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The Experimental Investigation of a New Design of Stirred Media Mill

Abstract. With the rapid development of nanotechnology, the need to improve the efficiency of material grinding processes has increased. One of the criteria for the effectiveness of the process is the product fineness. There are various types of mills for grinding materials, one of which is stirred media mills. The article presents the results of experimental studies of a new design of stirred media mill on the example of sand particles size reduction. The principle of operation of the new mill is based on the organization of complex radial and axial impact on the particles of the material by grinding balls. To ensure this principle, a typical stirred media mill design includes an ellipsoidal rotor and a vibratory drive with springs. The results of the study demonstrated that the maximal product fineness of the mill with an initial sand particle size of 100 μm accounted for 2.32 μm, which is 2.6 times higher than the product fineness obtained in typical stirred media mill designs.
Keywords: mill, experiment, product fineness, particle, comminution, grinding ball.

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1. Introduction

Nowadays, comminution processes are widespread in many areas of production (construction, mining, food, chemical, etc.). The main problems existing in the comminution process are related to the need to increase the efficiency and productivity of the particle size reduction.

Among the various types of technological eqiupments for particle size reduction, stirred media mill is one of the most common machines. The typical design of the stirred media mill is depicted in the Fig. 1.

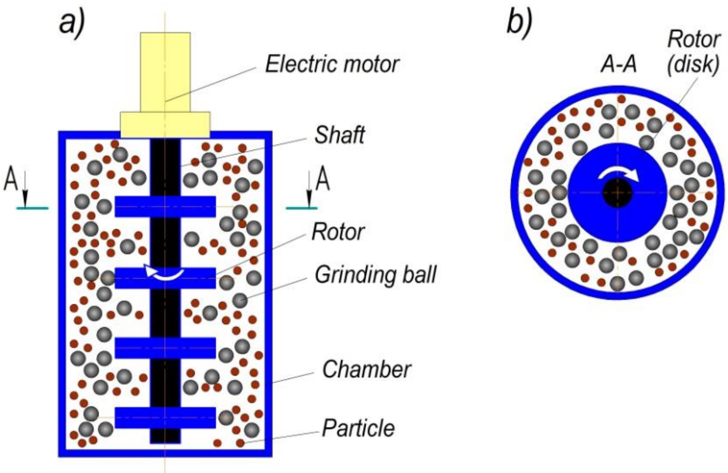


Figure 1. Typical desing of stirred media mill

According to the Fig. 1, the main elements of a stirred media mill are a chamber, a rotor, grinding balls, an electric motor. The principle of operation of the stirred media mill based on stirring the grinding balls and particles by the rotor.

To assess the factors determining the efficiency of the stirred media mill, many experimental studies have been conducted by other authors.

For instance, the authors of work [1] conducted an experimental study of the distribution of collision energy in a vertical stirred media mill. The results of investigation showed that a certain zone of high collision energy of the grinding balls is created during the spin of the rotor. With increasing the rotation speed of the rotor, the number of grinding balls in the zone of high collision energy has been decreased. As a result, while the value of collision energy increases, the stress number parameter decreases.

Authors of a research [2] found that the use of a disk-shaped (constant profile) rotor allows to achieve the highest product fineness and high energy efficiency of the process. However, the variable profile of the rotors (vane, pin-shaped) contributes to a more intensive circulation of the load, which is likely to lead to more collisions of the grinding balls.

The authors of a work [3] found that the frequency of collision of grinding balls and their destruction energy are inversely proportional [4, 5]. At a low value of chamber filling ratio, the probability of collision of the gridning balls is low. As a result, the probability of collision on the material is reduced. However, the balls moves greater distance to acquire acceleration, which leads to an increase in collision energy.

The authors of work [6-10] studied the effect of the shape of grinding balls on the efficiency of particle size reduction. As a sample of studies, spherical, square, and intermediate forms of grinding ball were selected.

To increase the efficiency of the grinding process by increasing the product fineness, the authors proposed a new design of the stirrred media mill, which is a vertical cylindrical chamber filled with grinding balls.

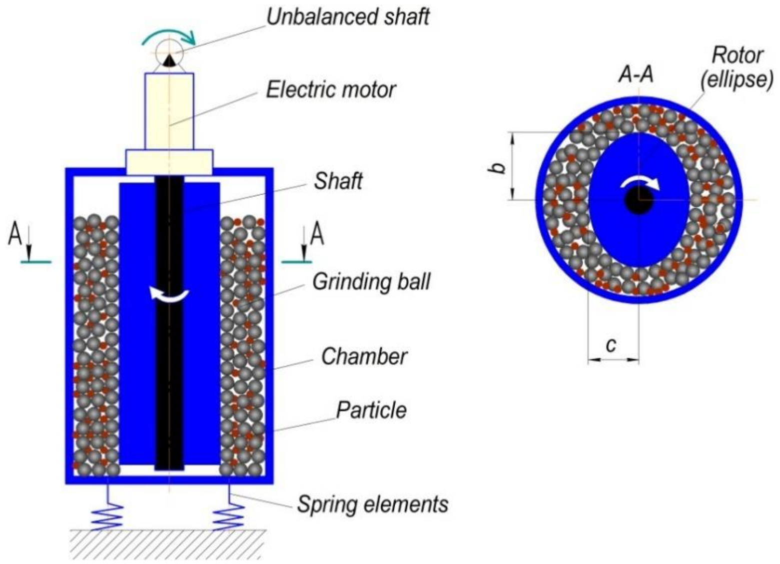


Figure 2. New design of the stirred media mill

To improve the efficiency of the grinding process, the following design innovations have been proposed in the traditional design of the mill:

1) the height of the rotor is approximately equal to the height of the mill chamber;

2) the shape of the rotor is ellipsoidal;

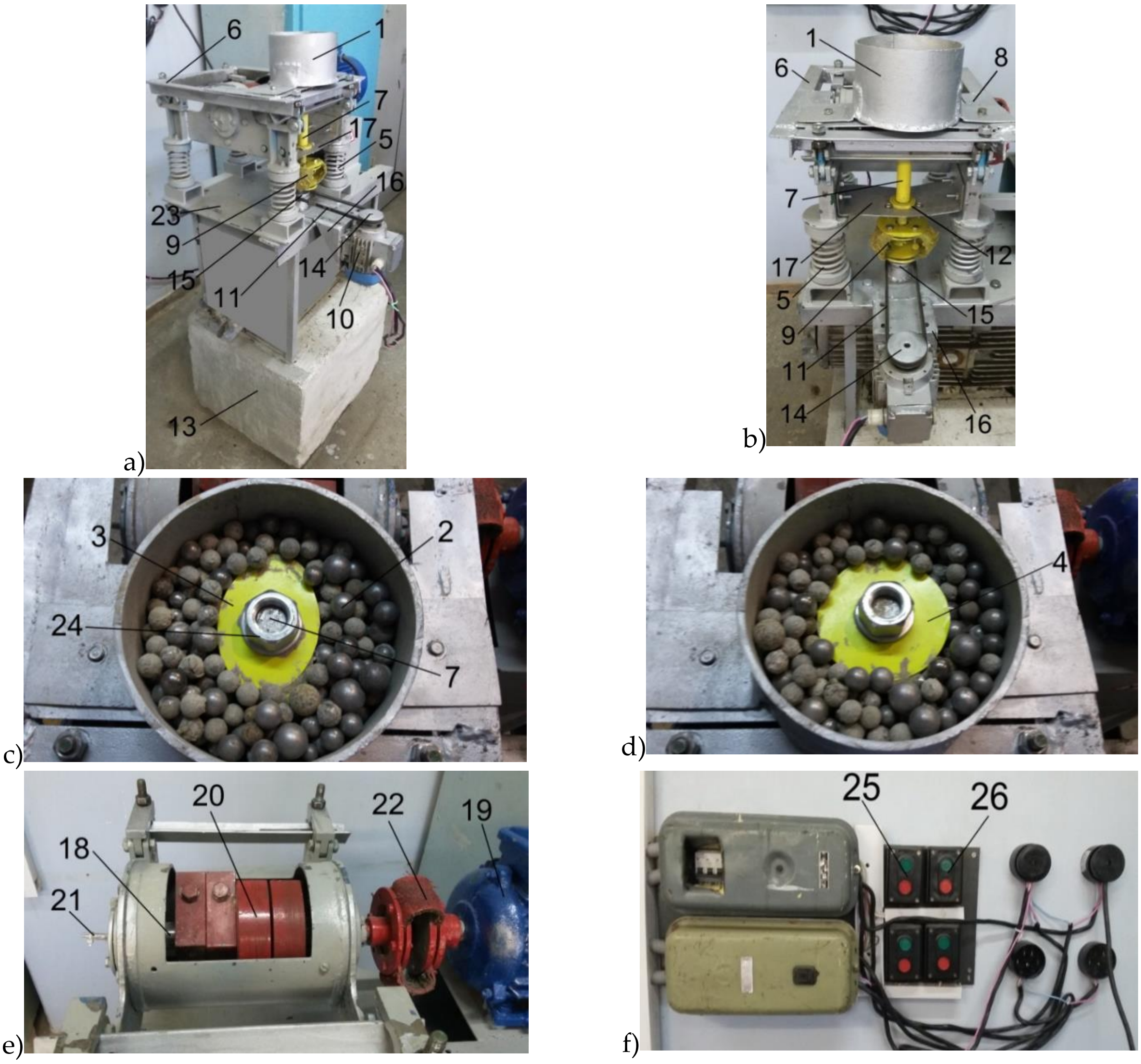
3) the mill includes a vibration drive system, consisting of an unbalanced shaft with an electric motor and elastic support elements similar to vibration vertical mills.

The purpose of this article is an experimental study the new design of stirred media mill.

2. Materials and method

2.1 Description of the experimental apparatus

In Fig. 3 the proposed design of a new stirred media mill has been presented. The mill consists of chamber 1, grinding balls 2, an ellipsoidal rotor 3, a disk rotor 4, a spring 5, a frame 6, a shaft 7, a spring 8, an elastic coupling to smooth out loads on the rotor shaft 9, the rotor motor 10, the drive belt 11, the bearing 12, the base 13, the driving pulley 14, the driven pulley 15, the bracket for mounting the rotor motor 16, support 17, an unbalanced shaft 18, an unbalanced shaft electric motor 19, an unbalance 20, an amplitude measuring device 21, an elastic coupling to smooth out loads on the unbalanced shaft electric motor 22, a support 23, nuts for fixing the rotor 24, switches 25 and 26.



a) Front view. b) Side view; c) Ellipsoidal rotor; d) Disc rotor; e) Vibration drive; f) Toggle switch
Figure 3. Experimental apparatus of the mill

The chamber is a vertical cylinder with a diameter of 120 mm and a height of 100 mm, fixed to a metal frame. Taking into account the high-speed mode of movement of the grinding balls, the thickness of the chamber wall with a size of 4.5 mm was chosen constructively.

The transmission of torque from the electric motor to the rotor shaft is conducted by a belt drive. The driving pulley is fixed on the motor shaft, and the driven pulley is fixed on the bearing support. The connection of the shaft with the driven pulley is provided through an elastic coupling. The elastic coupling is designed to smooth out the dynamic loads of the vibration drive.

The immobility of the shaft in the transverse direction is provided by three angular contact bearings. The vibratory drive of the mill is an unbalanced shaft connected through an elastic coupling with an electric motor. To damp vibration moving, the design of the vibration drive will be placed on four springs.

The ellipsoidal rotor (with a major semi-axis of 40 mm and a minor semi-axis of 30 mm)is the three-layer ellipse of dense rubber. The ellipsoidal rotor is rigidly fixed with an interference fit to the threaded part of the shaft. The choice of material for the ellipsoidal rotor is explained by the low rubber mass, which will prevent additional loads on the electric motor.

The experimental apparatus of the new mill consists of two separate drives. The first of drives ensures the rotation of the ellipsoidal rotor. The second of drives provides the vertical vibration mode of the chamber movement. The source of motion of the ellipsoidal rotor is an electric motor transmitting torque to the rotor shaft through a belt drive.

To assess effectivness of the new design of mill, the variant with using of disk rotor has been considered and investigated.

2.2 Input and output patameters

Taking into account the fact that the main parameter of the efficiency of mill is the product fineness d_p , the parameter has been chosen as the output parameter. Based on this, we have opted the input parameters (factors) of experimental studies.

Taking into account the quadratic functional dependence of the destruction (kinetic) energy on the speed of the grinding balls, we choose the rotational speed of the ellipsoidal rotor n_R as an input parameter affecting on the radial destructive effect of the mill.

Based on the existing studies of vibration machines [11], it should be stated that the main adjustable parameters in the axial direction are the amplitude A and frequency of vibrations n_A.

Thus, three main input parameters have been selected that can form the basis of a three-factor experimental study (Fig. 4).

Figure 4. Input and output parameters of experimental studies

The selected factors have been varied within the following ranges: $1000 < n_R \leq 2000$ rpm, $2{,}5 < A \leq 3{,}5$mm, $1000 < n_A < 3000$rpm.

The range for determining the factors was chosen based on the analysis of existing designs of the mills.

2.3 Milled material

Sand was chosen as the material for the experiment. Prior to the experiment, the ground material was previously sorted by size through a vibrating sieve to obtain the initial value of the particle size 100 μm (Fig. 5).

Figure 5. Sieve for preparing the initial particle size of the material

Sand has high strength physical and mechanical properties. The choice of a material with high strength characteristics will make it possible to adequately assess the effectiveness of the developed design of the mill.

2.4 Planning of experiment

To assess the effectiveness of the new desingn of mill, let us plan a first-order experiment. In accordance with [12, 13], we determine the total number of runs of a multifactorial experiment using the following formula:

$$N_{\exp} = n_{\deg}^{n_F} \tag{1}$$

In Eq. (1) $n_{\deg}$ is the number of factor levels; n_F - number of factors.

From expression (1) it follows that with the number of levels $n_{\deg} = 2$ and factors $n_F = 3$, the number of experiments will be $N_{\exp} = 2^3 = 8$.

Taking into account the interaction of factors, we will compose a planning matrix for this experiment (Table 1) with the following designations: $x_1 = n_R$, $x_2 = A$, $x_3 = n_A$.

Table 1. Experiment design matrix

Experience number	Planning matrix							Working matrix		
	x_1	x_2	x_3	x_1x_2	x_1x_3	x_2x_3	$x_1x_2x_3$	n_R, rpm	A, mm	n_A, rpm
1	+1	+1	-1	+1	-1	-1	-1	2000	3,5	1000
2	-1	+1	-1	-1	+1	-1	+1	1000	3,5	1000
3	+1	-1	-1	-1	-1	+1	+1	2000	2,5	1000
4	-1	-1	-1	+1	+1	+1	-1	1000	2,5	1000
5	+1	+1	+1	+1	+1	+1	+1	2000	3,5	3000
6	-1	+1	+1	-1	-1	+1	-1	1000	3,5	3000

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7	+1	-1	+1	-1	+1	-1	-1	2000	2,5	3000
8	-1	-1	+1	+1	-1	-1	+1	1000	2,5	3000

The matrix of the experiment, shown in Table 1, covers various level combinations of factor values and will allow determining the degree of influence of input parameters on the product fineness.

2.5 Experiment procedure

Before the experiment beginning, the sand has been put in the chamber (Fig. 6).

Figure 6. Filling the chamber with ground material

Then, using the switch, the drives of the experimental apparatus have been activated. As a result of the collisions of the grinding balls, the process of grinding sand in the mill chamber began. Further, turning off the rotor drive with an interval of one minute, the values of the product fineness were recorded, measured using an electronic device PSH-10 (Fig. 7).

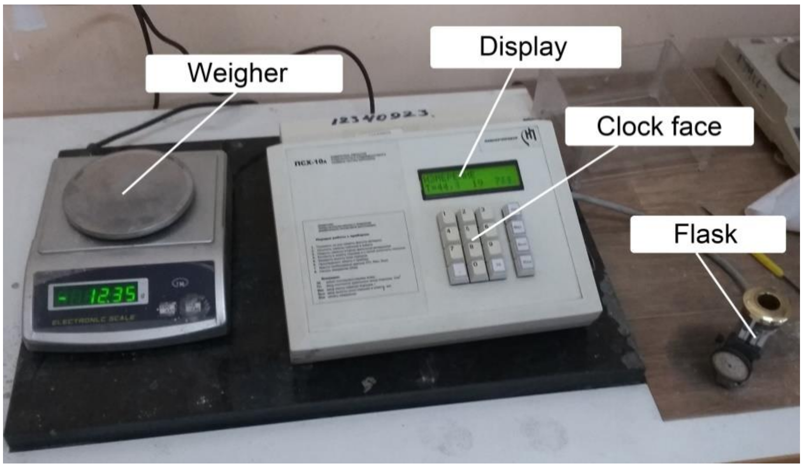

Figure 7. General view of the device PSH-10

To measure the product fineness, the mass and layer of the material destucted for one minute were previously determined using, respectively, electronic scales and a graduated cuvette of the device (Fig. 7).

The values of the mass and height of the layer are entered into the corresponding input fields using the dial of the PSH-10 device. The value of product fineness is displayed on the electronic display of the device after press the "Measurement" button. The procedure for measuring the product fineness every minute has been repeated five times. After measuring the product fineness in a minute, the ground material was reloaded into the grinding chamber and a similar process was repeated until a constant particle size of the product was reached.

Analogical procedure has been realised for different regimes, changing the values of the rotation speed of the ellipsoidal rotor, amplitude of the chamber vibration, and the rotation speed of the unbalanced shaft. The adjustment of the rotation speeds of the ellipsoidal rotor and unbalanced shaft has been conducted by the FR-E700 Mitsubishi Electric frequency converter (Fig. 8).

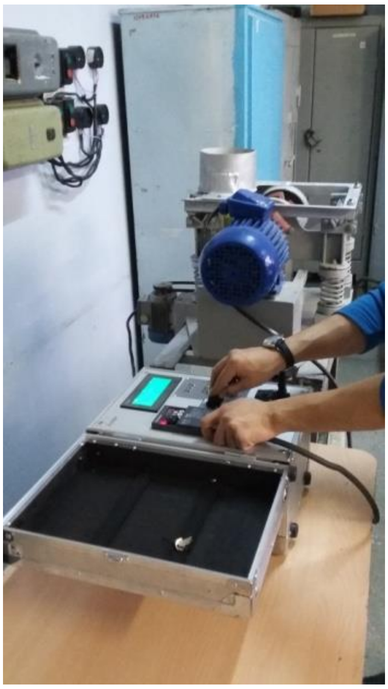

Figure 8. Frequency converter FR-E700 Mitsubishi Electric

The magnutude of vibration amplitude has been varied the positions of the unbalances.

3. Results and discussion

In Fig. 9 the results of the experiment corresponding to the following values of the rotation speed of the ellipsoidal rotor, the amplitude of the chamber vibration and the rotation speed of the unbalance shaft has been shown:

a) $n_R = 2000$ rpm, $A = 3{,}5$ mm и $n_A = 1000$ rpm (Fig. 9a);
b) $n_R = 1000$ rpm, $A = 3{,}5$ mm и $n_A = 1000$ rpm (Fig. 9b);
c) $n_R = 2000$ rpm, $A = 2{,}5$ mm и $n_A = 1000$ rpm (Fig. 9c);
d) $n_R = 1000$ rpm, $A = 2{,}5$ mm и $n_A = 1000$ rpm (Fig. 9d);
e) $n_R = 2000$ rpm, $A = 3{,}5$ mm и $n_A = 3000$ rpm (Fig. 9e);
f) $n_R = 1000$ rpm, $A = 3{,}5$ mm и $n_A = 3000$ rpm (Fig. 9f);
g) $n_R = 2000$ rpm, $A = 2{,}5$ mm и $n_A = 3000$ rpm (Fig. 9g);
h) $n_R = 1000$ rpm, $A = 2{,}5$ mm и $n_A = 3000$ rpm (Fig. 9h).

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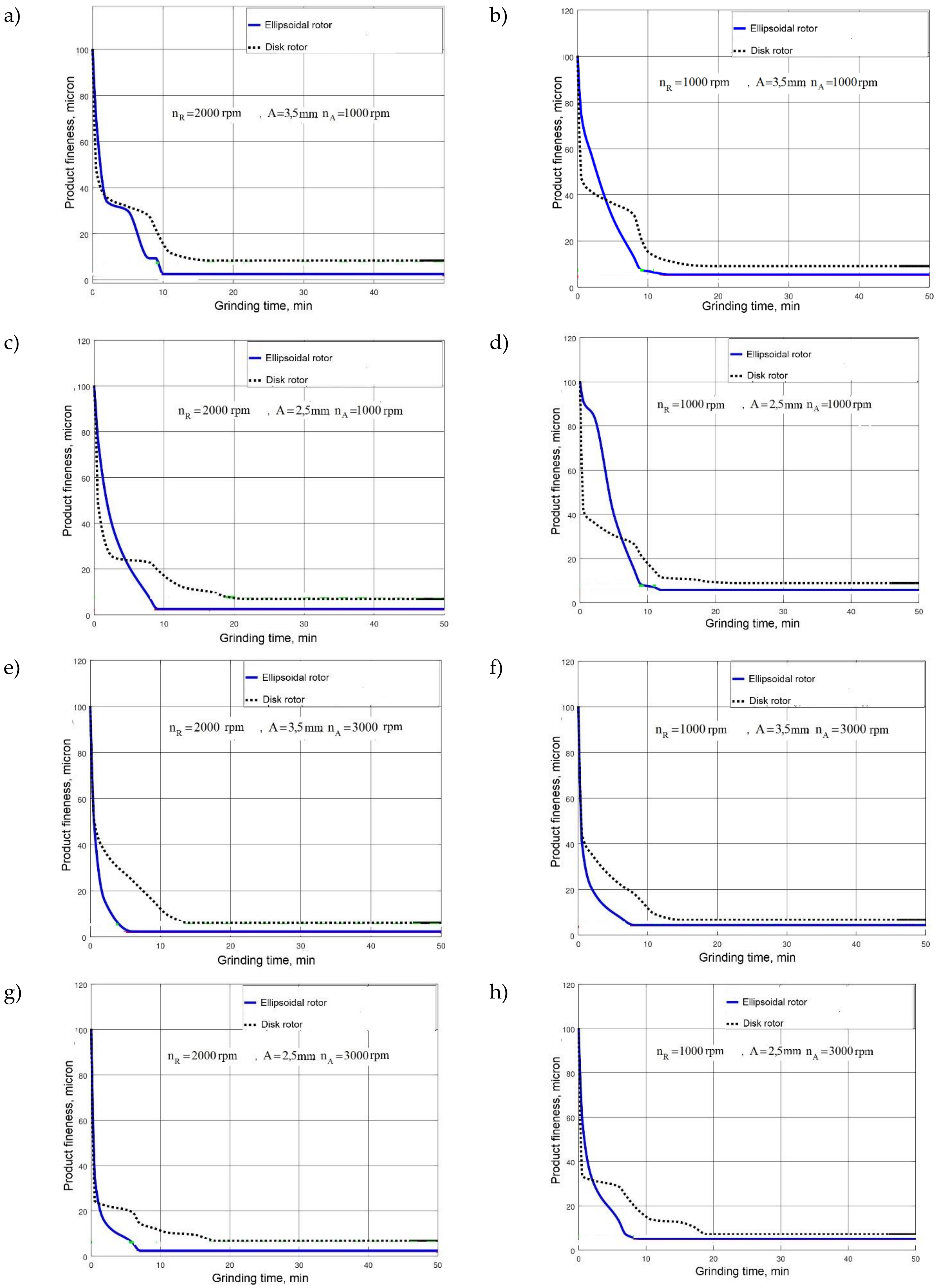

Figure 9. The results of theoretical and experimental studies

The results of the experiment are shown in Table 2.

Table 2. Experiment design matrix

#	The rotation speed of ellipsoidal rotor, rpm	Amplitude of the chamber oscillations, mm	The frequency of the chamber oscillations, об/мин	Theoretical product fineness (ellipsoidal rotor)	Experimental product fineness (ellipsoidal rotor)	Difference	Grinding time, min (ellipsoidal rotor)	Theoretical product fineness (disk rotor)	Experimental product fineness (disk rotor)	Difference	Grinding time, min (disk rotor)
1	2000	3.5	1000	2.04	2.52	19.05%	10	7.36	8.4	12.4%	17
2	1000	3.5	1000	4.46	5.48	18.61%	13	7.36	9.1	19.1%	19
3	2000	2.5	1000	2.1	2.62	19.85%	11	7.74	6.9	12.2%	22
4	1000	2.5	1000	4.71	5.76	18.09%	12	7.74	8.9	13.1%	24
5	2000	3.5	3000	1.86	2.32	19.83%	6	5.41	6.1	11.3%	14
6	1000	3.5	3000	3.66	4.42	17.19%	8	5.41	6.6	18.1%	15
7	2000	2.5	3000	1.99	2.44	18.78%	7	6.12	6.7	8.7%	18
8	1000	2.5	3000	4.3	5.26	18.25%	9	6.12	7.1	13.8%	19

Thus, it follows from Table 2 that the highest product fineness 3.03 μm has been achieved at $n_R = 2000$ rpm, $A = 3{,}5$ mm and $n_A = 3000$ rpm, i.e. the maximum values of the parameters.

Conclusion

Based on the results of the experimental investigations of the new design of stirred media mill, the following conclusions can be presented:

1. Experimental studies have been conducted with the comminution process of the sand with an initial size of 100 μm in the new mill. According to the results the maximum product fineness accounted for 2.32 μm.

2. The results of experimental studies have shown that the product fineness with using an ellipsoidal rotor at the maximum parameters of the mill is 2.6 times higher than when using a disk one. This fact confirms the relatively high efficiency of using the ellipsoidal rotor with a high degree of loading of the chamber with grinding balls.

3. It follows from the results of the experiment that the maximum grinding time is 2 times less in the case of using an ellipsoidal rotor than when using a disk rotor.

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Жаңа бисерлік ұсақтағыш конструкциясының эксперименттік зерттеуі

Аңдатпа. Нанотехнологияның қарқынды дамуымен материалды ұнтақтау үрдістерінің тиімділігін арттыру қажеттілігі артты. Үрдіс тиімділігінің сипаттамаларының бірі ұнтақтаудың жіңішкелігі болып табылады. Материалдарды ұнтақтауға арналған әр түрлі ұсақтағыштар бар, олардың бірі бисерлік ұсақтағышы. Мақалада бисерлік ұсақтағыштың жаңа конструкциясының эксперименттік зерттеулерінің нәтижелері берілген. Жаңа ұсақтағыштың жұмыс істеу принципі ұнтақтау шарлар арқылы ұнтақталатын материалдың бөлшектеріне бірлескен радиалды және аксиалды әсер етуді ұйымдастыруға негізделген. Бұл принципті қамтамасыз ету үшін бисерлік ұсақтағыштың типтік конструкциясы эллипсоидты профиль пішіні бар роторды және серіппелері бар діріл жетекті қамтиды. Зерттеу нәтижелері көрсеткендей, бастапқы бөлшектерінің мөлшері 100 мкм болатын құмды ұнтақтау кезінде зерттелетін ұсақтағыш ұнтақтауының максималды жіңішкелігі 2,32 мкм болды, бұл бисерлік ұсақтағыштың типтік конструкцияларында алынған ұнтақтау жіңішкелігінен 2,6 есе жоғары.

Түйін сөздер: ұсақтағыш, эксперимент, ұнтақтау жіңішкелігі, бөлшек, ұнтақтау, ұнтақтау шары.

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Экспериментальное исследование новой конструкции бисерной мельницы

Аннотация. С бурным развитием нанотехнологий возросла необходимость в повышении эффективности процессов измельчения материалов. Одним из критериев эффективности процесса является величина тонкости помола. Для осуществления измельчения материалов существуют различные типы мельниц, одним из которых являются бисерные мельницы. В статье приведены результаты экспериментальных исследований новой конструкции бисерной мельницы. Принцип работы новой мельницы основан на организации совместного радиального и аксиального воздействия на частицы измельчаемого материала мелющими шарами. Для обеспечения данного принципа в типовую конструкцию бисерной мельницы включены ротор с эллипсоидной формой профиля и вибрационный привод с пружинами. Как показали результаты исследований, максимальная тонкость помола исследуемой мельницы при измельчении песка с исходным размером частиц 100 мкм составила 2,32 мкм, что в 2,6 раза превышает тонкость помола, получаемую в типовых конструкциях бисерной мельницы.

Ключевые слова: мельница, эксперимент, тонкость помола, частица, измельчение, мелющий шар.

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