Portable drum grain dryer

X. Sobirov1* and M. Xakimov1
1Andijan Machine Building Institute, avenue Babur, 56, 170119 Andijan, Uzbekistan

Abstract. The article improves the method of increasing energy efficiency and the design of the dryer drum by accelerating the process of drying the grain of the grain dryer and reducing the time spent on drying the product.

1 Introduction

The device belongs to the agricultural sector and can be used, in particular, for drying grain products. A literary analysis of some existing devices was carried out [1-4]. The currently known stationary drum dryer of the SZSB-8A type is designed for drying grain crops of different moisture content [5]. This device provides a reduction in grain moisture from 20% to 14%, the dryer capacity is 10 t/h. The total power of the working bodies is 38 kW, fuel consumption is 12.8 kg/t. The main disadvantages of this device are: the device is stationary (i.e., unportable), high power consumption and large dimensions.

For currently known grain products, a portable grain dryer of the SZPB-2 type operates autonomously or as part of technological lines of stationary cleaning and drying stations [6]. The efficiency of the device is high (2.5 t/h), but it has the following disadvantages: complex design, large dimensions (8470 × 7600 × 2650 mm), high consumption of diesel fuel (35 kg/h).

Found analog close to the proposed device, ie. the prototype is a portable drum dryer used for drying grain crops [7].

2 Materials

The main part of the drying process is carried out in a tumble dryer using hot air generated in a heater. One of the disadvantages of this dryer is the complex design and high energy consumption, i.e. the screw transport of the dryer, which operates regularly, is located outside the drum. As a result, during the drying process, the grain passing through the auger is not spontaneously cooled, since the temperature of the auger is much lower than the temperature inside the drum, and at the same time, the consumption of electricity, the time spent on drying increases, and the process of uneven periodic drying also negatively affects the quality grains.

The task of the proposed device is to improve the process of moving and increase the intensity of drying grain by volume and reduce the time spent on drying the product by improving the design of the grain dryer drum for farmers.

In the proposed device, intensive mixing of the grain mass by volume is provided by a spiral-shaped rib fixed (welded) to the drying drum from the inside along the entire length

* Corresponding author: x.sobirov@gmail.com

© The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (http://creativecommons.org/licenses/by/4.0/).
In this case, the direction of the spiral coincides with the direction of rotation of the drum. The proposed drum provides grain movement not only down the slope due to gravity, but also partially up due to its spiral rib. As a result, the volume and movement of the moved grain increases. The accumulation of grain in the lower part of the drum is reduced, which improves the uniform drying process. The main part of the grain drying process is drying with hot air generated in the heater. The hot air generated in the heater accelerates the process of forced mixing of the dried grain mass with the help of spiral fins. This ensures that the grain is of the same quality by volume and reduces the time required to dry the product.

Fig. 1. Structural scheme of a portable grain dryer: 1 – loading bunker; 2 – drying drum; 3 – automatic control valve; 4 and 5 product sorting mechanisms; 6 – fixed section; 7 – heater; 8 – fan; 9 – electric motor; 10 and 12 front clutch and rear clutch; 11 – gearbox; 13 – trailer; 14 – belt drive.

The device is illustrated by the following drawings and photocopies: Structural diagram of a portable grain dryer in Fig. 1, view of the drying drum (section A-A, section B-B) in Fig. 2, axonometric projection of the drying drum in Fig. 3.

A portable dryer consists of a receiving hopper 1, fixed to a drying drum 2, located at an angle to the horizon. At the same time, the dryer drum has a mechanism for pouring 3 grains with automatic control. At the bottom of the automatically adjustable mechanism for pouring out the product, there are mechanisms for sorting 4 and 5 of the finished product. A stationary section 6 is coaxially installed at the top of the dryer drum, in which a heater 7 and a fan 8 are provided. with belt drive 14 and fan 15.

Fig. 2. Type of dryer’s drum.

The principle of operation of the portable dryer of the proposed grain products is as follows: a certain amount of dried grain is fed through the hopper 1 to the dryer drum 2. After the grain is poured into the dryer drum to a certain volume, the dryer drum starts to rotate and at the same time the heater 7 supplies a stream of hot air to the drum. Drying of grain is gradually carried out by a stream of hot air in a drum. In the grain dryer, the working drum...
is located at a certain angle relative to the horizon, most of the volume of the dried grain mass will begin to accumulate at the bottom of the drum. A spiral-shaped rib installed inside the dryer drum (Figure 2, 3 and 4) pushes the accumulated grain mass against the hot air flow created by the heater 7 located in the fixed section 6. The movement of the flow of grain in the lower part of the drum. As a result, the volume of grain to be displaced per revolution of the drum increases, and thus the drying of the grain is accelerated, which leads to a reduction in the time spent on drying the product.

The cycle (process) will continue until the grain moisture is reduced on demand.

The proposed device differs from the closest analogue (prototype) by the following advantages:

In the proposed device, the rejection of screw transport and the simplification of the drying device (Fig. 4).

2. The process of mixing and drying of grain is accelerated by a spiral-shaped rib fixed inside the drum. As a result, energy consumption is reduced.

Thus, the use of a new design working drum in the dryer reduces the time and energy required for drying the product, provides the same quality of grain drying by volume and at the same time increases the efficiency of the dryer.

3 Methods

To determine the main parameters that affect the regular opening and closing of lids, we will build a dynamic model of a rotating drum and a complex movable lid (Fig. 4). In this case, we consider this mechanical system as a two-mass mechanical system with respect to a stationary engine. We show the vectors of forces acting in a mechanical system and the directions of their moments in a dynamic model. Assume that the direction of the airing dryer is clockwise rotation.

In the diagram: D - electric motor; 1- dryer drum with grain; 2- cover; \( \varphi_1 \) - angular displacement of the drum, deg.; \( \varphi_2 \) - angular displacement of the cover, deg.; \( M_D \) - engine
torque, N.m.; \( M_{Q1} \) - torque relative to the axis of rotation of the sum of resistance forces (resistance forces and grain friction forces) to the rotation of the drum, N.m.; \( M_{G2} \) - the moment of gravity on the drum (relative to its axis of rotation, i.e. relative to the movable axis), N.m.; \( M_{Q2} \) - the moment of grain pressure force acting on the lid relative to the drum, N.m.; \( C_1 \) - stiffness coefficient of the belt and other gears between the electric motor and the dryer drum, Nm/rad; \( C_2 \) - coefficient of stiffness of the spring that opens and closes the lid, N/m.

We will now draw the following diagram to show the force vectors acting on the lid (Fig. 5).

Active forces acting on the cover:
- \( G_1 \) is the gravity force of the drum, N;
- \( G_D \) is the gravity force of rice, N;
- \( G_2 \) is the force of gravity of the lid, N;
- \( Q_D \) is the pressure force of rice on the lid, N;
- \( h_{2G} \) is the lever of gravity of the lid relative to point \( B \), m;
- \( \alpha = \phi_1 - \phi_2 \) - complementary angle, deg.
- \( \gamma \) - the angle of deviation of the gravity vector of rice (grain) from the OY axis due to the rotation of the drum.

Consider the moments of the acting forces on the cover relative to the point \( B \):

\[
M_B(G_2) = G_2 \cdot h_{2G} = 0.5 \cdot m_2 \cdot g \cdot l_2 \sin(\phi_1 - \phi_2)
\]  (1)

where \( M_B(G_2) \) is the moment of gravity of the lid relative to point \( B \), \( m_2 \) is the mass of the lid, kg; \( g \) is the free fall acceleration, m/s\(^2\); \( BK \) - half the length of the cover (\( BK = l_2 / 2 \), m; \( l_2 \) - cover length.

The moment of rice pressure force \( Q_D \) relative to point \( B \) is determined in this way

\[
M_B(Q_D) = Q_D \cdot BK = 0.5 \cdot S \cdot P_D \cdot l_2 \cdot \sin \phi_1
\]  (2)

where, \( S \) – cover window area, \( m^2 \); \( P_D \) – rice pressure on the lid, kg/m\(^2\).

**Fig. 5.** Calculation scheme of the mechanism.

Also, consider the moments of forces acting on the axis of rotation of the dryer drum:
- \( M_B \) - torque from the side of the engine, i.e.

\[
M_B = M_D \cdot l_{DB}
\]  (3)
where $M_D$ is the engine torque, $i_{DB}$ is the gear ratio between the rotation axes of the engine and the dryer drum.

$M_Q$ is the moment of the resistance force on the rotation of the drum, i.e.

$$M_Q = M_{DQ} + M_{ISh1} \quad (4)$$

where $M_{DQ}$ – moment of gravity of rice

$$M_{DQ} = G_D \cdot r_B \cdot \sin \gamma$$

where $r_B$ – part of the drum radius, $m$.

$M_{ISh1}$ - moment of frictional force during rotation of the drum.

$$M_{ISh1} \approx (G_1 + G_2 + G_3) \cdot r_B \cdot f \quad (5)$$

where $r_B$ is the drum shaft radius, $m$; $f$ is the coefficient of sliding friction in the drum shaft bearings.

In the two-mass mechanical system under consideration, according to the dynamic model, one can apply the Lagrange equations as in a system with two degrees of freedom.

The kinetic energy of the considered mechanical system is determined in this way:

$$T = T_B + T_K \quad (6)$$

where $T_B$ – kinetic energy of the dram; $T_K$ – kinetic energy of the cover.

We know that

$$T_B = 0.5 \cdot J_{OB} \cdot (\omega_B)^2 = 0.5 \cdot J_{OB} \cdot (\phi_1)^2 \quad (7)$$

where $J_{OB}$ – moment of inertia of the drum about its axis, $kg.m^2$; $\omega_B$ – drum angular speed ($\phi_1$), rad/s.

Likewise, we find

$$T_K = 0.5 \cdot J_{OK} \cdot (\omega_2)^2 = 0.5 \cdot J_{OK} \cdot (\phi_1 + \phi_2)^2 \quad (8)$$

where $J_{OK}$ – moment of inertia of the lid about its axis, $kg.m^2$; $\omega_K$ – relative angular velocity of the lid ($\phi_2$), rad/s.

So,

$$T = 0.5 \cdot J_{OB} \cdot (\phi_1)^2 + 0.5 \cdot J_{OK} \cdot (\phi_1 + \phi_2)^2 \quad (9)$$

The potential energy of the considered two-mass mechanical system is defined as follows:

When determining the potential energy of the considered mechanical system, the gravity force of rice in the drum, the elastic force of the V-belt transmission between the engine and the drum, as well as the elastic force of the spring for the cover are taken into account and we write:

$$\Pi = \Pi_D + \Pi_{C1} + \Pi_{C2} \quad (10)$$

where $\Pi_D$ - potential energy of rice in the drum; $\Pi_{C1}$ - potential energy of the elastic force of the V-belt transmission; $\Pi_{C2}$ is the potential energy of the elastic force of the spring.

The potential energy of the system has the form:
\[ \Pi = 0,15 \cdot G_D + 0,5 \cdot C_1 \cdot (\phi_1 - \phi_D \cdot \frac{1}{i_{PB}})^2 + 0,5 \cdot C_2 \cdot (l_2 \cdot \sin \phi_2)^2 \quad (11) \]

Thus, the generalized forces (moments) of the considered mechanical system will take the form:

\[ Q_1 = M_B - M_{K1} = M_D \cdot i_{DB} - G_D \cdot \tau_B \cdot \sin \gamma - (G_1 + G_2 + G_D) \cdot \tau_B \cdot f \]
\[ Q_2 = M_B(G_2) - M_B(Q_D) = m_2 \cdot g \cdot BK \cdot \sin(\phi_1 - \phi_2) - 0,5 \cdot S \cdot P_D \cdot l_2 \cdot \sin \phi_1 \quad (12) \]

\[ Q_1 = M_B - M_{K1} = M_D \cdot i_{DB} - G_D \cdot \tau_B \cdot \sin \gamma - (G_1 + G_2 + G_D) \cdot \tau_B \cdot f \]
\[ Q_2 = M_B(G_2) - M_B(Q_D) = m_2 \cdot g \cdot BK \cdot \sin(\phi_1 - \phi_2) - 0,5 \cdot S \cdot P_D \cdot l_2 \cdot \sin \phi_1 \quad (13) \]

### 4 Results

Now, substituting the found expressions into equations (6) and (7), we obtain the systems of equations of motion of the device mechanism:

\[
\begin{align*}
\dot{\varepsilon}_1 &= \frac{M_D \cdot i_{DB} - G_D \cdot \tau_B \cdot \sin \gamma - (G_1 + G_2 + G_D) \cdot \tau_B \cdot f - C_1 \cdot (\phi_1 - \phi_D \cdot \frac{1}{i_{PB}})}{(J_{OB} + J_{OK})} \\
\dot{\varepsilon}_2 &= \frac{0,5 \cdot l_2 (m_2 \cdot g \cdot \sin(\phi_1 - \phi_2) - S \cdot P_D \cdot \sin \phi_2 - C_2 \cdot l_2 \cdot \cos \phi_2)}{J_{OK}}
\end{align*}
\]

\[ (14) \]

We accept the initial conditions:

at \( t = 0; \quad \varphi_1^0 = \varphi_2^0 = 0; \quad \omega_1 = \omega_D; \quad \dot{\varepsilon}_1 = \dot{\varepsilon}_2 = 0 \]

border conditions:

at \( t = T; \quad \varphi_T = 180^\circ \), those. this corresponds to half a revolution of the drum, which is sufficient to analyze the process of opening and closing the lid during operation.

### 5 Discussions

Thus, we have obtained a system of equations (14), which takes into account almost all quantities (design parameters) that affect the mechanical system, that is, the mathematical model of the first approximation of this mechanical system. The parameters \( \dot{\varepsilon}_1 \) and \( \dot{\varepsilon}_2 \) in the mathematical model are the angular accelerations of the dryer drum and the lid, respectively.

To calculate their values, it is recommended to use the "numerical method".

Using the obtained mathematical model, it is possible to construct the following dependency diagrams, which are necessary for the synthesis of design parameters:

- \( \varphi_2 = \varphi_1 (f) \) - dependence diagram of the angular displacements of the drum and cover;
- \( \varphi_2 = S_2 (f) \) - diagram of the dependence of the angular displacement of the cover on the coefficient of spring stiffness;
- \( \varphi_2 = p_D (f) \) - diagram of the dependence of the angular displacement of the cover on the pressure of the grain;
- \( \varphi_2 = G_D (f) \) - diagram of the dependence of the angular displacement of the cover on the weight of the grain;
- \( \varphi_2 = G_Q (f) \) - diagram of dependence of the angular displacement of the lid on the weight of the lid;
- \( \varphi_2 = \omega_B (f) \) - diagram of dependence of the angular displacement of the lid on the angular velocity of the drum;

### 6 Conclusion

1. Thus, designed new device of the portable dryer for farmers and proposed new drum.
2. The use of a new design working drum in the dryer reduces the time and energy required for drying the product, provides the same quality of grain drying by volume and at the same time increases the efficiency of the dryer proposed for farmers.

3. A system of equations has been obtained that takes into account almost all quantities that affect the movement of a mechanical system, that is, a mathematical model of the first approximation of this mechanical system.

4. Using a mathematical model, it is possible to construct the necessary diagrams not only of the angular accelerations $\omega_1$ and $\omega_2$ of drums and covers, but also of their angular velocities $\omega_1$, $\omega_2$, and angular displacements $\varphi_1$, $\varphi_2$. It is possible to carry out the synthesis of parameters based on the given values of the coefficient of elasticity of the lid spring ($C_2$) and the area of the window for unloading dried rice ($S$), which is necessary for the proposed drying device.

References

9. B.R. Bekkulov, R. Aliev, T.B. Rakhmonkulov, Mobile device for drying the shawl. Patent for an industrial design. SAP No. 02239.01.27.2022 (2022)