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Investigation of iron ore material behavior in semi-autogenous grinding mill. Part I. Grinding with innovative lifter shape.

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Abstract: *In the presented paper attention is paid to semi-autogenous grinding mills. Great attention is paid to software, working on discrete element method. A simulation using innovative lifter shape is made. As a starting material for the simulation is used iron ore. Analysis of the simulation is made.*

Keywords: lifters, SAG mill, simulation, grinding.

1 Introduction

In the mining industry the most used method for changing the particles size is the use of ball mills. Mills, used in mining industry are few types. In this paper, attention is paid to semi-autogenous and autogenous mills. Autogenous mills grinds the ore by rotating the drum of the mill, which causes lifting of the ore material to a specific height. In the inner surface of the mill drum are placed lifters. After the ore

is lifted, it starts falling by its own weight. When falls, the ore causes brakeage of itself and other ore material in the mill. Semi-Autogenous Grinding (SAG) mills uses the same method as autogenous mills, but uses also a grinding media – mostly balls, which helps for the grinding. The SAG mills are used in the first stage of grinding.
The aim of this paper is to investigate the behavior of iron ore material for milling in semi-autonomous grinding mill for milling with innovative lifter shape [1-3].

2 Software description

For investigating the behavior of the iron ore in SAG mill is used software, using discrete element method. The software provides appropriate results such as velocity, compressive force, mass, potential energy, torque, volume, etc.
The used software is segmented on three main modules. First module is the creator, which is used for setting parameters such as materials, equipment geometry, physics, etc. The particles properties, needed for setting simulations are: density, Poisson's ratio, coefficient of restitution, coefficient of static friction, coefficient of rolling friction and interactions between materials of particles and geometry. Other parameter in creator tab is the equipment properties, which is used for setting the material and properties of the used in the simulation equipment. After setting particles parameters and equipment parameters, comes the geometries, used for the simulation. It can be imported geometry from other CAD software, which gives the possibility for very accurate CAD model and particle behavior. In the CAD model, also it can be selected different properties of the objects and movements such as linear translations, linear rotations, velocity, acceleration etc. The software also provides different calculation models of calculations of the simulations. Some of the models are Hertz-Mindlin (no slip), Hertz-Mindlin (no slip) with RVD Rolling friction, Hertz-Mindlin (no slip) with JKR Cohesion, etc. An attempt for simulation the behavior of iron ore in SAG mill is used the Hertz-Mindlin (no slip) model.
The Hertz-Mindlin (no slip) model is based of Hertzian contact theory (1882) [4, 5] and the Mindlin model is based on the tangential force [6, 7].

3 Methodology for investigation

For investigation of iron ore material behavior in semi-autogenous grinding mill a methodology was made. The methodology contains the following tasks:

1. Choosing Material for milling;
2. Choosing material equipment for milling the material;
3. Choosing the equipment, needed for simulation of the process;
4. Modelling the needed equipment in CAD software and importing it;
5. Setting kinematics of the CAD geometry, if needed. In the specific case a linear rotation is set to the movement parts;
6. Setting number of particles for the simulation;

7. Choosing the appropriate model of calculation;
8. Setting simulation parameters such as: simulation time, simulation grid, etc.
9. Running the simulation;
10. Analysis and investigations of the obtained results.

4. Modelling and simulating the process

The chosen material for the simulation is iron ore. The needed data for the material is obtained from the software cloud library. Data contains bulk density of the material, coefficient of restitution, coefficient of static friction and coefficient of rolling friction. The parameters are shown in table 1.

Table 1. Parameters for bulk material.

PARTICLE MATERIAL PROPERTIES	VALUES
Density of material [kg/m^3]	2463
Coefficient of restitution	0.15
Coefficient of static friction	0.20
Coefficient of rolling friction	0.20

The shape of the particles, representing iron ore are obtained from the software is and are shown on figure 1. It consist 3 spheres with physical radius of 9.5mm.

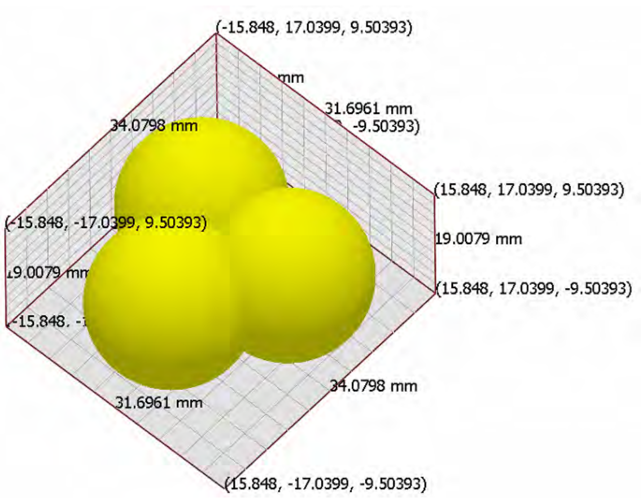

Fig. 1. Particle shape.

For material equipment is selected steel from the software library. Density of the material is 7850 kg/m^3 with coefficient of restitution 0.5, coefficient of static friction 0.5 and coefficient of rolling friction 0.01. For geometry is chosen laboratory mill (fig. 2), which is used also in other simulations [8-10], but with different shape and material of particles. The aim of this simulation is to be investigated the behavior of iron ore material with this specific geometry, which contains lifters with innovative shape, shown on fig. 3. [11]. Compressive force, angle of separation and angle of falling. The obtained results will be compared to the standard lifter shape of this laboratory mill.

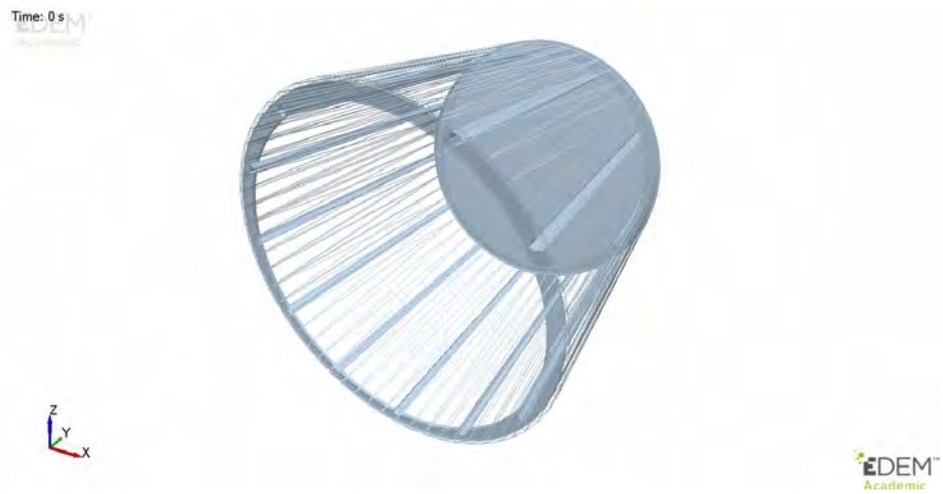

Fig. 2. Mill geometry.

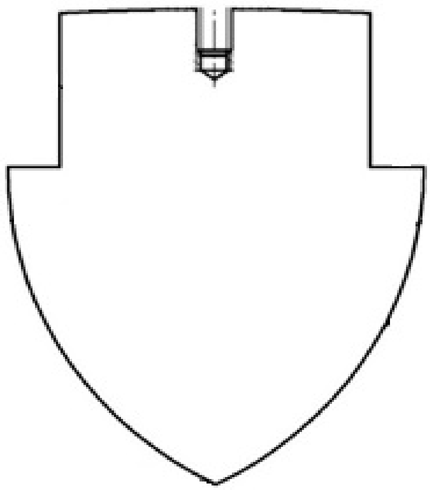

Fig. 3. Lifter shape.

5. Results and discussions

The obtained data from the simulation gives the opportunity to manually selection of different particles and to trace their trajectory, forces, velocities, etc. At the middle of the simulation are chosen numerous particles, which are at the top of the mill chamber, but still in contact with it. The contact is easily seeable by the usage of contact vector. For zero angle is selected the middle of the mill. And the obtained result is 100.42 degree, shown on figure 4. On the left side of the figure is shown legend with velocity of the ore particles in the simulation. The selected particles falls to the bottom side of the mill for a time of 0.25s. The angle of separation is important for the energy efficiency of the process. If it is possible to be reduced this angle, this can decrease the rotation speed of the drum, which will cause less energy consumption. Also, the form of the lifter can contribute for better crushing, by increasing the forces of the particles. Other simulations [8-10] shows that with the investigated lifter shape [11] are obtained bigger values for compressive force when are used steel spheres.

As the angle of separation, for angle of falling also zero is chosen for the middle of the mill. The falling angle is 72.63 degree and it is shown on figure 5.

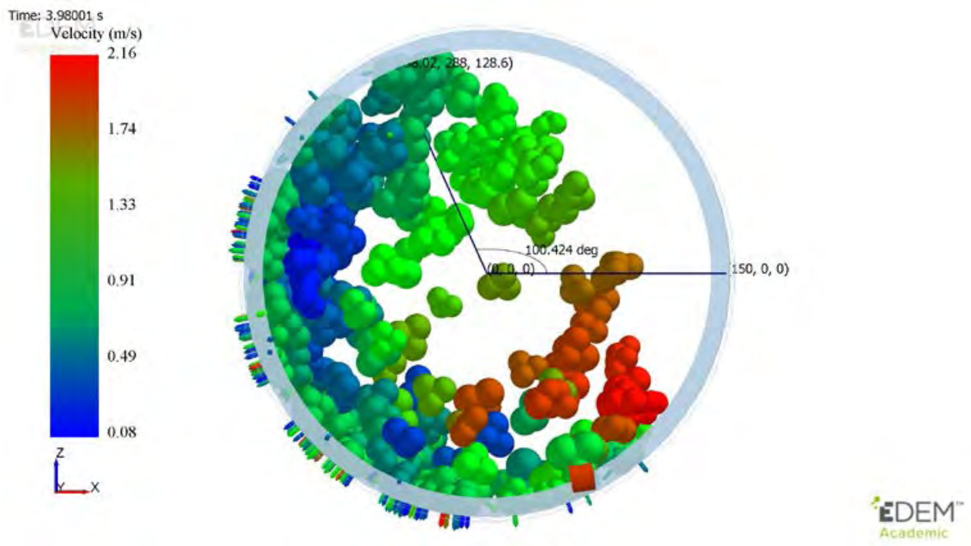

Fig. 4. Angle of separation.

The mass of the particles is about 10kg (fig. 6). To be close enough to real particles shapes and volumes, particle distribution is used. This is about 25% of the whole volume of the mill drum. With the chosen material properties, this is 350 particles – fig. 7. They are produced for 0.7s from the beginning of the simulation. When setting the simulation properties, it is good to check if all particles are processed and produced. Sometimes, when changing simulation parameters, that can affect to the particles behavior.

Figure 8 shows the average compressive force, obtained during the simulation. The data will be used to be compared with the standard lifters, used in the laboratory mill.

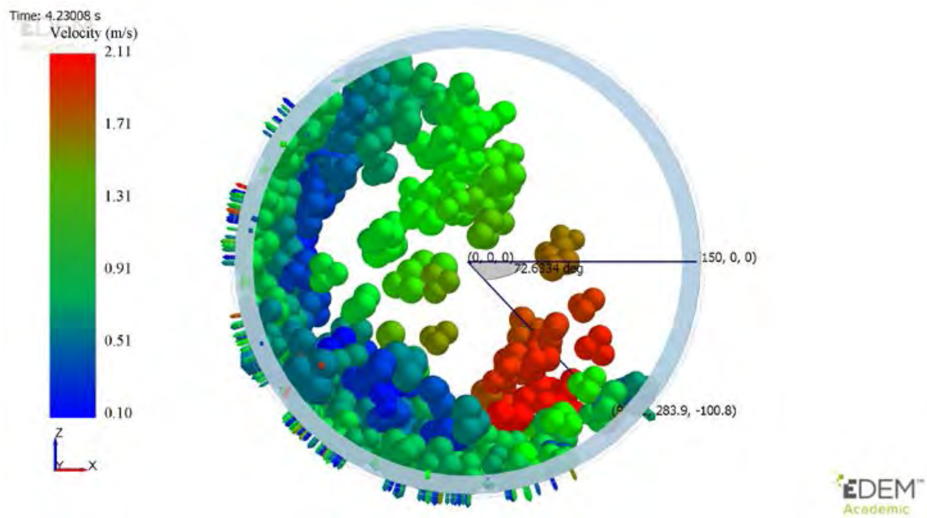

Fig. 5. Angle of falling.

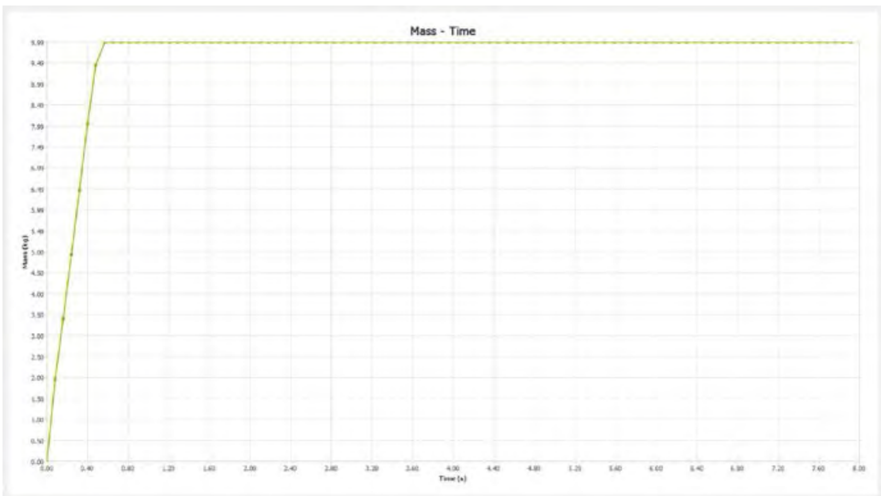

Fig. 6. Mass of the particles.

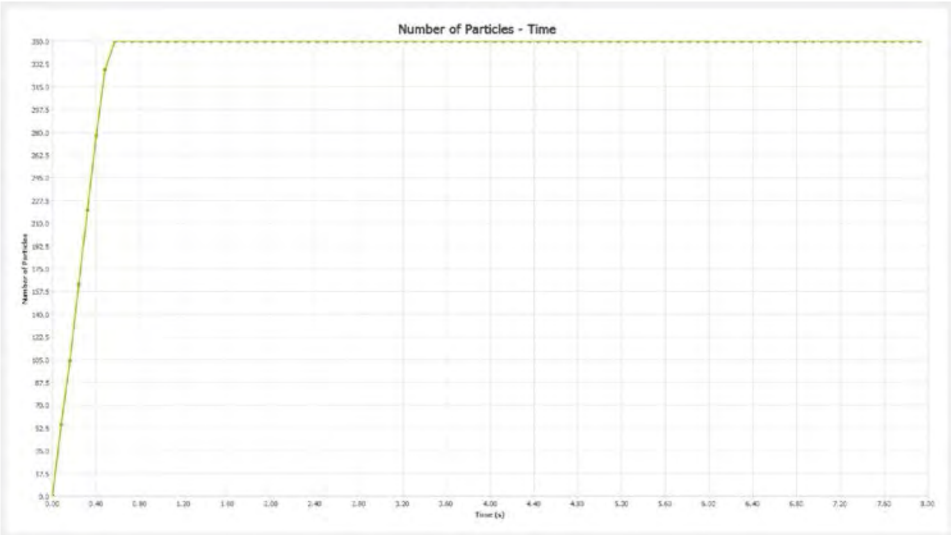

Fig. 7. Number of the particles.

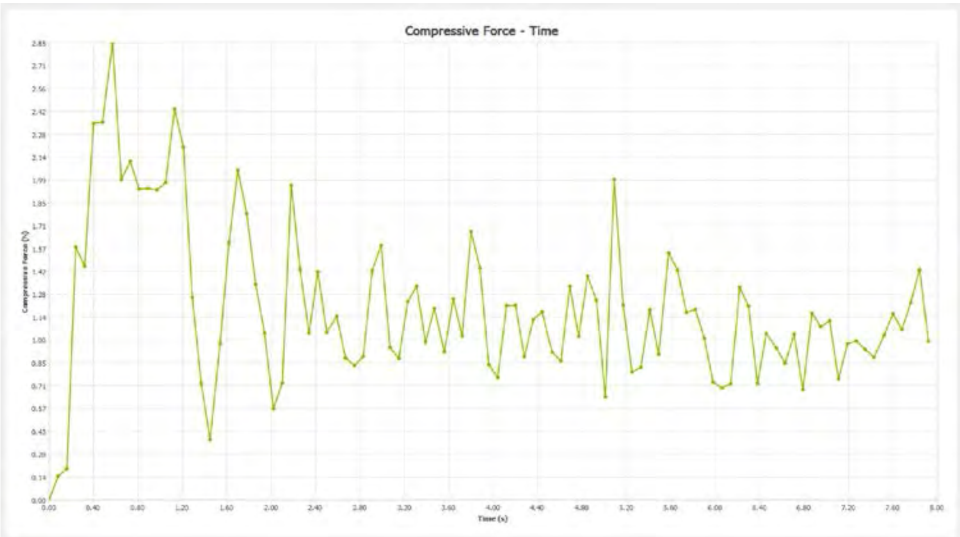

Fig. 8. Average compressive force of the simulation.

The selected particle group for investigating the angle of separation and angle of falling obtains maximum compressive force of 79.7N, shown on fig. 9. This force is achieved when particle falls and contacts with edge of the innovative lifter shape.
The average velocity of iron ore particles during the simulation is shown on fig. 10. Figure 11 shows the maximum achieved velocity of the manually selected iron ore particles.

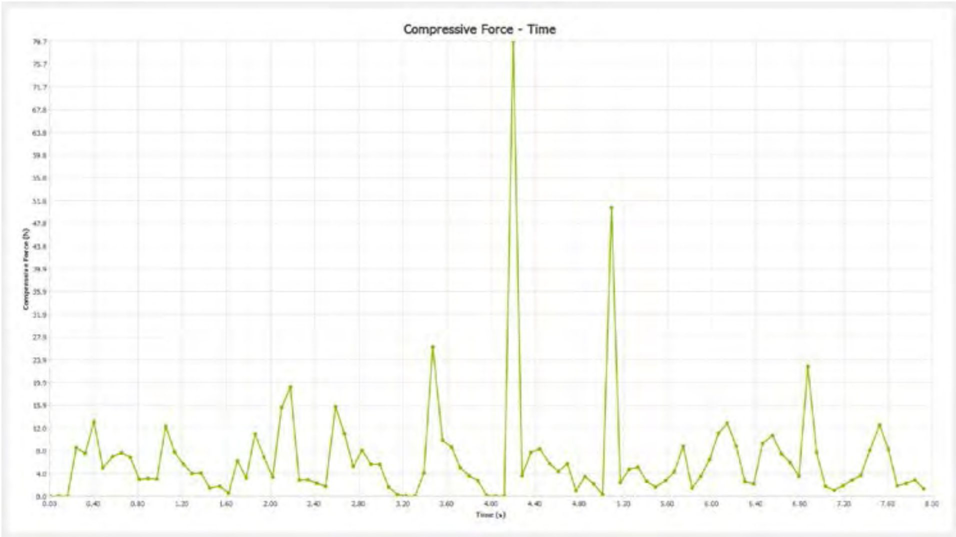

Fig. 9. Compressive force of manual selection.

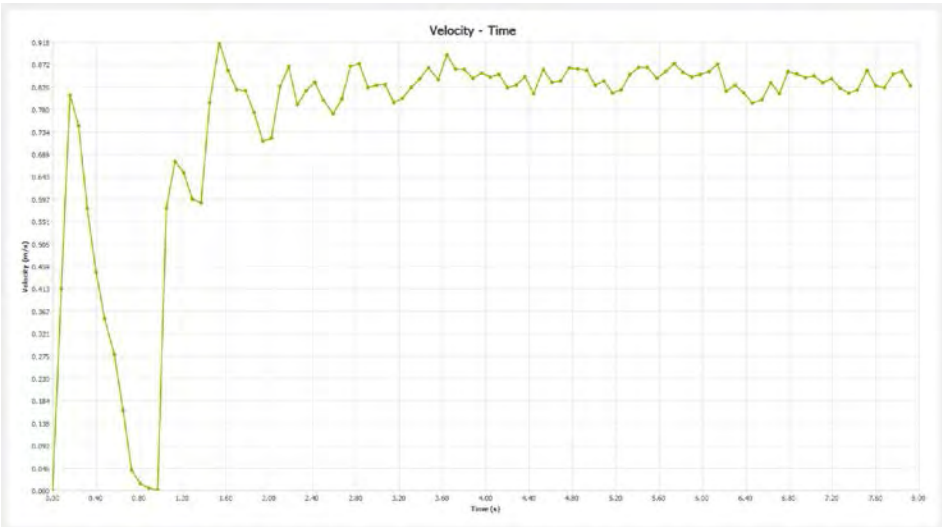

Fig. 10. Average velocity of the simulation.

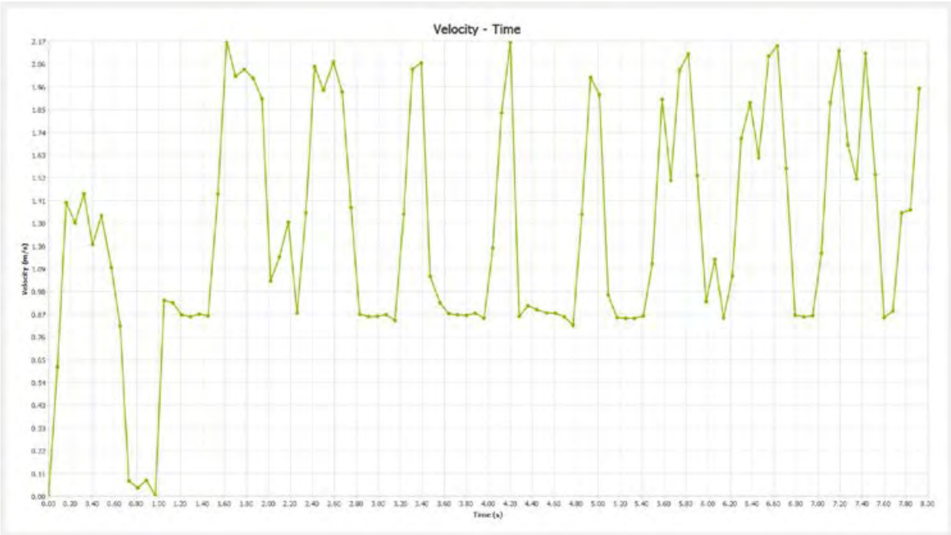

Fig. 11. Max achieved velocity of iron ore manual selected particles.

Conclusion

The obtained results from this simulation shows increased forces, velocities and angles of separation of the drum mill and angle of falling. This can contribute to energy efficiency of the process, by reducing milling time, energy consumption of the mill, etc. The obtained data will be compared with the standard lifter, used in the laboratory mill again with iron ore particle material. Previous investigations of this type of lifter shows better results for the innovative lifter shape instead of the standard for this laboratory mill, but in the previous simulations are used spheres. The process of milling is very complex and depends from various factors. Hence the process must be investigated with different shapes, sizes, and work regimes of particles, lifters, etc.

Acknowledgement

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References:

1. Jultov A., Machines for construction materials, Sofia, Technika, 1980 (in Bulgarian)
2. Tsvetkov H. Mineral processing machines, NP "Technology", Sofia, 1988 (in Bulgarian)
3. V. Monov, D. Karastoyanov and T. Penchev., Advanced Control Methods and Technologies for Two Industrial Processes., Third IEEE International Conference on Information Science and Technology ICIST 2013, March 23-25,2013; Yangzhou,Jiangsu, China., 978-1-4673-2764-0/13/ ©2013 IEEE., pp 187-194
4. EDEM Software manual – dem-solutions.com
5. Hertz H., On the contact of elastic solids, J. reine und angewandte Mathematik, 92 (1882) 156-171
6. Mindlin R. D., Compliance of elastic bodies in contact, Journal of Applied Mechanics, 16 (1949) 259-268
7. Mindlin R. D., Deresiewicz H., "Elastic spheres in contact under varying oblique forces." ASME, (1953) 327-344
8. Stoimenov N., Sabotinokv N., Sokolov B., Investigation relative wear of lifters with EDEM Software., International Conference Robotics, Automation and Mechatronics'16 RAM 2016, Byaga, Bulgaria, October 3-4, 2016, стр. 70-73, ISSN 1314-4634.
9. Stoimenov N., New Type of Lifters, International Scientific Conference "Machines. Technologies. Materials. 2016", September 2016, Varna, Bulgaria, ISBN: 1310-3946, pp. 32-34.
10. Stoimenov N., Innovative Relative wear of lifters, XIV International Scientific Congress "Machines. Technologies. Materials. 2017", 15-18 March 2017, Borovets, Bulgaria, volume 1, Section "Machines" pp. 25-28, ISSN: 2535-0021 (Print), 2535-003X (Online), Publisher: Scientific Technical Union of Mechanical Engineering Industry – 4.0
11. Karastoyanov D., Stoimenov N., Lifter, Bulgarian Patent Application, Reg.No 112174, priority from 14.12.2015

Исследование поведение железорудного материала в полу-автогенной мельнице. Часть I. Дробление с инновационной формой лифтера

Николай Стоименов, Никола Съботинков

Резюме

В представленной статье внимание уделено полуавтогенным мельницам. Большое внимание уделяется программному обеспечению, работающему по методу дискретных элементов. Проведено моделирование с использованием инновационной формы лифтера. В качестве исходного материала для моделирования используется железная руда. Проведен анализ моделирования.