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THEORY AND PRACTICE OF DEVELOPMENTS IN THE FIELD OF SEPARATION AND EXTRACTION OF METALS AT MINING AND METALLURGICAL ENTERPRISES

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Abstract: *The article discusses the theory and practice of development in the field of separation and extraction of metals at mining and metallurgical enterprises through the creation and implementation of mine and bunker vibrating feeders, vibrating screen feeders and new designs of screening surfaces for them, as well as devices for eliminating buildup in bunkers. New scientific and practical results of research on the substantiation of improved vibrating machines for auxiliary mining operations are presented, including: vibrating mining feeders of the PVG type; vibrating hopper feeders such as PVB and ZhVB; vibrating feeders-screens of the PGV and GPV types; sifting surfaces for them; devices for eliminating equilibrium arches and material adhesion in bunkers; complex for screening and feeding coke breeze into the crusher; vibration delivery and ballasting installations; sleeper tamping vibration installation, as well as a rock mass transfer point in the quarry. A new mathematical model of the tamping process and a method for improving the tamping mechanism are proposed, which will increase the productivity of the sleeper tamping vibration installation. New vibration complexes make it possible to reduce the energy intensity of crushing by 15% and reduce the wear of the working surfaces of the crusher. It is shown that the construction of transfer points is carried out without additional preparation of the entire working bench. The operational capacity of the warehouse is selected within the range of 15–25 thousand m3 of rock mass. when used for loading iron ore cars with EKG-8I excavators with a daily productivity of up to 5000 m3, the warehouse stock is 3-5 days. The minimum specific energy intensity of release and loading of one ton of rock mass at the maximum value of productivity is ensured at frequencies of forced oscillations of the system ω = 15.5–17.5 Hz. The efficiency of the feeder-screen operation with spatial oscillations of the working body created by two multidirectional driving forces applied at two points at a distance from each other equal to 0.5 was determined. the width of the working body increases by 15%. Developers of technical documentation – SE “UkrNIPIIpromtekhnologii” (Zhovti Vody, Ukraine); Manufacturers: Krivoy Rog Ore Repair Plant (Krivoy Rog, Ukraine); Mechanical repair plant of the State Enterprise "Vostok GOK" (Zhovti Vody, Ukraine); Mechanical repair workshops of quarries, mines and processing plants, etc. It has been established that the research results represent a step in the theoretical generalization of the problem of developing the theory of interaction of grinding media in the grinding chambers of mills and increasing the efficiency of equipment for fine grinding of rocks, which is important for mining and metallurgical enterprises.*
Keywords: *mining and metallurgical production, separation, vibration, screening, efficiency, safety, labor protection*

1. Introduction

Relevance of the problem. The increasingly complex mining, geological and technical conditions of mining deposits with a simultaneous increase in production volumes necessitate the use of reliable machines and mechanisms that ensure increased concentration and intensification of all processes of underground

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mining. One of the most important technological processes in the development of ore deposits is the release of broken rock mass from the mining area, its delivery and loading into vehicles; their labor intensity averages 25–50% of all labor costs for the development system [1], [2]. The most promising is the production of rock mass using vibration machines, which intensively influence the produced material, reduce the number of freezes and increase the productivity of the process. Existing designs of vibration machines are characterized by a significant range of parameters, various kinematic and dynamic schemes, but they do not provide high productivity and reliability of the release and loading process. Therefore, increasing the level of efficiency, safety and labor protection at enterprises of the mining and metallurgical industry based on the development of technical means for the mining and processing industries, the justification of new parameters and the development of designs for mine and bunker vibrating feeders, vibrating screen feeders, screening surfaces for them, devices for eliminating buildup in bunkers and rock mass transfer points in quarries, providing increased productivity, reliability and a reduction in the specific energy intensity of the release and loading of rock mass, the introduction of delivery-ballasting and tamping machines and screening complexes for coke breeze, activation of the components of the hardening backfill mixture using mining and metallurgical waste production, as well as the creation and industrial development of a parametric series of such machines, are important scientific and practical tasks [3], [4].

Object of study– traditional mining technologies and technical means using vibration machines that intensively affect the extracted material, reduce the number of hang-ups and increase the productivity of the technological process. One of the most problematic areas is the complexity of the release and loading of broken rock mass from production blocks and bunkers into transport vehicles while ensuring the maximum productivity value at the frequencies of forced vibrations of the system. In addition, provide mechanized feeding, backfilling and leveling of ballast material, as well as ballasting, compaction and tamping of ballast under the sleepers of mine tracks.

The purpose of the study is the– theory and practice of development in the field of separation and extraction of metals at mining and metallurgical enterprises using mine and bunker vibrating feeders, vibrating screen feeders and new designs of screening surfaces for them, as well as devices for eliminating buildup in bunkers and transfer points rock mass in quarries. This will increase productivity, reliability and reduce the specific energy intensity of the release and loading of rock mass.

To achieve this goal, the following tasks were solved:

1. Set the minimum specific energy intensity for the release and loading of the rock mass at the maximum productivity value is ensured at the frequencies of the forced oscillations of the system.
2. Develop mathematical modeling and calculate the main parameters of vibration mining and metallurgical equipment.
3. Create and test mine and bunker vibrating feeders, screen feeders, new designs of sifting surfaces for them, as well as devices for eliminating buildup in bunkers and overloading rock mass in a quarry.
4. Develop a vibration complex for mechanized feeding, filling and leveling of ballast material, as well as ballasting, compacting and tamping of ballast under the sleepers of mine tracks.

Research methods. A technological audit was carried out and an analysis of previously conducted research and control observations was carried out, mathematical and physical modeling in the field of development of methods, technical means for creating vibration equipment, laboratory studies and mine experiments, as well as theoretical analysis and generalization of the results of data studies according to standard and new techniques with the participation of the authors. Theoretical studies were carried out using classical methods of vibration theory using the concept of a complex modulus of elasticity introduced by E.V. Sorokin, and the Volterra principle when taking into account inelastic resistances.

2. Analysis of recent research and publications

A major role in developing the theory and generalizing the experience of designing and creating vibration-transporting machines and vibrating screens belongs to such scientists as I.I. Blekhman, L.A. Weisberg, I.F. Goncharevich, A.V. Dokukin, V.I. Dyrda, I.I. Kavarma, V.P. Inflated, Ya.G. Panovko, V.N. Poturaev, A.O. Spivakovsky, A.D. Teacher, V.P. Franchuk, Yu.N. Khazhinsky, M.V. Khvingia, A.G. Chervonenko and a number of others. Currently, in the practice of vibration separation of material into size classes, there are three groups of machines. The first group consists of vibrating screens, which combine screening of material with its movement along the working surface under the influence of its own weight. Vibration in these machines is used to reduce the angles of gravity movement of the material and forcibly clean the screening surface from jammed pieces, and to ensure the movement of the material and separate it by size, the working body of such machines is installed at an angle of 15–25 º to the horizontal.

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The second group is formed by vibrating screens with forced movement of material along the working body, during which the material comes into contact with the screening surface and is separated by size. The installation angle of the load-carrying body of such screens is in the range of 0 – 10 º [5], [6].

The third group consists of vibrating screen feeders, which combine two operations -forced release and screening of material during its forced transportation. Vibration in machines of this type, as well as in screens of the 2nd group, not only helps to reduce the angles of gravity movement of the material, but also ensures its movement along the working surface. The installation angle of the working parts of such machines is in the range of 5 - 10 º.

Scientific and practical results have been developed under the hour of scientific and research work on the topics (scientific core - V.I. Lyashenko): «Research and development of parameters for selective mining of uranium deposits with a feasibility study of unconventional development systems (Selective mining) » – State registration number No. 0102U000542); «Improvement and development of mechanisms for laying and repairing rail tracks at the mine of the State Enterprise «Directorate») – State registration number No. 0107U005386. The work is indicated for continued research, the basic scientific and practical results of which are the most achieved in robots [7], [8].

3. Theory of the issue

Mathematical modeling and calculation of parameters of a vibrating feeder-screen (the work was carried out under the scientific supervision of Professor V.P. Franchuk). Feeders and feeder screens with complex movement of the working surface are used in two types - with one two-shaft vibrator installed parallel to the working plane and two two-shaft vibrators installed at an angle β_0 to the working surface and having different directions of the disturbing force vector [9], [10]. Changing the direction of the vector is carried out due to the reversal of the imbalances of one vibrator relative to each other (Fig.1).

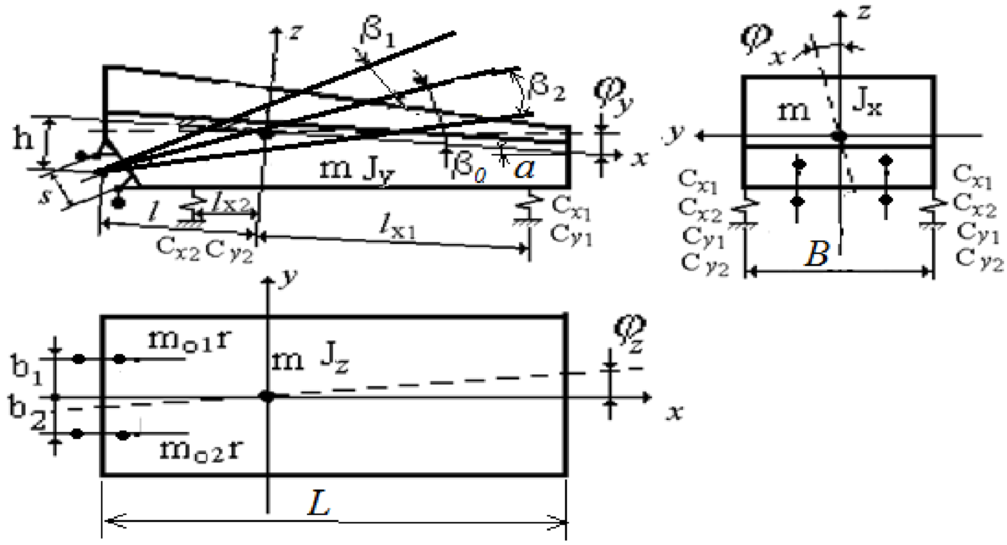

Fig.1. Dynamic design scheme of a screen with two differently directed self-balanced vibration exciters: h – distance from the center of rotation of the unbalanced masses to the center of mass of the screen in height; b_1 and b_2 – distance of the center of rotation of the unbalanced masses of vibration exciters along the width of the screen relative to the center of mass of the screen; β – base angle of direction of the driving force of the vibration exciter; β_1 and β_2 are the studied direction angles of the driving forces; l –is the distance from the center of rotation of the unbalanced masses to the center of mass of the screen along its length; Cx_1; Cy_1; Cx_2; Cy_2 – rigidity of elastic supports, respectively, in the front and rear parts of the screen; $l\,x_1$, $l\,x_2$, $l\,z$ – points of location of elastic supports relative to the center of mass of the screen, respectively, along its length and width; φ_x, φ_y, φ_z, – rotational vibrations of the box relative to the axes X, Y and Z, respectively; m_0r_1, m_0r_2 – respectively, kinetostatic moments of the first and second vibration exciters; s – is the distance between the axes of rotation of the unbalanced masses of the first and second vibration exciters

Vibrating feeders for mining, type PVG. They are designed to release rock mass from blocks, ore chutes and bunkers and load it into transport vehicles (mine cars, dump trucks, conveyors, etc.). They provide remote control of the release and loading process, reduce the frequency of bulk material hanging in the container, and allow crushing of oversized pieces on the bottom of the working element with an explosive

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mass of up to 200 g. They are used at enterprises in the mining, chemical, coal and construction industries (Table 1). The inertia force of the vibrators is determined according to the expressions:

Vibrator inertia force: $P_1 = 2m_0r_1\omega^2 \sin(\omega t + \xi_1)$, $P_2 = 2m_0r_2\omega^2 \sin(\omega t + \xi_2)$ (1)

where ω – is the angular frequency of forced oscillations; ξ_1, ξ_2– angle of rotation of the unbalances relative to the initial position. Due to the reversal of the unbalances, a disturbing moment of the vibrators appears:

$$M_1 = m_0r_1\omega^2 s\cos(\beta_1)\cos(\omega t + \xi_1), M_2 = m_0r_2\omega^2 s\cos(\beta_2)\cos(\omega t + \xi_2) \quad (2)$$

Table 1. Technical characteristics of vibrating mining feeders

Indicators	**Direct release of ore from the block**		**Release of ore from blocks and capital ore passes**		**Release of ore from ore passes and bunkers**		
	PVS-1.4/7.0	PVG-1.3/7.0	PVG -1.4/4.0	PVG -1.2/3.1	PVM-1.0/2.3	PVG -1.0/2.2	PVM-1.0/1.5
Productivity, t/h	600-1000	900-1500	1500-2000	800-1000	250-350	400-600	150-250
Transportation length, m	1.5	6.9	4.0	3.0	2.4	2.2	1.5
Tray width, m	1.4	1.2	1.4	1.2	1.0	1.0	1.0
Oscillation frequency, Hz	16	16	16	16	47	16	47
Driving force, kN	95-120	130-180	95-120	55-80	16-30	28-38	16-30
Drive power, kW	22	27	22	17	1.5	7.5	1.5
Overall dimensions, m							
length	7.3	7.1	4.2	3.2	2.3	2.3	1.5
width	1.8	1.7	1.8	1.5	1.2	1.4	1.2
height	1.5	1.2	1.3	1.0	0.6	0.8	0.5
Weight, kg	4750	1100	5610	2120	425	1000	320

The amplitude of linear and rotational oscillations, at frequencies close to the resonance of the system, increases sharply (Fig. 2), In the operating frequency range (ω =100–150 rad/s), the amplitude of oscillations in all coordinates is stabilized, i.e. the operation of the feeder screen will be more stable. The dependence of the vase on the oscillation frequency varies from 0 to $-\pi/2$ in pre-resonance and resonant modes; in the region of operating oscillation frequencies it is $-\pi$. Taking into account constructive phase shifts, the total phase in the operating frequency range is about 0 rad for linear movements, about 2 rad for rotary vibrations [11].

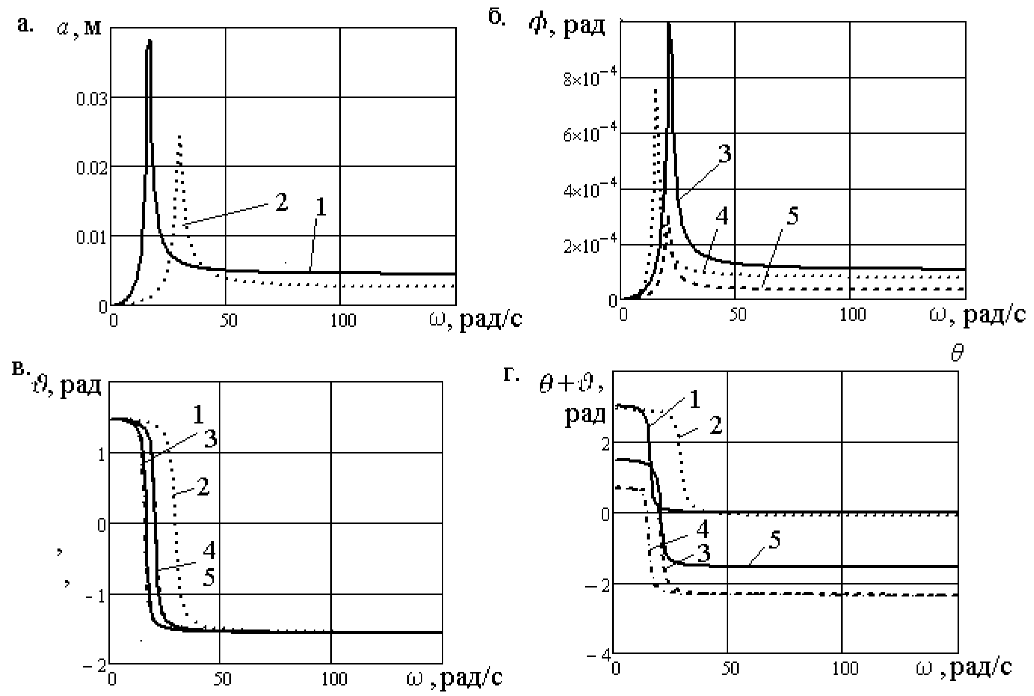

Fig. 2. Amplitude-frequency and phase-frequency characteristics of the screen-feeder: a – linear movements: 1 – along the working surface; 2 – normal to the working surface; b – rotational vibrations: 3 – around the x axis; 4 – around the z axis; 5 – around the y-axis; c – phase-frequency characteristics of the screen-feeder; d – total phase shift, structural and operating, numbers correspond to the indicated movements

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The motion of the screen-feeder in steady state is described by the following dependencies:

$$x = a_x \sin(\omega t + \theta_x + \vartheta_x)\,;\, z = a_z \sin(\omega t + \theta_z + \vartheta_z)\,;\, \varphi_x = \phi_x \sin(\omega t + \theta_{\varphi x} + \vartheta_{\varphi x})\,;$$

$$\varphi_z = \phi_z \sin(\omega t + \theta_{\varphi z} + \vartheta_{\varphi z})\,;\, \varphi_y = \phi_y \sin(\omega t + \theta_{\varphi y} + \vartheta_{\varphi y}) \qquad (3)$$

In the operating frequency range, the oscillations have a phase shift, shown in Fig. 3, *d*, according to their purpose they can be classified as movements affecting vertical vibrations (Fig. 3, *a*, position 2, Fig. 3, *b*, positions 3, 5), longitudinal movements (Fig. 3, *a*, position 1) and affecting lateral movements (Fig. 3, *b*, pos. 4). The vibration transport mode coefficient depends on the amplitude of normal vibrations to the working surface. The total displacement of any point on the working surface in the normal direction will be equal to:

$$Z_n = z + X\varphi_y + Y\varphi_x\,, \qquad (4)$$

where $-l \le X \le L - l\,; -B/2 \le Y \le B/2$ – coordinates of a point on the working surface, measured from the center of gravity of the screen-feeder (Fig. 3).

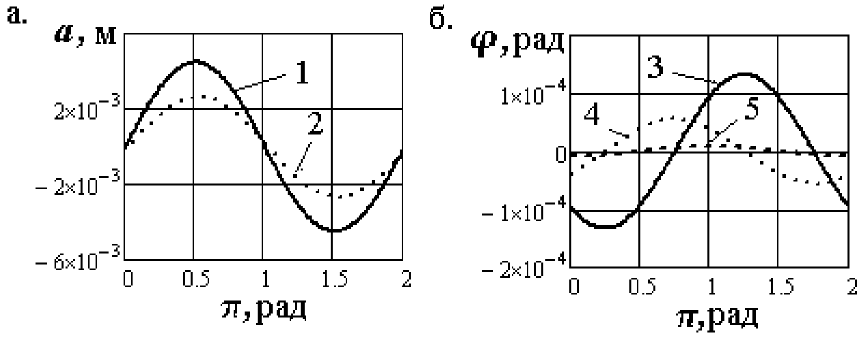

Fig. 3. Oscillograms of the motion of the screen-feeder: a – linear movements: 1 – along the x-axis, 2 – along the z-axis; b – rotational vibrations: around the x axis, around the z axis, around the y axis

4. Presentation of the material and results

Based on the results of many years of research, the effectiveness of the following vibration technical means and complexes for mining and metallurgical production has been developed and confirmed in practice.

Vibrating hopper feeders type PVB and ZhVB (Fig.4).

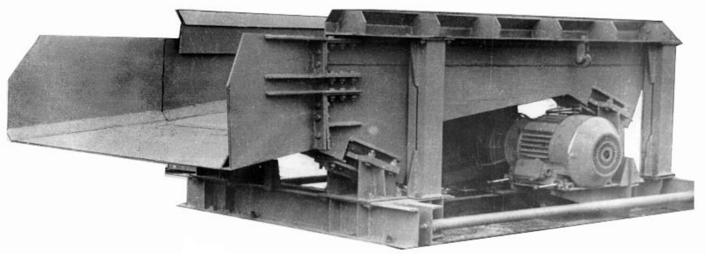

Fig. 4. Vibrating feeder PVG-1.2/3.1 (general view)

Designed for work at surface complexes of mines and processing factories for the enrichment of ores and coal, at crushing and screening complexes and factories for the preparation of crushed stone and other building materials [11]. The ZhVB vibrating feeder with an inertial drive allows for smooth regulation of productivity without stopping its operation and was produced to replace the vibrating feeder with an electromagnetic drive 196A-PT produced by the Elektrovibromashina plant (Tskhinvali, Georgia) (Table 2).

The vibrating feeder PVG 1.2/3.1 is designed for discharging and loading ore from ore passes, as well as for direct discharge from the production block, provided that the oversized output is up to 5%. When improving the feeder design, the sections of the stiffening ribs, their number, placement were changed, and the dimensions of the sub-vibrator plate were increased using a wedge mount for the vibration exciter, which made it possible to reduce stress concentration in the area of the vibration drive and increase the strength and reliability of the working element. According to the results of industrial operation, the service life of the vibrating feeder is 100-110 thousand tons of rock mass, and the maximum volume of ore released by one feeder reaches 500 thousand tons.

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Table 2. Technical characteristics of hopper vibratory feeders

Indicators	PVB-0.8/2.0	PVB—1.2/2.4	PV-1.2/2.2	ZhVB -0.8/2.0
Productivity, t/h	50-90	150-300	150-300	45-90
Transportation length, m	2.0	2.4	2.2	1.9
Oscillation frequency, Hz	16	16	16	16
Driving force, kN	7.7-11.2	18-23	18-23	5-8
Overall dimensions, m				
length	2.01	2.6	2.6	1.87
width	1.25	1.45	1.45	1.16
height	0.83	1.00	1.0	0.86
Weight, kg	530	670	670	470

Currently, more than 100 vibrating feeders with increased strength of the working element are manufactured and put into operation annually. These feeders are widely used in the mines of Kryvbas, Ukraine, and in the mines of the State Enterprise "Vostok GOK", Ukraine. For the needs of the production association "Krivbassruda", Ukraine, more than 860 feeders PVG-1.2/3.1 were manufactured.

Vibrating feeder-screens type PGV and GPV (Fig.5). Designed for screening rock abrasive materials and combining the operations of release, delivery and screening. They are used instead of a plate feeder in crushing and screening complexes of mines and factories, at quarry transfer points [12]. They provide high productivity and screening efficiency due to spatial vibrations of the working body (Table 3). The cramped conditions for servicing the feeder at the outlet of the rock mass determined the installation of a two-shaft vibration exciter of directed vibrations with the plane of the shaft axes parallel to the bottom of the load-carrying body.

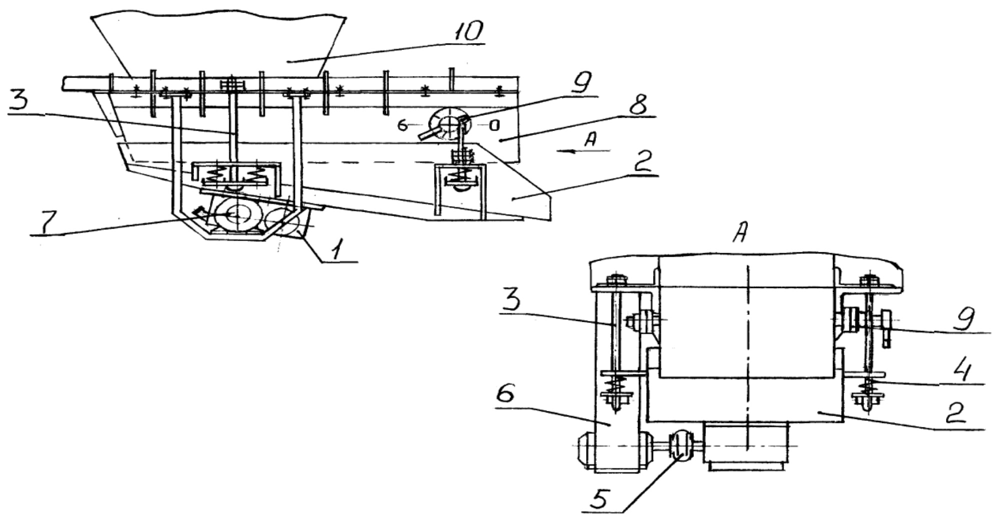

Fig. 5. Vibrating bunker feeder ZhVB-0.8/2.0: 1-vibration exciter; 2-tray; 3-thrust; 4-spring; 5-clutch; 6-engine frame; 7-engine; 8-funnel; 9-drum; 10 – bunker

Table 3. Technical characteristics of screen feeders

Indicators	GPV-100	GPV-350	GPV--40/400	GPV-200/400
Productivity, t/h	500	1000	400	400
Transportation length, m	4.0	5.0	2.5	5.0
Screening surface:				
length, m	1.9	2.3	1.57	1.9
width, m	1,2	1.2	1.2	1.4
slot width, mm	70-100	300-350	15-25	165-230
length, m	7.5	10	2x5.5	2 x 15
width, m				
length	4.1	5.8	2.74	5.0
width	1.77	2.5	1.74	3.15
height	1.15	1.7	1.2	2.24
Weight, kg	2875	7000	3050	8300

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The effect of the unbalanced masses of a vibrating drive in this design on the working body of the feeder is to create a directed harmonic force and additional torque ($M_{кр}$), the value of which is determined from the expression:

$$M_{кр} = \frac{P}{2}\rho_1 \cos\alpha \,, \tag{5}$$

where P –is the driving force of the vibration exciter kg; ρ_1 – center-to-center distance of vibration exciter shafts, m; α – angle of vibration direction, degrees.

Spatial vibrations of the screen are obtained from two differently directed driving forces applied at two points along the width of the working body. The distance between the points of application of the driving forces (***B₁***), as well as the width of the working body (***B***) and its length (***L***) are in the ratio:

$$B_1 = 0{,}5B; L = 3B\,. \tag{6}$$

The sifting surface is a set of elastic gratings with slot-like holes. The gratings are fixed to the box, forming a cascading work surface. The authors determined the efficiency of material screening (η) using the formula:

$$\eta = \frac{100(b-c)}{b(100-c)}100, \%, \tag{7}$$

where ***b, c*** – respectively, the content of the under-grid product in the initial feed and in the over-grid (determined by sifting part of the initial material and the output material).

For medium- and large-lump material, a cascade grate sieving surface with a curved profile of the cascades relative to the longitudinal axis of the screen working body is recommended. As a result of the analytical justification, the effective dimensions of the slots and the parameters of the grate profile were determined at a slot opening angle of 3-4°:

$$m = 0{,}6d;\ n = (0{,}8\text{-}1)d\ L_к = 2{,}5d. \tag{8}$$

Here *m* and *n* are the initial and final width of the slot; *d* – diameter of the screened piece; $L_к$– is the length of the grate. In addition, it was determined that the radii of curvature of the grate bars ($R_к$) and ($\boldsymbol{r_к}$) are in the ratio

$$R_к = (4{,}5\text{-}5{,}5)r_к. \tag{9}$$

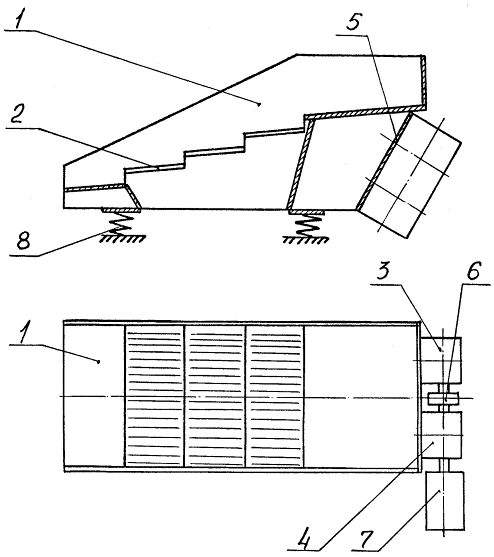

Fig.6. Vibrating screen feeder (assembly diagram): 1 – box; 2 – sifting surface; 3 and 4 – vibration exciters; 5 – plate; 6 – coupling; 7 – electric motor; 8 – elastic support

New scientific and practical results of work on the creation and implementation of vibrating feeder screens (GPV-350, GPV-100, PVG-40/400, PVG-200/400) at mining enterprises of Ukraine, Balaklava Mining Administration, OJSC Priargunsky Industrial Mining and Chemical Plant Association (PIMCU) named after E.P. Slavsky" and PA "Uralzoloto" (Russian Federation) [13], [14].

Screening surfaces for vibrating screens and feeder screens (Fig.7**).** The screening surface is made cascade with a curved profile of the cascades, the curvature of which increases in the direction of material movement to increase the efficiency of screening and increase the reliability of the sieve when dividing rock abrasive material into size classes.

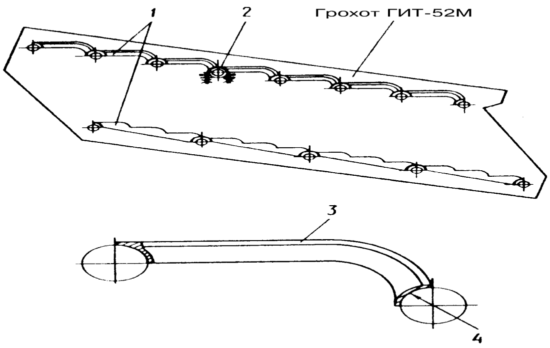

Fig.7. Screening surface of the screen with a curved grate profile: 1 – grate grates; 2 – clamp; 3 – grate; 4 – support platform

Cast steel grates. They are assembled from separate sections on the transverse beams of vibrating screens GIT and GIL and attached to the beams with clamps. Designed to separate material into size classes ± 350 mm, ± 200 mm, ± 100 mm, ± 70 mm. They provide screening efficiency of 90-95% and increase the reliability of the screen by 3-4 times.

Welded cascade grates (Fig.8). Designed for screening coal, crushed stone and other building materials into classes ± 70 mm, ± 50 mm, ± 40 mm. In plan, the grating holes look like slits that widen in the direction of material movement. They increase screening efficiency by 20-25% and eliminate jamming of pieces of material in cracks.

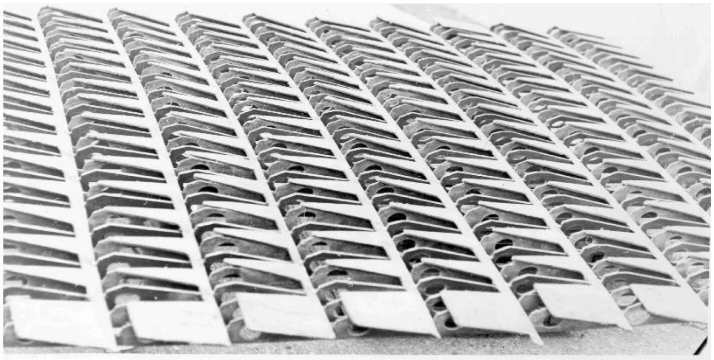

Fig.8. Welded cascade screen grid (general view)

Rubber gratings with elliptical holes and curved protrusions on the working surface. Designed for separating material with a particle size of 40 mm and 20 mm. Curvilinear protrusions ensure the orientation of unscreened pieces of material into the holes, help to increase screening efficiency by 20-25% and increase the reliability of the sieve by 3-4 times. Feeders are manufactured at repair and mechanical plants of mining enterprises (mines of JSC Krivbaszhelezorudkom, State Enterprise Vostok GOK (Ukraine), etc. Experience in operating vibrating mining feeders has shown their high productivity, cost-effectiveness and efficiency. New designs of screening surfaces designed to separate material into various classes of fineness were manufactured at the enterprises of the State Enterprise " Vostok GOK" and introduced at mining enterprises in Ukraine [15], [16].

Devices for eliminating equilibrium arches and material build-up in bins (Fig.9). Several designs of bunker devices have been developed that take into account the physical and mechanical properties of the material and the design features of bunkers, which can be used independently or in combination with each other[17], [18]:

– installation of additional movable walls in the bunker driven by a vibration exciter, pneumatic cylinder or pneumatic cylinders;

– a device for loosening hard-to-flow caked materials using a rotary cutter with sliding rippers;

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– cleaning the walls of bunkers using vibrating scrapers;
– lining the walls of the hopper with conveyor belts and creating a traveling wave on the surface of he lining;
– elimination of arches of balance using vibrating rods or gratings.

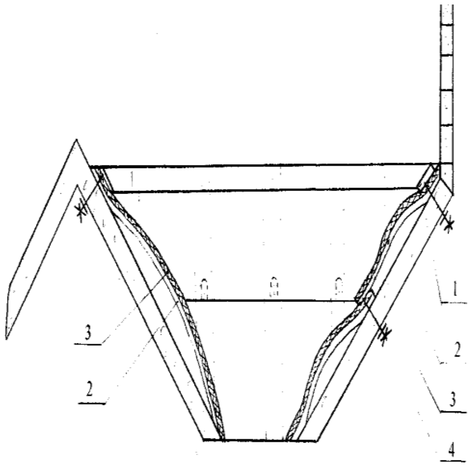

*Fig.9. Device for eliminating equilibrium arches and material buildup in bins:
1-bar; 2-elastic plate; 3-rubber band; 4-mount*

Complex for screening and feeding coke breeze into the crusher (Fig.10). The main reason for overgrinding of coke breeze is the entry into the crusher of a fine fraction of material 0-3 mm. To eliminate this drawback, it is necessary to sift out the fine fraction of coke when releasing it from the bunker and feed only large pieces into the crusher. Screened coke breeze must be fed to the lower belt conveyor, bypassing the crusher, connecting it with the crushed material obtained after passing through the crusher. Based on the requirements of the technological process in the coke crushing building (crusher feed capacity – 15 t/h, crushed coke size – 3 mm, its humidity in the hopper – to 17%), a new set of mechanisms has been developed for releasing material from the hopper, screening out the fine fraction (0-3 mm), collecting it and feeding it to the lower conveyor, as well as forming a flow of coarse fraction and feeding it to the crusher [19].

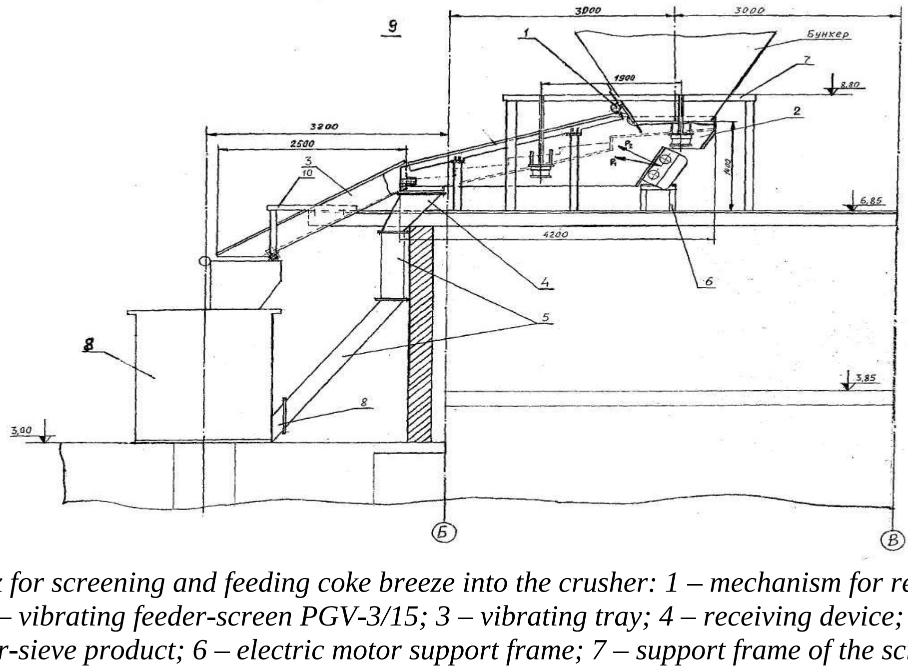

Fig.10. Complex for screening and feeding coke breeze into the crusher: 1 – mechanism for regulating the material layer; 2 – vibrating feeder-screen PGV-3/15; 3 – vibrating tray; 4 – receiving device; 5 – device for delivering under-sieve product; 6 – electric motor support frame; 7 – support frame of the screen feeder; 8 – crusher; 9 – shelter; 10 – bracket; B, C - designation of the axes of the crushing body

The created vibration complex for the preparation of coke breeze was installed in the crushing building of the Krivoy Rog Metallurgical Plant (JSC Arcelor Mittal Krivoy Rog) and implemented with positive results. Thus, a receiving device for an under-grid product with inclined internal platforms and an inclined bottom of the delivery device reduces the overgrinding of the fine fraction of the material and ensures gravity

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flow of the under-grid product into the receiving conveyor of crushed material; a vibrating tray for feeding large pieces of coke into the crusher reduces wear on the working surface of the tray due to the movement of material along it with tossing and reduces the metal consumption of the structure [20].

Vibrating delivery and ballasting unit VDBU-3.0 (Fig.11). The construction of mine rail tracks includes such technological operations as preparing the base of the excavation (soil), adding and leveling ballast material, laying the sleeper-rail grid, tamping ballast under the sleepers, monitoring the profile and gauge of the rail track, etc. Delivery of ballast material to the place of installation or Rail track repairs are currently carried out using loading and delivery machines (LODs) or mine trolleys with bottom unloading of material, followed by leveling and distributing it along the width of the working with shovels manually. This process hinders the efficiency of spreading ballast material onto the soil and reduces the accuracy of its layer thickness. When unloading material from a mine car through the bottom slot, frequent jamming and hanging of pieces of ballast occur, the elimination of which takes time. Manual tamping of ballast material causes unevenness of the process, which leads to a decrease in the quality of laying rail tracks. Currently, a vibration delivery and ballasting unit VDBU-3.0 with an electric drive has been developed for the Novokonstantinovskaya mine of the State Enterprise « Vostok GOK» (Ukraine) [21].

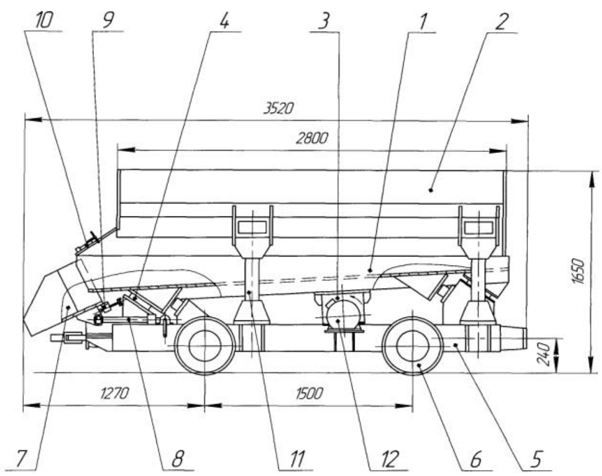

Fig.11. Vibrating delivery and ballasting installation VDBU-3.0: 1 – tray; 2 – bunker; 3 - vibration exciter; 4 – elastic support; 5 – supporting frame; 6 – wheelset; 7 – unloading estrus; 8 – mechanism for raising and lowering the estrus; 9 – drive for turning the sides of the chute; 10 – estrus clamp; 11 – support post; 12 – electric motor

The improved installation compared to the ballasting feeder PVP-2.5 is made with a bunker volume increased to 3 m^3, equipped with a chute lock in the transport position, a mechanism for turning the chute sides, the pneumatic drive of the vibration exciter is replaced with an electric drive. The creation of a ballasting machine based on a vibrating feeder installed on a platform with wheel sets will make it possible to unload material onto the soil from the front end of the machine due to the vibration created by the vibration exciter. This eliminates hanging and jamming of the material in the hopper, dosed unloading is carried out, and the design of the unloading chute allows you to regulate the spread of material along the width of the rail track. The technical characteristics of the vibration installation are given in the table. The operating principle of the installation is to create directed vibrations of the tray from a vibration exciter with a circular driving force and inclined elastic supports on which the tray rests.

The directed driving force causes the translational movement of the material along the inclined bottom of the tray towards the unloading side. When the chute is lowered and the tray vibrates, the material on it will begin to spill out of the hopper. In order to uniformly add ballast material to the sleeper grid, the installation during the unloading process must move slowly along the rails opposite to the movement of the flow of bulk material. The width of the material spreading front is adjusted by turning the sides of the chute.

Sleeper tamping vibration USHPV-750EG ((Fig.12). The principle of operation is to use the vibration received from a self-balanced vibration exciter, devices for converging the tamps and returning them to their original position to compact the material under the sleepers by compressing and the dynamic effect of the vibrating tamps when immersed in the material. Tamping the material under the sleepers is carried out in the following sequence. Initial position - installation with tampers installed opposite the sleeper.

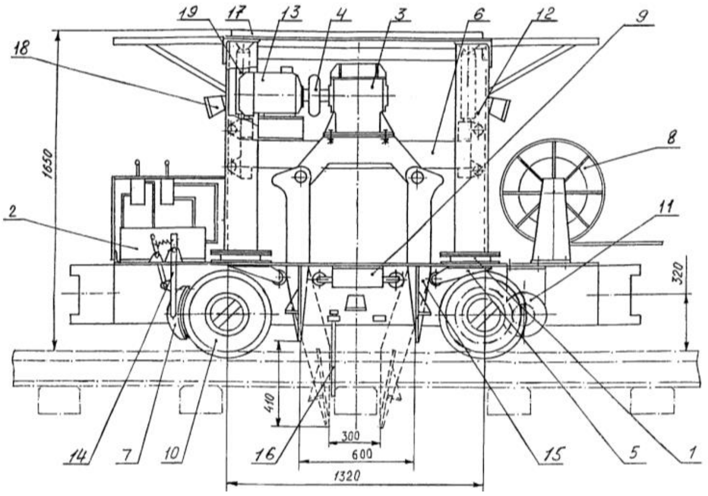

Fig.12. Sleeper tamping unit USHPV-750EG with electric hydraulic drive: 1 – shock absorber; 2 – hydraulic tank; 3 – vibration exciter; 4 – coupling; 5 – deflecting roller; 6 – movable frame; 7 – brake pad; 8 – coil; 9 – pressure rollers; 10 – wheelset; 11 – hydraulic motor; 12 – guide frame; 13 – electric motor; 14 – brake drive; 15 – tamper; 16 – sleeper indicator; 17– roof; 18 – headlight; 19 – hydraulic cylinder

Using a hand brake, the installation is secured against displacement, and the movable frame, moving along the guides, is lowered down using hydraulic cylinders. At this time, the vibration drive must be turned on. When the vibrating tampers are lowered, they roll along the deflection rollers and plunge into the ballast material, and begin to converge towards the sleeper, compacting the material under it. When the tamps converge, the spring-loaded pressure rollers deviate towards the axis of symmetry of the installation and, compressing the springs, are in constant contact with the tamps. After the tampers are immersed in the ballast material, hydraulic cylinders lift the movable frame with the tampers, while the springs of the pressure rollers, unclamping, return the tampers to their original position.

After lifting the movable frame to the upper position, the vibration drive is turned off, and the brake releases the installation from fixation. Then the hydraulic motor is turned on, which, through a gearbox, rotates one of the wheel pairs and the installation moves to the next sleeper. After the pointer contacts the sleeper, the hydraulic motor is turned off and the device stops. The operations of tamping ballast material under the sleeper are repeated. Further studies of the sleeper tamping vibration installation were aimed at achieving conditions for increasing the torque of the tamper immersed in ballast material, which made it possible to increase the efficiency of tamping ballast material under sleepers.

To achieve this goal, a new kinematic scheme for the interaction of the profiled working surface of the tamper with the deflecting roller was adopted. If in the first version the deflecting roller was located below the axis of rotation of the tamper O, then in the new version the deflecting roller is placed above the axis of rotation of the tamper and the profiled working surface of the tamper is made in its upper part. This scheme of force loading when lowering the tampers helps to increase the shoulder ***p*** of application of the deflecting reactive force ***R,*** which occurs when the deflecting roller comes into contact with the profiled working surface of the tamper, and increases its torque [22]. The torque relative to the tamper suspension hinge ***(M)*** will be determined by the formula

$$M = R \cdot p = \frac{P}{\sin\left(\mu - \alpha_1 + \alpha_2\right)} \times \\ \times \frac{\left(a_0 + x\right) \cdot \sin\left(90 - \mu + \alpha_1\right)}{\cos \alpha_1}, \tag{10}$$

where R – is the reactive force; P – driving force acting on the tamper; p – arm of application of reactive force; a_0 – is the vertical distance between points $\boldsymbol{O}$ and $\boldsymbol{D_0}$ in the original position; x – movement of the deflecting roller from point $\boldsymbol{D_0}$ to point $\boldsymbol{D}$ parallel to the axis ox; μ – angle of inclination of the tangent to the guide surface of the tamper at the point of support on the roller; α_1 – is the angle of inclination of the straight line connecting the center of the coordinate system xoy with the point of support on the deflecting roller to the ox axis in the initial position of the tamper; α_2 – is the angle of inclination of the straight line connecting the center of the coordinate system xoy with the point of support on the deflecting roller to the axis ox after the tamper rotation process.

The driving force of the vibration exciter ***(Pв)*** is determined by the formula

$$P_в = Am_{гр}\omega^2, \text{Н}, \qquad (11)$$

where A – is the amplitude of oscillations, m; ***ω*** - circular frequency of forced oscillations, s-1; ***g*** – acceleration of debalance masses (g=981 m/s^2); m_{gr} – mass of unbalanced loads, N.

Improved sleeper tamping and delivery-ballasting installations can be used in mining and coal mines of the Ukraine (Krivbass, ZZhRK, Donbass, etc.), Kazakhstan and other mining countries, helping to reduce manual labor, increase productivity and quality of track-laying work.

Rock transfer point in a quarry (Fig. 13). Designed for reloading mass in a combined scheme of road-rail transport of quarries and accumulating rock mass in warehouses without the use of mobile quarry equipment for its formation. Allows the formation of accumulating warehouses without the use of bulldozers and reduces capital and operating costs during reloading operations in a quarry with combined road and rail transport. The estimated annual economic effect per 1 transshipment point will be at least 500 thousand hryvnia. Thus, the considered machines and mechanisms are distinguished by their simplicity of design, high operational reliability and low manufacturing cost [23].

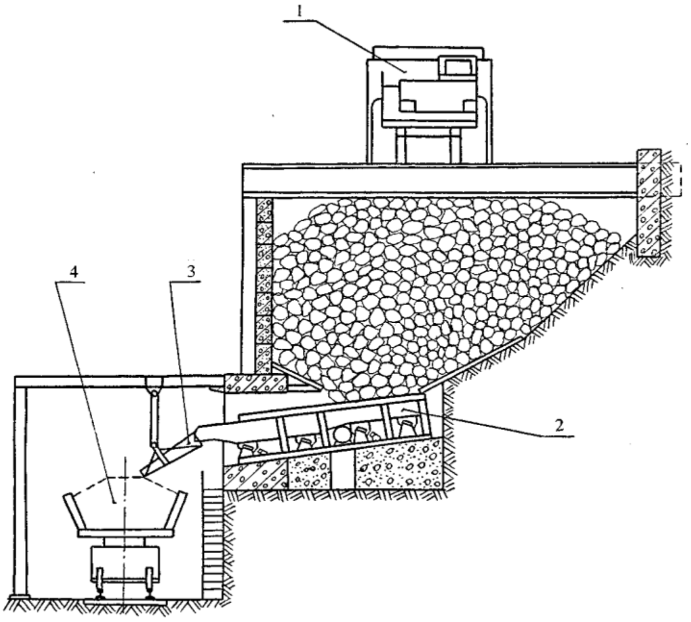

Fig. 13. Ore transfer point with vibrating feeders VPR-ZK (quarry version): 1 - dump truck; 2 - vibration feeder; 3 - shutter; 4 – dump car

Technical documentation developer – SE "UkrNIPIIpromtekhnologii" (Zheltye Vody, Ukraine).

Manufacturers: Krivoy Rog Ore Repair Plant (Krivoy Rog, Ukraine); Mechanical and repair plant of the State Enterprise " Vostok GOK" (Zhovti Vody, Ukraine); Mechanical repair shops of quarries, mines and processing plants, etc.

Implementation of work results. The results of the research were used by UkrNIPIIpromtekhnologii (Zhovti Vody, Ukraine) in the development of a number of designs of vibrating feeder screens of the type (GPV-350, GPV-100, PGV-40/400, PGV-200/400) and screening surfaces for them, and also for screens such as GIL and GIT; during industrial testing of the GPV-100 screen-feeder at the enterprises of the Ukraine; during industrial testing of the PGV-40/400 screen feeder at the; during industrial testing of cast steel screening surfaces with a curved grate profile at the Vostok GOK State Enterprise for separating ore with a particle size of 200 mm and 70 mm; during industrial testing of welded cascade gratings and rubber sieves with curved protrusions on the working surface at the Balaklava mine to produce crushed stone of 40 mm and 15 mm class (Balaklava village, Ukraine) and at the for ore dressing; Institute "UkrNIIugleobogashcheniya" (Lugansk, Ukraine) applied a methodology for calculating and selecting the dynamic parameters of a vibrating screen feeder when modernizing transport and transfer points of coal processing enterprises.

Promising areas of research. Continue research to improve the efficient operation of mining enterprises, including ferrous metallurgy mines, by providing high-quality binding components for preparing hardening mixtures and filling man-made voids formed during underground mining of solid mineral deposits. The use of research results opens up prospects for the survival of depressed mining and related enterprises in an emerging market. In particular, the use of enrichment waste as an inert filler in the filling mixture allows them to be recycled, which leads to a reduction in filling costs, a reduction in the cost and environmental safety of ore mining [24].

Recently, the backfill has been prepared by replacing cement with crushed binders mixed with sand and gravel materials. The strength of the bookmark varies widely, depending on the purpose of the artificial masses. In a number of deposits, hardening backfill mixture is used due to the need to preserve the earth's surface according to environmental conditions and improve life safety in mining regions.

Technologies involving filling voids with hardening mixtures occupy priority positions in the underground development of mineral deposits, in any conditions ensuring the safety of operational objects, safe mining operations, complete use and protection of subsoil and the environment. The main tool for activating the ingredients of a hardening mixture is a disintegrator, which, when exposed to a substance, creates an impact speed that is an order of magnitude greater than in vibration and ball mills and an acceleration of millions of free fall accelerations. Activation of ores in a disintegrator is an element of combining technologies for leaching metals from substandard raw materials, increasing the extraction of metals and accelerating the processes of metal leaching. Disintegrator technology provides an increase in the activity of binders by up to 40% [25].

The study of the parameters of a single process for processing ore enrichment tailings - mechanical activation in a disintegrator with chemical leaching was carried out in a DESI-11 type installation. Activation of mixture components on a vibrating screen, in a disintegrator and a vibrating pipeline with activation of water by deposition of salts and impurities expands the limits of the use of advanced technologies with filling with hardening mixtures.

It is necessary to conduct intensive research aimed at solving the problem of recycling accumulated waste from mining and metallurgical production. The implementation of effective methods for extracting metals from such waste will improve the environmental situation in the areas where they are stored and will ensure an increase in the mineral resource base of the mining industry. Wide involvement in the production of technogenic reserves of ore enrichment tailings, as well as the processing of off-balance ore dumps in terms of the content of useful components in modular plants contribute to obtaining an additional source for the industry in metals. And also to reduce environmental pollution in developed mining countries of the world . The technology and technical means for cleaning the internal surfaces of bunkers without the presence of maintenance personnel inside the bunker are most fully described in [26].

In our opinion, the following new scientific and methodological provisions deserve attention:

A mathematical model of a feeder-screen has been developed, taking into account the behavior of the box under the action of two multidirectional vibrator forces, providing both a directional forcing force and a moment that appears when the direction of forces changes.

The process of obtaining spatial oscillations of a feeder-screen from two multidirectional forcing forces applied at different points along the width of the working element, which affect its length, has been studied.

The analytical dependencies obtained for determining the parameters of vibration movement of the material take into account the behavior features of the working surface at different points along the length and width of the feeder-screen.

The movement of the material, taking into account the curvilinear nature of the working surface, has been substantiated and its parameters have been determined depending on the size of the separation product.

5. Conclusions

The minimum specific energy intensity of the release and loading of one ton of rock mass was established at the maximum value of productivity, which is ensured at frequencies of forced oscillations of the system $\omega =$ 15.5–17.5 Hz. It was shown that the use of a two-shaft inertial vibration exciter of directional oscillations with displaced unbalances allows increasing the free space under the working element and increasing the feeder productivity by 30–35%.

It was shown that the elastic system of the feeder with a buffer shock absorber installed in the direction of the driving force increases the load-bearing capacity, reduces the power consumption during transient processes and increases the technical productivity of the feeder by 1.15–1.25 times without an additional increase in power. The screening productivity of feeder-screens of the GPV-100 and PVG-40/400 types is substantiated by changing the direction of the driving forces of vibration exciters, which increased by 1.5 times. In this case, the rational vibration angles are $\beta_1 = 45°$ и $\beta_2 = 15°$.

It is proven that the recommended new designs of feeder-screens and screening surfaces made it possible to increase the efficiency of screening the material by 20-25%, productivity - by 12-15% and wear resistance of the screen - by 3-4 times due to changing and lengthening the trajectory of movement of pieces of material along the screen, eliminating their jamming in the screening holes, reorienting (turning over) large pieces in the process of their movement along the curvilinear working surface. It has been proven in practice that the use of new bunker device designs will allow: to mechanize the process of eliminating arches in the bunker and cleaning its walls from adhered material; to increase the productivity of material release by 2-3 times; to reduce the labor intensity of the process.

It is recommended to build transfer points, which is carried out without additional preparation of the working bench pillar. The operational capacity of the warehouse is selected within 15 ÷ 25 thousand m3 of rock mass. When used for loading into iron ore cars by EKG-8I excavators with a daily productivity of up to 5000 m^3, the warehouse reserve is 3-5 days.The efficiency of the feeder-screen with spatial oscillations of the working element created by two oppositely directed driving forces applied at two points at a distance from each other equal to 0.5 of the working element width is substantiated; it increases by 15%.

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