Investigation Of Beater Blade Deflection During Interaction with Haulm-Removing Conveyor Bars

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Annotation
The article deals with the issue of determining the thickness of the beater blade when interacting with the bars of the haulm-removing conveyor and the conclusion about the advisability of using a new working body for separating potato tubers

Keywords: blade, cantilever beam, haulm conveyor, rods, flexibility.

When interacting with the bars, the beater webs receive large elastic displacements. In this regard, we will solve the problem posed using the method of theories of flexible rods.

Consider the blade as a cantilever beam (Fig. 1), one end of which is rigidly fixed, and a pressing force N and a friction force F are applied to the free end. The resultant of these forces is equal to

$$P=\sqrt{N^2+F^2}=N\sqrt{1+f^2}$$
.

Let's make the following assumptions:

1. Force P acts on the free end of the blade.

2. Bend of the blade occurs in the plane of rotation of the beater.

The calculation scheme of the blade bending is shown in Fig. 1, where the straight line

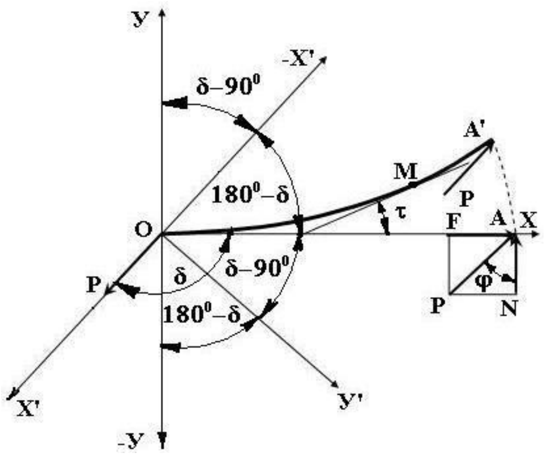

Fig.1. Design scheme for blade bending

OA depicts its original axis, and OA1 is curved.

The differential equation of the bent axis of the blade has the following form

$$l_л^2 d^2\varepsilon / ds^2 = -\beta^2 \sin\varepsilon, \tag{1}$$

Where $l_л$ - full length of the axial line of the beater blade, m;

s - the length of the arc of the elastic line at an arbitrary point M, counted from its beginning Oh, m,

$$\beta = l_л \sqrt{P/H}, \tag{2}$$

$$\varepsilon = \tau + \delta, \tag{3}$$

Where $H=EI$- bending stiffness of the blade cross section, Hм^2;

E – modulus of elasticity of the blade material, Pa;

I - moment of inertia of the blade cross section, m ^{4};

τ - angle of inclination of a tangent drawn to a curved axis at the point T to the axis X ;

δ - the angle of inclination of the force P to the X axis.

In equation (2), the quantities $l_л$, β And δ are constant and known.

To solve equation (2), we take

$$d\varepsilon / ds = z. \tag{4}$$

Taking into account this equation (3.7) will have the following form.

$$l_л^2 dz / ds = -\beta^2 \sin\varepsilon. \tag{5}$$

Passing to the half argument and multiplying both parts of equation (5) by the corresponding parts of the following identity (its validity follows from (4))

$$zds = d\varepsilon, \tag{6}$$

we get

$$2l_л^2 zdz = -4\beta^2 \sin(\varepsilon/2)\cos(\varepsilon/2)d\varepsilon. \tag{7}$$

Integrating this equation, we get

$$(l_{л}z)^2 = -4\beta^2 \sin(\varepsilon/2) + C, \qquad (8)$$

where C is an arbitrary constant.

Having defined $C=4\beta^2 D$ and taking into account equation (4), we obtain

$$\left(l_{л} d\varepsilon/ds\right)^2 = 4\beta^2\left(D - \sin^2\frac{\varepsilon}{2}\right), \qquad (9)$$

From the condition of the validity of the quantity $d\varepsilon/ds$ from equation (9) it follows that

$$D \ge \sin^2\frac{\varepsilon}{2} \qquad (10)$$

Here the following two cases are possible

$$1 \ge D \ge \sin^2\frac{\varepsilon}{2} \qquad (11)$$

And

$$1 \le D \ge \infty\,. \qquad (12)$$

The solution of equation (9) in each of these cases will be different, and when considering a specific problem, it will be determined in advance which case it belongs to. The problem we are considering refers to the first case, and to solve equation (10), taking into account condition (11), we can introduce the following notation

$$D = \kappa^2 \qquad (13)$$

And

$$\sin^2\frac{\varepsilon}{2} = \kappa^2 \sin^2\psi, \qquad (14)$$

Where κ = *const*

ψ - new variable to look for instead of angle ε.

$$0 \le \kappa \le 1; \qquad 0 \le \psi \le \frac{\pi}{2}\,. \qquad (15)$$

Taking into account (13) and (14), equation (9) takes the following form

$$l_{л}\frac{d\varepsilon}{ds} = 2\beta\kappa\cos\psi\,. \qquad (16)$$

Differentiating equations (14) with respect to S and solving it with respect to $\frac{d\varepsilon}{ds}$, we get

$$\frac{d\varepsilon}{ds}=\frac{2\kappa^2\sin\psi\cos\psi}{\sin\frac{\varepsilon}{2}\cdot\cos\frac{\varepsilon}{2}}\cdot\frac{d\psi}{ds}. \tag{17}$$

Substituting this values *dε/ds* in (16) and taking into account (14), we have

$$l_л\frac{d\psi}{ds}=\beta\sqrt{1-\kappa^2\sin^2\psi}\ . \tag{18}$$

Integration of this equation from the starting point 0(s = 0; $\psi=\psi_0$) to an arbitrary point M (s, ψ), gives

$$S=\frac{l_л}{\beta}\left[F(\psi)-F(\psi_0)\right], \tag{19}$$

Where $F(\psi)$ And $F(\psi_0)$ - elliptic integrals of the first kind

$$F(\psi)=\int_0^{\psi}\frac{d\psi}{\sqrt{1-\kappa^2\sin\psi}}; \tag{20}$$

$$F(\psi_0)=\int_0^{\psi_0}\frac{d\psi}{\sqrt{1-\kappa^2\sin^2\psi}}. \tag{21}$$

Here the constant k is called the modulus, and the variable ψ - amplitude of the elliptic integral.

For blade end $S=l_л$ и $\psi=\psi_L$. Substituting these values of S and ψ in (19), we get

$$\beta=F(\psi_L)-F(\psi_0). \tag{22}$$

Next, we find the equation of the curved axis of the blade in the coordinate system *XOУ*. To do this, we introduce an additional coordinate system *X′OУ′*, oriented in the direction of the force P applied at the starting point O (Fig. 1). From the diagram shown in Fig. 1, we have

$$dX'=-ds\cos\left(180^0-\varepsilon\right)=ds\cos\varepsilon=ds\left(2\cos^2(\frac{\varepsilon}{2})-1\right); \tag{23}$$

$$dY' = ds\cos\left(\varepsilon - 90^0\right) = ds\sin\varepsilon = 2ds\sin(\frac{\varepsilon}{2})\cdot\cos(\frac{\varepsilon}{2}). \qquad (24)$$

Taking into account (14) and (18), we rewrite these equations in the following form

$$\frac{dX^/}{l_л} = \frac{2}{\beta}\sqrt{1-\kappa^2\sin\psi}\,d\psi - \frac{ds}{l_л} \qquad (25)$$

And

$$\frac{dY^/}{l_л} = \frac{2}{\beta}\kappa\sin\psi d\psi. \qquad (26)$$

Integrating these equations gives

$$X^/ = \frac{2l_л}{\beta}\left[E(\psi) - E(\psi_0)\right] - S \qquad (27)$$

And

$$Y^/ = \frac{2kl}{\beta}(\cos\psi_0 - \cos\psi), \qquad (28)$$

Where $E\ (\psi)$ и $E(\psi_0)$ - elliptic integrals of the second kind;

$$E(\psi) = \int_0^{\psi}\sqrt{1-\kappa^2\sin^2\psi}\,d\psi \qquad (29)$$

And

$$E(\psi_0) = \int_0^{\psi_0}\sqrt{1-\kappa^2\sin^2\psi}\,d\psi. \qquad (30)$$

Now we move from the additional coordinate system to the original coordinate system *XOY*.

$$X = X^/\cos\delta + Y^/\sin\delta \qquad (31)$$

$$Y = Y^/\cos\delta - X^/\sin\delta \qquad (32)$$

Substituting into (30) and (31) above the found values $X^/$ And $Y^/$, we get

$$X = \left\{\frac{2l_л}{\beta}\left[E(\psi) - E(\psi_0)\right] - S\right\}\cos\delta + \frac{2l_л}{\beta}\kappa\left(\cos\psi_0 - \cos\psi\right)\sin\delta\ , \qquad (32)$$

$$У = \frac{2l_л}{\beta}\kappa(\cos\psi_0 - \cos\psi)\cdot\cos\delta - \left\{\frac{2l_л}{\beta}\left[E(\psi) - E(\psi_0)\right] - S\right\}\sin\delta. \qquad (33)$$

For the end point of the blade, these equations will take the form

$$X_L = \left\{\frac{2l_л}{\beta}\left[E(\psi_L) - E(\psi_0)\right] - l_л\right\}\cos\delta + \frac{2l_л}{\beta}\kappa(\cos\psi_0 - \cos\psi_L)\sin\delta; \qquad (34)$$

$$У_L = \frac{2l_л}{\beta}\kappa(\cos\psi_0 - \cos\psi_L)\cdot\cos\delta - \left\{\frac{2l_л}{\beta}\left[E(\psi_L) - E(\psi_0)\right] - l_л\right\}\sin\delta. \qquad (35)$$

Using these formulas, we can determine the coordinates of the end point of the blade if the elliptical parameters are known κ, ψ_0 And ψ_L. For determining κ, ψ_0 And ψ_L we use the following data.

1. For starting point O $\psi = \psi_0$ And $\tau = 0$, a hence according to (3) and (14)

$$\kappa\sin\psi_0 = \sin\frac{\delta}{2}. \qquad (36)$$

2. Given that

$$\frac{d\varepsilon}{ds} = \frac{d\tau}{ds} = \frac{M}{EJ} \qquad (37)$$

according to (16), we get

$$\kappa\cos\psi = \frac{l_л}{2\beta}\cdot\frac{M}{EJ}, \qquad (38)$$

Where M - bending moment in the considered section of the blade.

For blade end point $M = 0$, and consequently

$$\kappa\cos\psi_L = 0 \qquad (39)$$

Where

$$\psi_L = \frac{\pi}{2} \qquad (40)$$

3. The third equation for determining the elliptic parameters is expression (22), which, taking into account (40), has the form

$$F(\kappa) - F(\psi_0) = \beta,$$

Where $F(\kappa) = \int_0^{\frac{\pi}{2}} \frac{d\psi}{\sqrt{1-\kappa^2\sin^2\psi}}$ - complete elliptic integral of the first kind.

Thus, we have obtained the following three equations for determining the values of the elliptic parameters *κ*, ψ_0 And ψ_L

$$\kappa \sin\psi_0 = \sin\frac{\delta}{2}; \tag{41}$$

$$\psi_L = \frac{\pi}{2}; \tag{42}$$

$$F(\kappa) - F(\psi_0) = \beta . \tag{43}$$

One of the unknowns ψ_L is determined from (42), two other unknowns *κ* And ψ_0 from (41) and (43) by selection. To do this, according to the tables of elliptic integrals, the value is found *κ*, *F(κ)* And *F(*ψ_0*)*depending on the angle α (where is the angle α Connected with *κ* equation *κ*=sinα).

Giving α some values, find the corresponding angles ψ_0 according to expression

$$\sin\alpha \cdot \sin\psi_0 = \sin\frac{\delta}{2}, \tag{44}$$

where

$$\psi_0 = \arcsin\left(\frac{\sin\frac{\delta}{2}}{\sin\alpha}\right). \tag{45}$$

For selected corners α And ψ_0 from the table of elliptic integrals we find the values *F(κ)* And *F(*ψ_0*)*.Then changing the angle α, and therefore ψ_0, we make sure that the difference *F(κ)* And *F(*ψ_0*)*was equal β.

Substituting the found values *κ* And ψ_0 in (45) and (46) we determine the coordinates X_L And y_L end point of the blade.

Considering that for our case

$\psi_L = \dfrac{\pi}{2}$ And $\delta = \dfrac{\pi}{2} + \varphi_л$ (

Where $\varphi_л$ - angle of friction of the material of the blade on the leaves), expressions (34) and (35) will have the following form.

$$X_L = \left\{\frac{2l_л}{\beta}\left[E(\kappa) - E(\psi_0)\right] - l_л\right\}\cos\left(\frac{\pi}{2} + \frac{\varphi_л}{2}\right) + \frac{2l_л}{\beta}\kappa\cos\psi_0 \sin\left(\frac{\pi}{2} + \frac{\varphi_л}{2}\right)$$

(47)

And

$$У_L = \frac{2l_л}{\beta}\kappa\cos\psi_0\cos\left(\frac{\pi}{2}+\frac{\varphi_л}{2}\right)-\left\{\frac{2l_л}{\beta}\left[E(\kappa)-E(\psi_0)\right]-l_л\right\}\cdot\sin\left(\frac{\pi}{2}+\frac{\varphi_л}{2}\right) \quad (48)$$

Where - $E(\kappa)=\int_0^{\frac{\pi}{2}}\sqrt{1-\kappa^2\sin^2\psi}\,d\psi$ complete elliptic integral second kind.

From the analysis of dependences (47) and (48) it follows that the deflection of the beater blade when interacting with the bars of the haulm-removing conveyor depends on its length, the properties of the material from which the blades are made (E And $\varphi_л$), the shape and size of their cross section, the direction and magnitude of the emerging forces.

Let us determine the stress that occurs in the seal of the blade

$$\sigma_0 = \omega_0\beta E h_л/(2l_л), \quad (49)$$

Where $\omega_0 = 2\kappa\cos\psi_0$; (50)

$h_л$ - blade thickness, m;

E – modulus of elasticity of the blade material, Pa;

Taking into account (49) and (50), as well as the fact that $H = EJ$ (Where J – moment of inertia of the cross section of the blade), and $J= B_л h^3_л /12$ expression (51) will have the following form

$$\sigma_0 = \left(2\kappa\sqrt{3EP}/\sqrt{B_л h_л}\right)\cos\psi_0 . \quad (51)$$

Using this formula, you can determine the thickness of the blade, i.e.

$$h_л \geq 12\kappa^2 EP/\left(B_л[\sigma]^2\cos^2\psi\right), \quad (52)$$

Where $[\sigma]$ – allowable stress, MPa.

Calculations carried out by formula (52) for $[\sigma]$ = 7 МПа, E=200 МПа, N=800Н, $\varphi_л$=30^0, $B_л$ =1м, κ=0,82 And ψ_0 = 54^0 showed that the thickness of the blade should be at least 9.2 mm.

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