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EQUIPMENT AND TECHNOLOGIES OF SAFE GRINDING OF FERROALLOYS OF ELECTRODE PRODUCTION

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The preferred types of equipment are considered to provide safe grinding of ferromaterials used in electrode production. The design features of the equipment, their advantages and disadvantages are described. 6 Ref., 8 Figures.

Keywords: *electrode production, ferromaterials, fire and explosion safe grinding, slotted mill, vibration mill, paddle-type grinder, vibroinertial grinder*

When choosing grinding equipment intended for fire and explosion safe grinding of ferroalloys, the preference is given to installations that:

- are characterized by low specific energy consumption for grinding and, consequently, insignificant heating of material during grinding;
- have small sizes of grinding chamber;
- provide a quick withdrawal of the grinded material outside the grinding chamber, preventing its heating, overgrinding and minimizing the change in the energy state of the surface layer of its particles;
- allow not only isolating working space of the grinding chamber from the surrounding atmosphere, but also its connections with loading-unloading units, as well as in the zone of extraction of target fractions.

The experience of electrode-manufacturing enterprises showed that these requirements are met to the greatest extent by:

- modernized slotted ball mill of drum type with peripheral screening of the Institute «Giprometiz»;
- two-chamber rod-type vibration mill of a tube type of the model PALLA-U (KHD HUMBOLDT WEDAG Company);
- conical vibroinertial grinder of the «Mechanobr» Institute (model KID 300);
- vertical paddle-type grinder Pluristadio GR 80 (GUSSEO Company).

Let us consider the design features of the listed grinders, including providing the required degree of fire and explosion safety of the grinding process.

Slotted mill of Giprometiz. In the traditional technology of grinding ferroalloys in shielding gas, a conventional slotted mill with a drum of 700 mm diameter of Giprometiz was used, which was placed in a sealed chamber with a volume of 25.5 m^3. Such an installation has the following disadvantages:

- low efficiency, which is predetermined by the duration of preparatory operations, including also switching the installation to a safe mode of operation;
- complexity of maintenance;
- large volume of the sealed chamber;
- high dustiness of the working space and accumulation of deposits of toxic, pyrophoric and explosive dust in the chamber in the amount exceeding 20 kg per day; when this dust is swept up during cleaning, it can exceed MAC and the lower flammability concentration limit (LFCL).

Based on the results of mathematical modeling and production experiments performed on one of the operating grinding installations of this type, the authors of works [1, 2] modernized the schemes and modes of shielding gas supply, as well as the aspiration system, which provide fire-explosion-safe oxygen concentrations in the active zone (8 %) and the acceptable dust level of aspirated air.

The scheme of the modernized installation is shown in Figure 1.

According to this scheme, there is no need in a special chamber, a standard casing with five inert gas (IG)-nitrogen supplies is enough: into the drum cavity (pointlike supply through the collet through the pipe of 10 mm diameter), into the upper and hopper parts of the casing and also into the over and under sieve area of the shelter of the vibrating screen and the Kibble for the finished powder (by a perforated pipe providing a uniform spatial distribution of IG).

Aspiration shelters are mounted on the end walls of the mill casing. They communicate with the cavi-

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[*] Retrospective review of publications in small editions and sources of non-welding profile.

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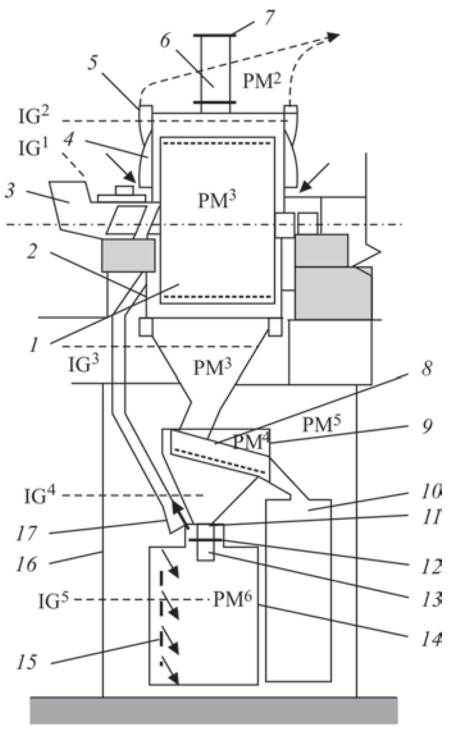

Figure 1. Scheme of installation for fire and explosion safe grinding of ferroalloys on the basis of slotted mill Giprometiz [2]: *1* — mill drum; *2* — mill casing; *3* — supplier; *4* — aspiration shelter; *5* — aspiration branch-pipe; *6* — pipeline for pressure diffusion; *7* — membrane; *8*, *9* — vibrating screen with aspiration shelter; *10* — capacity for over-lattice product; *11* — slotted adjustable diaphragm; *12–14* — slotted adjustable diaphragm, loading branch-pipe and Kibble of the finished product; *15* — device, distributing inert gas in the Kibble; *16* — general chamber of the vibrating screen and the receiving Kibble; *17* — branch-pipe and funnel of the ejection device; IG and PM points for inert gas supply and pressure measurements

ties of the drum and the casing only through leakages in the places of passage of collets, they are open from the bottom and taper up. The air drawn in from the room through the lower openings, washing the collets, entrains dust emissions from the mill at the places of indicated leakages, almost without violating the composition of shielding gas inside the mill casing and the drum and keeping the concentration of suspended particles in the suction pumps at a sufficiently low level. The increasing rate of aspirated air in the narrowing section of external chambers prevents deposition of particles from the stream and their accumulation on the collets surface.

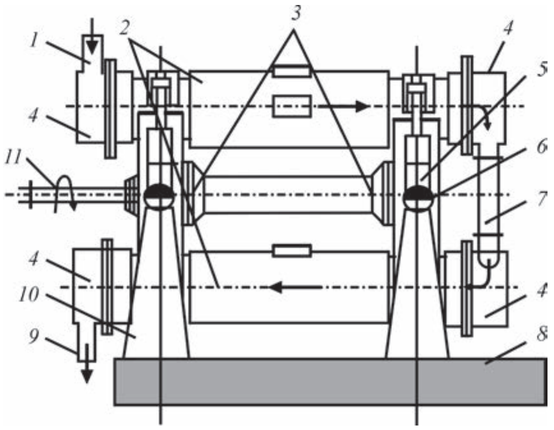

Figure 2. Scheme of vibration mill PALLA-U of the Company KHD HUMBOLDT WEDAG; *1* — loading branch-pipe; *2* — tube mill chambers; *3* — units of unbalanced vibrating exciters; *4* — replaceable end bottoms of mill chambers; *5* — tube bundles; *6* — shock absorbers; *7* — transfer sleeve; *8* — vibration-insulated foundation; *9* — outlet fitting-pipe; *10* — fixed frame; *11* — driven shaft

Aspiration of the loading unit of the Kibble localizes the possible dust emissions here, as well as in the powder classification zone on the vibrating screen.

The selected optimal supplying modes and the ratios of the specific flow rates of nitrogen supplied to the mill cavity and to the cavity between the drum and the casing, aerodynamically connected with the vibrating screen and the Kibble, provide a reliable prevention of inflammations and explosions.

The concentration of dust in the workplace decreased to the level of total background dustiness in the workshop space.

The duration of purging the cavities with nitrogen before starting the mill was reduced from 2.0–2.25 h (designing variant for placing the grinding installation in the sealed chamber with a volume of 25.5 m^3) to 15 min.

Vibration mill of the model PALLA-U is shown in Figure 2.

The installation consists of a movable (grinding) and a fixed part. A fixed part in the form of a rigid metal frame *10* is mounted on a vibration-insulated foundation *8*. A movable part consists of two horizontal, tube grinding chambers *5* located one above the other, reliably connected to each other by means of steel coupling bands. The vibration-excitation units *3* are located in the gap between the mill chambers, strictly vertically equidistant from them. Each of the units represents a short unbalanced shaft on rolling bearings, and they being located in a protective tube, are interconnected by means of an intermediate shaft with cross-bars. Through the driveshaft *11* they are driven by an asynchronous electric motor mounted on a console-mounted platform located on the front-facial side of the installation. A movable part of the installation rests on a fixed frame through elastic elements-shock absorbers *6*. The general view of the mill is shown in Figure 3 [2–4].

At the outlet of the chamber, an end grating of high-strength steel is installed, which as to the sizes and a number of holes is designed for the maximum passage of the finished product.

This allows producing it without a risk of overgrinding, without classification on screening. Depending on the grinded material, 55–65 vol.% of the cavity of each milling chamber is filled with cylinders, which additionally guarantees the prevention of overgrinding.

At a continuous supply of material into the chamber, the friction arising from vibration on the surface of horizontal grinding cylinders allows not only grinding, but also moving the material in the space between them along a spiral path to the exit from the chamber. Efficiency of a mill is controlled by the angle of internal friction at unloading, by standard types and sizes of grinding bodies, coarseness of the supply, properties of the material and a circular movement of the chamber. The degree of grinding depends mainly on the time of retention of particles in the chambers, i.e., on the variant of connecting grinding chambers — in series, as is shown by the arrows in Figure 2, parallel or combined.

On the first mode, the material sequentially passes through the upper, and then through the lower chamber. According to this mode, ferromanganese, ferrotitanium and ferrosilicon are grinded. When working in parallel mode, those materials are grinded which one less strength than ferroalloys. The material is loaded separately into each chamber, and at the output the target product is obtained. The efficiency of the process grows twice, and the achieved degree of grinding is determined by the value of the material grindability factor. In the manufacture of electrodes on this mode, quartz sand, rutile concentrate and marble are grinded. The third mode is designed for the most easily milled materials. They are loaded into the tube chambers through the central hatches, and the grinding products move from the central section to the outlet hatches of each chamber. The degree of grinding is minimal and the efficiency of the process is the highest as compared to serial and parallel modes of operation.

The modes and efficiency of grinding of each new material are selected by conducting preliminary tests, on the results of which the type of grinding bodies (steel balls, cylinders, rods) and the mill operating mode (frequency, vibration amplitude, grinding duration) are determined. In the former Soviet Union, the electrode shops used two-chamber mills PALLA-U to grind not only ferroalloys, but also ore-mineral coating ingredients. At the same time, coarser powders were produced than those when using other types of through drum ball mills, even with peripheral screening.

The cavities of mill chambers are sealed with heat-resistant sealing rings, the branch pipes at the inlet and outlet are connected to the shelters of the loading and receiving units by elastic corrugated transitions.

The mills are equipped with a carbon dioxide generator and a soundproof capsule. Therefore, grinding installations based on the vibration mills PALLA-U provide operating conditions for service personnel that are safe from the point of view of sanitary and hygienic regulations, and, when grinding ferroalloys, the fire and explosion safety regulatory requirements.

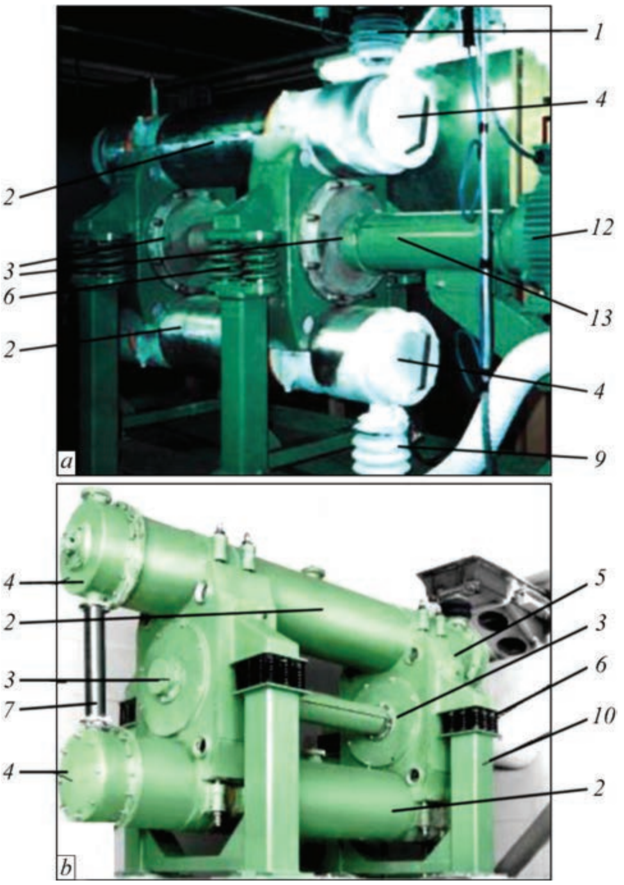

Figure 3. Frontal-facial (*a*) and rear (*b*) apperance of vibration mill PALLA-U: *12* — electric motor; *13* — casing of driving shaft (other designations see in Figure 2)

Paddle-type grinder of the model Pluristadio GR 80 of the Italian Company GUSSEO is presented in Figure 4, and as a part of the grinding installation — in Figure 5. It consists of a lined armored cylindrical body and a rotor — a vertical shaft with two three-tier sections of beaters mounted on it, spaced apart in height. The lower section *1* is equipped with larger beaters and is designed to destroy large fractions. The upper section *2* carries out fine grinding, it is assembled from beaters of a smaller size. In the space between them, screw feeder *3* evenly supplies material to the disk of the lower section of the rotor.

The rotor, made in the form of a centrifugal distributor, on the one hand, directs the material to be grinded into the circumferential gap along the cylindrical surface of the mill body, and, on the other hand, reflects and directs the gas flow pumped by the fan into this gap. Relatively small particles of the material are entrained by the gas flow and directed through the beater of the upper section of the rotor into the separator *4*, in which they are divided into two fractions:

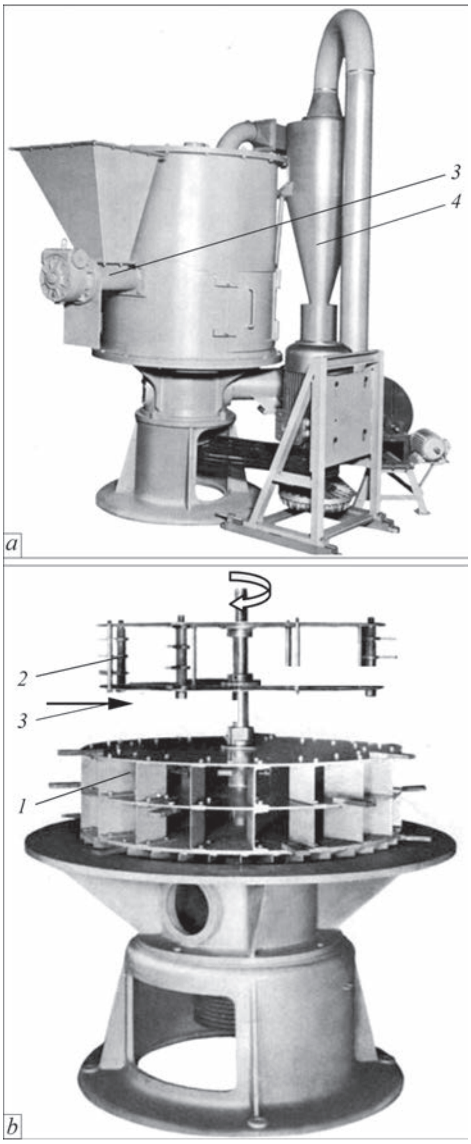

Figure 4. General view (*a*) and grinding rotor (*b*) of paddle-type mill Pluristadio GR 80 (see designations in the text)

the fine (commercial) fraction is carried away and deposited in the cyclone, and a large one is returned to regrinding. Coarser (heavier) particles fall for some time in the circumferential gap of the mill downward, towards the gas flow, get under the beaters of the lower section of the rotor, grinded, and then also carried away upwards, finally grinded by the upper beaters to the end and also directed to the separator *4*.

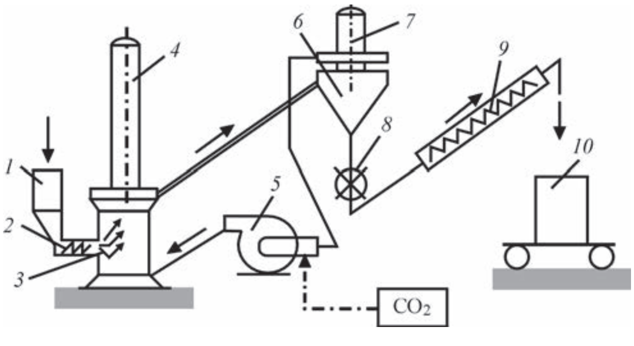

Figure 5. Technological scheme of grinding installation for ferroalloys: *1*, *2* — hopper with screw; *3* — mill; *4*, *7* — inflatable explosion safe valve; *5* — fan; *6* — hopper of cyclone; *8* — stopping valve; *9* — screw; *10* — trolley

The scheme of the installation for grinding ferromanganese, ferrotitanium and ferrosilicon based on the paddle-type mill Pluristadio GR 80 is shown in Figure 5.

The granulometric composition of the powder is regulated when the mill is set up by changing the number of beaters suspended on the rotor disks, by the gas flow rate using the separator louvers, and also by changing the rotor speed of the fan impeller. The higher the rate of the gas flow, the coarser particles it picks up and rushes upward under the beaters of the upper section of the rotor. In this case, the integral degree of grinding of the material decreases, and the efficiency of the mill increases. With a decrease in the gas flow rate, the grinding is finer, but the amount of material grinded by the mill decreases.

Since the supplying device is located in the middle part of the mill, i.e., between the upper and lower rotors, and the gas is pumped through the nozzle mount-

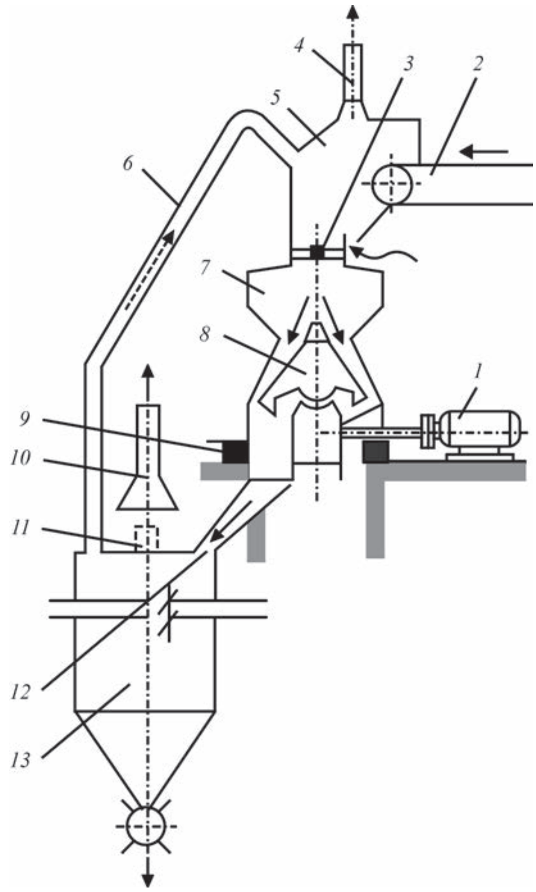

Figure 6. Scheme of aspiration of cone vibration grinder KID-300 [6]: *1* — drive; *2* — supplier; *3–5* — collecting launder, shelter of loading device with aspiration suction; *6* — tapping pipe; *7*, *8* — outer and inner cone of the grinder; *9* — shock absorber; *10*, *11* — funnel and branch-pipe of ejection device (in the variant without a tapping pipe); *12* — discharge launder; *13* — hopper with Kibble for grinded material

ed under the lower grinding disk, overgrinding of the material is excluded.

The system is sealed. CO_2 is supplied to the system, if necessary, with the addition of oxygen, in the amount sufficient to make up losses. The sealing of the system is confirmed by filling the fabric filter bags, with which the mill and the separator are equipped. As a shielding atmosphere, a mixture of nitrogen with oxygen can be used.

The mill Pluristadio GR 80 has a small volume of the working chamber — its diameter is 800 mm, and a height is 1200 mm. It is easily and quickly, within 30 min, cleaned of remnants of the previous material. In terms of efficiency, it meets the requirements for the above-mentioned ferroalloys of the workshop with a capacity of up to 12.5 thou t of electrodes per year, 70 % of which are with rutile and 30 % with low hydrogen coating.

Vibroinertial cone grinder KID-300 [5, 6]. The profile of the grinding chamber of a vibroinertial cone grinder, like that of traditional cone-type vibrogrinders, is formed by the armored surfaces of grinding cones, which mate each other — a stationary outer and a rotating inner one. The outer cone and the spherical support of the inner cone are mounted on the bed of the grinder. The inner cone is driven by electric motor not through the eccentric sleeve, as in a cone grinder of a conventional type, but through the unbalanced vibration exciter. It has a socket of a ball-type profile for the spherical support of the inner cone and is mounted beneath on the driving shaft. As a result of using such a drive, the inner cone, along with the rotation, performs gyrational movements, i.e., the swings characteristic of a conical pendulum.

The resulting force of both centrifugal components, which presses the inner cone to the outer one in a pulsating mode, is the force grinding the material loaded into the milling chamber of the grinder. The working surfaces of grinding bodies act on the grain through the grains surrounding it during cyclic compaction of the layer in the working zone.

During a short time of passing the grinding chamber, the initial material is in a bulk stressed state under the conditions of repeated cycles of compression, bending and unloading. Under such conditions, the material is destroyed mostly according to the laws of fractal kinetics along the weakest surfaces. The coarseness of the powder is regulated by the position of the unbalancing device and the efficiency of the grinder — by changing the size of the unloading slot, i.e., the slot between the linings of the cone and the bowl.

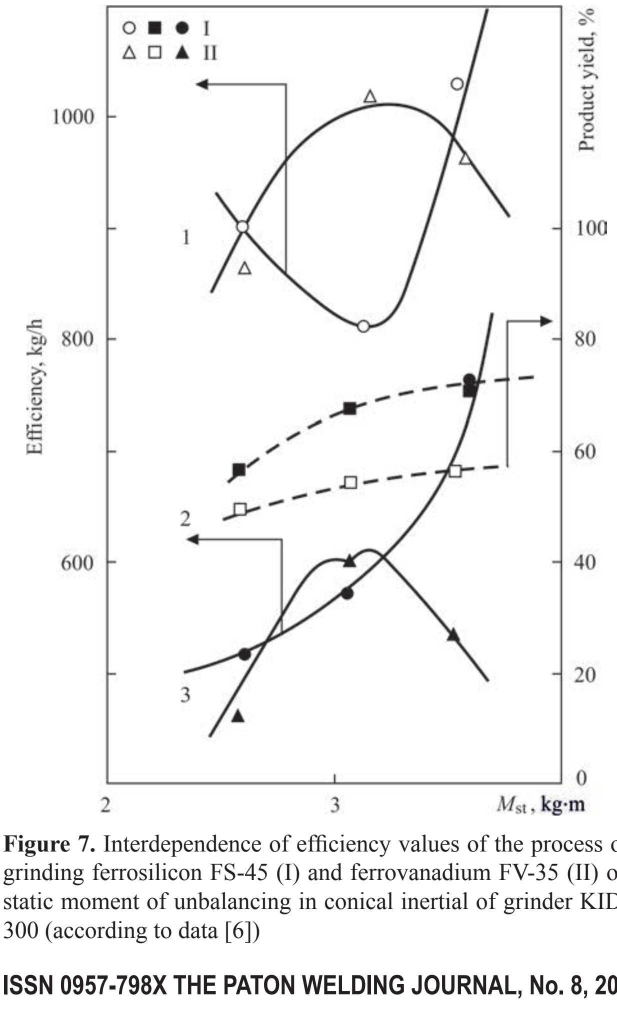

Figure 7. Interdependence of efficiency values of the process of grinding ferrosilicon FS-45 (I) and ferrovanadium FV-35 (II) on static moment of unbalancing in conical inertial of grinder KID-300 (according to data [6])

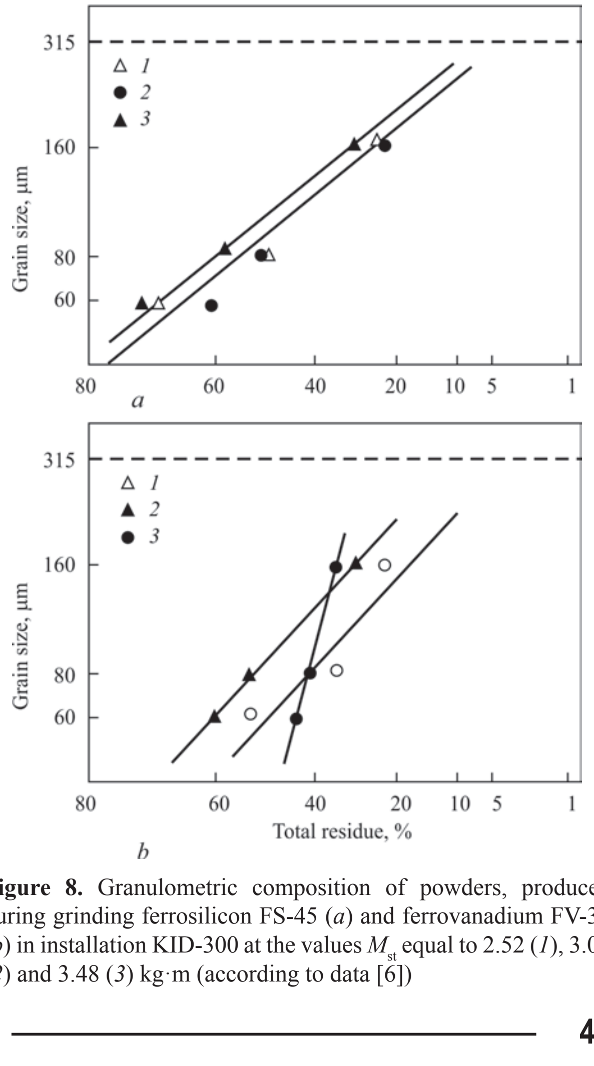

Figure 8. Granulometric composition of powders, produced during grinding ferrosilicon FS-45 (*a*) and ferrovanadium FV-35 (*b*) in installation KID-300 at the values M_{st} equal to 2.52 (*1*), 3.08 (*2*) and 3.48 (*3*) kg·m (according to data [6])

The advantages of inertial grinders such as KID as compared to conventional cone grinders with an eccentric drive include:

- three-... five-time increase in the grinding ratio (up to 15–18, in comparison with the traditional index at the level of 3–5);
- increase in the product yield;
- ability of the grinder to operate under bulk, as well as starting and stopping under the load;
- negligible level of dust above the level of the layer of grinded material in the loading zone.

At the I.M. Frantsevich IPMS of the NAS of Ukraine the grinder KID-300 was tested during grinding a number of ferroalloys, including ferrosilicon of grades FS-45 and ferrovanadium of grades FV-35 with an initial lumps size of 20 mm [6]. The scheme of experimental installation is shown in Figure 6.

Performance indicators of the grinder during the tests are the following:

- rotation speed of unbalanced vibrator $w = 20$ s^{-1};
- static moments of M_{st}, (2.52; 3.08 and 3.48 kg·m);
- width of unloading slot $\Delta = 6$ mm.

The dependences of the performance indicators achieved during this grinding process on the mass of the treated material and the produced target product, kg/h, as well as by the product yield, %, the values of the static moment of unbalancing device, are shown in Figure 7.

The presented data showed that the grinder KID-300 can be used for the preparation of ferroalloy powders that, in terms of grain composition, meet the requirements to the technology of production of low-hydrogen electrodes of general purpose with the aspiration design used in this work, providing a dust concentration in aspirated air not exceeding 1.2 g·m^{-3} with a suction capacity of 900 m^3·h^{-1} [5].

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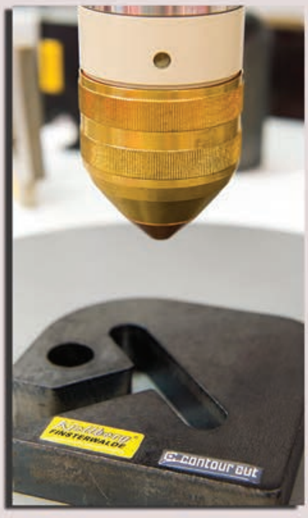

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