Research on the power parameters of the screw conveyor safety clutch

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Abstract. *An experimental model of a safety clutch has been developed and manufactured, which will improve the efficiency of screw conveyors by increasing the axial displacement of the driven half-clutch with a jammed working body, while reducing dynamic loads during overload. When conducting a multifactorial experiment to determine the moment of operation T of the safety clutch of a screw conveyor, the variable factors were the angle of inclination of the working body to the horizon* α*, the rotation frequency of the screw working body n, and the time of increase in the resistance moment* T_o*. Based on the results of experimental studies, corresponding regression equations, response surfaces, and their two-dimensional cross-sections were constructed to establish the influence of controlled factors on the moment of operation of the safety clutch under extreme operating conditions. The obtained regression equation can be used to determine the moment of clutch engagement during the transportation of bulk and lump agricultural materials by a screw conveyor.*
KEYWORDS: *COUPLING, TORQUE, SCREW WORKING BODY, CONVEYOR.*

Introduction

The efficiency and reliability of machines and mechanisms largely depend on the correct choice of their layout, calculation and substantiation of rational and optimal design, kinematic and dynamic parameters, compliance with the manufacturing and assembly technology of basic units, compliance with operating conditions, as well as ensuring high-precision and reliable protection of working parts and machine drives in the event of overloads. This is especially true for agricultural and processing machines, where the probability of technological (due to clogging of working parts) and accidental overloads is quite high.

Screw conveyors are widely used to transport bulk agricultural materials in various production processes. However, during the transportation of such bulk materials, the screw working body may become jammed due to the gap between the surface of the screw rotation and the inner surface of the conveyor casing. To restore the conveyor's operability, it is necessary to move the jammed screw edge away from contact with the material in the axial direction, and then, after removing the overload, the drive elements must ensure that the working body returns to its original position for further transportation of the material to the unloading area.

The jammed working body is reversed according to a well-known principle, which is implemented using planetary safety couplings. They ensure the reverse rotation of the screw from a slight angle of rotation to several revolutions, followed by the restoration of its initial position. It is also possible to axially remove a jammed screw working body using ball safety couplings with profiled holes, both when disengaging and when engaging.

Analysis of recent studies and publications. Analysis of studies has shown that the main disadvantages of existing safety clutches, which ensure the reversal of overloaded working bodies, are their structural and technological complexity, high material consumption, and insufficient reliability [1-3]. They also have significant dimensions, and during their operation, significant dynamic loads arise due to the action of the inertial forces of the driven links of the drive and the working body with automatic restoration of its initial position [4-6]. Theoretical studies of safety clutches are mainly aimed at deriving dependencies that describe the influence of structural, kinematic, and dynamic parameters on the torque transmitted by the clutches when they are activated. The main part of the experimental studies is devoted to determining the coefficients of clutch accuracy and their resource indicators [7, 8].

Works [9, 10] examine the operation of a ball safety clutch with profiled holes, both when disengaging and when engaging, and investigate the change in torque during their operation. It has been established that although this safety mechanism significantly reduces the dynamic load during its operation, it has a small axial displacement of the driven half-coupling with a jammed working body. This limits the use of such a safety coupling in screw conveyors.

Therefore, it is important to develop new designs and justify the structural and power parameters of safety couplings for screw conveyors for axial removal of the working body in case of overload and to ensure its return to the initial position.

Results and discussion

To solve this problem, a safety clutch with separate modes for slippage and axial displacement of the screw working body has been developed, which will allow the conveyor to resume operation. The design diagram of such a safety coupling is shown in Fig. 1.

The safety coupling consists of a drive half-coupling 1, which is fixed on the hub 2. Cylindrical pins 4 are fixed on the end surface of the driven half-coupling 3, which is installed on the hub 2 using a spline connection. These pins are spherical on the working side and are located in through axial holes in the anti-friction bushings 5 of the driven half-coupling 3. The cylindrical pins 4, which are pressed by the pressure disc 6, engage with the holes 7 of the drive half-coupling 1. The torque is adjusted by compressing the springs 8 with nuts 9. Grooves 10 are made on both sides of each hole on the end surface of the driven half-coupling 1 along the diameter of the cylindrical pins 4 and holes 7, with the angle of inclination φ of the circular groove on the working side of the hole being significantly smaller than the angle of inclination γ of the circular groove on the non-working side of the hole.

The safety clutch operates as follows. During torque transmission, the cylindrical pins 4 engage with the holes 7 of the drive half-coupling 1. In the event of overload, the driven half-coupling 3 stops, while the drive half-coupling 1 continues to rotate, causing the cylindrical pins 4 to disengage from the holes 7 and move along the circular groove 10, which has a hole angle φ on the end surface of the drive half-coupling 1. As a result of the rotation of the drive half-coupling 1, the cylindrical pins 4 return to their previous position and the initial state is restored. At the same time, the cylindrical pins 4 move along the circular groove 10, which has an angle of inclination γ on the end surface of the drive half-coupling 1.

A general view of the safety coupling is shown in Fig. 2.

The proposed design of the safety coupling allows to increase the axial displacement of the driven half-coupling together with the jammed working body of the screw conveyor, as well as to significantly reduce the dynamic load on the drive under extreme operating conditions.

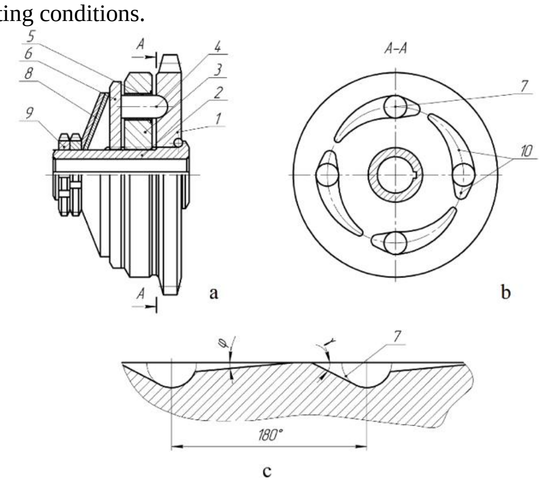

Figure 1. *Design of the safety coupling:*
a – front view of the coupling; b – cross-section A-A; c – view of the grooves on the end surface of the drive half-coupling

a

b

Figure 2. *General view of the safety coupling (a) and the working surface of the drive half-coupling (b)*

To determine the moment of operation of the developed coupling, an experimental setup was developed to study the operation of a screw conveyor under extreme operating conditions, which is shown in Fig. 3.

A frequency converter (Altivar 71) with Power Suite v.2.5.0 software was used to start the motor and regulate its rotation speed. The Altivar 71 system is connected to the network and to a computer.

Figure 3. *General view of the experimental setup for studying a screw conveyor with a safety clutch*

When the required rotation speed is set using a computer with the Altivar 71 system, a command is sent to the electric motor, which starts to rotate the screw shaft with the set parameters using a safety clutch. If the working part of the screw conveyor jams, the drive half-coupling continues to rotate, while the driven half-coupling is braked, which causes the safety coupling under test to activate.

The methodology for conducting experimental studies is as follows. Lumpy or loose material is loaded into a hopper with a screw working body and transported to the unloading area. The load can be set either by a braking element or by closing the slide gate.

After completing the material transportation process, data on torque changes were obtained in the Power Suite program window on the computer display. Its fluctuations were evaluated by constructing and conducting a multifactorial experiment.

To obtain a regression model of the optimization parameter, which was accepted in the form of a functional $T = f\left(x_1, x_2, x_3,...\right)$, where T – is the torque on the drive shaft from 1 to the i-th case; $x_1, x_2, x_3,...$ – are natural independent variable factors, a corresponding conditional plan of a multifactorial experiment was selected, the implementation of which was carried out in the following sequence.

To determine the change in torque T during the operation of the safety clutch, the following independent variables were taken: the angle of inclination of the working body to the horizon α, which was coded with the index X_1, the rotation frequency of the screw n, which was coded with the index X_2, and the time of increase in resistance torque T_o, which was coded with the index X_3.

Since, during the experiments, the independent variables are heterogeneous and have different units of measurement, and the numbers expressing the values of these factors are of different orders, they were brought to a single calculation system by converting from real values to coded ones.

Research into the torque T during operation of the safety clutch made it possible to determine its dependence on many factors, namely: the angle of inclination of the working body to the horizon α, deg, the rotation frequency of the screw n, rpm, the time of increase in resistance torque T_o, s, within the following ranges of input factors: $0 \le \alpha \le 40$ (deg); $50 \le n \le 250$ (rpm); $0.15 \le T_o \le 0.65$ (s).

The change in the angle of inclination of the working body to the horizon is provided by the design of the screw conveyor, the rotation frequency of the working body and the time of increase in the resistance moment were changed using the Altivar 71 frequency converter.

The processing of the obtained experimental data was carried out using well-known methods and methods of statistical processing with the use of well-known methods of correlation and regression analysis to obtain empirical regression equations as the final result [11, 12].

The response function (optimization parameter), i.e., the moment $T = f(\alpha, n, T_o)$, determined experimentally, is represented as a mathematical model of a complete quadratic polynomial [11].

The general form of the regression equation for determining the moment of operation T of the safety clutch of a screw conveyor is as follows:

$$\begin{aligned} T = 110,499 - 0,3538\alpha + 0,0061n - 27,3342T_o + 0,0016\alpha n - \\ -0,0506nT_o - 0,2884\alpha T_o + 0,0023\alpha^2 - 0,0008n^2 + 44,368T_o^{\,2}. \end{aligned} \quad (1)$$

The resulting regression equation (1) can be used to determine the moment of operation T of the safety clutch of the screw conveyor depending on the angle of inclination of the working body to the horizon α, the rotation frequency of the screw working body n, and the time of increase in the resistance torque T_o under extreme operating conditions within the following ranges of input factors: 0

$\leq \alpha \leq 40$ (deg); $50 \leq n \leq 250$ (rpm); $0.15 \leq T_o \leq 0.65$ (s).

Using the STATISTICA application, we constructed a graphical representation of intermediate general regression models in the form of quadratic response surfaces and their two-dimensional cross-section of the change in the operating torque of the screw conveyor safety clutch T as a function of two variable factors $x_{i(1,2)}$ at a constant level of the corresponding third factor $x_{i(3)} = \text{const}$, whose value was at zero (Fig. 4).

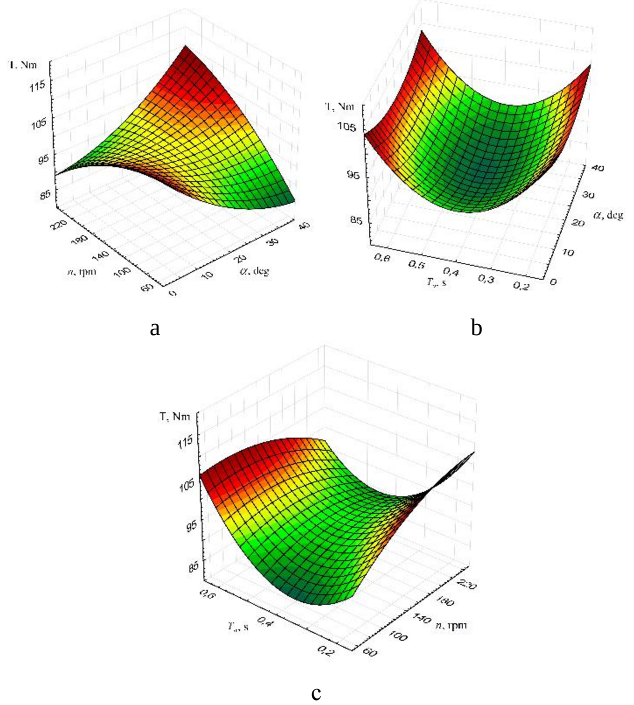

***Figure 4**. Surface response of corn grain injury magnitude from: a) $T = (\alpha\,; n)$; b) $(\alpha\,;\, T_o)$; c) $T = (n;\, T_o)$*

Analysis of the regression equation shows that the greatest influence on the value of T is exerted by the rotational speed of the screw working body n (a change in n within the range of 50–250 rpm leads to an increase in T by a factor of 1.12). Next in terms of intensity of influence on the moment of operation T is the angle of inclination of the working body to the horizon α (a change α within 0°...40° leads to a decrease in T by 1.05 times), and the least influence on the value of T is the time of increase in the moment of resistance T_o (a change T_o within 0.15...0. 65 *s* leads to a decrease in T by 1.04 times).

Conclusions

Based on experimental studies of the operating torque of the safety clutch of a screw conveyor under extreme operating conditions, it has been established that the greatest influence on the value of T is the rotational speed of the screw working body n. Next in terms of intensity of influence on the moment of operation T is the angle of inclination of the working member to the horizon, and the least influence on the value of T is the time of increase in the moment of resistance T_o. Analysis of the regression equation has shown that a change in n within the range of 50–250 rpm leads to an increase in T by 1.12 times, a change in within the range of 0° to 40° leads to a decrease in T by 1.05 times, and a change T_o in within the range of 0.15 to 0.65 s leads to a decrease in T by 1.04 times.

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