Automation experimental studies of grinding process in jaw crusher using DEM simulation

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Automation experimental studies of grinding process in jaw cruiser using DEM simulation

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Abstract. In this paper, an algorithm for automating experimental research using computer modeling is presented. The grinding process in the jaw cruiser was chosen as the process for the study. Conducting experimental studies of crushing processes is a time-consuming process that takes considerable time. To obtain and confirm the characteristics of equipment and particles involved in the grinding process, it is necessary to conduct auxiliary experiments, which also require a long time and special equipment. Therefore, to accelerate the process of experimental studies of work in particular new equipment, it is effective to use numerical simulation. The main goal of the project was to create a methodology for determining the conditions and results of the crushing process instead of numerous experiments, which in turn would greatly accelerate and facilitate the research process. In the presented work, a model of the crushing process in a jaw cruiser using the Discrete Element Method (DEM) was realized. The use of modern software allowed studying in detail the impact of the cheeks of the cruiser on the crushing material. In the article, the process of modeling is considered step by step, starting with the design of the cruiser construction and ending with a comparative analysis of the results obtained with the experimental data. The obtained results were compared with computer simulation in accordance with the features of the operation of the presented installation, the nature of the destruction and the distribution of particles by size. The above analysis and comparison of results show the comparison of physical experiment and computer simulation.

1. Introduction

Preparation of rock mass for enrichment includes the power-consuming processes of crushing and grinding. Initial rock mass crushing is performed by means of drilling and blasting operations. To reduce the average size of a rock piece, primary crushers, mostly jaw crushers, are further applied. The advantages of the jaw cruiser are simple design, easy maintenance and repair. One of the drawbacks is large oscillating masses and, thus, high power consumption during operation (55 - 200 kW). Jaw crushing simulation will help optimize the crushing process and improve further rock transportation and processing performance.

Interactions between walls and material using the Discrete Element Method (DEM). Mainly ball mills, autogenous and semi-autogenous mills were investigated [1-4], whereas simulations of impact crushers are very rare [5-9]. The jaw cruiser with complex motion jaws has not been modelled yet. Therefore, the simulation of the comminution process in an impact cruiser is an interesting challenge we face.

The Discrete Element Simulation is one of the emerging tools for investigation of the fracture behaviour of compound materials, such as concrete. It has rapidly developed into a powerful instrument during the last years. The method treats the examined material as a composition consisting of individual small polygonal-shaped particles, which represent the components. These particles are considered as distinct elements and the Newton's law of motion and various contact laws are applied to each of these elements, which allow the visualisation and tracking of the crack propagation.
The Discrete Element Simulation is one of the emerging tools for investigation of the fracture behaviour of compound materials, such as concrete. It has rapidly developed into a powerful instrument during the last years [9-12]. The method treats the examined material as a composition consisting of individual small polygonal-shaped particles which represent the components. These particles are considered as distinct elements and the Newton's law of motion and various contact laws are applied to each of these elements, which allow the visualisation and tracking of the crack propagation.

The use of DEM requires simple but intensive computer calculation. It is also necessary to use modern graphical software to maintain the flexibility of predicting the initial values, promptly modify model properties, optimize parameters, include the properties not predicted at the initial development stage and simply select the best design from a number of options.

To perform the calculations, a low-frequency crusher with a complex swing of the cheeks was selected. [14]. Let us note that with the same overall dimensions, crushers with a complex movement of the jaws are more productive. It is this feature of crushers with complex movement of the cheeks that is of interest for modeling and optimization of motion.

![Figure 1](image)

**Figure 1.** Geometrical model of low-frequency jaw crusher

From a variety of available software packages and open integrated platforms, the Rocky software complex was selected as an optimization tool to simulate bulk processing processes and equipment. The simulation was conducted by means of the Mining University (Saint Petersburg, Russia) technology base with a high-performance workstation, with support of the company “CADFEM CIS”, and involved complex motion jaw crusher experiments performed in the production shop of the company “Mekhanobr-Tekhnika”.

2. **Initial data**

2.1 **Material modeling**

The commonly available construction material "granite" was chosen as the material to be examined. It was selected because of the numerous pieces of information about concrete properties available from
mechanics and civil engineering, and the practical experience which had been gained by preliminary studies at our department. So, the granite is modelled by larger particles representing the aggregates and smaller ones representing the hardened cement paste. The required micro-properties were assigned to the generated particles, which fill exactly the same shape of particles. In the presented work, the simulation was performed for the fineness of the finished fractions greater than 0.5 mm.

Features of the software package Rocky allow you to specify the parameters of the source material, as well as take into account the interaction of particles with each other and with the working elements of equipment (Table 1). The parameters identified in Table 1 are specified in this package as the initial conditions for the rock. Dimensional parameters are selected based on the average dimensions of the real piece of material.

| Parameter                      | Value       |
|-------------------------------|-------------|
| Vertical size factor          | 1.50        |
| Horizontal size factor        | 0.75        |
| Number of faces               | 25          |
| Density                       | 2.600       |
| Young’s modulus               | 1*10^8      |

Unlike many other DEM tools, there is modeling of spherical particles [13-14], Rocky deals with a wide range of standard particle shapes and is able to model custom particle shapes, which helps capture the destruction behavior of the material. A complex polyhedral shape of the particle was selected (Figure 4).

\[ E_{\text{min}} = E_{\text{min},r}(L_r/L) \]  

where \(L\) – particle size,  
\(L_r\) – average particle size,  
\(E_{\text{min},r}\) – minimum specific energy for the average particle size of the material (material constant).

The total interparticle energy is equal to the accumulated energy of previous interactions with consideration of the difference between interparticle energy and minimum energy:

\[ E_t = E_{\text{cum}} + \max(0, E - E_{\text{min}}). \]
The probability of particle breakage $P$ is calculated as follows [15]:

$$P = 1 - \exp(-S \cdot (L/L_r) \cdot E_t)$$  \hspace{1cm} (3)

where $S$ - particle strength parameter.

Upon particle breakage, the resulting geometric fragments are generated by Voronoi [16] shattering algorithm in the distribution as represented by the integrated function $T_{10}$:

$$T_{10} = M \cdot (1 - \exp(-S \cdot (L/L_r) \cdot E_t))$$  \hspace{1cm} (4)

where $M$ is a constant for the work material. Size distribution of the fragments formed as a result of breakage is calculated from $T_{10}$. Particle size distribution is calculated according to the Gaudin-Schumann model [18], where the mass fraction of particles remains constant in each calculation interval and is calculated by the equation with two given constants:

$$W_p = 100 \cdot \left( \frac{x}{k} \right)^m$$  \hspace{1cm} (5)

where $W_p$ – mass output, %

$x$ – particle size,

$k$ – particle size constant,

$m$ – distribution constant.

The parameters ($E_{min}$, $S$, $L$) are calculated with the JKMRC drop-weight tester. Let us note that the table above only contains some of the model parameters.

It is also necessary to consider the number of particles involved in the simulation. In the crushing process, the number of particles increases by several orders of magnitude with a significant increase in the duration of simulation.

3. Process Modeling

The crushing process is simulated to the extent of the working area where the material is crushed and the adjacent geometries (crusher jaws) move. The full-size geometrical model of the crusher is made by means of the solid-state modeling. The solid model was further prepared for calculation: all design elements (such as the frame, fasteners, etc.) which could complicate or were not involved in the simulation process were removed from the solid model. The prepared model was parametrized in ANSYS SpaceClaim, with the lower gap between the jaws being the output parameter. Multivariant calculation was performed in the ANSYS Workbench environment (Figure 3) designed for multiple automated variable-based calculations.
Figure 3 – ANSYS Workbench model

This system helps calibrate model parameters against physical data by creating a variety of models, which determines the effect of the initial parameters on the values considered and results in the most accurate and reliable models.

Then a special computer model was created to determine the kinematics and dynamics of the movement of the jaws in ANSYS Rigid Body Dynamics. Based on the obtained data, a trajectory of the motion of the jaws was provided, consisting of simple motions.

Geometrical model parametrization also enables output size control and model optimization for certain conditions. The prepared model can be easily imported to Rocky (Figure 4).

Figure 4 – Rocky DEM simulation of the complex motion jaw crusher with material processing. To observe the crushing process, different viewing angles can be set

4. Results and discussion
As mentioned above, we conducted a full-scale experiment at the company “Mekhanobr-Technika” to determine the crushing behavior of granite in the complex motion jaw crusher. The experiment involved
crushing a single piece of rock (50 mm) and removing various parameters from the model (particle size distribution (Table 2). Particle velocity, crushing time, power and performance are calculated with built-in Rocky functions from initial and boundary conditions.

| Table 2- Average distribution by class as shown by the experiment |
|------------------|-------|------|-----|-----|-----|-----|-----|
| Sieve cell, mm   | 5     | 2.5  | 1.25| 0.8 | 0.5 | 0.18| 0.074|
| Mass of class, g  | 0.832 | 20.982| 54.350| 22.236| 5.564| 19.664| 8.579|

Based on the experimental data (Figure 5), the model was calibrated to match real-life results. The model calibration against the experimental data was described above in detail.

**Figure 5** – Particle size distribution as shown by the experiment on 3 samples of granite

To obtain the required crushing parameters, we created a correlation model using the ANSYS DesignXplorer parametric optimization package built in the ANSYS Workbench environment. The correlation model helps evaluate the effect of the required parameters on the size of the output material.

The model-based table (Figure 6) is a visual representation of interdependence of the parameters. The red color represents direct dependence, and the blue color – inverse dependence, and the other colors represent the interdependence of the parameters.
Figure 6. Effect of crushing parameters (Ems - Minimum specific energy, Csf - selection function coefficient, T10) on fractional yield (P19-0.8 - fractional yield 0.8 mm, P20-1.25 – fractional yield 1.25 mm, etc.). The next step was to build a model that would closely match the experiment by the yield of small fractions by selecting the crushing parameters for the granite particle. Figure 7 shows a comparison of the experimental data and the simulation results.

Figure 7 – Particle size distribution after experiment and simulation

Figure 7 shows particle size distribution of the output crushed product. The experiment bar graph shown in Figure 6 correlates with the simulation bar graph which is mostly above the experimental data. The lower limit of particle size was set at 0.5 mm, primarily due to the fact that simulation of fine particles takes a lot of time even with the use of high-performance workstations. The proposed model certainly requires further refinement and adjustment, especially against different operating modes of the jaw crusher and different densities of the material. The obtained model for particle size exceeding 0.5 mm accurately matches the experiment, although with a certain degree of error.

One of the solutions to this problem is using a cluster (a group of computers linked by high-speed communication channels) or applying the Maxwell-Boltzmann distribution for the analysis of fine-particle systems. In this case, there will be no need to perform numerical calculations for each element,
but rather use a probability distribution model. Since the interaction fine particles during crushing tends to be relatively poor, the Maxwell distribution will provide good approximation.

5. Conclusion
Simulation of the crushing process in the jaw crushe is one of many DEM application examples. Simulation approaches can become the basis for further detailed studies of the process. The proposed approach involves the substitution of complex and costly crushability tests (drop test) performed to obtain the parameters for the mathematical model for the selection of the required parameters based on the experimental crushing results with the use of correlation analysis and multivariant calculation.

Using specialized software and parametric models enables prompt design modification and equipment optimization. When modeling the process, it is difficult to predict the number of output crushed particles. The inaccuracy of the simulation results is due to the practical complexity of modeling the particle size of less than 0.5 mm. Generation of finer particles results in the increased calculation time. The number of particles in the model largely determines the accuracy of the results.

In summary, we can state that in this paper we propose a technique for automating experimental data that allows us to optimize the parameters of technological equipment and significantly reduce the cost of additional experiments. In addition, in the process of modeling, it is possible to conduct an analysis of durability and calculation of fatigue of structures. This problem can be solved by further research.

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