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RESEARCH OF THE COTTON SEALING PROCESS IN FACILITIES OF A FRAME-TYPE

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ABSTRACT: The article presents the results of studies of the process of compaction of cotton collected in the hopper of a cotton picker with analysis of the conditions of power loading and justification of the design parameters of the mechanical seal.

KEYWORDS: Raw cotton, Machine hopper, Compaction, Vertical pressures, Friction forces, Force loading, Paddle seal, Cotton mass density, Pitched hopper wall, Force intensity, Analytical functions.

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I. INTRODUCTION

Studies of the compaction of cotton harvested on a machine during the collection process in containers of rigid frame and elastic container types are described in [1,2–4], in which the conditions of force loading were analyzed and the parameters of a number of designs of mechanical seals were substantiated. It is reasonable to further develop these studies in the direction of more accurately taking into account the influence of the functions of the intensities of vertical pressures and friction forces on compaction processes.

II. MATERIALS

We will solve this problem based on the use of materials for investigating the process of cotton compaction in frame-type bunkers described in [3-6, 9,10] and a number of assumptions..

In studies [2,3,4], a range of fluctuations in the density of the mass of cotton in the bunkers of the used cotton pickers was established from γ_0=30÷40kg/m^3 -mainly in their upper part and up to = $\gamma_к$=130-150kg/m^3 - near the bottom of the bunker. The overall dimensions of the frame of the bottom of the hopper reach a height of H_0=2m, an average width of b_0 = 2,5m and a length of a = 2,5÷3,6m.

Tested options for paddle cotton seals created a pressure p_0= 100-700kg/m^2 [5,6,9,10] on the upper layers of the mass of cotton.

III. METHODS

In our studies, we accept the condition that, in all cases, the average density $\gamma_c = 0{,}5\left(\gamma_k + \gamma_0\right)$ cotton remains in the bunker of the cotton picker in the process of filling it. In this case, we obtain the function of changing the density of cotton inside the hopper in the form

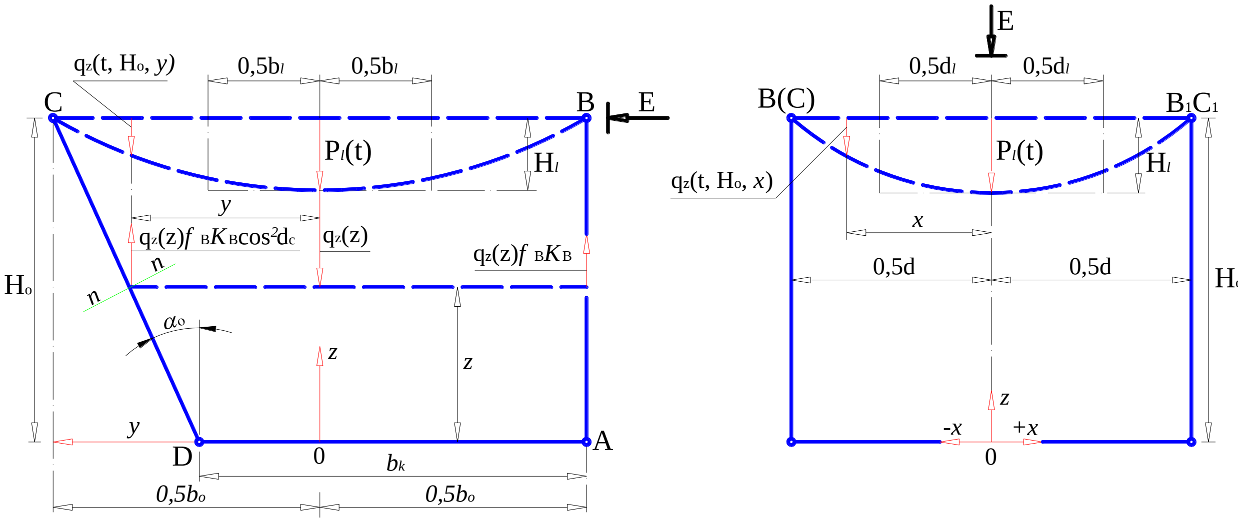
$$\gamma(z) = \gamma_k - \left(\gamma_k - \gamma_0\right)\frac{z}{H_0} \quad (1)$$

For subsequent calculations, we accept three options for changing the average density inside the hopper:

- c γ_{c1}= 50kg/m^3, wherein γ_{k1}=70 kg/m^3 determined by the formula (1) for z=0

- c γ_{c2} = 65kg/m^3 at γ_{k2} =100kg/m^3

- c γ_{c3} = 80kg/m^3 at γ_{k3} =130kg/m^3



VG - pitched bunker wall

Figure 1: Calculation Scheme for Cotton Compaction in the Cotton Hopper

Taking into account the figure, we determine the function of vertical pressures on the mass of cotton (at $p_0 = 0$)

$$P_z(z) = [\gamma_0 + \gamma(z)]\frac{H_0 - z}{2} = \frac{\gamma_0 + \gamma_k}{2}H_0 - \gamma_k z + \frac{\gamma_k - \gamma_0}{2H_0}z^2 \quad (2)$$

In this case, we obtain the pressure function on the side walls of the hopper frame in the form

$$P_y(z) = P_x(z) = k_b P_z(z) \quad (3)$$

Further, by integration we determine the intensity function of the vertical forces acting on the cotton mass layers inside the hopper frame

$$q_z(z) = \int_0^z P_z(z)dz = \int_0^z \left(\frac{\gamma_0 + \gamma_k}{2}H_0 - \gamma_k z + \frac{\gamma_k - \gamma_0}{2H_0}z^2\right)dz = \frac{\gamma_0 + \gamma_{ki}}{2}H_0 z - \gamma_{ki}\frac{z^2}{2} + \frac{\gamma_{ki} - \gamma_0}{6H_0}z^3 + q_{ki}$$

(4)

The intensity q_{ki} in the layer with z =0 is established taking into account the condition $q_z(H_0)=0$ and we obtain the formula

$$q_{ki} = -\frac{H_0^2}{6}(\gamma_{ki} + 2\gamma_0), \quad (5)$$

in accordance with (4)

$$q_z(z) = \frac{\gamma_0 + \gamma_{ki}}{2}H_0 z - \gamma_{ki}\frac{z^2}{2} + \frac{\gamma_{ki} - \gamma_0}{6H_0}z^3 - \frac{H_0^2}{6}(\gamma_{ki} + 2\gamma_0). \quad (6)$$

We assume that the functions of the intensities of the friction forces on the three side walls repeat the function $q_z(z)$, for the fourth pitched wall, while additionally taking into account $\cos^2\alpha_c$ (α_c is the angle of inclination of the pitched wall to the vertical plane in Fig. 1

$$2q_{TX}(z) = 2k_b f_b q_z(z)\frac{F_x}{F_{zc}} \ (7, a) \quad 2q_{TY}(z) = (k_b + \cos^2\alpha) f_b q_z(z)\frac{F_Y}{F_{zc}}, \ (7, б)$$

где, $F_x = H_0 a$ и $F_y = \frac{H_0}{2}\left(b_0 + b_k \right)$ - the surface of the side walls of the frame of the bunker of the cotton picker (BHM), $F_{zc} = a\frac{b_0 + b_k}{2}$ - the average value of the compressible cotton surface in BXM along the axis Z, $b_c = 0,5(b_c+b_k)$.

For subsequent calculations of mass compression strains, a search is needed for approximating functions for (6), convenient for differentiation and integration actions when solving partial differential equations.

For the model of the hopper frame with dimensions H_0=2m, a=2,5m, b_c=2,5m and volume V_0=12,5m^3 (an analogue of the hopper of the machine in Fig.), Taking into account the previously obtained data, we obtain the following functions $q_z(z)$ for options:

The first $q_z(z)$=100z-35z^2+3,33z^3-86,67 [kg/m] (8)

Second $q_z(z)$=130z-50z^2+5,83z^3-106,67 [kg/m] (9)

Third $q_z(z)$=160z-65z^2+8,33z^3-126,67 [kg/m] (10)

We select options for approximating functions

$$q_k \cos\frac{\pi z}{2H_0},\ q_k e^{-\lambda_1 z},\ q_k e^{-\lambda_2 z}, q_k e^{-\lambda_3 z},$$

Where, $$\lambda_1 = \frac{1}{0{,}5H_0}\ln\frac{q_k}{q_z\left(0{,}5H_0\right)} \quad (11)$$

$$\lambda_2 = \frac{1}{0{,}75H_0}\ln\frac{q_k}{q_z\left(0{,}75H_0\right)} \quad (12)$$

$$\lambda_3 = \frac{1}{0{,}875H_0}\ln\frac{q_k}{q_z\left(0{,}875H_0\right)} \quad (13)$$

for H_0=2m and data $q_z(z)$ according to (6), the values

$$\lambda_1 = 1{,}69,\ \lambda_2 = 2{,}18,\ \lambda_3 = 2{,}766.$$

IV. RESULTS

The results of calculating the values of these functions for the third variant (10) are summarized in the table.

Table 1: The Calculated Values of the Basic and Approximating Functions for the Intensities $q_z(z)$ in the Bunker of a Cotton Picker

Z, m	$q_z(z)$= -4,6	$q_k cos\frac{\pi я}{2H_0}$	$q_k e^{-\lambda_1 z}$	$q_k e^{-\lambda_2 z}$	$q_k e^{-\lambda_3 z}$
0	126,67	126,67	126,67	126,67	126,6
0,25	90,6	124,1	33,32	73,44	63,54
0,50	61,82	116,92	54,47	42,56	31,87
0,75	39,72	104,25	35,21	24,45	15,96
1,0	23,37	89,56	23,37	14,31	8,02
1,25	11,96	70,18	15,32	8,3	4,03
1,50	4,81	48,51	9,39	4,81	2,03
1,75	1,09	24,83	6,56	2,76	1,01
2,0	0	0	4,31	1,65	0,51

arithmetic mean,	40,9	78,34	39,95	33,22	28,18
average integral					
the values	36,69	30,68	36,20	28,68	22,81

An additional comparison of the functions $q_z(z)$ and those approximating by (11) - (13) is carried out by the arithmetic mean and mean integral values

$$q_{zn} = \frac{1}{H_0}\int_0^{H_0} q_z(z)dz\ ,\ \frac{q_k}{H_0}\int_0^{H_0}\cos\frac{\pi z}{2H_0}dz = \frac{2}{\pi}q_k$$

$$q_{kn} = \frac{q_k}{H_0}\int_0^{H_0} e^{-\lambda_i z}dz = \frac{q_k}{H_0\lambda_i}\left(1-e^{-\lambda_i H_0}\right) \qquad (14)$$

Based on the data in the table, the best approximating function is established from λ_1 =1,69 according to (11).

By similar calculations, functions of the type (11) - (13) are derived for loading options of the cotton hopper hopper:

- Second λ_1=1,63 при q_{zn}=31,66kg/m, q_{kn}=31,48kg/m,
- First λ_1=1,58 при q_{zn}=26,68kg/m, q_{kn}=26,28kg/m.

Thus, in the loading range of the cotton layers inside the machine hopper frame, approximate approximating functions of the type $q_k e^{\lambda_i z}$ can replace power ones in the form of a polynomial of type (6).

For further calculations, we introduce the function of taking into account the laws of change in the compressible cotton mass area by

$$OZ\ F_z(z) = F_0 e^{kz} = ab_k e^{kz}, \qquad (15)$$

Where, $k = \frac{1}{H_0}\ln\frac{b_0}{b_k}$ (16)

b_0 and b_k - the maximum (in the layer with $Z=H_0$) and minimum (in the layer with $Z=0$) the width of the section of the bunker of the cotton picker.

This function is characterized by a dependence $\frac{\partial F_z(z)}{\partial z} = F_0 k e^{kz}$, (17) convenient for subsequent simplifications of the equations.

Given the constant increase in the mass of the mass of cotton in the hopper, we introduce the functions

$$G_x(t) = G_x(0)e^{\beta t}, \qquad (18)$$

$$\beta = \frac{1}{\tau_b}\ln\frac{G_x(\tau_B)}{G_x(0)}, \qquad (19)$$

Where, $G_x(0) = \gamma_0 V_0$ - the initial mass of cotton in the hopper of the machine, after exceeding which it is rational to use the operations of the processes of self-compaction or compaction of cotton — the duration of the period of self-compaction (or compaction) at which the maximum

$\gamma_{см}$ the average mass density of the cotton inside the hopper frame and its maximum mass is accumulated $G_x(\tau_b) = G_{xM}$. The use of the latter assumption does not interfere with the functioning of those substantiated in paragraphs. (6) approximating functions $q_z(Z)$ и $q_T(Z)$.

We evaluate the range of elastic modulus for the working conditions in the hopper of the machine. From [6,7,10,11,12] the function of changing the elastic modulus of cotton of machine harvest for the range is known γ_x =50÷130 kg/m^3, with an average value $\gamma_{x\,c}$=90kg/m^3.

$E(p_{zc})=$255+0,75p_{zc} (kg/m^2) by (12) at p_{zc} (kg/m^2).

Additional pressure from the middle layer of the hopper with Z=$0,5H_0$=1m will be $\gamma_{xc}\cdot 1 = p_{zc} = 90$ kg/m^2.

In the tested versions of cotton compactors, the maximum vibration ranges for the modulus of elasticity of the mass of cotton are for processes:

- Self sealing E=255+0,75x90=255$\div$332,5kg/m^2, with an average value E_c =289kg/m^2;
- Mechanical seal E=(255$\div$405)kg/m^2, with an average value E_c=289kg/m^2, dependent on $p_{ом.}$

To determine the intensity function, we introduce the function of elastic compression strains $U_Б(t,z,y,x)$ of points in the mass of cotton inside the hopper frame, for which the coordinates are counted from point O passing through the center of gravity of the hopper and placed on the bottom of the hopper, at this range of coordinates cover the following:

$-Z=0 - H_0$, $Y=\pm 0,5b_0$, $X=\pm 0,5\,a$, time $t=0 - \tau_b$.

The properties of the mass of cotton are characterized by constant values of the elastic modulus E_c, the lateral pressure coefficient k_b and friction f_b,, the cosine of the angle cos$^2\alpha$ for the inclined ramp wall.

The functions of the intensities of the vertical forces acting on the cotton mass layers in the cotton hopper are taken into account in the form

$$q_z(t,z) = q_k e^{-\lambda z} e^{\beta t} \ldots, \qquad (20)$$

and the functions of the intensity of the friction forces in the form

$$q_{TY}(t,z,y) = q_{TY}(t,z)\cdot\left(1-\cos\frac{\pi y}{b_0}\right) \qquad (21)$$

$$q_{TX}(t,z,x) = q_{TX}(t,z)\left(1-\cos\frac{\pi x}{a}\right). \qquad (22)$$

To the average integral reduction of these forces to (20), taking into account the area ratio $F_y = b_c H_0$ и $F_x = H_0 a$ the side walls of the frame of the hopper of the machine to $F_{zc} = ab_c$ characterized by the coefficients

$$\mu_x = 0,5\frac{f_b}{b_c}k_b\left(1+\cos^2\alpha\right)\frac{F_y}{F_{zc}}\int_{-0,5b_c}^{+0,5b}\left(1-\cos\frac{\pi y}{b_0}\right)dy$$

$$\mu_y = 0,182\frac{b_c}{a}f_b k_b\left(1+\cos^2\alpha\right) \quad (23)$$

$$\mu_x = \frac{F_x}{F_{zc}}\cdot\frac{k_b}{a}f_b\int_{-0,5a}^{+0,5a}\left(1-\cos\frac{\pi x}{a}\right)dx$$

$$\mu_x = 0,363\frac{H_0}{b_c}k_b f_b\,. \quad (24)$$

The assumptions introduced allow:

- Get the function of the reduced intensity of the forces from the vertical pressure of the mass of cotton, friction on the side walls of the hopper and inside this mass $q_n(t,z,y,x) = q_z(t,z)e^{-\lambda z}\cdot e^{\beta t}\cdot\left[1-\mu_y\left(1-\cos\frac{\pi y}{b_0}\right)-\mu_x\left(1-\cos\frac{\pi x}{a}\right)\right]$ (25)

- use the equation to estimate the compressive strain of the mass of cotton in the bunker of the cotton picker

$$F_0 e^{kz}\cdot\frac{\gamma_{xc}}{g}\cdot\frac{\partial^2 U_b}{\partial t^2} - E_c F_0 k e^{kz}\frac{\partial U_b}{\partial z} - E_c F_0 e^{kz}\left(\frac{\partial^2 U_b}{\partial z^2}+\frac{b_c}{a}\cdot\frac{\partial^2 U_b}{\partial y^2}+\frac{H_0}{b_c}\cdot\frac{\partial^2 U_b}{\partial x^2}\right)=$$

$$= q_k e^{-\lambda z} \cdot e^{\beta t}\left(1-\mu_y-\mu_x+\mu_y\cos\frac{\pi y}{b_0}+\mu_x\cos\frac{\pi x}{a}\right). \quad (26)$$

After dividing all the terms of the equation by $F_0 e^{kz}\cdot\frac{\gamma_{xc}}{g}$ we get an equation with constant coefficients on the left side, the solution of which will contain 3 components, determined from the solution of the equations

$$\frac{\partial^2 U_{b1}}{\partial t^2}-k\frac{E_c g}{\gamma_{xc}}\cdot\frac{\partial U_{b1}}{\partial z}-\frac{E_c g}{\gamma_{xc}}\cdot\frac{\partial^2 U_{b1}}{\partial z^2}=\frac{q_k g}{F_0\gamma_{xc}}e^{-(\lambda+k)z}\cdot e^{\beta t}\left(1-\mu_y-\mu_x\right) \quad (27)$$

at $U_{Б1}(t,z)$,

$$\frac{\partial^2 U_{b2}}{\partial t^2}-k\frac{E_c g}{\gamma_{xc}}\cdot\frac{\partial U_{b2}}{\partial z}-\frac{E_c g}{\gamma_{xc}}\left(\frac{\partial^2 U_{b2}}{\partial z^2}+\frac{b_c}{a}\cdot\frac{\partial\, U_{b2}}{\partial y^2}\right)=\mu_y q_k e^{-(\lambda+k)z}\cdot e^{\beta t}\cdot\cos\frac{\pi y}{b_0}\ldots \quad (28)$$

at $U_{b2}(t,z,y)$,

$$\frac{\partial^2 U_{b3}}{\partial t}-k\frac{E_c g}{\gamma_{xc}}\cdot\frac{\partial U_{b3}}{\partial z}-\frac{E_c g}{\gamma_{xc}}\left(\frac{\partial^2 U_{b3}}{\partial z^2}+\frac{H_0}{b_c}\cdot\frac{\partial^2 U}{\partial x^2}\right)=\mu_x q_k e^{-(\lambda+k)z}\cdot\cos\frac{\pi x}{a}. \quad (29)$$

We solve these equations:

1. For (27) in the form

$$U_{b1}(t,z)=U_{b1}(t)e^{-(\lambda+k)z}, \quad (30)$$

Wherein $U_{B1}(t)$ determined by solving the equation

$$\frac{d^2U_{b1}}{dt^2}-\psi_{b1}^2 U_{b1}=\frac{q_k g}{F_0\gamma_{xc}}e^{\beta t}\left(1-\mu_y-\mu_x\right) \quad (31)$$

at $\psi_{b1}^2=\frac{E_c g}{\gamma_{xc}}\lambda(\lambda+k)$ $U_b(0)=\frac{dU_{b1}(0)}{dt}=0$.

The last equation is solved by the operational calculus method and we obtain

$$U_{b1}(t)=\frac{q_k g}{F_0\gamma_{xc}\left(\psi_{b1}^2-\beta^2\right)}\left(ch\psi_{b1}t+\frac{\beta}{\psi_{b1}}sh\psi_{b1}t-e^{-\beta t}\right). \quad (32)$$

2. For (28) in the form $U_{b2}(t,z,y)=U_{b2}(t)e^{-(\lambda+k)z}\cos\frac{\pi y}{b_0}$, (33)

wherein $U_{Б2}(t)$ determined by solving the equation

$$\frac{d^2U_{b2}}{dt^2}+\psi_{b2}^2 U_{b2}=\frac{g q_k\mu_y}{F_0\gamma_{xc}}e^{\beta t} \quad (34)$$

at $\psi_{b2}^2=\frac{E_c g}{\gamma_{xc}}\cdot\left[\frac{\pi^2 b_c}{ab_0^2}-\lambda(\lambda+k)\right]$, $U_{b2}(0)=\frac{dU_{b2}(0)}{dt}=0$

Solution (34) is obtained in the form $U_{b2}(t)=\frac{q_k g\mu_y}{F_0\gamma_{xc}\left(\beta^2+\psi_{b2}^2\right)}\left(e^{\beta t}-\cos\psi_{b2}t-\frac{\beta}{\psi_{b2}}\sin\psi_{b2}t\right)$ (35)

3. For (29), in the form

$$U_{b3}(t,z,x)=U_{b3}(t)e^{-(\lambda+k)z}\cos\frac{\pi x}{a}, \quad (36)$$

wherein $U_{Б3}(t)$ determined from the equation

$$\frac{d^2U_{b3}}{dt^2} + \psi_{b3}^2 U_{b3} = \frac{gq_k\mu_x}{F_0\gamma_{xc}} e^{\beta t} \qquad (37)$$

at $\psi_{b3}^2 = \frac{E_c g}{\gamma_{xc}}\left[\frac{H_0\pi^2}{b_c a^2} - \lambda(\lambda + k)\right]$, $U_{b3}(0) = \frac{dU_{b3}(0)}{dt} = 0$ and solutions (37) in the form

$$U_{b3}(t) = \frac{q_k g\mu_x}{F_0\gamma_{xc}\left(\beta^2 + \psi_{b3}^2\right)}\left(e^{\beta t} - \cos\psi_{b2}t - \frac{\beta}{\psi_{b3}}\sin\psi_{b3}t\right) \qquad (38)$$

When the values ψ_{b2} and ψ_{b3} turn out to be less than zero, the solutions of equations (34) and (37) are similar to (32).

V. DISCUSSION

The results obtained make it possible to evaluate the residual deformations of the self-compaction process through:

- Coefficients μ_x and μ_y for the total volume of cotton in the bunker of the cotton picker;
- Odds $k_b f_b$ close to the three side walls and $\mu_b f_b$ for inclined pitched wall.

When used to seal the mass of cotton, a surface having vertical impulse movements with amplitude H_l and exposure areas $F_l = a_l b_l$ in the middle of the bunker frame of the cotton picker, the maximum force achieved P_l can be determined by the formula:

$$P_l = E_c \frac{H_l}{H_0} a_l b_l \left(1 + \mu_x + \mu_y\right). \qquad (39)$$

We evaluate such impact:

- Using the averaged function of vertical pressures, taking into account the increase in pressure on $\frac{P_l}{2ab_c}$

  Compared to (2)

$$P_{zy}(z) = \frac{P_l}{2ab_c} + \frac{\gamma_0 + \gamma_k}{2} H_0 - \gamma_k z - (\gamma_k - \gamma_0)\frac{z^2}{2H_0} ... \qquad (40)$$

and intensities of vertical forces

$$q_{zy}(z) = \int_0^z P_{zy}(z)dz = \frac{z}{2}\left[\frac{P_l}{ab_c} + (\gamma_0 + \gamma_k)H_0\right] - \gamma_k \frac{z^2}{2} + \frac{\gamma_k - \gamma_0}{6H_0} z^3 + q_{ky} ..., \qquad (41)$$

for q_{ky} use the condition for a layer of cotton with

Z=H₁=H₀ - 0,5Hₗ

$$q_{zy}(H_1) = \frac{P_l H_1}{2ab_c} = \frac{H_1}{2}\left[\frac{P_l}{ab_c} + (\gamma_0 + \gamma_\kappa)H_1\right] - \gamma_\kappa \frac{H_1^2}{2} + \frac{\gamma_\kappa - \gamma_0}{6} H_1^2 + q_{ky} \text{ where from}$$

$$q_{ky} = \frac{P_l H_1}{2ab_c} + \frac{H_1^2}{6}(2\gamma_k - \gamma_0) - \frac{H_1}{2}\left[\frac{P_l}{ab_c} + H_1(\gamma_0 + \gamma_k)\right]; \qquad (42)$$

- Selection of the approximating function

$$q_{zy}(z) = q_{ky} e^{-\lambda_y z} \qquad (43)$$

in which $\lambda_y = \frac{1}{H_0}\ln\frac{q_{ky}}{q_{zy}H_1}$ or

$$\lambda_y = \frac{1}{H_0}\ln\frac{\frac{P_l H_1}{2ab_c} + \frac{H_1^2}{6}(2\gamma_k - \gamma_0 - \frac{H_1}{2}\left[\frac{P_l}{ab_c} + H_1(\gamma_0 + \gamma_k)\right]}{P_l H_l} \cdot a(b_k + b_0); \quad (44)$$

- Representations of the intensity function of vertical forces in the form

$$q_z(t,z,y,x) = q_{ky}(1-\cos\omega_n t)e^{-\lambda_y z} \cdot \cos\frac{\pi y}{b_0}\cos\frac{\pi x}{a}, \quad (45)$$

Where $\omega_n = \frac{2\pi}{\tau_n}$, τ_n - force impulse duration $P_l(t)$;

- The value of the increment of the average integral pressure on the mass of cotton inside the BHM along the *OZ* axis from the effect of the force *P$_l$(t)*

$$P_n = \frac{P_l}{2ab_c}\cdot\frac{1}{H_0}\int_0^{H_0} q_{ky}e^{-\lambda_y z}dz \cdot \frac{1}{b_0}\int_{-0,5b_0}^{+0,5b_0}\cos\frac{\pi y}{b_0}dy \cdot \frac{1}{a}\int_{-0,5a}^{+0,5a}\cos\frac{\pi x}{a}dx = \frac{2P_l}{\pi^2 ab_0\lambda_y}\left(1-e^{-\lambda_y H_0}\right); \quad (46)$$

- The average modulus of elasticity of the mass of compressed cotton over time $t = 0 \div \tau_n$

$$E_y = E_c + 0{,}75P_n = E_c + \frac{1{,}5P_l}{\pi^2 ab_0\lambda_y}\left(1-e^{-\lambda_y H_0}\right) \quad (47)$$

and function $F_z(z) = F_0 e^{kz} = ab_k e^{kz}$;

the introduction of the function $U_y(t,z,y,x)$, taking into account elastic compression deformations (along the *Z* axis) of the mass of cotton inside the hopper during $t = 0 \div \tau_n$ compaction cycle, using an equation to find this function of type (26) with the function of the right-hand side according to (45)

$$F_0 e^{kz}\cdot\frac{\gamma_{xc}}{g}\cdot\frac{\partial^2 U_y}{\partial t^2} - E_y F_0 k e^{kz}\frac{\partial U_y}{\partial z} - E_y F_0 \cdot e^{kz}\left(\frac{\partial^2 U_y}{\partial z^2} + \frac{b_c}{a}\cdot\frac{\partial^2 U_y}{\partial y^2} + \frac{H_0}{b_c}\cdot\frac{\partial^2 U_y}{\partial x^2}\right) =$$

$$= q_{ky}(1-\cos\omega_n t)e^{-\lambda_y z}\cdot\cos\frac{\pi y}{b_0}\cos\frac{\pi x}{a}. \quad (48)$$

We find the solution to this equation in the form $U_y(t,z,y,x) = U_y(t)e^{-(k+\lambda_y)z}\cos\frac{\pi y}{b_0}\cos\frac{\pi x}{a}$. (49)

After substituting the partial derivatives of (49) and carrying out the transformations, we obtain the equation

$$\frac{d^2U_y}{dt^2} + \psi_y^2 U_y = \frac{q_{ky}g}{F_0\gamma_{xc}}(1-\cos\omega_n t) \quad (50)$$

at $\psi_y^2 = \frac{E_y g}{\gamma_{xc}}\left[\pi^2\left(\frac{b_c}{ab_0^2} + \frac{H_0}{b_c a^2}\right) - \lambda_y(\lambda_y + k)\right]$ и $U_y(0) = \frac{dU_y(0)}{dz} = 0$.

The solution (50), made by the operational calculus method, we obtain in the form

$$U_y(t) = \frac{q_{ky}g}{F_0\gamma_{xc}(\psi_y^2 - \omega_n^2)}\left[1-\cos\omega_n t - \frac{\omega_n^2}{\psi_y^2}(1-\cos\psi_y t)\right]. \quad (51)$$

at $\psi_y^2 \rangle\rangle \omega_n^2$, maximum amplitudes will be achieved at $t = 0{,}5\tau_n$ and are equal

$$U_{ym} \approx \frac{2q_{ky}}{F_0 E_y \left[\pi^2 \left(\frac{b_c}{ab_0^2} + \frac{H_0}{b_c a^2} \right) - \lambda_y \left(\lambda_y + k \right) \right]} . \quad (52)$$

Residual deformations amount to one seal stroke

$$U_{ym}\left(\mu_x + \mu_y\right) = U_{01} . \quad (53)$$

At the initial density of cotton γ_0 and the average maximum achievable $\gamma_{xм}$ total residual strain must be realized

$$U_{0c} = H_0 \left(1 - \frac{\gamma_0}{\gamma_{xм}} \right) . \quad (54)$$

To do this, the following number of strokes of the seal must be sequentially performed:

$$W_y = \frac{U_{0c}}{U_{01}} \approx \frac{\gamma_{xм} H_0}{\frac{2q_{ky}}{F_0 E_y \left[\pi^2 \left(\frac{b_c}{ab_0^2} + \frac{H_0}{b_c a^2} \right) - \lambda_y \left(\lambda_y + k \right) \right]} \cdot \left(\mu_x + \mu_y \right)} \quad (55)$$

VI. CONCLUSION

Here is an example of calculating the process of compaction of cotton in the hopper of the machine, according to Fig. 1, with dimensions:a=2,5m, b_0=3m, b_k =2,5m, H_0 =2m. The side walls of the hopper are mesh, so we accept f_B=1,0, κ_B =0,5. Sealing surface dimensions a_l = b_l= 1,5m, ее ход H_l=0,5m, H_1=1,75m, cosα =0,707 (α =45^0). We apply the following sequence of calculations

1. Using formulas (23) and (24), we determine

$$\mu_y = 0{,}182 \frac{2{,}5}{2{,}5} 0{,}5\left(1 + 0{,}707^2\right) = 0{,}136$$

$$\mu_x = 0{,}363 \frac{2}{2{,}5} \cdot 0{,}5 = 0{,}145$$

2. To a first approximation, we determine the maximum force Pl applied along the Z axis to the sealing surface, while taking

E_c=289kg/m^2. For this we use the formula (39),

$$P_l = 289 \cdot \frac{0.5}{2} \cdot 1{,}5 \cdot 1{,}5 \cdot 1{,}281 = 208{,}2 \text{ kg.}$$

For subsequent calculations, we take P_l=250kg, determine the average additional pressure on the layers of compressible mass of cotton inside the hopper

$$P_{zy} = \frac{P_l}{2ab_c} = \frac{250}{2 \cdot 2{,}5 \cdot 2{,}5} = 20\, kg/m^2$$ and specify the modulus of elasticity

$$E_y = E_c + 0{,}75 P_{zy} = 289 + 0{,}75 \cdot 20 = 304\, kg/m^2$$

3. By the formula (42) we determine

$$q_{ky} = \frac{250 \cdot 0{,}5}{2 \cdot 2{,}5 \cdot 2{,}5} + \frac{1{,}75^2}{6}\left(2 \cdot 130 - 30\right) - \frac{1{,}75}{2} \cdot \left[\frac{250}{2{,}5 \cdot 2{,}5} + 1{,}75\left(130 + 30\right) \right] = 152{,}6$$ kg/m in this

formula taken γ_0 =30 kg/m и γ_{k3} =130 kg/m при γ_{i3} =80 kg/m.

4. By the formula (44) we calculate $\lambda_y = \frac{1}{2} \ln \frac{152{,}6}{250 \cdot 0{,}5} \cdot 2{,}5\left(2 + 3\right) = 1{,}353$

5. By the formula (16) we determine

$$k = \frac{1}{2}\ln\frac{3}{2} = 0{,}203 \text{, so } \lambda_y + k = 1{,}363 + 0{,}203 = 1{,}566$$

6. We specify the value of the elastic modulus for the compaction cycle, corresponding to the achievement γ_{c3} =80kg/m by the formula (47)

$$E_y = 289 + \frac{1{,}5 \cdot 250}{\pi^2 \cdot 2{,}5 \cdot 3 \cdot 1{,}363}\left(1 - e^{-2.726}\right),\ E_y \approx 292 \text{ kg/m}^2.$$

7. Determine the elastic maximum compression strain of the mass of cotton under the action of force $P_l(t)$ according to the formula (52)

$$U_{ym} = \frac{2 \cdot 152{,}6}{6 \cdot 292\left[\pi^2\left(\frac{2{,}5}{2{,}5 \cdot 3^2} + \frac{2}{2{,}5 \cdot 2{,}5^2}\right) = 1{,}363 \cdot 1{,}566\right]} = 0{,}787\, m$$

When using a seal mechanism designed for movement H_l = 0,5m, actual $U_y = H_l$ = 0,5m.

8. By (53) we calculate $U_{01} = U_y(\mu_x + \mu_y) = 0{,}5 \cdot (0{,}136 + 0{,}145)$, $U_{01} = 0{,}14m$,further required residual deformation according to (54) $U_{0c} = \left(1 - \frac{\gamma_0}{\gamma_{c3}}\right)H_0 = \left(1 - \frac{30}{80}\right) \cdot 2 = 1{,}25m$ number of consecutive strokes of the seal

$$W_y = \frac{U_{0c}}{U_{01}} = \frac{1{,}25}{0{,}14} = 8{,}93$$

The proposed method for calculating the process of compaction of cotton in the hopper of the machine allows us to solve the problem of optimizing the design options of such seals.

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