SPIRAL-SCREWING DEVICE FOR GRAINING OF GRAIN MATERIAL

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ABSTRACT

The present article is devoted to the study of technological processes that occur when a grain embankment is torn by a device with a working member in the form of a spiral screw in the conditions of grain storage facilities, in particular, theoretical and practical research of processes in the device for stirring grain. The graphic relationship of the speed of movement of the technical means of stirring grain to the grain embankment and the ability of the technical means to pass through the amount of grain embankment at different rotational speeds of the spiral screw are compared with theoretical studies. As a result of the studies, rational values of the parameters of the grain torsion device were obtained, as well as regression equations allowing to determine the necessary rotation frequency of the spiral screw in order to provide the required device capacity at different spiral pitch. In this comparison of the results obtained experimentally and theoretically showed that the convergence of the results is 94%.

Key words: Displacement, stirring, throughput, regression equations, velocity of grain movement.


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1. INTRODUCTION
When storing grain there are many problems associated with its movement, large material costs, the lack of appropriate means of mechanization, etc. One of the main indicators for the storage of grain is its temperature, as self-heating of grain inside the mound violates the process of its storage. To prevent self-warming, you need to use grain drying, active ventilation, etc. One of the best ways to prevent the self-heating of the grain and its consequent deterioration is to mix the whole of the shoe with a device for rotating the grain with a working member in the form of a spiral screw.

At the same time, the development of a new, simple and reliable device for rotating the grain on the basis of a spiral-screw working organ is an urgent task [1].

2. MATERIALS AND METHODS OF RESEARCH
The grain that fills the interstitial space of the spiral is in cramped conditions, as a result of which the investigation of the movement of grain material by a helical-screw working organ represents one of the complex experimental and theoretical problems [2, 3].

The principle of operation of the tearing device (Figure 1) is as follows. The device is placed on a grain shroud and the electric motor is turned on. Then the working organ is introduced into the thickness of the grain, and the device is placed in an upright position. The grains are gripped by a spiral-helical working element from the lower part of the collar and moves up along the body of the device, and then is removed from it through the outlet nozzle. Items denote the following elements 1 - body; 2 - spiral screw; 3 - shaft; 4 - outlet nozzle; 5 - reducer; 6 - electric motor.

![Figure 1 Scheme of the device for stirring grain material](image)

Turning to the movement of the bulk grain flow, we will write the formula for determining the throughput, kg/s, the device for stirring the bulk material [6]:

\[ Q = k_n \cdot F \cdot \nu_{0cp} \cdot \rho, \] (1)
where is $k_n$ - the throughput factor; $F$ - working area of the cross section of the spiral, $m^2$; $v_{0cp}$ - average axial velocity of the material, m/s; $\rho$ - bulk density of grain, kg/m$^3$.

The coefficient of throughput $k_n$ should be understood as a number equal to or less than unity, showing that part of the working area of the cross section of the spiral $F$, in which all material is conventionally moved with an average velocity $v_{0cp}$.

Let us give the formula (1) a detailed view:

$$Q = \pi \cdot v_{0cp} \cdot \rho \cdot k_n (r_2^2 - r_1^2) .$$

(2)

where is $r_2$ – the outer radius of the spiral screw, m; $r_1$ – inner radius of spiral screw, m.

We select on the projection of the helical surface of the helix on the plane perpendicular to the $z$ axis an elementary infinitesimal area $dF = r dr dQ$, where $r$ – is the distance from the center of rotation of the spiral to the elementary area, m (Figure 2).

![Figure 2](image)

**Figure 2** Determination of the average grain speed

Assuming for the elementary area the velocities $v_0$ and $v_s$ are constant, we determine the average axial velocity of the grain material on the elementary area $dr$ [4, 5] (Figure 2a):

$$v_{0cp} = \frac{\int_0^{2\pi} \int_0^r v_0 dQ r dr}{\int_0^{2\pi} \int_0^r dQ r dr} ,$$

(3)

where $v_0$ – is the axial velocity of each unit grain located on the $dr$ area, m/s.

The average circumferential velocity of a unit grain in terms of the cross-sectional area of the helix

$$v_{scp} = \frac{\int_0^{2\pi} \int_0^r v_s dQ r dr}{\int_0^{2\pi} \int_0^r dQ r dr} .$$

(4)

where $v_s$ – is the transport speed of each unit grain located on the $dr$ site, m/s.
Let us replace trigonometric functions in formulas (3) and (4) with dependencies, which can be written by considering the development of the helix (Figure 2b):

\[
\sin \alpha = \frac{s}{\sqrt{s^2 + 4\pi^2 r^2}}, \quad \cos \alpha = \frac{2\pi r}{\sqrt{s^2 + 4\pi^2 r^2}},
\]

where \( s \) – is the pitch of the screw, m.

To simplify the mathematical transformations, we denote \( c = s / 2\pi \) the part of the helix pitch of the helix per one radian of rotation of the generator and express the values \( \sin \alpha \) and \( \cos \alpha \) in terms of \( c \) [6, 7]:

\[
\sin \alpha = \frac{c}{\sqrt{c^2 + r^2}}, \quad \cos \alpha = \frac{r}{\sqrt{c^2 + r^2}}.
\]

Then, respectively, the axial and portable velocities:

\[
\nu_0 = \frac{\omega c r \tan \beta}{c + \tan \beta \cdot r}, \quad (5)
\]

\[
\nu_s = \frac{\omega c r}{c + \tan \beta \cdot r}, \quad (6)
\]

where \( \omega \) - is the rotational speed of the spiral, min\(^{-1}\); \( \beta \) - is the angle between the velocity vectors \( \nu_0 \) and \( \nu_s \), deg.

Denoting \( q = \tan \beta \) and substituting the values of \( \nu_0 \) and \( \nu_s \) into expressions (5) and (6), we obtain:

\[
\nu_{0cp} = \frac{\omega c}{2q^2 (r_2^2 - r_1^2)} \left[ q^2 (r_2^2 - r_1^2) - 2qc (r_2 - r_1) + c^2 \ln \frac{c + qr_2}{c + qr_1} \right]. \quad (7)
\]

Average circumferential speed of grain:

\[
\nu_{scp} = \frac{\omega c}{2q^3 (r_2^2 - r_1^2)} \left[ q^2 (r_2^2 - r_1^2) - 2qc (r_2 - r_1) + c^2 \ln \frac{c + qr_2}{c + qr_1} \right]. \quad (8)
\]

Formulas (7) and (8) are derived taking into account the fact that the interturn space of the helix is completely filled with grain.

For spiral screws used for tearing grain, with a spiral from 50 mm to 100 mm and coefficient \( t=s/(2r_2)=0.7…1.3 \), expression (7) can be greatly simplified. The value \( \ln \frac{c + qr_2}{c + qr_1} \) can be expanded in series and, neglecting the values of small order, can be written in the following form [8, 9]:

\[
\ln \frac{c + qr_2}{c + qr_1} \approx \frac{q(r_2 - r_1)}{c + qr_1}.
\]

Then the expressions (7) and (8) take the form:

\[
\nu_{0cp} = \frac{\omega c}{2q^2 (r_2^2 - r_1^2)} \left[ q^2 (r_2^2 - r_1^2) - 2qc (r_2 - r_1) + c^2 \frac{q(r_2 - r_1)}{c + qr_1} \right];
\]

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\[
\nu_{0,cp} = \frac{\omega c}{2} \left[ 1 - \frac{2cr_1}{(c + qr_i)(r_2 + r_i)} \right]; \\
\nu_{scp} = \frac{\omega c}{2q} \left[ 1 - \frac{2cr_i}{(c + qr_i)(r_2 + r_i)} \right].
\]

Substituting the value \( \nu_{0,cp} \) in (2), we get:

\[
Q = \frac{\pi \omega c \rho k_n}{2} \left[ (r_2^2 - r_1^2) - \frac{2cr_i(r_2 - r_i)}{(c + qr_i)} \right].
\]

3. RESULTS OF THE RESEARCH

A spiral screw was installed in the grain tumbler with the following parameters: outer spiral screw radius \( r_2 = 35 \) mm; the pitch of the helical helix line is \( s = 0.07 \) m; diameter of the wire from which the spiral was made, \( d_n = 0.008 \) m, the total height of the helix was \( H = 2 \) m. The device was examined in a wheat mound with a bulk density \( \rho = 780 \) kg/m\(^3\). Based on the results of the research, dependences of the speed of movement \( v \) of the torsion device on the surface of the grain cotter at a certain capacity \( Q \) of the device on the frequency \( \omega \) of the helix are plotted (Figure 3).

In this case, the linear equation of regression of the velocity of the device moving along the surface of the grain mound has the form:

\[
\nu(\omega) = 0.85 \cdot 10^{-3} \omega - 0.303.
\]

Figure 3 shows the dependences of the throughput \( Q \) (solid line) and the velocity \( \nu \) of the device (point) for breaking grain from the rotational frequency \( \omega \) of the coil.

![Figure 3](image-url)
**Spiral-Screwing Device for Graining of Grain Material**

Also, an experimental study was made of the influence of the spiral pitch at its constant diameter on the throughput of the device at various helix frequencies (Figure 4).

Figure 4 Dependence of the capacity $Q$ from the pitch of helix $s$ and the frequency of its rotation $\omega$

Based on the results of studies on the effect of step $s$ of the spiral on the capacity of the device at various frequencies $\omega$, equation (13) was also obtained in terms of the natural values of the factors:

$$Q = 0.312 - 1.02 \cdot 10^{-3} \omega - 5.8 \cdot 10^{-7} \omega^2 + 4.67s + 0.018s\omega.$$  \hspace{1cm} (13)

The regression equation (13) in the coded values of the factors has the form:

$$y = 0.606 + 0.235x_1 + 0.041x_1^2 + 0.218x_2 + 0.104x_1x_2,$$  \hspace{1cm} (14)

where $y$ is the capacity of the device, kg/s; $x_1$ - rotational speed of the spiral; $x_2$ is the spiral pitch, m.

Regression equations (13) and (14) allow you to select the frequency of rotation of the spiral screw to ensure the required throughput of the device at different spiral steps.

**4. CONCLUSION**

With the spiral pitch $s = 0.07$ m, the optimal speed of the torsion device displacement $v = 0.68$ m/min is achieved at a helix frequency $\omega = 930$ min$^{-1}$. At the same time, the capacity of the device $Q = 1.1$ kg/s. A comparison of the experimental and theoretical data obtained showed that the convergence of the results is 94%. Consequently, the results of experimental studies prove the validity of the proposed theoretical dependences.

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REFERENCES