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# Kinetic parameters of grinding media in ball mills with various liner design and mill speed based on DEM modeling

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**Abstract.** The article presents analysis of the experiments in the ball mill of 0.5x0.3 m with four different liner types based on DEM modeling. The numerical experiment always complements laboratory research and allow obtaining high accuracy output data. An important property of the numerical experiment is the possibility of visualization of the results. The EDEM software allows calculating trajectory of the grinding bodies and kinetic parameters of each ball for the relative mill speed and the different types of mill's liners.

## 1. Introduction

In Russia the overall production in building industry is growing each year and this determines necessity of reconstruction and modernization of enterprises producing construction materials and products. The ball mills proved themselves as reliable and productive equipment in the grinding of the clinker. The ball mills are simple in design and maintenance. However, ball mills are not deprived of disadvantages, the main is the low efficiency [1, 2, 3]. Therefore, an important aim is to increase the efficiency of the grinding process by providing an optimal motion mode of grinding media.

Lining profile significantly affects the motion mode of the grinding media and the wear of the mill drum and grinding bodies. Engineers and researchers aim to reduce the energy consumption of grinding plants, at the same time to reduce wear of the grinding bodies and to maintain the high quality of the finished product [4, 5, 6].

Simulations (based on the discrete-element method) were carried out in the software EDEM Solutions. EDEM allows creating models of granular systems of rigid bodies with specified parameters. The functionality of the EDEM allow one to combine mechanical, material and other physical properties in the simulation of systems in solids. Final models can be stored in the library which simplifies and accelerates the process of project implementation by the user [7].

The software manages and tracks information about each particle (mass, temperature, speed, etc.), and the forces that acting on it. For the post-processing analysis, EDEM provides data simulation and 3D visualization of the particle flux.

Interaction of elastic bodies is determined using a contact model based on Mindlin and Hertz theory [8]. The basis of the software package EDEM for account of the large number of particles is a discrete element method. The core of the program complex uses a physical model of contact interaction of elastic bodies of spherical shape, which defines how particles behave in the process of interaction with each other.

The article describes the results of the simulation of the grinding media motion in the ball mill



(overall dimension – 0.5x0.3 m) with different liners depending on the relative mill speed.

## 2. Method and discussion

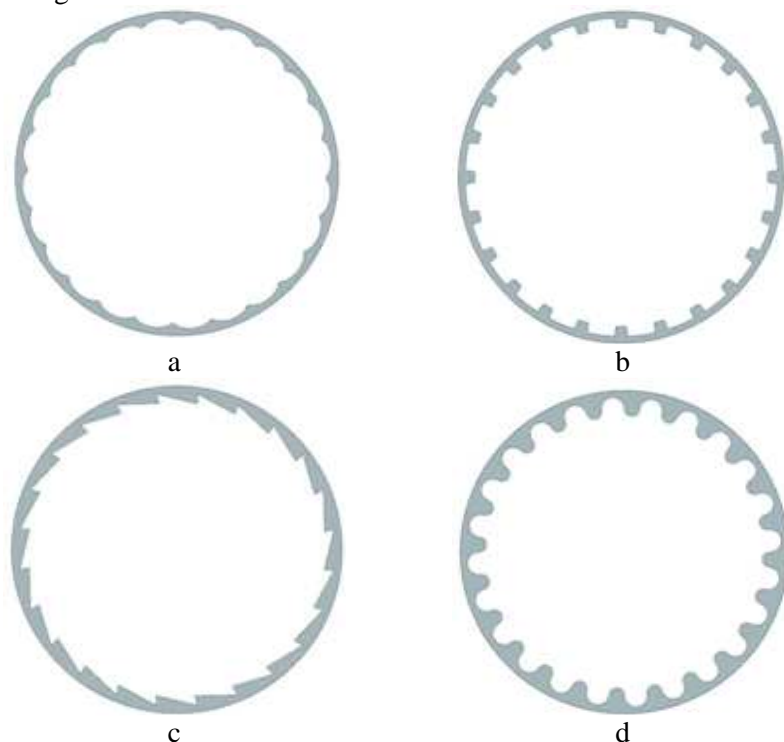
Mill drum and grinding bodies are made of a particular material. All materials and interactions between them must be defined. Materials can be created directly in the simulation or imported from the materials database. The values of the coefficient of restitution, the coefficient of static friction and the coefficient of rolling friction were meant to set to determine the parameters of interactions (contacts) of the materials and grinding bodies with each other. Interaction was determined for all materials used in the model, including when the material comes in contact with itself (in the case where two grinding bodies collide with each other). The diameter of the grinding bodies was set to 30 (mm). To define the kinematic parameters, the operating speed of the mill body must be determined. The required number of balls 30 (mm) for mill filling  $[\phi]=0.3$  is equal to 640 pieces [9, 10].

The initial parameters to create a simulation in the software EDEM are presented in table 1.

**Table 1.** Initial parameters for DEM simulation

Material	Poisson ratio	Density( $\text{kg/m}^3$ )	Shear modulus (Pa)	Coefficient of restitution	Coefficient of static friction	Coefficient of rolling friction	Grinding body (mm)
1.11	0.29	7800	$7.93e^{10}$	0.556	0.74	0.002	30 (ball)

The geometric models can be defined in EDEM or imported from any CAD package that allows one to export data in formats (Parasolid, Step203, Iges, etc.). In EDEM with standard system tools, one can create only simple volumes: a cube, a cylinder, a spatial polygon. 3D models of the liners were created in the CAD system NX and then exported in the format Parasolid. The profiles of the linings of the mill are shown in figure 1.



**Figure 1.** Types of mill liner: a – wave liner; b – lifter; c – step liner; d – double wave liner.

Simulations were made for each type of liners. The results were values of the average kinetic energy of the ball (table 2). Postprocessing was performed in EDEM Analyst, which is used to study the simulation results: playback the simulation, build a graph, create a video or export data to research in other places (e.g. Microsoft Excel).

**Table 2.** Average kinetic energy of grinding body in ball mill with various liners (J)

Wave liner	Lifter	Step liner	Double wave liner
0.042557	0.06425	0.02682	0.050798

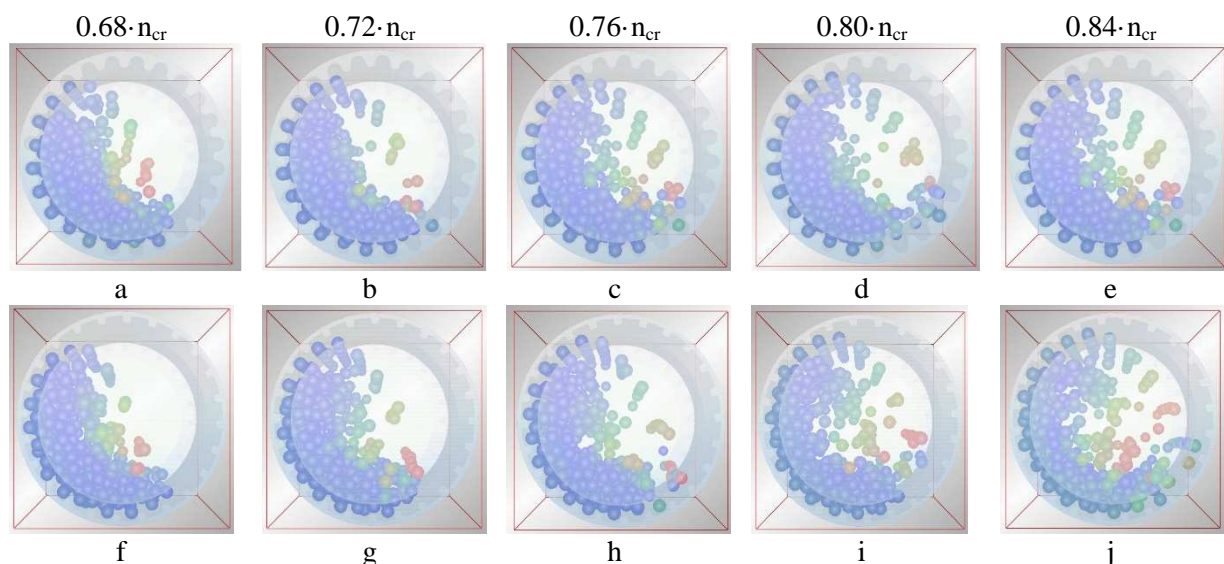
The double wave liner and the liner with lifters are the most effective because the average kinetic energy of the balls is higher than other type of liners (wave liner and step liner). For the double wave liner and the liner with lifters, liners simulations were calculated.

Mill speed was selected as a varied parameter. The estimated parameter is the average kinetic energy of the ball (table 3). It is known that with increasing the mill speed, the kinetic energy of the grinding media increases stepwise, and when it reaches values above the critical speed, kinetic energy increases steeply.

**Table 3.** Average kinetic energy of grinding body (J)

	Speed ratio				
	$0.68 \cdot n_{cr}$	$0.72 \cdot n_{cr}$	$0.76 \cdot n_{cr}$	$0.80 \cdot n_{cr}$	$0.84 \cdot n_{cr}$
Liner with lifter	0.050414	0.055817	0.06425	0.069035	0.076044
Wave type liner	0.041184	0.042073	0.050798	0.054484	0.059238

The result of post-processing of the simulations was the trajectories of the grinding media (provided steady run of the grinding process, Figure 2) depending on the different mill speed.



**Figure 2.** The trajectory of the grinding media depending on various mill speeds: a-e – wave liner, f-j – liner with lifters

By analyzing the trajectory of the grinding media in the mill drum (figure 2), the following conclusions can be made. Low mill speed results in the going up of a grinding media to a lower height (a smaller angle of separation). With increasing the mill speed for any type of liner separation, the

angle grows, helping to lift the grinding media to a great height, (values of kinetic and potential energy of the balls increase). However, when the mill speed is  $0.84 \cdot n_{cr}$ , the grinding media are going to throw on the liners, which will lead to rapid surface wear of the liners. Figures a-e show that the operation mode of grinding media changes. The transition to waterfall mode of motion is visible plainly (this mode is more energy-consuming, because it increases the moment of resistance to rotation). The same phenomenon is observed in figures f-j. Thus it is seen that the lifting height of grinding media in the mill with a lifters is more than in the mill with double wave liner. This is confirmed by the average kinetic speed of the grinding media (table 3).

### 3. Conclusion

Simulations of the grinding process allowed one to design profile of the inner surface of the drum (liner) in the mill; determined the motion path of grinding media; explored its features and assess the energy efficiency of the grinding process; predicted the intensity of liner and grinding body wear. The results of simulation provided to conclusion that the most effective is the profile with lifter.

The static images showed that the allocation of balls in the cross section of the drum is ineffective (mill speed is  $0.84 \cdot n_{cr}$  for both liner types, figure 2, e, j), and this mode of operation is non-optimal. The most effective profile is liner with lifters, the mill speed is  $0.76 \cdot n_{cr}$  (the average kinetic energy of the ball is 0.06425 J). Further planned research aims to evaluate the kinematic indicators of the grinding media insedentary core aimed at the increasing the efficiency of the mill and to analyze the influence of geometrical parameters of the lining on the grinding process.

### 4. Acknowledgments

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