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Innovative solution of coal slurry mixer

During the coal-enrichment process in mechanical processing plants, fine-grained high-moisture coal slurries are produced. These waste products may be used in energetic blends after a special moisture-reducing treatment. Therefore, coal slurry pelletizers are produced (among other things).
In the Department of Mining, Dressing, and Transport Machines, a project of a prototypical installation for coal slurry pelletization with a capacity of 50 Mg/h was constructed. The main part of the installation is the mixer. At its bottom part, an opening is placed that is closed by a metal plate. During the pelletization work, a plate is half-opening and rotates around its own axis. The rotation of the drum and agitators installed inside the mixer causes sludge grinding and its homogenization. A properly working drum closure system is important for the proper exploitation of the mixer. The designed mechanism allows us to lower the plate linearly in the first phase and then turn it with a predetermined angle after the complete removal of material from the drum. The project required an examination of the kinematics of the system and determination of the drive system load, which allowed us to designate the working parameters. This paper presents the course of the taken actions and results of the fundamental research, along with their analysis. A selection of optimum design and exploitation parameters was performed on the basis of the graphical synthesis method, created simulation model, and tests of the prototype device.

Key words: *pelletization, agglomeration, mixer, alternative fuels, coal slurries, pellets, granulation, tank closure mechanisms*

1. INTRODUCTION

During coal-enrichment processes in hard coal mine mechanical processing plants, fine-grained and high-moisture industrial waste is produced, which is called coal slurry. These slurries are the smallest grain classes with a grain size below 1 mm in which fractions of less than 0.035 mm represent 60% of the mass. Depending on the quality parameters (ash and sulfur content, caloric value), the slurries could be addressed directly to an energy mix or deposited in mine ground sedimentation tanks. The high surface moisture of the slurry (within a range of 25 to 30% after filter dehydration) results in difficulties in unloading the product from wagons, especially in the winter (due to the lack of effective low-cost anti-freezing solutions). The most-preferred way to reduce the moisture content of the coal is a chemical interaction, resulting in a lowered free moisture ratio of the coal slurry. Thus, the prepared energy mix can be subjected to pressure agglomeration [1] or non-pressure agglomeration (pelletization) [2–9]. The preferred solution is to use pelletization due to the lower energy consumption of the process.

In the AGH Department of Mining, Dressing, and Transport Machines, a project of a prototypical installation for coal slurry pelletization (Fig. 1) with a capacity of 50 Mg/h has been undertaken.

The coal slurry pelletization plant consists of the following components:
- coal slurry feeding system (1),
- mixer (2),
- balling plate (3),
- binding additives delivery system (4),
- product output system (5).

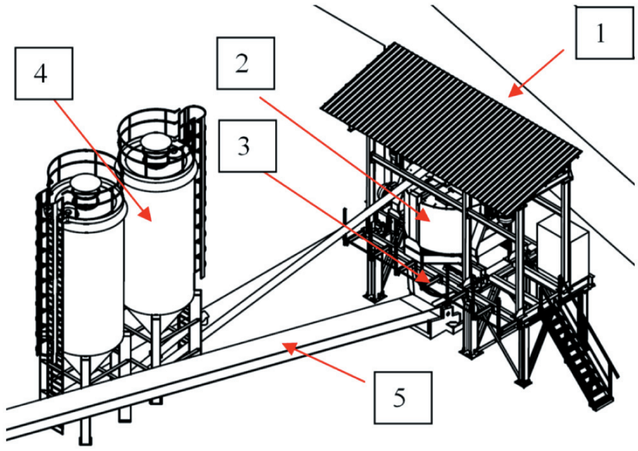

Fig. 1. Coal slurry pelletization station: 1 – coal slurry feeding system; 2 – mixer; 3 – balling plate; 4 – binding additives feeding system; 5 – slurry output conveyor

An essential part of the installation is the mixer (Fig. 2), which is built with a rotating drum with a diameter of 2.7 m and height of 1.6 m, to which coal sludge is fed along with binding agents (limestone). Inside the mixer, two stirrers with independent drives are installed whose task is to grind the sludge, feed in pieces, and mix it with a special substance fed from the silo by a screw conveyor, which ultimately decreases the moisture of the slurry. In the lower part of the mixing drum, a material output opening is situated; this opening is closed by a plate. During operation, the balling plate is tilted and rotates around its own axis. This system helps in emptying the drum and partially causing a pelletization of the material.

After establishing a steady homogenization process through the inclined plate, the material is fed to the balling disc where is pelletized. After leaving the balling disc, the pelletized material is fed onto a conveyor belt, on which the pelletized slurry is transported to a storage yard. The station's design allows us to add other components to the fuel mixtures produced on the basis of coal sludge or dust. Essential for the proper operation of the mixing system is a properly functioning drum-closing system. In principle, this system should tightly close the container; after opening the locking plate, it should incline to a certain angle of up to 30°. The bearing system limits the size of the drum outlet to 730 mm. This limits the size of the diameter of the locking plate. For proper operation, the locking plate should reduce the discharge area of the material (reducing the risk of mud overhangs). The research shows that the height of this space with the assumed diameter should not exceed 200 mm. In the case of the AGH mixer structure, this causes the necessity of placing the closure plate to a depth of at least 125 mm. These requirements led to the need of designing a system that would allow us to lower the plate linearly in the first step inside the drum, and after passing the discharge opening, to incline at a predetermined angle.

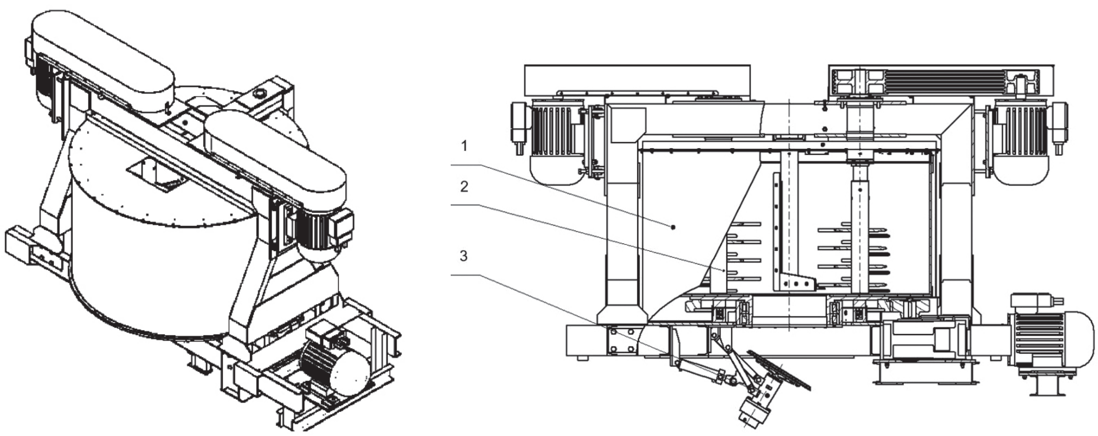

Fig. 2. Coal slurry mixer: 1 – mixer drum; 2 – stirrer arrangement; 3 – drum-closing system

2. DETERMINATION OF ARMS' KINEMATIC PARAMETERS

Knowing the design assumptions (730 mm diameter of the plate, offset from the base of the drum at a min. of 125 mm, a maximum inclination angle of 30°), a four-bar linkage system in which different arm lengths (R, r) that are parallel to each other in the raised position was proposed [10]. The first step was to determine the suitable length of the arms so as to not incur a collision between the plate and the opening in the drum mixer. In the design of the mixer, a clearance of 15 mm between the plate and drum opening was provided, allowing for the free movement of the closing plate.

2.1. The geometrical calculation of the arm lengths

Initially, the length of the arms was selected using the graphical synthesis method for the four-bar linkage performing the transition between three set positions (Fig. 3).

Figure 3 shows the arm structure of the analyzed mechanism in accordance with the initially chosen assumptions. The plate's relative displacement to the hole (point T1) does not exceed the established 15 mm. The analysis shows that the upper arm should have a greater length than the bottom one. A length of 620 mm was chosen for the upper arm, and a 480 mm length was chosen for the lower one.

2.2. Verification of system operation correctness

The proposed four-bar linkage (Fig. 3) allowed us to create a planar model of the closing system that allows us to analyze the kinematics (Fig. 4) [11].

It was assumed that the system would be driven by double-acting hydraulic cylinder, which causes AD element rotation. The starting point to solve the kinematics is given as the following vector equation:

$$\overline{DA}+\overline{AB}+\overline{BC}=\overline{CD} \tag{1}$$

where the vector's length is:

$$R=\overline{BC},\quad r=\overline{AD},\quad l=\overline{AB},\quad d=\overline{CD}$$

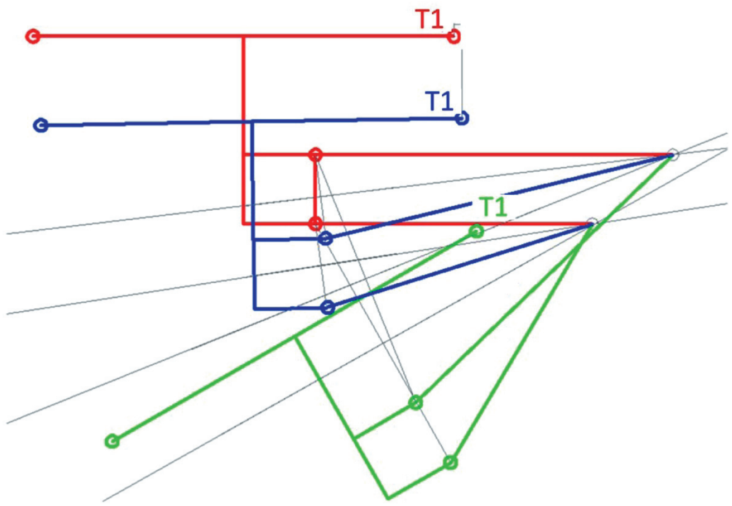

Fig. 3. Four-bar linkage analysis of transition between three set positions: red – drum closed; blue – plate in lower position of drum plane; green – maximum opening and plate inclination

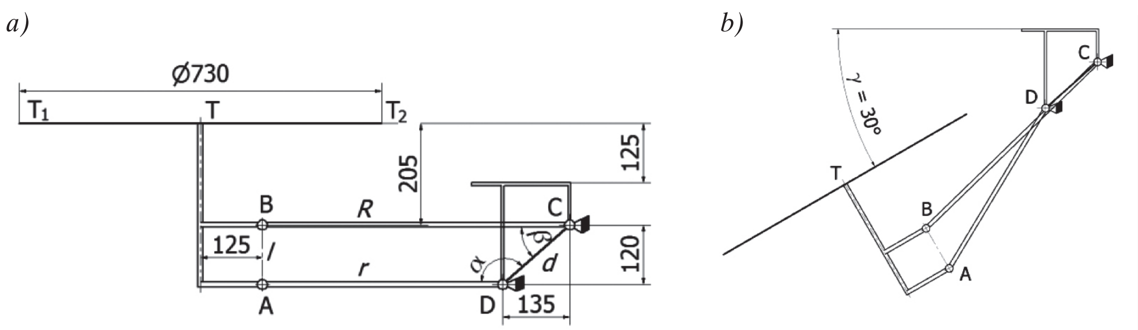

Fig. 4. Planar model of drum-closing system: a) plate in upper position; b) plate in lowered position

Based on which:

$$\overline{DA}=\begin{bmatrix} r\cos\alpha \\ r\sin\alpha \end{bmatrix},\quad \overline{BC}=\begin{bmatrix} R\cos\beta \\ -R\sin\beta \end{bmatrix},\quad \overline{CD}=\begin{bmatrix} d \\ 0 \end{bmatrix}$$

So, the following can be written:

$$\overline{AB}^T\cdot\overline{AB}=l^2 \qquad (2)$$

After expansion:

$$(R\sin\beta-r\sin\alpha)^2+(d-R\cos\beta-r\cos\alpha)^2=l^2 \qquad (3)$$

the assembly will be inclined by section r, so we assume that the angle is known.

In further considerations, the following substitution will be used:

$$p=\operatorname{tg}\frac{1}{2}\beta \qquad (4)$$

Equation (3) after using substitution (4) and known trigonometric relationships takes the following form:

$$\left(R\frac{2p}{p^2+1}-r\sin\alpha\right)^2+ \left(d-R\frac{(1-p^2)}{p^2+1}-r\cos\alpha\right)^2=l^2 \qquad (5)$$

The presented equation has two solutions, from which one that was appropriate to the assumed geometry was chosen (Fig. 4):

$$\beta=\operatorname{arctg}\frac{\sqrt{K}+2Rr\sin\alpha}{R^2+2Rd-2Rr\cos\alpha+d^2-2dr\cos\alpha-l^2+r^2} \qquad (6)$$

where:

$$\begin{aligned} K=&-R^4-d^4-l^4-r^4+2R^2d^2+\\ &+2R^2l^2+2R^2r^2+2d^2l^2-4d^2r^2+\\ &+2l^2r^2-2d^2r^2\cos 2\alpha+\\ &+4dr(-R^2+d^2-l^2+r^2)\cos\alpha \end{aligned} \qquad (7)$$

Knowing the value of the β angle, the position of points A and B and value of angle γ can be obtained, which allows us to determine point T's trajectory. In Figure 5, the exemplary chart is shown of points A, B, T positions with the assumed center of the coordinate system at point C, with the x axis oriented horizontally and y axis vertically.

To avoid a collision between the plate and mixer drum, it is important to provide that, during its 125 mm movement along the y axis, point T2 (Fig. 4) does not move along the x axis further than the predicted clearance. To verify the design assumptions, a chart location of the three characteristic points of the plate (T, T_1, T_2) was made (Fig. 6).

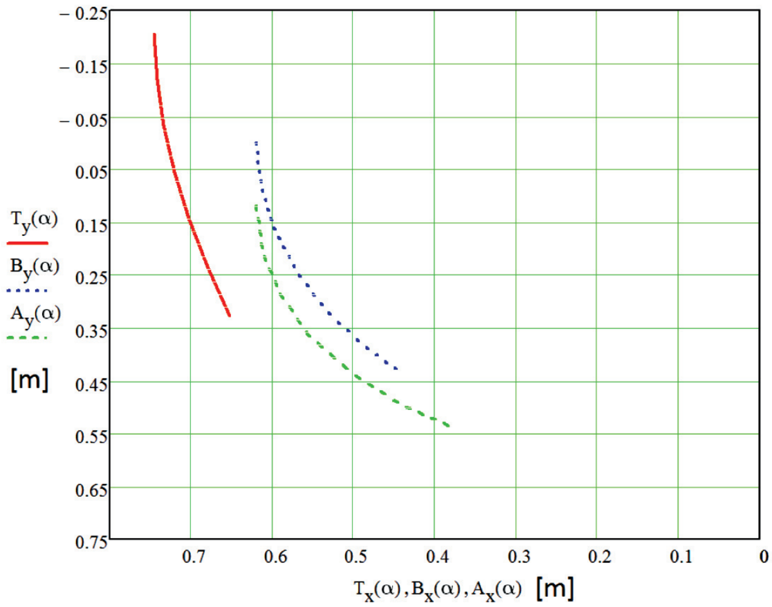

Fig. 5. Exemplary trajectories of points A, B and depending on inclination angle of element AD (α)

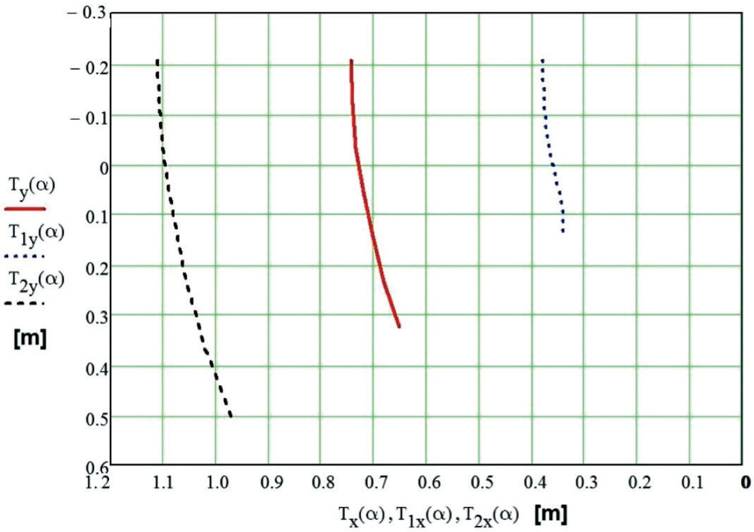

Fig. 6. Trajectories of three characteristic plate points

The position analysis shows that this arrangement meets the kinematic structure expectations. Also, angle α was determined, of which the lower arm should be rotated to achieve the necessary 30° of plate inclination. This angle was determined on 58°. The next stage of the work was to create a model of the clamping unit (Fig. 7) supplemented with the plate drive system.

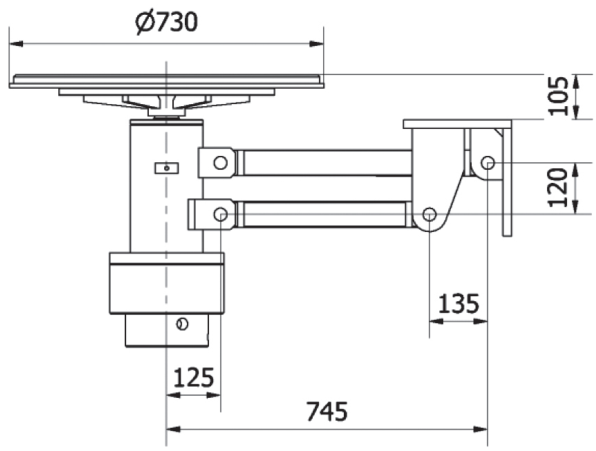

Fig. 7. Drum clamping unit model

For the plate drive, a hydraulic motor with following parameters was selected:
- unit motor absorption: 1000 cm^3/rev,
- nominal pressure: 16 MPa,
- maximum pressure: 25 MPa,
- nominal torque: 2500 Nm,
- maximum rotational speed: 160 rev/min,
- work with the assumed speed in the range of 30–50 rev/min.

2.3. Model verification for assumed design parameters

Essential for the system's proper operation is the appropriate design of the lower arm lift. It was assumed that the hydraulic actuator will be used to drive the lower arm. The earlier-created model of the closing system was complemented by a hydraulic cylinder mounted on an additional holder (Fig. 8).

For such a system, the hydraulic cylinder piston stroke should be at least 220 mm (determined on the basis of a kinematics analysis). On this basis, a hydraulic cylinder with a stroke of 230 mm was chosen.

a) *b)* *c)*

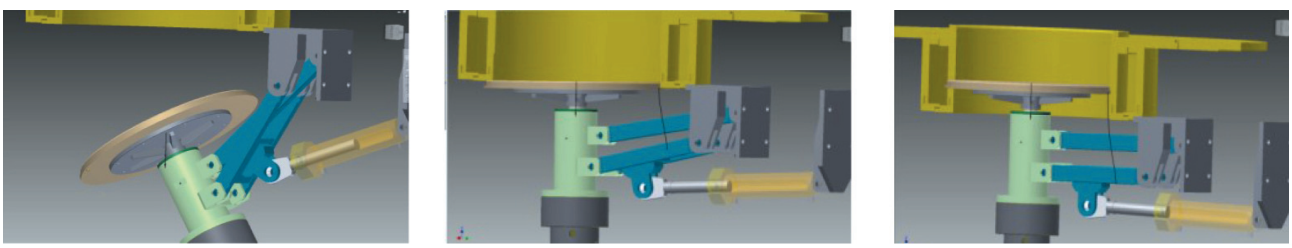

Fig. 8. Drum-closing system model in three stages:
a) open; b) lower plane of drum; c) closed

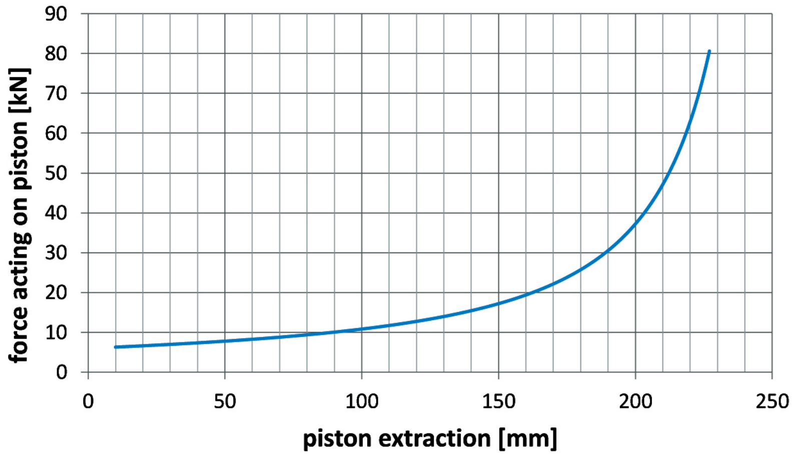

Fig. 9. Value of force acting on piston

In order to determine the remaining parameters of the hydraulic cylinder, the system was subjected to a dynamic analysis. Based on this analysis, the forces acting on the piston of the actuator were determined, assuming the 150 kg maximum of material load on the plate. During the analysis, a constant rate of piston extension was assumed. On the basis of the simulation, the force acting on the piston versus the degree of extraction were plotted (Fig. 9).

The maximum value of the force acting on the piston occurs at the closing of the drum; this amounts to 80 kN. For the designed construction of the plate lifting, a hydraulic cylinder was chosen:

- actuator: hydraulic cylinder ∅80/45 single-sided double-acting piston rod, mounted on spherical joints,
- active circular piston surface area: 50.30 cm^2,
- active ring piston surface area: 34.4 cm^2,
- stroke: 230 mm,
- constant speed ejection rod: approx. 4.9 c/s,
- adjustable rod insertion speed: max. approx. 7.1 cm/s,
- maximum thrust: approx. 80 kN (for $p = 16$ MPa),
- required push force during rod ejection: 70 kN (for $p = 13.9$ MPa),
- maximum pulling force: approx. 55 kN (for $p = 16$ MPa),
- required plate-lowering force during rod insertion: 25 kN ($p \approx 5.0$ MPa).

3. FIELD TESTS OF THE CLOSING SYSTEM

On the basis of the prepared documentation, a prototypical device of the coal sludge pelletization system with the proposed closure of the tank was constructed. The first stage of the device's field tests was the plate movement validation. Pictures from the tests are shown in Figure 10.

During the opening and closing of the drum, there were no collisions between the plate and drum (Fig. 10b). Tests have shown that the length of the arms and their mounting points were chosen correctly. The actuator worked properly and without exceeding its technical parameters.

4. OPERATING NOTES

The proper work of the rotational plate is conditioned by ensuring adequate lubrication. During the assembly, all bolt and joint mating surfaces must be covered with graphite grease. In Figure 11, the lubrication points are shown. Table 1 shows the location and method of lubrication, type of lubricant, and lubrication timing.

a) *b)* *c)*

Fig. 10. Mixer closing system: a) in closed position; b) in middle position; c) in open position

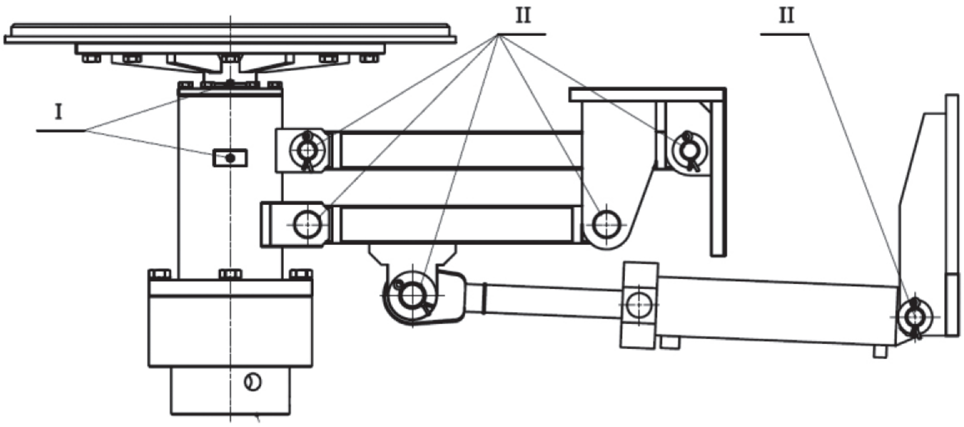

Fig. 11. Location of lubrication points in rotational plate assembly

Table 1

Location and method of rotational plate assembly lubrication

Lubrication point number	Lubricated part	Lubrication method	Lubrication timing
I	shaft bearings	lubricator	once every 3 months
II	bolts	by drops	once every 3 months

5. SUMMARY

The performed basic model research and its analysis as well as the designed and created tank closing system fully met the assigned task during the mixer field tests. The proposed system allows for the precise regulation of the outlet slot, which makes it possible to achieve a material output with specific granulation. The proposed system allows us to precisely determine the balling performance. The use of bolt joints as connections (without using elastic elements) allowed us to obtain higher durability. In the late lifting and tilting device, a single cylinder was used, which greatly simplifies the control and regulation of the technological parameters of the mixer. During the operation of the device over an entire year, it has produced 70,000 Mg of the product. This product has met customer expectations, and the device has not posed any serious operational problems.

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