartheta_{pp}} = \frac{a_y}{\pi n_{pp} R_{pp}}, \quad (7)$$

where n_{pp} – the speed of rotation of the press plane, sec^{-1} ; R_{pp} – radius of the rotating press plane, m.

Or taking into account formula (6), we get:

$$\tau_{stab} = \frac{2 \sqrt{\frac{P_y r_B (1-\mu^2)}{\pi E}}}{\pi n_{pp} R_{pp}} = 0.64 \frac{\sqrt{\frac{P_y r_B (1-\mu^2)}{\pi E}}}{n_{pp} R_{pp}}. \quad (8)$$

The current stress σ_τ of the charge and the initial stress σ_0 are related [10]:

$$\sigma_\tau = \sigma_0 e^{-\frac{\tau}{\theta}}, \quad (9)$$

where τ – standing time of the charge under pressure, sec; θ – forming material relaxation time, sec.

From (9) we have: $e^{-\frac{\tau}{\theta}} = \frac{\sigma_\tau}{\sigma_0}$, after logarithm: $-\frac{\tau}{\theta} \lg e = \lg \sigma_\tau - \lg \sigma_0$,

then

$$\tau = \frac{(\lg \sigma_0 - \lg \sigma_\tau) \theta}{\lg e}.$$

A necessary condition for the formation of the charge is $\tau \geq \tau_{stab}$, according to which, using formulas (8) and (9), we obtain the value of the frequency of rotation of the press plane:

$$n_{pp} \leq \frac{0.64 \sqrt{\frac{P r_B (1-\mu^2)}{\pi E}} \ln e}{(\lg \sigma_0 - \lg \sigma_\tau) \theta R_{pp}}. \quad (10)$$

The frequency of rotation of the pressing rolls is equal to:

$$n_B = n_{pp} \cdot \frac{R_{pp}}{r_B} \cdot K_{pp},$$

where $K_{pp} = 0.96 \dots 0.98$ – the coefficient of roll slip relative to the rotating press plane.

4. Conclusion

Thus, the obtained analytical expression allows for given geometrical parameters and material characteristics of working bodies of PRE: R_{pp} , r_B , E , μ , initial σ_0 and current σ_τ stresses created by compressive force P_y , material relaxation period θ (material rheological characteristic) to set the required rotation frequency of the press plane – n_{pp} , which allows determining the kinematic and energy-power parameters of the press-roller extruder.

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