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Vibrating device for the collapse of bulk materials in the hoppers of the sintering shop

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It was established as a result of the analysis of the operability of bunkers for temporary storage and dosage of bulk materials in the dosage site of the sintering shop, that an arching effect in the process of their long-term operation appears; this effect concludes in sticking of materials above the hopper outlet, which are temporarily or permanently preventing material flow. For normal operation of dosing devices, it is necessary to ensure the continuous flow of material from the bins, since the main purpose of the dosage is to ensure continuous material flow from hoppers, because production of sinter with established quality and constant physicochemical properties is the main aim of dosing. To eliminate hangings in hoppers along their walls, manual labor is used, which poses a high danger to human health, due to high dustiness and high trauma hazard of the work performed. In order to eliminate the problem of arching and sticking, it is proposed to apply a vibrating method for influencing on charge materials, namely installation of a vibrating device of the "false wall" type. This device is a vibration exciter (vibrator), rigidly fixed on a vibrating panel via support element. A vibrating shield (false wall) is a steel plate that makes oscillating motions. There is a rubber damper between vibrating shield and hopper wall, designed to protect both these components against wear. The main advantages of using a vibrating device of the "false wall" type are small capital costs for reengineering, simplicity of installation and suitability for use in a sintering shop. Introduction of the designed device ensures improvement of manufactured sinter quality by improving flowability of materials in the dosage site of the sintering shop and a more accurate dosage, as well as rejection of operations associated with cleaning of hoppers, which are hazardous for human health. The economic calculation confirms the feasibility of the conducting measures for reengineering of hoppers in the conditions of a sintering shop.
Key words: sintering production, dosage of charge materials, hopper, arching of bulk material, vibrator, false wall.
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Introduction

Recently reliability of technical systems acquires the most importance and becomes one of the main problems for metallurgical machines and equipment [1–4]. Insufficient reliability of technological machines and their components leads to significant rise of expenses for their technical maintenance and essential decrease of metallurgical productivity. More strict requirements to the quality of technological machines and equipment are aimed on lowering of material, labour and financial expenses for technical maintenance and repair and leads to necessity of their modernization and reconstruction [5–9]. Large attention is paid in this case to reengineering of the equipment for mining and metallurgical production [10–13].

The paper considers the problems of reengineering of hoppers for temporary storage and dosage of bulk materials in the dosage site of the sintering shop in order to provide continuity of materials flow via mounting of vibrating device of "false wall" type.

Goal setting

Charge materials (such as iron ore, iron ore concentrate, blast furnace dust, screening dust of sinter and pellets, limestone etc.), which are entering a sintering shop in open-box cars, are unloaded with use of car tipplers and then are forwarded to accumulating storehouse, hoppers of a dosage site and limestone storehouse via the system of belt conveyors. Then raw materials from accumulating storehouse are taken by grab cranes with lifting capacity 20 t and loaded in one of 8 stationary hoppers, which are located on conveyors; afterwards raw materials are transported to a dosage site for charge materials using the conveyors system. The components of sintering mix are transferred directly in hoppers, where they are accumulating until unloading time.

The dosage site consists of 36 hoppers, which are located in two parallel rows. Both of them are identical and repeat each other meaning destination of hoppers. Each row includes 18 hoppers for dosing of bulk materials, presented in the **Fig. 1**: B-01 – B-04 (limestone), B-05 and B-06 (return of sinter), B-07 – B-012 (ore materials), B-13 and B-14 (slag, dust), B-15 – B-18 (coke). Obtaining of sintering mix with preset composition and with constant physicochemical properties is the aim of dosing.

Dosing hoppers, which are intended for dosing and charging of bulk materials (granules, flour), with possible dosing by volume or mass applying to a place of further processing, are used in charge materials area of a dosage

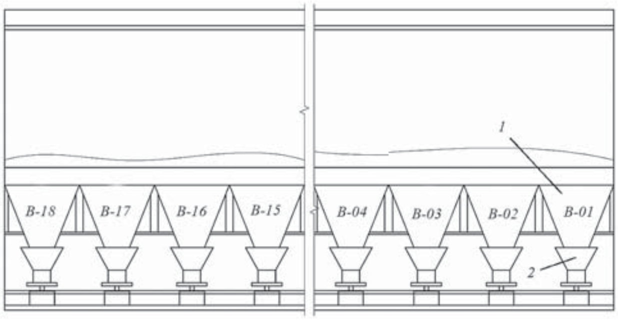

Fig. 1. Layout of the hoppers of the bulk materials dosing site: *1* – hoppers; *2* – funnels

site. Rectangular-shape hoppers with a pyramid bottom are used, they are located vertically. Such hoppers are also called as "silo". The hoppers of a dosage site are metallic, usually made of St3 steel with thickness 20–25 mm. Maximal volume of hoppers, which are used in a dosage site, makes V_H = 150 t.

The hoppers of charge materials area of a dosage site in the sintering shop participate directly in manufacturing of fluxed sinter, which is a raw material for iron making in a blast furnace [14, 15]. Thereby, continuous sinter production is required for continuous iron making, respectively continuous dosing of sinter mix components is also required. Based on this, the hoppers of charge materials area of a dosage site in the sintering shop of "Ural Steel" JSC are operating day and night.

It is shown that the charge materials area of a dosage site in the sintering shop uses hoppers for temporary storage and dosage of bulk materials, such as iron ore concentrates, iron ore, slimes, scale, fluxes etc. Normal operation of hoppers is considered as the base for continuous production. A hopper is a metallic tank with charge and discharge holes; it is intended for accumulation, storage and transfer of different bulk materials and loads to transportation remedies for their consequent processing.

Durable operation of a hopper causes origination of an arching effect, which means a kind of bulk material hanging in the area of a hopper outlet, when material is sticking, impeding temporarily of permanently to material flow, appear in funnels above a hopper hole. This property is typical for all minds of bulk loads [16–18]. Arch forming occurs as a result of friction between moving load particles and particles being in the state of rest, with their consequent sticking. The main negative consequence of arching is violation of normal operation mode of dosing. Providing continuous metal flow out of hoppers is the required condition for normal operation of dosing devices, because the main aim of dosing is ensuring of sinter production with required quality and constant physicochemical properties.

Another cause of violation of normal operation mode is forming of inert areas, when discharge of bulk material occurs only from the area located above a discharge hole; it decreases principally the useful volume of a hopper. This process is called "tube-forming". Appearing of "tube-forming" in a hopper cavity is accompanied by forming of a cylinder channel from hopper inlet to its outlet. "Tube-forming" appearance presents the worse variant of forming of arch structures, because not only the useful volume of hopper cavity decreases, but also complete sticking of bulk material in a hopper cavity takes place, what will finalize in discharge termination.

The most part of hopper units, which are operating and designing at present time, are working only for gravitation discharge of bulk material under gravity forces. When discharging and temporary storage of dry and well-bulk materials, such method does not violate normal mode of operation and takes place without material sticking. During storage of sticking, sopping and caked materials we can observe violation of normal mode of operation and forming of arches on inclined walls, outlet holes as well as sticking processes. It can lead to complete or partial termination of discharge. Usually raw materials are stored in open storehouses at metallurgical works, what finalizes in soaking of bulk materials. Material hangings occur with time interval about one hour. To eliminate hangings in hoppers along their walls, in the points of critical arching (theoretically it is about 1/3–1/4 of height of inclined hopper wall), a worker uses a heavy hammer for striking. This process takes 3–10 min. This operation is usually executed by one dosing worker in charge material area. Based on the above-mentioned description, it can be concluded, that regular mode of operation of vertical hoppers does not correspond to the normal mode of operation, and it is necessary to provide designing and putting into practice of vibrating device for collapsing of bulk materials, which are liable to hanging.

Analysis of different methods for solving these problems was carried out in order to eliminate the arching and sticking problems. As a result, it is proposed to use vibrating method of the effect on charge materials, which has proved its efficiency in different technological processes [19–22]. For our case, the decision to mount a square vibrator on a hopper wall was taken.

Conducted researches

To provide reengineering hoppers, rather simple and efficient variant – vibration arch breaking machine of the "false wall" type – was chosen [23-26]. This device has no complicated structural elements, what provides its high reliability and maintenance simplicity. Correct vibrator location (about 1/3–1/4 of height between hopper and hopper outlet) is very important for effective operation. The scheme of this device is presented in the **Fig. 2**.

This device includes vibration exciter (vibrator) *6*, rigidly fixed on a vibrating panel *2* via support element *5*. A vibrating shield (false wall) is a steel plate that makes oscillating motions. There is a rubber damper *5* between vibrating shield *2* and hopper wall *1*, designed to protect both these components against wear. Welded chain or cable *3*, which supports the whole structure in preset position, is used for fixing of a vibrating shield.

The arch-destructing effect of such device is provided as a result of transferring oscillating motions not on whole hopper wall (as in the case of using the device "vibrating hopper"), but on separate volumes of bulk material. This method

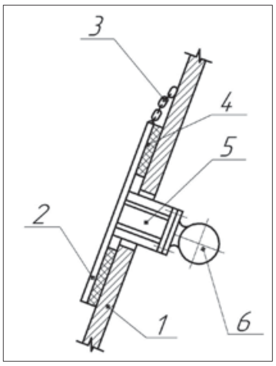

Fig. 2. Scheme of the vibrating device of the "false wall" type: *1* – bunker wall; *2* – vibration shield (false wall); *3* – chain (cable); *4* – damper; *5* – vibrator support; *6* – vibrator.

of vibrating intensification of material flow is high-efficient and allows to obtain substantial arch-breaking effect. Such effect is sufficient for continuous uninterrupted material flow out of a hopper, such as bulk materials (limestone, pellets) and powder material.

Use of a vibration unit of the "false wall" type is characterized by such main advantages as low capital expenses for reengineering, mounting simplicity and suitability for application in the conditions of a sintering shop. It also allows to reject from the human-dangerous operations and to work with the whole useful hopper volume.

Vibrator is a debalanced centrifugal mechanism, with its impact force caused by rotating motion of an inertial element. It is an electric drive with disbalances mounted on the ends of rotor shaft, which create centrifugal (impact) force during rotation. Tuning of the value of vibrator impact force is realized via varying of mutual location of disbalances on both shaft ends. Circular vibrator oscillations are transferred to the structure where it is mounted.

Selection of a suitable vibrator occurs by the value of the required impact force. To discharge a hopper, it is recommended to use vibrators with frequency 3,000 min^{-1} (IV-01-50, IV-05-50, IV-11-50, IV-20-50, IV-40-50, IV-60-50). In this case the impact force $F_{вс}$ should make about 1/5 of material mass in a hopper cross section [27, 28]. In our research

$$F_{if} = \frac{m_{ach}}{5} = \frac{150}{5} = 30 \text{ kN},$$

where m_{ach} = 150 t – maximal mass of charge material in a hopper.

Based on the calculated value of the impact force F_{if} = 30 kN, we select from the catalogue a square vibrator of general use and high resource, of the type IV-105-2.2, which has the following technical parameters:

Synchronous frequency of oscillations, min^{-1}	3,000
Maximal impact force for synchronous frequency of oscillations, кN	40
Nominal consumption power, kWt (not more)	2.2
Nominal voltage, V	380
Current frequency, Hz	50
Vibrator mass, kg	77.5
Mean operating resource until reject, h (not less)	500

Debalanced regulated type of vibrating mechanism and asynchronous three-phase electric motor with short-circuit rotor were used in this vibrator.

According to the recommendations of the GOST R 52776-2007 (MEK 60034-1–2004), we accept the typical operating conditions S3 60 % – intermittent periodic duty [29]. This procedure constitutes a sequence of operating cycles, each of them includes operating time for constant load and dwell time. For this procedure, the operating cycle is characterized by no essential effect of starting current on temperature excess. To provide normal arch breaking, it is sufficient to switch on vibrator for a short time during the process of bulk material discharge out of the hopper.

Obtained results

General view of the hopper in the dosage site of the sintering shop after reengineering is presented in the **Fig. 3**. Choice of vibrator fixing height was realized in correspondence with recommendations, it should make 0.25–0.33 of the hopper conic part length [24, 25]. Welded frame from rolled components (such as E-channels and angles) is usually used for vibrator fixing. The vibrator with large impact force is used in the charging site of the sintering shop, thereby welded structure can be failed in use quickly owing to destruction of welded seams in the conditions of strong vibration during operation. Based on the above-mentioned conclusion, a cast cross-shape frame made of 30GSL steel was chosen as a frame element for vibrator [30, 31] and was fixed at vibrating shield using electric arc welding. To provide more reliable vibrator golding on the hopper, it was additionally fixed at the wall using steel rope of the type 1×37(1+6+12+18); this rope is made of galvanized wire and is characterized by long service life in aggressive media [32],

To transfer vibrating oscillations directly to bulk material, vibrating shield is used; it is suitable for operation in hoppers of charge material area in the dosage site of the sintering shop. Taking into account the size of a hopper wall, where vibrating shield is fixed, steel plate of trapezoid shape, with thickness 15 mm, sizes of bases 1,600 and 3,000 mm as well

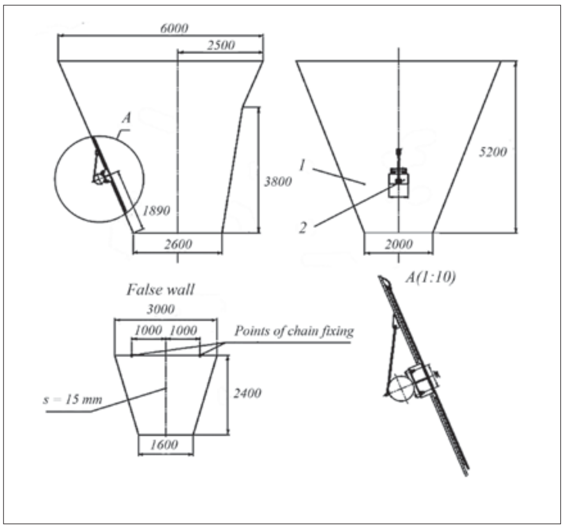

Fig. 3. General view of the hopper of the dosing site in the sintering shop after reengineering: *1* – bunker; *2* – vibrating device

height 2,400 mm, was chosen (see Fig. 3). This plate was manufactured of hot-rolled sheet of St3ps steel [33]. A rubber damper is used for protection of contacting areas of vibrating shield and hopper walls from friction. Rubber-fabric transportation band with thickness 30 mm can be used as a damper. Vibrating shield is connected with a hopper wall by welded chains, which are characterized by hardened round links with increased strength (T8 class), with size 13×39 mm [34], which is widely used as pulling or hanging remedies.

Advantage of a false wall is concluded in direct transfer of vibrations and oscillations to charge material, not to hopper walls, what leads to lowering of the required impact power of vibrator. Use of a false wall can provide significant saving of expenses for electric power consumption and financial expenses for vibrator buying.

Additional capital expenses, which are required for reengineering of hoppers, contain buying of vibrators, manufacture and mounting of false walls and cast frames. Total capital expenses for buying of equipment, auxiliaries, logistics and mounting cost of new equipment for 36 hoppers in a dosage site does not exceed 3 mln. rubles; the payback period of this investing project is less than 1 month.

Conclusion

Possibility of reengineering of hoppers for storage and dosage of charge materials in sinter production, including designing of vibrating device for collapsing of bulk materials, is considered. Technical solutions for designing and putting into practice vibrating devices are determined, corresponding machines and mechanisms are calculated and designed, economic efficiency and payback of the suggested investing project are assessed. Putting the designed device into operation provides quality improvement of manufactured sinter owing to better flowability of materials in a dosage site of sinter mix and more precise dosage, as well as rejecting from the human dangerous operations connected with cleaning of hoppers. Economic calculation confirms expedience of the conducted measures aimed on reengineering of hoppers in the conditions of a sinter shop at metallurgical works.

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