STUDY OF FINGER-TYPE SAFETY CLUTCH

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Abstract. The article presents the design of a finger-type safety clutch for a screw conveyor, for which experimental studies were used to determine the optimal parameters and operating modes of the conveyor when its working mechanism is overloaded. Based on the results of the experimental studies of the finger-type safety clutch, the extent to which a particular parameter affects the torque at different stages of the device operation has been established. The results of the studies are presented in the form of graphs showing the torque as a function of the screw conveyor rotational speed. Analysis of the graphs shows that the torque T at which the finger-type safety clutch engages increases with an increase in the rotational speed of the screw conveyor. The graphs also show that as design parameters such as the angle α of the working body inclination to the horizontal, the spring stiffness c, and the clearance Δ increase, the torque T increases. In the range of the working body rotational speeds from 50 rpm to 200 rpm, the torque increases by 24-28%. As the particle size distribution of the transported material changes, the torque T increases: for sand – by 35%; for wheat – by 26%; for maize – by 24%; and for expanded clay – by 18%. Thus, the results of the experimental tests of the developed safety clutch for a screw conveyor have sufficiently confirmed the theoretical studies, which, in a simplified form, can be applied to justify and select rational parameters for protective mechanisms and their engineering design.

Keywords: screw conveyor, finger-type safety clutch, half-clutch, torque, groove.

Introduction

In various industrial processes, screw conveyors have become widely used for handling bulk and lumpy materials. However, during material transport, jamming of the screw working element may occur due to the gap between the screw rotating surface and the inner surface of the casing. To restore the conveyor's operational capability, the jammed screw flight must be moved axially away from contact with the material; subsequently, once the overload has been relieved, the drive components must return the working element to its initial position to transport the material to the discharge zone.

Other devices are also known for reversing a jammed working element. A jammed screw conveyor can be moved axially using planetary safety couplings. These can facilitate the reverse rotation of the screw conveyor from a slight angle of rotation to several revolutions, subsequently restoring the working element to its original position [1-3]. Ball safety couplings, which feature profiled bores both at disengagement and engagement, can also be used to achieve axial disengagement of a jammed screw working element [4-6].

An analysis of the available literature and research has established that the main drawbacks of existing safety clutches, which are used to reverse overloaded working components, are their high material consumption, structural and manufacturing complexity, and insufficient reliability [8-12]. Furthermore, existing safety mechanisms are of considerable size; during their operation, significant dynamic loads arise due to the inertial forces of the driven drive components and the working component, with automatic restoration of its initial position [14-16]. The design features of couplings and drives aimed at improving their functional characteristics were studied by [17-20].

It is therefore essential to improve the performance and operational efficiency of screw conveyors under extreme operating conditions by developing and justifying optimal parameters for the safety clutch of the screw conveyor working element.

Materials and methods

A safety clutch has been developed to improve the performance of a screw conveyor when its working element is overloaded. The design diagram and general view of this safety clutch are shown in Fig. 1. The torque between the half-couplings in the finger-type safety clutch is transmitted via the fingers, which are rounded on the working side and are positioned in through-holes in the anti-friction bushings of the driving half-coupling 1. The fingers are arranged in a circle on the driving half-coupling

1 and engage with the holes 3 of the driven half-coupling 2, ensuring the rotation of the finger-type safety coupling and the screw-type working element of the conveyor. Circular working grooves 4 and return grooves 5 are machined on both sides of the diameter of the holes 3 on the end face of the driven half-coupling 2, with the angle of inclination of the working groove being significantly smaller than that of the return groove [11].

When the screw-type working element becomes jammed, the driven half-coupling 2 stops, whilst the driving half-coupling 1 continues to rotate. This causes the fingers with rounded ends on the working side to disengage from the recesses 3. The fingers then move along the circular working grooves 4. Meanwhile, the drive half-sleeve 1 continues to rotate, causing the fingers to move along the circular return grooves 5. In this way, the fingers return to their previous position and the initial state is restored.

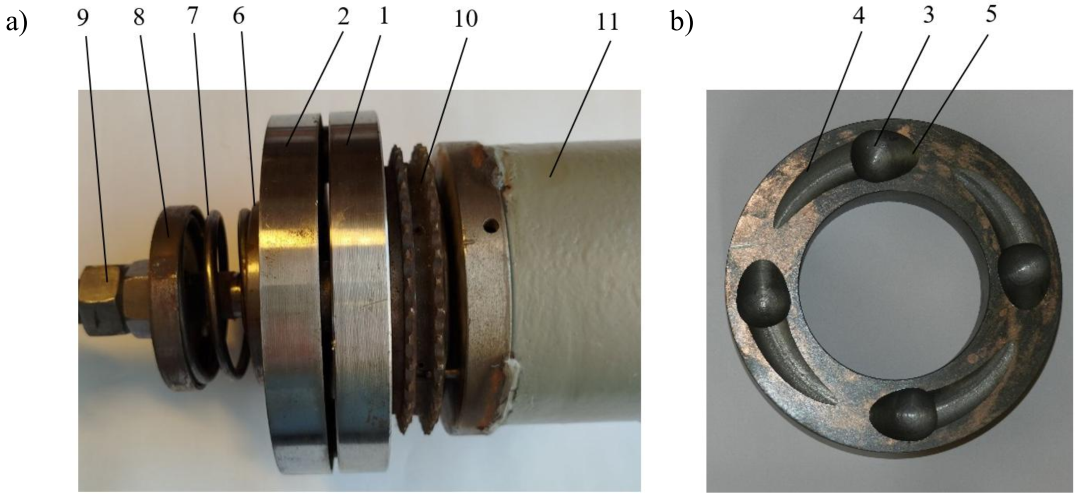

Fig. 1. **General views of the finger-type safety coupling (a) and the driven half-coupling (b):** 1 – drive half-coupling with axial bores, in which pins are housed within anti-friction bushings, these pins are rounded on the working side; 2 – driven half-coupling; 3 – recesses; 4 – circular working grooves; 5 – circular return grooves; 6 – pressure disc; 7 – spring; 8 – washer; 9 – nut; 10 – drive sprocket; 11 – conveyor housing with screw-type working element

For the experimental studies, the finger-type safety clutch was manufactured with the following parameters: finger radius r = 12 mm; finger pitch diameter D = 115 mm; slot depth $h = 0.53r$; spring preload δ_0 = 15 mm; angle of inclination of the working groove on the end face of the driving half-clutch β = 5°; angle of inclination of the return groove on the end face of the drive half-coupling γ = 35°.

The methodology for conducting the experimental studies was as follows. First, lumpy or loose material was fed into the hopper of a screw conveyor, which rotated and transported the material to the discharge zone. The load on the coupling and the conveyor drive was applied both by a braking element and by closing the slide gate. Upon completion of the material transport process, the results of the experimental studies regarding the operation of the finger-type safety clutch – in the form of curves showing changes in the drive shaft rotational speed, torque and power – were recorded on the computer display in the Power Suite programme window [12].

The experiments were conducted for four rotational speeds of the working body, namely: n = 50; 100; 150 and 200 rpm. The rotational speed of the working component was adjusted using a frequency converter; to do this, the frequency of the voltage supplied to the motor was altered.

The angle of inclination of the working element relative to the horizontal is determined by the design of the screw conveyor; to adjust the spring stiffness, rods of different diameters were wound onto the spring.

The clearance between the screw surface of revolution and the inner surface of the casing was adjusted by using working elements of different diameters.

The experiments were conducted whilst transporting the following materials with the corresponding densities: sand – 1600 $\text{kg}\cdot\text{m}^{-3}$; wheat – 760 $\text{kg}\cdot\text{m}^{-3}$; maize – 800 $\text{kg}\cdot\text{m}^{-3}$; and expanded clay – 400 $\text{kg}\cdot\text{m}^{-3}$. The moisture content was W = 12-15% for grain materials, W = 3-7% for sand and

W = 5-15% for expanded clay (due to porosity). The particle size distribution of the granular material was characterised by the geometric dimensions of the grains; for wheat, the average grain size was 4 mm, and for maize – 6 mm. The average particle diameter of sand was 0.25-0.5 mm, and for expanded clay – 10-20 mm.

The following parameters were also varied during the experimental studies:

- angle α of the screw inclination to the horizontal: $\alpha = 0°$; $\alpha = 10°$; $\alpha = 20°$; $\alpha = 30°$;
- spring stiffness c: $c = 15$ N·mm^{-1}; $c = 16.5$ N·mm^{-1}; $c = 18.0$ N·mm^{-1}; $c = 19.5$ N·mm^{-1};
- clearance between the screw surface of revolution and the inner surface of the casing: $\Delta = 1.0$ mm; $\Delta = 1.5$ mm; $\Delta = 2.0$ mm; $\Delta = 2.5$ mm;
- nature of the transported material: sand, wheat, maize, expanded clay.

To determine the effect on the torque T and engine power N as a function of the rotational speed of the working component n during overload, the specified parameters were varied.

Results and discussion

Based on the results of experimental studies, graphs showing the relationship between the torque and the rotational speed of the screw conveyor auger have been plotted; these are shown in Fig. 2-5. The peak (maximum) values of the data obtained from the studies were used to plot these graphs.

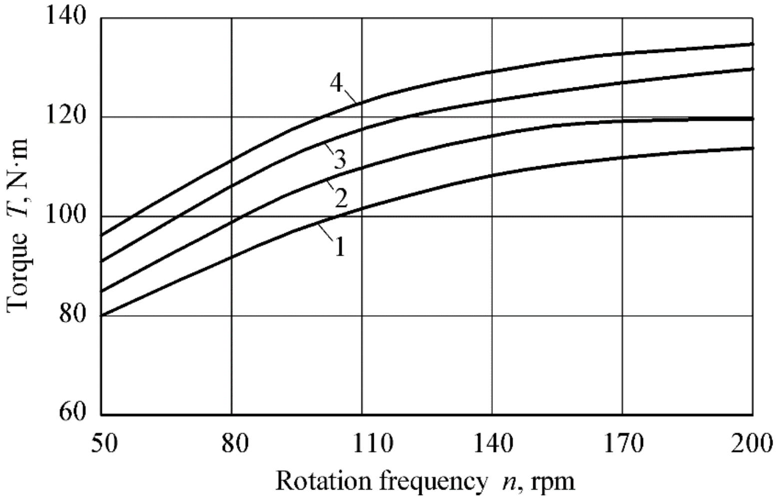

Fig. 2. **Graphs showing the variation in the torque at which the finger-type safety clutch engages as a function of the drive shaft rotation frequency for different values of the angle α of the screw inclination to horizontal:** 1 – $\alpha = 0°$; 2 – $\alpha = 10°$; 3 – $\alpha = 20°$; 4 – $\alpha = 30°$

Analysis of the graphs in Fig. 2 shows that the torque T increases proportionally as the angle α of the working body inclination relative to the horizontal increases. The torque T increases proportionally, with the maximum torque occurring when the angle of inclination of the working body relative to the horizontal is $\alpha = 30°$ and the rotational speed is $n = 200$ rpm, and the minimum torque occurring when $\alpha = 30°$ and $n = 50$ rpm. An increase in the angle α of the working body inclination relative to the horizontal within the range of 0°-30° leads to an increase in the torque T of 30-32.5%.

Analysis of the graphs in Fig. 3 shows that the torque T also increases as the spring stiffness c increases. The graphs show that the torque T initially increases faster than the rotational speed $n = 100$ rpm, followed by a slower proportional increase; the maximum torque value occurs at a spring constant $c = 19.5$ N·mm^{-1} and a rotational speed $n = 200$ rpm, whilst the minimum occurs at $c = 15$ N·mm^{-1} and $n = 50$ rpm. An increase in spring stiffness c from 15 N·mm^{-1} to 19.5 N·mm^{-1} leads to an increase in the torque T of 29-30.5%.

The graphs in Fig. 4 show that the torque T increases proportionally as the clearance Δ increases. The graphs show that the torque curves T exhibit a concave-curved profile, with a proportional increase in the torque; the maximum value is observed at a clearance of $\Delta = 2.5$ mm and a rotational speed of $n = 200$ rpm, whilst the minimum value is observed at $\Delta = 1$ mm and $n = 50$ rpm. An increase in the clearance Δ between the screw rotating surface and the inner surface of the guide tube from 1 mm to 2.5 mm results in an increase in the torque *T* by 18-20%.

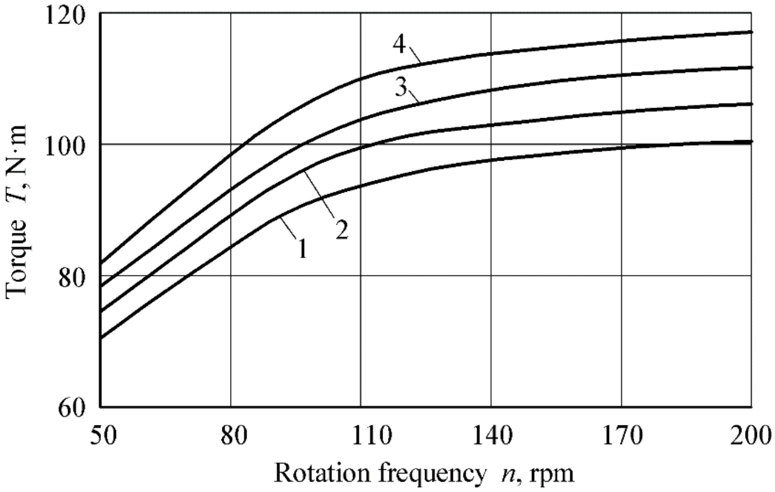

Fig. 3. **Graphs showing the variation in the tripping torque of a finger-type safety clutch as a function of the drive shaft speed for different spring stiffness values *c*:** 1 – *c* = 15.0 N·mm^{-1}; 2 – *c* = 16.5 N·mm^{-1}; 3 – *c* = 18.0 N·mm^{-1}; 4 – *c* = 19.5 N·mm^{-1}

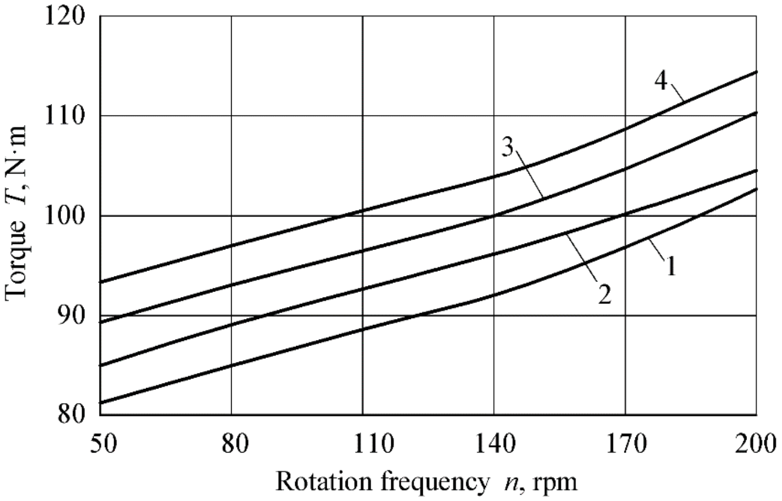

Fig. 4. **Graphs showing the variation in the operating torque of the finger-type safety clutch as a function of the drive shaft rotational speed for different values of the clearance Δ:** 1 – Δ = 1.0 mm; 2 – Δ = 1.5 mm; 3 – Δ = 2.0 mm; 4 – Δ = 2.5 mm

The graphs in Fig. 5 also show that the torque *T* increases proportionally with changes in the particle size distribution of the material. The torque values *T* increase proportionally, with the highest torque occurring for caramsite at a rotational speed of *n* = 200 rpm, and the lowest for sand at *n* = 50 rpm. As the particle size distribution of the transported material changes, the torque *T* increases: for sand – by 35%; for wheat – by 26%; for maize – by 24%; and for expanded clay – by 18%.

Analysis of the graphs Fig. 2-5 shows that the operating torque *T* of the finger-type safety clutch increases with an increase in the rotational speed of the conveyor screw. In the range of working body rotational speeds from 50 rpm to 200 rpm, the torque increases by 24-28%.

Thus, the results of the experimental tests of the developed safety clutch for a screw conveyor have sufficiently confirmed the theoretical studies, which, in a simplified form, can be applied to justify and select rational parameters for protective mechanisms and their engineering design.

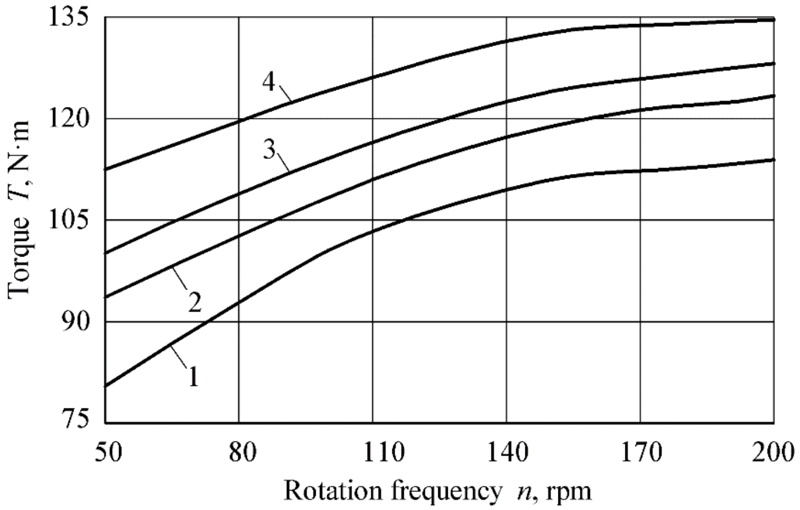

Fig. 5. **Graphs showing the variation in the operating torque of the finger-type safety clutch as a function of the drive shaft rotational speed for different materials:**
1 – sand, 2 – wheat, 3 – maize, 4 – expanded clay

Conclusions

1. A safety coupling design has been developed to increase the axial displacement of the driven half-coupling with a jammed working element, whilst reducing dynamic loads during overload conditions.
2. The results of the experimental studies of the finger-type safety clutch are presented, which allow the intensity of the influence of a particular parameter on the torque value at different stages of operation to be assessed.
3. Based on the results of the experimental studies, graphical dependencies of the torque on the screw speed of the screw conveyor have been plotted. Analysis of the graphs shows that the operating torque T of the finger-type safety clutch increases with an increase in the rotational speed of the screw conveyor. It has also been established that the torque T increases proportionally with the increase in the angle α of inclination of the working body relative to the horizontal, the spring stiffness c, the clearance Δ, and the particle size distribution of the material. An increase in the angle α of the working body inclination relative to the horizontal within the range of 0°-30° leads to an increase in the torque T by 30-32.5%. An increase in spring stiffness c from 15 N·mm^{-1} to 19.5 N·mm^{-1} leads to an increase in the torque T by 29-30.5%. An increase in the clearance Δ between the screw rotating surface and the inner surface of the guide tube from 1 mm to 2.5 mm results in an increase in the torque T by 18-20%. As the the particle size distribution of the transported material changes, the torque T increases: for sand – by 35%; for wheat – by 26%; for maize – by 24%; and for expanded clay – by 18%.
4. Thus, the results of the experimental tests of the developed safety clutch for a screw conveyor have sufficiently confirmed the theoretical studies, which, in a simplified form, can be applied to justify and select rational parameters for protective mechanisms and their engineering design.

Author contributions

Conceptualization, V.B., O.G.; methodology, A.A. and A.A.; investigation, O.T., Z.R., M.C. and A.A. All authors have read and agreed to the published version of the manuscript.

References

[1] Rucins A., Kolomiiets L., Shevchenko I., Bulgakov V., Holovach I., Trokhaniak O., Kiernicki Z. Research of the systems of environmental and soil protection technologies in erosion-hazardous agrolandscapes. Journal of Ecological Engineering, 26 (4), 2025, pp. 15-27.

[2] Dubyniak T., Lutsiv I., Stashkiv M., Komar R., Buhovets V., Senyk A. Load research on the elements of a toothed safety clutch, Procedia Structural Integrity, Volume 81, 2026, pp. 562-569, ISSN 2452-3216, DOI: 10.1016/j.prostr.2026.03.096

[3] Hevko R.B., Klendiy M.B., Klendiy O.M. Investigation of a transfer branch of a flexible screw conveyer, INMATEH: Agricultural engineering, vol.48, no.1, 2016, pp. 29-34.

[4] Hevko R.B., Rozum R.I., Klendiy O.M. Development of design and investigation of operation processes of loading pipes of screw conveyors, INMATEH: Agricultural engineering, vol.50, no.3, 2016, pp. 89-94.

[5] Hevko R.B., Klendiy O.M. The investigation of the process of a screw conveyer safety device actuation, INMATEH: Agricultural Engineering, vol.42, no.1, 2014, pp. 55-60.

[6] Bulgakov, V., Trokhaniak, O., Adamchuk, V., Chernovol, M., Korenko, M., Dukulis, I., Ivanovs, S. A study of dynamic loads of a flexible sectional screw conveyor. Acta Technologica Agriculturae, 25 (3), 2022, pp. 131-136. DOI: 10.2478/ata-2022-0020

[7] Lutsiv I.V., Hevko I.B., Lyashuk O.L., Dubynyak T.S. Investigation of dynamical impact loads in screw conveyer drives with safety clutches. INMATEH - Agricultural Engineering, 51 (1), 2017, pp. 69-76.

[8] Güneş E.C., Çelik İ. Use of disc springs in a pellet fuel machine, Czech Technical University in Prague, Acta Polytechnica, 57(2), 2017, pp. 89-96. DOI: 10.14311/AP.2017.57.0089.

[9] Xiong, Q., Aramideh, S., Passalacqua, A. and Kong, S. C. Characterizing Effects of the Shape of Screw Conveyors in Gas–Solid Fluidized Beds Using Advanced Numerical Models. Journal of Heat Transfe, 137(6), 2015.

[10] Owen, P.J., Cleary, P.W. Prediction of screw conveyor performance using the Discrete Element Method (DEM). Powder Technology, 193(3), 2009, pp. 274-288.

[11] Bulgakov V., Trokhaniak O., Kovalchuk S., Dubrovina O. Research on the power parameters of the screw conveyor safety clutch. Machines. Technologies. Materials International Scientific Journal. Issue 11/2025, 2025, pp. 430-433.

[12] Bulgakov V., Adamchuk V., Trokhaniak O. Experimental study of a finger safety clutch of a screw conveyor. Agricultural Machinery. Proceedings. Vol. 1/11, 2024, pp. 35-38.

[13] Hevko R.B., Zalutskyi S.Z., Tkachenko I.G., Klendiy O.M. Development and investigation of reciprocating screw with flexible helical surface. INMATEH - Agricultural Engineering, 46 (2), 2015, pp. 133-138.

[14] Dutt K., Joshi S., Shah D., Prajapati D., Experimental investigations and finite element simulation for predicting wear life of overrunning. clutches. Engineering Research Express 6 (3), 2024, 035522.

[15] Hanqi Y., Chenyi Z., Bmgzhao G. Fork-less two-speed I-AMT with overrunning clutch for light electric vehicle. Mechanism and Machine Theory 130, 2018, pp. 157-169.

[16] Liu Z., Dave S., Rinderknecht S., Energy loss and efficiency investigations of a dual clutch transmission based on adaptive experiment and analytical simulation. Forschung im Ingenieurwesen/Engineering Research 88 (1), 2024, 22.

[17] Sawarkar N., Zakiuddin K., Sakhale C., Investigating stresses and deformations in three jaw type flexible clutch using finite element analysis. Advances in Nonlinear Variational Inequalities 28 (3S), 2025, pp. 581-590.

[18] Soleimani A., Rohani A., Abbaspour-Fard M., Optimizing cone clutch design for enhanced maneuverability in walking tractors using machine learning and finite element analysis. International Journal on Interactive Design and Manufacturing 19, 2025, pp. 8585-8603.

[19] Yin K., Yin J., Huang H., Clutch spring performance optimization and computer aided design system. Lecture Notes in Electrical Engineering 1356, 2025, pp. 287-293.

[20] Zhang C., Yu W., Zhang Y., Xu J., Zeng Q., Li L., Wang L., Huang W. Dynamics modeling and analysis of the multistage planetary gear set-bearing-rotor-clutch coupling system considering the tooth impacts of clutches. Mechanical Systems and Signal Processing 214, 2024, 111365.