Improving the technological reliability and safety of feed mills production lines

T. Belova¹*, E. Agashkov², S. Terekhov¹, L. Markaryants¹

¹ Bryansk State Agrarian University, Bryansk, Russia
² Oryol State University named after I.S. Turgenev

E-mail: belova911@mail.ru

Annotation. One of the problems in the production of animal feed is the need for frequent repairs of the receiving point equipment, due to the uneven supply of raw materials to the transporter, which reduces technological reliability and does not provide necessary safety level on the line. The developed design for automated unloading from transport at the elevator receiving area and a laboratory unit for obtaining a uniform consumption of bulk materials and studying the process of its expiration at different loads in order to increase the technological reliability of the bulk materials transporter drive and mechanical elements at the stage of reception the raw materials from the feed mills are presented.

1. Abstract
In the context of rapidly changing livestock industry /1/ the technological reliability to operate feed mills enterprises is largely determined by the processes of unloading and transportation of various bulk materials (wheat, barley, oats, sunflower meal, soybean, etc.). At the same time, the main negative factor is the probability of a sudden raw materials income (Carol Jones 2017), which leads to a high local load on the elements of the receiving point (hopper, transporter). This causes stoning of the outlet openings of the hopper, damage to the transporter and, as a consequence, an emergency stop of the transporter, which requires frequent repair works in harmful and dangerous working conditions (Treskova 2017). Due to the dust accumulation on the surfaces of the receiving point and in the technological equipment, as well as uncleansed raw materials from the hopper, may cause dust emissions during repairs, as in the air of the working area and as in the atmosphere. It follows that by increasing the time between maintenance and repair works by improving the process reliability and safety of production lines, it is possible to reduce dust emissions into the environment (World Health Statistics 2016, Report 2016, Ordinance 2003).

2. Analysis of the existing scientific studies.
Existing scientific studies of this problem (Gyachev 1992, Yudaev 2008, Voblikov 2010, Berlin 2005, Bogomyagki 2015, Bogomyagki 2015, Savenkov 2014) are devoted to the study the receiving hopper parameters (dimensions, shape, surface properties of the walls), outlet openings and structures of their closures, properties of bulk (grain) materials (arching and its destruction, distribution of bulk material pressure components), affecting the uniformity and other parameters of the expiration process. However, these works did not fully address the issues of ensuring an even supply of bulk materials. When using
receiving bins at receiving centers of feed mills with a large loading volume, it is necessary to take into account the transporting capacity depending on its initial filling, the dependence of the bulk material consumption on its type and properties, the initial and subsequent volumes, the area of the outlet openings, taking into account the nominal discharge capacity transporter, and also the influence of these factors on the workers and the environment safety (Bedarev 1992, Adejumo 2013, Howard 1993, Shkrabak 1994, Shkrabak 1995).

3. A case study of feed mills production lines.

3.1 The purpose of research is to increase the technological reliability of equipment and the safety of feed mills operating on production lines.

The main objectives of the research are:

3.1.1. To theoretically justify the increase in technological reliability of feed mills production lines at various levels of bulk material in the hopper;
3.1.2. To develop the design of a device for automated unloading of the elevator receiving station from automobile transport and to make an experimental laboratory setup for the feed mill section of the feed mill to obtain mathematical models that establish the relationship between the areas of the hopper outlet openings with a uniform consumption rate of bulk material in the terms of safe functioning of the receiving station equipment: from the type of material to be poured (wheat, oats), hopper fullness, volume of bulk material.

The probability of dust emissions into the environment $P_{dem}$ depends on the probability of failure-free operation of the $P_{ref}$ equipment, which, in turn, can be determined from the expression (Belova 2018):

$$P_{ref(t)} = Q_{ec}/Q_r,$$

where $Q_{ec}$ - maximum throughput of bulk material from the outlet of the hopper, $m/h$; $Q_r$ - discharge transporter rated capacity, $m/h$, $Q_r = (0.6-0.8) Q_{max}$; $Q_{max}$ - maximum (according to the technical characteristics of the transporter) discharge transporter performance.

Minimum dust emissions into the environment are provided at a ratio (Belova 2018)

$$Q_{ec}/Q_{max} < 1$$

Figure 1. Schematic diagram of the receiving device of the feed mill elevator

The hopper of the elevator receiving device in the situation under consideration (Fig. 1) has the shape of an inverted, truncated pyramid, consists of thirteen identical sections, each of which has an outlet equipped with a sliding shutter.

The maximum throughput of bulk material from the outlet of the hopper according to the expiration law /1/ section of the discharge hopper (Fig. 2) of the feed mill elevator receiving device in connection with its changing load for the $H_n$ level is determined from the expression (Belova 2018):
\[ Q_{\text{v,n}} = 4r^2 \sqrt{\frac{q4r^2}{R_1(B_1 + B_2) + B_3(R_{1,n} + R_{2,n})}} \]  

(3)

where \( B_1, B_2, B_3 \) - consequently \( \tan \alpha_1, \tan \alpha_2, \tan \alpha_3 \);
\( q \) – volumetric consumption of the bulk material, \( t/h \);
\( r \) – outlet radius;

Figure 2. Diagram of one section of the discharge hopper: \( \alpha_1, \alpha_2, \alpha_3 \) – angles between the walls of the hopper, consequently, \( A, B, C \) and the vertical; \( H_1, H_2, H_3, H_n \) – hopper filling levels with bulk material; \( R_{1,1}^{\prime}, R_{1,2}^{\prime}, R_{1,3}^{\prime}; R_{2,1}^{\prime}, R_{2,2}^{\prime}, R_{2,3}^{\prime}; R_{3,1}^{\prime}, R_{3,2}^{\prime}, R_{3,3}^{\prime}, R_{3,n}^{\prime} \) are the sizes of cross sections at the levels, consequently, \( H_1, H_2, H_3, H_n \).

The proposed elevator receiving device (Belova 2018) allows you to automatically adjust the supply of bulk material from the unloading hopper to the receiving conveyor due to the fact that when the vehicle 1 with bulk material enters the truck unloader 2, the mass sensor 3 is triggered and through the control unit 4 the signals are sent to the electric motor of receiving conveyor and to the electric motor of the sliding shutters 6, which are opened by means of a worm gear 7 at the minimum allowable gap. When unloading, the bulk material is poured out of the receiving hopper 8 through a gap controlled by the sliding shutters 9 to the receiving conveyor 10. After some time, the sliding shutters open a certain width depending on the load on the receiving conveyor. The load on the receiving conveyor is controlled by the consumed current strength of the conveyor drive motor using the current sensor 11. When a signal is received from the current sensor about the minimum current consumption by the electric drive motor of the receiving conveyor in the case of maximally open sliding shutter, a signal is sent through the control unit to stop the receiving conveyor and return the shutters to their original position.

To study the process of bulk materials expiration from hoppers, an experimental setup was made (Fig. 3, a-b) and research methods developed (Ermolyev 2003).

For oat expiration:

\[ Y = 0.450765x^3 - 3.2698x^2 + 7.040942x - 0.58705 \]  
with 0.03 m³

\[ Y = 0.460898x^3 - 3.39142x^2 + 4.298121x + 0.04 \]  
with 0.04 m³

\[ Y = 0.275538x^3 - 3.39142x^2 + 4.298121x + 1.046353 \]  
with 0.05 m³

For the expiration of wheat:

\[ Y = 0.231646x^3 - 3.2698x^2 + 7.040942x - 0.58705 \]  
with 0.03 m³

\[ Y = 0.232558x^3 - 3.39142x^2 + 3.679822x + 0.475339 \]  
with 0.04 m³

\[ Y = 0.14387x^3 - 1.025223x^2 + 2.1822x + 1.352205 \]  
with 0.05 m³

The pouring out process (Fig. 4) in this case can be divided into 3 stages. The first stage is the process of opening the outlet openings to reach a given consumption rate, the second stage is the maintenance of a given consumption rate with a slight change in the outlet openings area, and the third stage is the process of a sharp increase in the area of the outlet openings also to maintain a given consumption rate.
until the hopper is completely empty, which can be explained by a decrease in pressure bulk material (oats, wheat).

Figure 3. Laboratory installation to obtain a uniform flow rate of bulk material: a - general view; b - functional diagram: 1 - loading hopper; 2 - bulk material; 3 - hopper flap; 4 - coupling; 5 - optical sensors of full opening and closing of the shutter; 6 - electric motor; 7 - hairpin M5; 8 - nut M5; 9 - control unit; 10 - discharge hopper; 11 - mass sensor; 12 - PC; 13 - optical shaft speed sensor; 14 - blade fixing nuts; 15 - blade; 16 - bracket fixing the studs; 17 - power supply

The result of experimental studies is (Fig. 4) obtaining the values distribution of the outlet openings areas during the entire time of emptying the discharge hopper to ensure a certain uniform consumption rate of bulk material.

Figure 4. Distribution of the values of outlet openings areas during the entire emptying time of the hopper to ensure a certain uniform consumption of bulk material: 1 - hopper filling 0.03m³, 2 - hopper filling 0.04m³, 3 - hopper filling 0.05m³ (oats); 4 - hopper filling 0.03m³, 5 - hopper filling 0.04m³, 6 - hopper filling 0.05m³ (wheat); Io, IIo, IIIo - stages of the bulk material expiration process (oats), Iw, IIw, IIIw - stages of the bulk material expiration process (wheat)
The graphs show that the values of the areas of the exhaust openings since the beginning of the emptying hopper starts emptying until it is completely emptied, to ensure a uniform flow of oat bulk material at all values of the initial hopper filling \((0.03 \text{ m}^3; 0.04 \text{ m}^3; 0.05 \text{ m}^3)\) above than for wheat at all three stages (I, II, III) of the pouring out process, which is explained by its lower density.

3.3. Evaluation of automated unloading systems usage

Thus, a technological process with the usage of automated unloading system using a receiving elevator device, mathematical models for determining the maximum throughput of the receiving hopper and ensuring a uniform consumption rate depending on the volume of bulk material will increase the technological reliability of the equipment and the safety of the production line, as well as reduce the dust impact on workers and the environment during repair works due to the increase in time intervals between them.

Summary

The automated unloading system, mathematical determination models for the maximum throughput of the receiving hopper and solutions to ensure uniform consumption depending on the volume of bulk material can be recommended for practical use in the reconstruction of existing and designing new reception centers for animal feed productions.

References

[1] Recommended Citation FAO and IFIF. Good practices for the feed industry - Implementing the Codex Alimentarius Code of Practice on Good Animal Feeding 2010 (Rome, FAO Animal Production and Health Manual) 9.

[2] Carol Jones 2017 Preventing Grain Dust Explosions / Division of Agricultural Sciences and Natural Resources (Oklahoma State University) Information on http://osufacts.okstate.edu.

[3] Treskova Yu. 2017 Problems of rationing fine dust particles in Russia and abroad (Young scientist) 23 17-19. Information on http://moluch.ru/archive/157/44398/ (date of the application: 08.07.2019).

[4] World Health Statistics 2016 (Monitoring health for the SDGs).

[5] Report 2016 WHO air quality recommendations for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Global updated data (Geneva: WHO Regional Office for Europe) 16. 27.

[6] Gyachev L.V. 1992 Fundamentals of hoppers theory (Novosibirsk, Novosibirsk University Press).

[7] Yudaev N.V. 2008 Elevators, warehouses, grain dryers (St. Petersburg, GIORD).

[8] Voblikov EM 2010 Technology of the elevator industry (St. Petersburg, Publishing House "Lan").

[9] Berlin NP 2005 Loading-unloading, transporting and auxiliary machines and devices (Gomel: Editorial and Publishing Department of UO BelGUT).

[10] Bogomyagki VA, Skudina AA 2015 The influence of some arch-forming factors on the time of cereals expiration from the hoppers of the highest consumption (Young scientist) 14 (94) 133-135.

[11] Bogomyagkikh VA, Skudina AA 2015 The influence of moisture content of grain materials on their expiration from the highest hopper consumption (Young scientist) 14(94) 131-133.

[12] Savenkov DN 2014 Justification of the hopper outlet shape, providing a uniform supply of grain material (Bulletin of Kazan GAU) 1(31) 79-83.

[13] Bedarev VV 1992 Methods and technical means to increase the safety of technological lines operators for post-harvest grain processing (Diss ... Ph.D. Engineering. S-Pb-Pushkin).

[14] Adejumo B A and Haruna S A 2013 Workers Health and Safety in Bulk Handling Of Grains for Storage in Metallic Silos (International Journal of Engineering Science Invention) 2(9) 78-83. ISSN (Online): 2319 - 6734, ISSN (Print): 2319 - 6726. Information on http://www.ijesi.org.

[15] Howard J 1993 Doss and William McLeod. Avoid Risks. When Working Around Grain Handling and Processing Equipment (Michigan State University Extencion) 1-4.

[16] Shkrabak VS, Vergun PI, Bedarev VV, Ilyashchenko AA, Morozov VA, Eliseikin VA 1994 Pat. RF №2023640. Device for controlling the supply of bulk material.
[17] Shkrabak VS, Bedarev VV, Ilyashchenko AA, Eliseikin VA, Selivanova MA 1995 Pat. RF №2027652. A device for locking the slide shutters of grain storage bins.

[18] Belova T.I., Agashkov E.M., Terekhov S.V., Chernova E.G. 2018 Reducing the dangers of injury to operators of elevator reception centers “Innovative solutions to urgent problems of environmental management and environmental protection” (collection of reports from the International Scientific and Technical Conference Belgor State Technological University: Belgorod) I 26-31.

[18] Belova T.I., Agashkov E.M., Gavrishchuk V.I., Terekhov S.V., Chernova E.G. 2018 RF Patent No. 2017133586. Elevator receiving device.

[19] Ermolyev Yu. I 2003 Fundamentals of Scientific Research in Agricultural Engineering (Rostov n / a, Publishing Center DSTU) 82-85.