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THE CONTROL METHOD CONCEPT OF THE BULK MATERIAL BEHAVIOR IN THE PELLETIZING DRUM FOR IMPROVING THE RESULTS OF DEM-MODELING

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ABSTRACT

One of the problems of the use of drum pelletizers in metallurgy is the lining wear, as well as the economic costs associated with it, including increased energy costs during operation and the need to periodically stop the units and then replace the lining.
Most significantly the trajectory of particle motion affects the lining wear profile and wear intensity. It is assumed that during the implementation of the technological process, a monodisperse occurs, which has the greatest effect on the wear profile. In addition, the lining wear is influenced by the impact of particles at an acute angle, with a maximum impact caused by a collision at an angle of 39°18′.
At present there are no universal solutions for determining the degree of lining wear in real time with a corresponding adjustment of the pelletizing process parameters. Creating a system for monitoring the lining wear is necessary for timely repair and maintenance of equipment to prevent an emergency situation, as well as increase the service life of the aggregates.
This article proposes a concept of a method that allows to evaluate the trajectory of the charge during the technological process according to the coordinates of the movement and acceleration of the probe in the unit during the implementation of the technological process.
The digitization and analysis of data obtained from the probe will allow to assess the integrity of the lining surface, the degree of lining wear and places with increased wear rate in real time with the possibility of adjusting technological processes to increase the lining service life.
The obtained data will allow to clarify the computer model of the process by assessing the behavior of the charge in the unit and create a reserve for the further implementation of digital twin equipment.

Introduction

Pelletizers are traditionally used in processes where it is necessary to minimize the loss of fine particles and at the same time effectively average the mixture by composition [1]. As an example, it is the furnace charge pelletizing as a preliminary stage of sintering in the process of cast iron production [2]. At present, the use of drum-type units is characterized by increased energy consumption [3]. The importance of reducing energy losses is evidenced by the fact that the specific energy consumption for the grinding process of the charge in ball mills is 14–21.7 kW·h/t. At the same time, the additional costs due to the lining wear range from 0.007 kg for each kW·h of electricity used for grinding [4].

To minimize abrasive lining wear, the direction of combining various materials, such as steel and rubber, is possible [5]. This approach allows to maximize the benefits of both one and the other materials - elasticity of rubber, as well as its ability to dampen shocks, and wear resistance of steel [6]. Meanwhile, this solution does not completely solve the existing problem of wear, which requires the use of additional methods to minimize it, including the specification of the mathematical models parameters of the bulk materials behavior in these units, the use of methods for monitoring the state of the lining in situ and other.

Agenda

Based on the analysis of lining mills and pelletizers industrial scale, it was concluded that the lining wear profile for any type of implementation (“Plita-Volna”, “Plita-Liftyor-Volna”, etc.). According to the data given in [7], the phenomenon of wave wear is explained by the appearance of a structural formation characterized by increased pressure — a monodispersoid and its trajectory. This structural formation is one of the main factors of the rubber lining destruction, because it is characterized by increased pressure on it and has surface heterogeneity due to the heterogeneity of the particle size distribution of the incoming mixture. Various types of the rubber lining loading are observed in the contact zone: impact, indentation and abrasive-fatigue wear, which are greatly intensified with increasing speed of the unit rotation and other types of influence on the particle trajectory.

According to the data presented in [8], a significant part of the load moves only by touching the surface of the lining at angles of attack close to 0 degrees, while frequent sliding occurs. At angles of attack close to 90 degrees, the abrasive particles, hitting the surface, deform the lining material, penetrating into it. It is believed that the maximum amount of wear on the lining surface is observed at an angle of attack of 39°18′. The above can be leveled at the design stage as well as in real time at the expense of automation tools when affecting the particle trajectory due to the parameters of the drum pelletizer.

The lining wear degree often affects the volume of the unit and its ore filling [9]. At the same time, the actual degree of wear at the current time in real-time mode can only be determined indirectly, by the spectral and moment characteristics of the energy signals, including the power consumption signal [10, 11]. Meanwhile, these solutions can only partly allow to estimate the lining wear degree, and the results will be generalized relative to the volume of the unit, which will make it difficult to determine the wear location. Thus, the only possible reliable method of monitoring the lining condition on the equipment is its stop and further visual assessment of the wear degree.

At present there is no unique solution for determining the degree of the lining wear the drum pelletizers in real time with the possibility of adjusting the parameters of the work in the process of pelletizing. Based on the above theoretical information, we can conclude that the technological process parameters such as the speed and trajectory of the particles in the unit have a significant effect on the lining wear. Accordingly, for correct and effective process control, it is required either to extract these parameters in real time at the facility, or to gain knowledge of these parameters, resorting to various methods of process modeling [12–15].

Proposed solutions

Using DEM-modeling to evaluate the behavior of the charge in drum-type equipment

At present, DEM-modeling has been widely used both to determine the charge trajectory in drum-type equipment and to further adjust the process parameters, and to determine places with the highest wear rate for the implementation of additional preventive measures [16, 17].

To model typical units, various approaches to the selection of modeling parameters are possible, which may include both the use of typical values and adjusting the results of DEM-modeling by varying the parameters of bulk materials to the result of physical modeling on a laboratory scale model [18].

Meanwhile, significant errors are possible when transferring the results of DEM-modeling to industrial-scale aggregates. This causes difficulties in determining the parameters of bulk materials [19–21]. Currently, there are no methods for the DEM parameters determining, which allow to obtain values with sufficient accuracy, which is associated both with a significant human factor influence on measurement error and the lack of standardized methods for determining a specific parameter without the additional influence of other unaccounted physical quantities [22].

Improving the accuracy of the data obtained in mathematical modeling is possible when determining the parameters of the bulk materials movement in the considered unit in real time, which can be done using the device and method, the concept of which is presented below.

The device concept for monitoring the lining wear degree of drum pelletizers

To implement the monitoring of the metallurgical units lining, it is proposed to develop a special device, which is a probe in a shock-resistant housing that protects the electronic components of the device from the destructive impact of bulk material and equipment elements. Moving along with the material in the housing of the unit, the probe will repeat the trajectory of its movement, which will allow analyzing the behavior of the material throughout the process.

The location of the probe at each time point will be carried out by inertial navigation. For this purpose, the probe is supposed to be equipped with accelerometers and gyroscopes based on microelectromechanical systems (MEMS). The data collection from the sensors (accelerations and angles) will be carried out by the microcontroller, and then transmitted via a wireless communication channel. In order to ensure the longest battery life of the device, it is supposed to use microcontrollers that support ultra-low power consumption modes such as TI MSP430 or ATMEL PicoPower. However, the probe will need to periodically recharge the battery, which should be carried out in the intervals between the extraction of the probe from the material and re-loading into the unit.

The data transmitted by the probe to the computer will be a set of accelerations and angles obtained from the sensors; according to this data, a specially developed algorithm will reproduce the trajectory of the probe, and accordingly the material, in the device. According to the data obtained from accelerometers, it is possible to determine not only the trajectories, but also the speed of the material movement at different stages of the technological process.

To obtain a clearer picture of the processes occurring in the apparatus, it is proposed to immerse in the apparatus a group of several such capsules (tens or hundreds of pieces, depending on the size of the apparatus). Moving inside the technological device along with the material, the group of probes will be able to accurately recreate its movements in detail, thus providing information previously inaccessible to engineers.

The trajectories obtained using the proposed device are also of particular interest for research. As the trajectory of the material in drum devices largely depends on such important technological parameters as the particle size distribution of the material, the condition of the unit's lining and the execution option of the unit, the accumulation of statistical information about the nature of material movements in the device and their subsequent analysis should play an important role in technological control process and in the design of new equipment. Different kinds of deviations in the paths of movement of the material may indicate the lining wear degree or deviations from the established mode of operation. The use of such a method of monitoring the technological process in drum units, in theory, will minimize the lining wear degree by varying the process parameters to reduce the

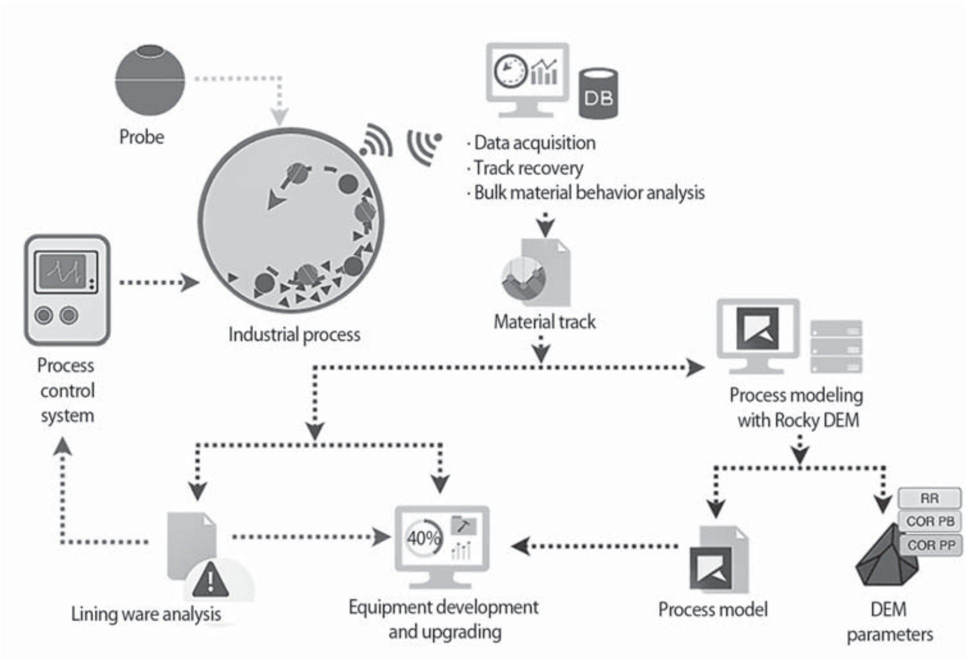

Fig. 1. The concept of using probes in the technological process

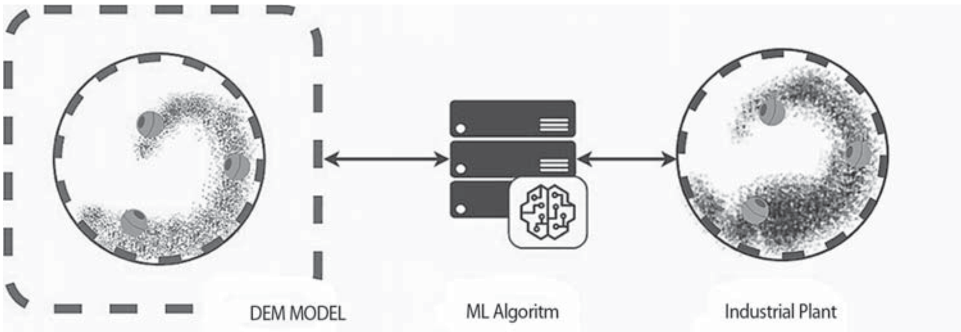

Fig. 2. Modeling the process of pelletizing based on data obtained using probes

load on areas of wear intensification, as well as to carry out timely replacement of the lining (**Fig. 1**).

In the future, equipping metallurgical facility with measuring systems based on probes will allow comprehensive monitoring of the technological unit's state and processes in general. A subsequent assessment of the changes dynamics in the observed parameters will make it possible to identify the likely patterns between changes in the behavior of the material and the technical condition of the equipment. The study of these patterns can make a significant contribution to understanding the nature of the processes occurring in pelletizers and equipment with a similar principle of operation.

The application of the proposed probes in industry is possible not only for the purpose of monitoring and controlling technological equipment, but also for extrapolating its future states by creating a digital twin [23]. This approach involves the creation of digital models of each specific technological device updated and supplemented with data obtained from the probes described above (**Fig. 2**). The digital model, existing and "functioning" in parallel with the actual installation and continuously supplemented by new data, will allow to predict and evaluate possible equipment failures in the future under various operating conditions.

Of particular interest is the use of digital twins based on the proposed probes for the developers of the mill equipment. It is assumed that the developer will complete the installation of probes, which, in turn, will transmit data for the digital twin via the Internet. Development companies can upgrade the equipment based on actual experience, receiving and accumulating information about the nature of the processes occurring in the equipment, and in some cases, this information may cause refusal of warranty repair or maintenance in case of violation of the recommended operating conditions.

Obtaining trajectories opens up additional possibilities for numerical modeling of technological objects. So, the trajectories of the material can be very useful when calibrating DEM-models [19–21].

Conclusion

Using the device, the concept of which is presented in this article, will solve a number of existing problems, including determining the furnace charge behavior and the state of the lining in real time without the need to stop the unit. Changes in the trajectory of the device will also allow to determine both places with increased wear and stagnant zones.

At the moment, there is no uniform methodology that allows to unambiguously determine the physico-mechanical parameters of the bulk material with sufficient accuracy and without significant human labor costs. The trajectories of the bulk material, in turn, may contain certain dependencies that will uniquely determine the rheological properties of a specific bulk material. The creation of a new method, which will be based on the application of this device, will be distinguished by low human labor costs (in the future — fully automatic), the possibility of using it in almost all processes of the mining and metallurgical industry and relatively low.

The data obtained from the device will improve the accuracy of the used DEM-models, which will significantly affect their correctness according to predictability of emergency situations. The combination of the above will allow to optimize the parameters of the equipment during the design and further its using, as well as to modernize the existing technological processes in order to increase equipment service life.

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