International Journal of GEOMATE, Sept. 2023, Vol. 25, Issue 109, pp.173-180
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2023.109.m2318
Geotechnique, Construction Materials and Environment

IMPROVING THE DESIGN AND OPERATING PARAMETERS OF THE BELT CONVEYOR FOR WORKING WITH HEAVILY IMPURE GRAIN CROPS

*Zhumash Bekmyrza[1], Bulat Salykov[2], Kuanysh Ryspayev[3] and Ayap Kurmanov[4]

[1,3,4] Department of Mechanical Engineering, Engineering and Technical Institute named after A. Aitmukhambetov, A. Baitursynov Kostanay Regional University, Kostanay, Kazakhstan; [2]Department of Machines, Tractors and Automobiles, Engineering and Technical Institute named after A. Aitmukhambetov, A. Baitursynov Kostanay Regional University, Kostanay, Kazakhstan

*Corresponding Author, Received: 21 March 2023, Revised: 16 May 2023, Accepted: 5 July 2023

ABSTRACT: The purpose of the study is to examine the efficiency of transportation and productivity of the process of moving grain cargoes, with the improvement of the design and technological scheme of the belt conveyor when clogged with grain dust. Using the methods of analysis, synthesis, and comparison, the basic concepts and applied studies of belt conveyor performance by operating parameters are investigated to justify the optimal design and technological actions that reduce energy intensity and substantiate the economic efficiency of agricultural production. The results indicate that the study allowed determining the dynamic loads that lead to failures of conveyor elements, dust clogging of roller supports, and belt ruptures. The study emphasizes the issues with dynamic loads that result in conveyor element failures, clogged roller supports from dust, and ruptured belts. A review and analysis of studies on existing technologies showed the impact of design features on the productivity and quality of grain transportation. Modification of the rollers on the ascending branch of the working body of the belt reduces grain losses on both sides when slipping on the drive drum.

Keywords: Mechanisation, Bulk raw materials, Impurities, Dust, Transportation.

1. INTRODUCTION

The constant growth of bulk cargo flows, the intensification of logistics processes, and global transportation create the need for diversification and improvement of methods of transportation and storage of grain crops. Among all the means of mechanisation, lifting machines, represented by periodic and continuous belt conveyors, play an important role. The grain industry is the most profitable and export-oriented agriculture of the Republic of Kazakhstan. In accordance with the data of the Bureau of National Statistics of the Republic of Kazakhstan, 16.4 million tonnes of grain and leguminous crops were harvested in 2021, based on an average yield of 10.4 c/ha (Table 1)

Table 1 Statistics of the Republic of Kazakhstan regarding grain and leguminous crops in 2021

Grain and leguminous crops	
Wheat	11.8 million tonnes
Oilseeds	2.4 million tonnes
Rice	503.8 thousand tonnes

The cultivation of wheat, one of the most famous Kazakhstani goods in the world, largely depends on the quality of grain processing, methods of transportation, and storage conditions of grain raw materials. Dzhankurazov et al. reported that currently, about 230 licensed grain silos with a total volume of 14.1 million tonnes are operated in Kazakhstan; thus, with the stable operation of the agricultural sector of Kazakhstan, the conveyor equipment market is rapidly developing [1].

The mass share of bulk cargo transportation in the total volume of world transportation is very substantial for grain crops. Wheat and Leali state that grain elevators and grain-receiving enterprises, together with grain, contain dust up to 0.3% of the total harvested mass [2]. Jin et al. argued that to reduce energy consumption when using an adjustable electric drive, it is necessary to stabilise the amount of grain [3]. The development of conveyor load control systems in the presence of a delay of pure links in the circuits is regulated by the compensation of the delay of short-length conveyors and linear regulators with differential components. With an increase in the delay time, the use of such controllers becomes less efficient, and the quality of transients is less optimal.

The studies by Shayakhmetov et al. showed that grain dust contains soil elements, chemical additives, plant residues, insects, and pollen [4]. Prolonged exposure to grain dust can cause health problems for workers, such as respiratory tract infections, pneumonia, and allergic rhinitis. Roman-Sanchez et al. identified that grain raw materials have fine-grained and pulverised elements, creating an unfavourable environment in the

atmosphere since intense dustiness negatively affects metal parts, therefore accelerating the wear of mechanical parts and with the additional overload of grab cranes, thereby reducing the annual cargo turnover by 0.1-0.5%, increases equipment wear and leads to grain losses of 1-3% [5]. New energy-saving and environmental technologies are being systematically introduced at the elevators of agricultural holdings to maintain the competitiveness of cargo turnover.

The purpose of this study is to examine the efficiency of transportation and productivity of the process of moving grain cargoes, with the improvement of the design and technological scheme of the belt conveyor when clogged with grain dust.

2. RESEARCH SIGNIFICANCE

There are important practical and financial aspects for the agriculture sector from studies on enhancing the belt conveyor's design and operational characteristics for handling highly impure grain harvests. With an enhancement to the design and technology framework of the belt conveyor when clogged with grain dust, the study's findings offer insights into the productivity of moving grain cargoes and the efficiency of transportation. The study emphasizes the issues with dynamic loads that result in conveyor element failures, clogged roller supports from dust, and ruptured belts. It also takes into account the potential for using cleaning procedures for bulk grain cargo throughout transit, storage, and processing to reduce the production of further dust.

3. LITERATURE REVIEW

Grain transportation is a complex technological process that requires a lot of labour and financial investments. Grain belongs to the group of bulk cargoes transported under a canopy, which do not require packaging during storage and transportation. M.E.A. Ingles et al. estimate the bulk density of grain raw materials in their paper at 0.7-0.8 t/m^3, while the angle of the natural slope at rest is 35° [6]. Williams and Rosentrater believe that due to hygroscopicity, the grain must be protected from atmospheric influences; therefore, special requirements are imposed on grain transportation [7]. When the silo valve is opened when the grain is released, the capacity of the transport line is 100, 175, 350, and 500 t/h. The author of the study “Providing the lacking timeline – Chernozem evolution in Central Germany clarified by single grain luminescence data” reports that when entering the conveyor belt, the speed of grain movement varies depending on the height of the fall, reaching more than 10 m/s, on average, the speed of movement of the conveyor belt is within 3-4 m/s [8]. As per Wu et al., the mass fraction of grain waste containing dust reaches up to 26% of the total mass of raw materials [9]. Two types of grain dust are constantly present during grain processing: settled powder and floating aerosol.

Jia et al. systematised various types of grain conveyors, which are widely used in agricultural production for moving bulk, sticky, and dense loads [10] (Fig. 1).

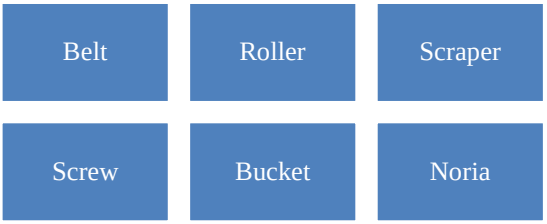

Fig.1 Systematized various types of grain conveyors, which are widely used in agricultural production

The roller conveyor works based on the principle of the movement of goods on rotating rollers with axles mounted in the frame. A plate conveyor is a transport device with a load-bearing sheet made of a steel plate attached to the body of a chain rod. Scraper conveyors are continuous-acting machines in which bulk cargoes are moved along fixed chutes or scraper trays. The screw conveyor is used for bulk, small-lump, pulverised, and powdery materials. Noria is a device designed for the vertical lifting of liquids or bulk agricultural raw materials. The latest belt conveyors are characterised by low operating costs, high reliability, and safety. Friso evaluated the belt conveyor, which is one of the most popular transport vehicles, due to its high performance, simplicity of design, low energy consumption, reliability, and ability to transport loads at high speed over long distances [11].

Pursuant to Heilman, the principle of operation of the belt conveyor is based on the fit of the belt to the drive drum, which ensures the movement of the belt (Fig. 2) [12]. The support is provided by fixed roller supports located along the entire length. Belt conveyors are equipped with belt catchers, cargo weighing systems, and belt cleaning mechanisms. The drive mechanism consists of gearboxes, electric motors, clutches, brakes, and drive drums. The studies of Permyakov et al. noted that rubber-wire and rubber-fabric belts are used in belt conveyors, and their purpose is the transportation of bulk cargo diagonally in various industries [13]. Suglobov et al. described rubber-fabric tapes, which are made based on synthetic yarns, polyamide fibres, and bicomponent fibres of a mixture of cotton and polyester [14]. Such tapes consist of a load-bearing layer and a textile frame. The joining of the tape is

conducted by hot vulcanisation to the required dimensions.

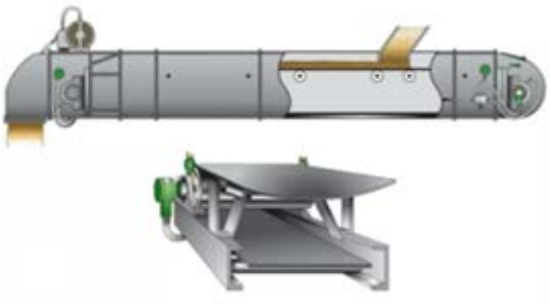

Fig.2 Belt conveyor

Gella et al. distinguish the following types of conveyor belts: rubber rope, plastic tape, modular, and metal [15]. Belt conveyors have the following advantages: high automation and continuity of action, the ability to transport goods at large angles, ease of operational management, and low metal consumption. Conveyor belts can be horizontal, inclined, closed, open, or covered. Pozeliene et al. identified that when loading, a large amount of grain dust is released, settling around the conveyor, however, closed-belt conveyors do not have this disadvantage [16]. Types of conveyor belts: chevron – suitable for transporting grain at an angle of up to 18°; oil-resistant – less deformed and resistant to vegetable oils and fats.

Kumar evaluates the operation of closed belt conveyors, which are used mainly in port and linear elevators, where the high capacity and length of the conveyor are required [17]. Hrabovsky and Fries report that grain cleaning at elevators is conducted preliminary, primary, and secondary: grain cleaning machine ZD-10000, separator heap cleaner OVS-25, pre-cleaning machine MPO-50, seed cleaning machines SM-4 and K-527A [18]. The main working elements of the equipment are pneumatic separating oscillating channels and a conveyor sieve. If the moisture content in the processed grain exceeds 16%, the productivity of the used grain washing machine is reduced by 6%.

Van Oorschot investigated grain raw materials, which after harvesting, need to be transported with the least losses and costs [19]. A popular method of grain storage is outdoor, with a full filling of the barn space; grain cargo transportation is conducted by belt conveyors 150-200 m long, which are used for automatic loading and unloading. Bellochio and Coradi report that for a long time, grain raw materials are subject to storage in specially equipped granaries and elevators and compliance with grain quality indicators at the level of all producers: farmers, agricultural firms, united associations, industrial grain combines [20]. Kholy and Kamel describe the condition of grain warehouses in conformity with their purpose, dividing them into purchasing, transhipment, production, and basic [21]. Grain warehouses can be both transhipment and production.

4. MATERIALS AND METHODS

The main concepts and applied research presented and demonstrated in the papers of leading researchers and practitioners were used as a theoretical basis for the study. The parameters of operation of belt conveyors using modern technologies are considered: cargo transportation, rotation of nylon brushes, dedusting of rotary drums of over-silo belt conveyors, modernisation of cleaning roller supports on the lower branch of the belt, equipment with aspiration systems for cleaning grain from dust impurities. The main types of belt conveyors are grouped by: purpose (general, underground, special), performance, type of route (rectilinear, curved), and the structure of the tape.

When designing modern belt conveyors, the method of analysis and synthesis of parameters and operability of conveyor systems was used as objects of universal movement of bulk cargo with reduced costs and time, increased efficiency and ease of management, identification of key parameters and conditions that determine the prospects for the development of modern mechanical engineering in agriculture. The analysis of the physical and mechanical properties of the belt conveyor by bulk density, the angle of natural inclination in motion and at rest, and the coefficient of external and internal friction on the rubber and steel surface.

The classification of grain cleaning machines and installations that perform preliminary heap cleaning, primary and secondary cleaning, and systems of additional and special processing of grain and seed raw materials is systematised.

5. RESULTS

Conveyor belts are installed at elevator plants, near receiving sites close to road and rail transportation. For agricultural purposes, belt-scraper conveyors (TLS-300, TLS-500) are more often used in elevators for the transportation of bulk cargo, pellets, rye, wheat, barley, oats, corn, rice, millet, sorghum, spelt, weeds, cake, meal, compound feeds, crushed hay, haylage, and silage. Belt conveyors (LT-6, LT-10) with a standard conveyor belt are used for horizontal and shallow-inclined transportation of grain and grain products, oilseeds, and granules. Ziegler et al. determined that the rollers in belt conveyors form the basis of efficiency and energy consumption, affect the durability of the tape, but the cost of the rollers is 25-30% of the cost of the entire installation, and 40% of all maintenance and repair costs [22]. The conveyor belt consists of the following parts:

polyvinyl chloride conveyor belt, which combines flexibility and high resistance to wear; conveyor rollers withstand increased loads and critical temperatures; conveyor drums provide traction force that drives the conveyor mechanism; roller supports, designed for installation in the conveyor rollers, are made of metal resistant to negative influences (Fig. 3).

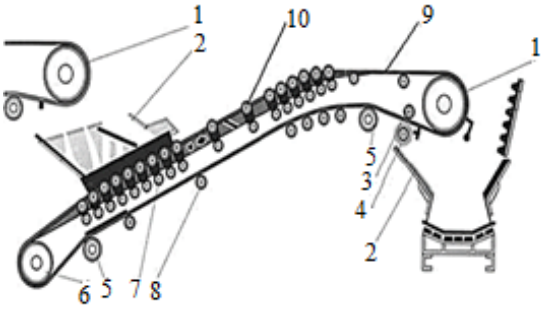

Fig.3 Belt conveyor scheme [23]

Belt conveyors are usually similar in design and include the typical elements indicated in Fig. 1: drive drum (1), loading tray (2), pressure rollers (3), cleaning device (4), deflection drum (5), end drum (6), shock-absorbing roller support (7), lower roller supports (8), transport belt (9), upper roller supports (10). As per Bucklin et al., the following physical and mechanical properties of the conveyor are used for grain transportation: average bulk density is 0.6-0.8 t/m^3, angle of natural inclination at rest – 22°, in motion 19°, the abrasive group – A, with a slight degree of mobility, coefficient of external friction on rubber – 0.4-0.5 t/m^3, on steel – 0.3-0.4 t/m^3, internal friction coefficient – 0.5-0.8 t/m^3 [24]. The throughput capacity reaches up to 2400 t/h for wheat with a conveyor length of up to 500 m.

Elevators process 1.5-5 thousand tonnes of grain per day for land transport, 1.5-2.5 thousand tonnes for loading wagons, 1.5-5 thousand tonnes for cleaning, and 175-2500 tonnes for drying. In accordance with Syed et al., the air purity levels in the working room should not exceed the maximum permissible values for grain dust of 4 mg/m^3, and for flour dust of 6 mg/m^3; these indicators are achieved by aspiration [25]. It is recommended to be installed directly on the equipment, providing a vacuum of 20-30 Pa in it. The speed of the tape should be at least 1-3 m/s, and the route length should be at least 100 m.

The cleaning plant on the lower branch of roller supports has become quite widespread in recent years. The failure of the roller occurs when the torsion function is violated and the bearing rings are displaced under a load. In line with Uebersax et al., the permissible displacement angle for single-row deep groove ball bearings is 0° in 8 minutes without considering the deformation of the element, then considering the deformation, the skew angle reaches 0° in 17 minutes, so the performance of the roller depends on the permissible residual angle allowed during manufacture and installation [26]. A brief description of the belt conveyor roller is shown in Fig. 4.

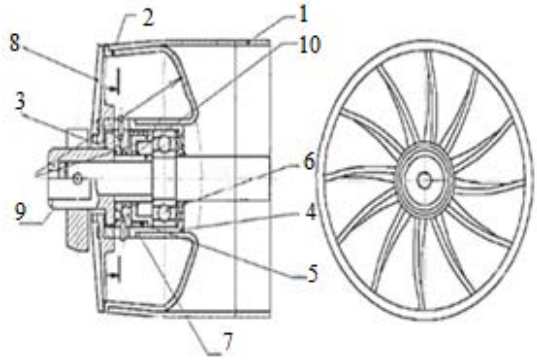

Fig.4 Rollers of new design [27]

On the rollers of the conveyor belt, there is a movable disc (1) with a copper foil glued on, which contacts the stationary disc when stopped as a result of the action of springs (2). In this case, a contact seal of the disk is created, which excludes the ingress of particles, for example, dust, from the environment. When the roller rotates, the ball (3) under the action of centrifugal force overcomes the compressive force of the spring (5) and moves along the groove, pressing the movable disk (7) against the vertical wall of the L-shaped cup (4). When moving the load, the necessary gap is formed between the inherent disk labyrinth seals and through the impeller cover (8), where air enters the hub (2) and passes through the holes in the movable disk to displace dust from the pre-chamber bearing assembly. The cleaning cylinder of the fixed disk (9) leads to a double cleaning effect. The supply of lubricant to the bearing (6) is conducted in the cavity of an L-shaped cup (4) held by a membrane ring (10).

Bortnowski et al. describe a transportation belt supported by three-roller supports, where the cross-sectional area of the bulk cargo consists of the sum of the areas of a trapezoid and an isosceles triangle [28]. This system is often used in flour mills, feed mills, fat-and-oil, and starch plants. The cross-sectional area depends on the type of roller. Among the three rollers, the central rollers remain in a horizontal position, while the other two are in an inclined position or at a trough angle from 20° to 45°. For a lower load capacity, flat belts can be used. The width of the belt depends on the power requirements, the speed of the conveyor, and the angle of inclination.

After threshing by combine harvesters, the grain is brought to the appropriate standards, through the

air and air-sieve machines combined with triers, pre-cleaning and partial sorting of seeds of various crops are conducted to the norms of the seed material. The main requirement applicable to grain cleaning machines is the purification of seed or food material, considering the amount of waste and damage to grain, which should not exceed permissible values. The airflow velocity of these machines is regulated by a replaceable set of grilles and trier cylinders. Cleaning of grain crops from impurities is conducted pursuant to the following indicators: thickness, width, length, aerodynamic properties, density, configuration, bumpiness, and roughness, depending on the condition of the surface. The components of the mechanisms for sorting grain include a trier cylinder trough, a fan, bunker storage, a separating flap, a vibration deck, a pile fabric tape, a drum, and a magnet. Grains whose width is less than the diameter of the holes fly through the gratings, and the larger components of the grain mixture move further. The grain is divided into sieves in thickness with oblong and round holes.

Along the length, the grain mixture is separated into bucket-shaped trier cylinders, rotating around its axis located at an angle. Grain cleaning in conformity with aerodynamic properties occurs due to the effect of airflow in grain cleaning sorting machines with a powerful ventilation system. In keeping with the density, the seeds are separated on pneumatic sorting tables. During the operation of magnetic separators, the grain surface is treated with magnetic powder and grain with a high coefficient of friction is carried up, and smaller seeds are rolled down. Grain is mixed with magnetic powder and fed to the cylinder of rotation, and when a magnetic field is applied, it is retained.

Grain cleaning machines with high technical and economic indicators of the Petkus Gigant K535 type, a machine for the secondary processing and sorting of cereals, legumes, and oilseeds, are widely used for grain cleaning, as noted in Fig. 5.

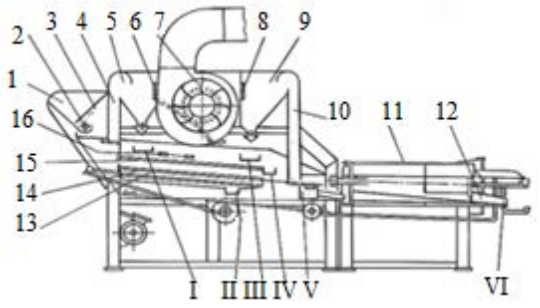

Fig.5 Scheme of the Petkus Gigant seed cleaning machine [29]

The Petkus Gigant grain cleaning machine consists of: grain receiving hopper (1); feed rollers (2); flaps (3); aspiration channels (4, 10); deposition chambers (5, 9); air gates (6, 8); fan (7); trier cylinder (11); tray (12); brush (13); lower and upper sieves (14, 15); cleaner (16). In concordance with the scheme, the grain mixture with impurities is decanted, located in the departments of the device as follows: light impurities (I, III); fine grain with impurities (II); large impurities (IV); grain of air-lattice purification (V); short impurities (VI).

In agreement with Patel et al. [30] it was established that dust extraction from the air is conducted as per the filtration method for particles up to 0.1 microns in size, and through electrostatic, centrifugal, and inertial deposition – for those over 0.5-1 microns. Based on the degree of air purification, filters are divided into three types: high – with a final dust content in the air of 12 mg/m^3, medium – 40-50 mg/m^3, and coarse – over 50 mg/m^3. The most effective technical measures to prevent the formation and spread of dust include the introduction of continuous production technology, automation, and mechanisation of processes.

6. DISCUSSION

Grain crops arriving at the grain receiving point contain a certain number of weeds, mineral and organic impurities, damaged, defective, and small grains of the main crop. In accordance with Jones, the characteristics of grain raw materials are as follows: bulk weight – 0.7-0.8 t/m^3, residual angle of natural slope – 35° [31]. Grain dust in dry grains of wheat, rye, millet, barley, and triticale reduces the service life of the conveyor belt. The main causes of malfunction are clogging of roller bearings with subsequent locking; lack of lubrication of bearings; fitting of bearings in hubs and casing, not on a rotating axis; uniform erasure of the shell around the circumference [32].

Grain dust is subjected to cleaning and sorting, considering the characteristics of the crop being cleaned, the presence of weeds, and additional particles. When grain is processed on the elevator, its friction occurs against the walls of pipes, bunkers, mutual friction of grains, and interaction of device parts. Therefore, their surface is abraded with the formation of organic dust. At the stage of pre-cleaning, particles of straw, wood, rope or paper and corn cobs are removed from grain products. The cleaning equipment is installed mandatorily: the place of grain acceptance in silo-type storages; the system of transhipment of raw materials; processing complex. Productivity indicates the maximum amount of grain raw materials that grain cleaning equipment is capable of processing per unit of time and is in the range of 4-150 t/h.

The cleaning methods used more than 10 years ago are no longer practical today. Therefore, they must be adjusted in grain processing operations and

optimised for the changed conditions of dust control. The ventilation of grain mass by means of shifting from a silo is accompanied by considerable operating costs [33]. According to the standards, the capacity of each conveyor belt is equal to 18.5 kW; aspiration systems – 25 kW; vertical burrows – 21.5 kW; simultaneously, for one transport and technological system, the total cost of electricity for 1 hour is 2670 tg/h; thus, the cost of grain 30000 tg/t is the cost of the existing method of grain ventilation for 1 hour will be 2670/30000=0.089 t/h or 89 kg/h (Table 2; Fig. 6).

Table 2 Standard capacities of the conveyor

Capacities of the conveyor	
Capacity of each conveyor belt	18.5 kW
Aspiration systems	25 kW
Vertical burrows	21.5 kW

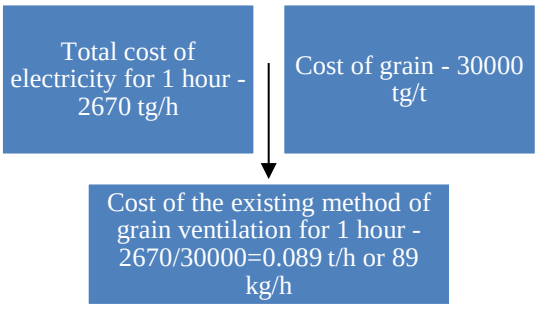

Fig.6 Calculation of the cost for the existing method of grain ventilation in 1 hour

Conveyor transport systems should be designed from the very beginning considering appropriate dust control measures [34-36]. The improvement of the designs of universal grain cleaning machines or separation conveyors by effective directions, which are installed at the beginning of the technological cycle, allows the grain to be cleaned from large impurities at the loading stage [37-39]. Jiru and Usmane assess the systems for automatic regulation of belt conveyor operating modes and provide protective adjustment of the belt speed in accordance with the installed performance, moderate speed tension for the drive operation without slippage, distribution of the drive drum thrust, automatic centering of the belt, and maintenance of normal operation of the reloading device [40]. Transportation of grain raw materials by belt conveyors is conducted using tension rollers with deep grooves at moderate belt speed and controlled airflow around the belt. Sufficient belt tension minimises sagging between the tension rollers and eliminates grain bouncing on each grooved tension roller [41].

7. CONCLUSION

In keeping with the results of the review, it can be concluded that Kazakhstan is a major producer and exporter of grain crops. Therefore, the processing and storage of grain products need the improvement of transport lines, especially in matters of ventilation. Modern grain cleaning equipment must meet agrotechnical requirements, be effective in grain cleaning processes without damage, have high productivity, and ensure the purity of grain material according to the standard. It is necessary to monitor the quality of the composition of grain and grain dust during transportation, processing, and storage, assess the level of ventilation of grain for cooling, reduce humidity, and maintain optimal temperature.

General requirements for modern transport and grain cleaning plants are designed to increase productivity, reliability, and vibration resistance, with the protection of the surrounding air and machinery from pollution. The necessity of using cleaning devices that substantially reduce the amount of grain dust in the area of the drive drum and the over-silo belt conveyor was established. Grain-cleaning plants should be installed in a small space and be able to clean various crops without wasting time and additional space. Summarising the analysis results, it can be noted that the belt conveyor and dust cleaning operations technologies are constantly being upgraded. Today, systems that automatically regulate the operating mode of belt conveyors are of great importance. These include adjustment of the belt speed in accordance with the required performance, adjustment of the belt tension to operate the drive without sliding, automatic distribution of thrust on the drive drum, automatic centering to prevent the belt from skidding, and automatic maintenance of normal operation of overload devices. Based on the above, the need for new technical projects to reduce the risks of environmental pollution by dust, improve the aspiration system, and the resistance of equipment to severe operating conditions is increasing every day.

The materials of the study highlight the problems in the field of cargo turnover, modernisation of transportation belts, roller supports, and ventilation systems, have a beneficial effect on preventing additional costs, efficient use of labour, improving the economic performance of an agricultural enterprise.

8. REFERENCES

[1] Dzhankurazov B.O., Akhmedzhanov T.K. and Dzhankurazov K.B., Stratification in the volume of the grain mass and fluctuation of heat and moisture parameters as a factor in the

spontaneous occurrence of exothermic processes in granaries. Bulletin of the Kyrgyz National Agrarian University named after K.I. Skryabin, Vol. 1, 2020, pp. 106-116.

[2] Wheat J. and Leali A., Hazard monitoring equipment selection, installation, and maintenance. In: Storage of cereal grains and their products. Sawston: Woodhead Publishing, 2022, pp. 371-405.

[3] Jin H., Hu S., Xie B., Yan Y., Yang M. and Zhou F., Experimental optimization for cleaning parameters and field application of cartridge filter in bulk grain loading. Powder Technology, Vol. 378, 2021, pp. 421-429.

[4] Shayakhmetov Y.Y., Temirtasov O.T. and Mendebayev T.M., Analysis of work and ways to improve belt conveyors at elevators. Bulletin of the Kazakh Academy of Transport and Communications named after M. Tynyshpaev, Vol. 5, 2014, pp. 44-48.

[5] Roman-Sanchez A., Laguna A., Reimann T., Giraldez J.V., Pena A. and Vanwalleghem T., Bioturbation and erosion rates along the soil‐hillslope conveyor belt, part 2: Quantification using an analytical solution of the diffusion-advection equation. Earth Surface Processes and Landforms, Vol. 44, Issue 10, 2019, pp. 2066-2080.

[6] Ingles M.E.A., Casada M.E. and Maghirang R.G., Handling effects on commingling and residual grain in an elevator. Transactions of the ASAE, Vol. 46, Issue 6, 2003, pp. 1625-1631.

[7] Williams G.D. and Rosentrater K.A., Design and engineering considerations for grain storage, handling, and processing facilities. In: Storage of cereal grains and their products. Sawston: Woodhead Publishing, 2022, pp. 179-246.

[8] van Meer M., Providing the lacking timeline – Chernozem evolution in Central Germany clarified by single grain luminescence data. 2020. Wageningen: Wageningen University and Research, 2020, pp. 23-27.

[9] Wu Y., Li X., Mao E., Du Y. and Yang F., Design and development of monitoring device for corn grain cleaning loss based on piezoelectric effect. Computers and Electronics in Agriculture, Vol. 179, 2020, Article: 105793.

[10] Jia H., Wu K., Wang Y. and Sun Y., Conveyor belt structure of belt dryer: Analysis and optimization. Engineering Failure Analysis, Vol. 115, 2020, Article: 104686.

[11] Friso D., Conveyor-belt dryers with tangential flow for food drying: Development of drying ODEs useful to design and process adjustment. Inventions, Vol. 6, Issue 1, 2021, pp. 16-25.

[12] Heilman M., The racial elevator speech: How multiracial individuals respond to racial identity inquiries. Sociology of Race and Ethnicity, Vol. 8, Issue 3, 2022, pp. 370-385.

[13] Permyakov V., Ganeev I., Akhmetyanov I., Karimov K. and Verzilov S., Improving the efficiency of corn drying in a conveyor belt dryer. Journal of Environmental Science and Health, Part B, Vol. 56, Issue 10, 2021, pp. 861-868.

[14] Suglobov V.V., Raksha S.V. and Hrynko P.A., Rationale for centering capacity of redisigned belt conveyor drums. Science and Transport Progress, Vol. 1, Issue 61, 2021, pp. 158-168.

[15] Gella D., Maza D. and Zuriguel I., Granular internal dynamics in a silo discharged with a conveyor belt. Journal of Fluid Mechanics, Vol. 925, 2021, Article: A24.

[16] Pozeliene A., Lynikiene S., Sapailaite I. and Sakalauskas A., Utilization of strong electric field for special cleaning buckwheat seeds. Agronomy Research, 6, 2008, pp. 291-298.

[17] Kumar N., Fundamentals of conveyors. In: Transporting operations of food materials within food factories. Sawston: Woodhead Publishing, 2023, pp. 221-251.

[18] Hrabovsky L. and Fries J., Transport performance of a steeply situated belt conveyor. Energies, Vol. 14, Issue 23, 2021, Article: 7984.

[19] van Oorschot A., Quantifying reworking and accumulation rates in a plaggic anthrosol using feldspar single-grain luminescence dating. Wageningen: Soil Geography and Landscape Group, 2018, pp. 36-51.

[20] Bellochio S.D.C. and Coradi P.C., Systematic review of occupational hazards at postharvest grain operations. Injury Prevention, Vol. 28, Issue 2, 2022, pp. 165-174.

[21] Kholy M.M. and Kamel R.M., Development and evaluation of an innovative grain cart with a pneumatic conveyor. Heliyon, Vol. 7, Issue 11, 2021, Article: e08461.

[22] Ziegler T., Jubaer H. and Teodorov T., Bottlenecks in continuous hops drying with conveyor-belt dryer. Drying Technology, Vol. 40, Issue 13, 2021, pp. 2598-2616.

[23] Romanyuk N.N., Eskhozhin D.Z., Ageichik V.A., Nukeshev S.O., Toygambaev S.K. and Shilo I.N., Patent No. 28323 “Belt conveyor”, 2014, https://kzpatents.com/5-ip28323-lentochnyjj-konvejjer.html.

[24] Bucklin R., Thompson S., Montross M. and Abdel-Hadi A., Grain storage systems design. In: Handbook of farm, dairy and food machinery engineering. Cambridge: Academic Press, 2019, pp 175-223.

[25] Syed I., Kommineni H.K., Sunkara S.S. and Abdul I.B., Hydraulic conveyors, bucket conveyors, and monorails. In: Transporting operations of food materials within food factories. Swaston: Woodhead Publishing,

2023, pp. 293-313.
[26] Uebersax M.A., Siddiq M., Cramer J. and Bales S., Harvesting, postharvest handling, distribution, and marketing of dry beans. In: Dry beans and pulses: Production, processing, and nutrition. Hoboken: John Wiley & Sons, 2022, pp. 81-104.
[27] Ra Y., Kim J., Kim H., Cho S., Lee D., Jang S. and Choi D., Smart conveyor roller system for self-powered product size identification in electrically off-grid condition via hybridization of triboelectric-electromagnetic generators. Nano Energy, Vol. 100, 2022, Article: 107447.
[28] Bortnowski P., Kawalec W., Krol R. and Ozdoba M., Types and causes of damage to the conveyor belt-review, classification and mutual relations. Engineering Failure Analysis, Vol. 140, 2022, Article: 106520.
[29] Astanakulov K.D., Karimov M.R., Khudaev I., Israilova D.A. and Muradimova F.B., The separation of light impurities of safflower seeds in the cyclone of the grain cleaning machine. IOP Conference Series: Earth and Environmental Science, Vol. 614, Issue 1, 2020, Article: 012141.
[30] Patel S., Patel S. and Patel J., A review on design and analysis of bucket elevator. International Journal of Engineering Research and Applications, Vol. 2, Issue 5, 2012, pp. 18-22.
[31] Jones C.L., Dust control and explosion prevention. In: Storage of cereal grains and their products. Swaston: Woodhead Publishing, 2022, pp. 431-442.
[32] Tultayev B., Balbayev G. and Zhauyt A., A Kinematic Analysis of Flat Leverage Mechanism of the Fourth Class for Manipulators. IOP Conference Series: Materials Science and Engineering, Vol. 230, Issue 1, 2017, Article: 012047.
[33] Askarov A., Tlevlessova D., Ostrikov A., Shambulov Y. and Kairbayeva A., Developing a statistical model for the active ventilation of a grainlayer with high moisture content. Eastern-European Journal of Enterprise Technologies, Vol. 1, Issue 11-115, 2022, pp. 6-14.
[34] Abdelrazek A.G.D. and Akl S.A.Y., Estimating liquefaction resistance improvement due to stone columns from quality control tests. International Journal of GEOMATE, Vol. 21, Issue 86, 2021, pp. 147-158.
[35] Fialko N.M., Prokopov V.G., Meranova N.O., Borisov Yu.S., Korzhik V.N. and Sherenkovskaya G.P., Heat transport processes in coating-substrate systems under gas-thermal deposition. Fizika i Khimiya Obrabotki Materialov, Issue 2, 1994, pp. 68-75.
[36] Smailova G., Yussupova S., Uderbaeva A., Kurmangaliyeva L., Balbayev G. and Zhauyt A., Calculation and construction of the tolling roller table. Vibroengineering Procedia, Vol. 18, 2018, pp. 14-19.
[37] Hidayawanti R., Latief Y., Rahayu Y., Wachid F.I. and Widodo R.P.A., Utilization of GGBFS as cement substitute to reduce production cost of construction project. International Journal of GEOMATE, Vol. 21, Issue 86, 2021, pp. 9-16.
[38] Mushtruk M., Bal-Prylypko L., Slobodyanyuk N., Boyko Y. and Nikolaienko M., Design of Reactors with Mechanical Mixers in Biodiesel Production. Lecture Notes in Mechanical Engineering, 2022, pp. 197-207.
[39] Danchuk V., Bakulich O. and Svatko V., Identifying optimal location and necessary quantity of warehouses in logistic system using a radiation therapy method. Transport, Vol. 34, Issue 2, 2019, pp. 175-186.
[40] Jiru T.U. and Usmane I.A., Development and evaluation of hand operated seed cleaner for small-holder farmers in East Hararghe, Oromia. Journal of Civil Engineering and Environmental Sciences, Vol. 7, Issue 1, 2021, pp. 18-24.
[41] Danchuk V., Bakulich O., Taraban S. and Bieliatynskyi A., Simulation of traffic flows optimization in road networks using electrical analogue model. Advances in Intelligent Systems and Computing, Vol. 1258 AISC, 2021, pp. 238-254.