The simulation analysis of different tooth numbers of loader bucket based on EDEM

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Abstract. To study the loader from the aspects of bucket tooth numbers in the process of shoveling. Firstly, to simplify the three-dimensional geometric modeling in "four basic parameters method". Then simulation experiment is applied by a shovel-loader for different teeth in the discrete software EDEM, the influence of the number of bucket teeth is analyzed by using the single factor analysis method about resistance of the shovel. To determine whether the number of teeth is significant. Research results show that the resistance of the shovel gradually increases and renders the index distribution when the shovel is in the insertion phase, it has an influence on shovel loading about the numbers. The number of bucket tooth almost has no effect on shoveling loading resistance in lifting stage. According to the whole process, considering the factor of full bucket rate and the resistance of the shovel, five bucket tooth uneven distribution model will be the right choice.

1. The introduction
The loader is a very common type of transportation machinery in engineering machinery. It is mainly used to shovel, unload, transport and smooth bulk materials. Because of many advantages, it is widely used in industrial production[1]. The bucket tooth of the loader is an important component of the loader structure, as well as a vulnerable part, the mounting part of the bucket tooth is at the front end of the bucket and belongs to the cantilever beam structure. In the process of shoveling loading, the bucket tooth is contact with the material, not only the reaction force is from the material pile, but also the very large bending moment. Accordingly, its working condition is very bad, it not only increases the wear amount of the bucket tooth, but also affects the life of the bucket, which causes a great economic loss, therefore. In some working conditions, how to fit the bucket teeth on the bucket, indent teeth have great significance to improve the loader's shoveling performance and shoveling loading efficiency.

In this paper, the loading test of different materials is carried out to obtain the working resistance and full bucket rate about different bucket teeth in the shoveling loading process, the kind of pure experiment has many influent factors, not only can not accurately obtain the shovel-loading resistance in the shoveling loading process[2], it is also difficult to guarantee the reproducibility and repeatability of the experiment, which will lead to a great error, the current research on this aspect, whether in universities or enterprises, the numerical simulation technology is combined with CAD and CAE.

2. The basic theory of discrete element method and the establishment of model

2.1. The basic principle of discrete element method
Discrete element method is a kind of numerical simulation method which is used to solve the problem of
discontinuous media. The basic principle is to divide the subjects into independent units, because of the interaction between independent units, on the basis of Newton's laws of motion. The dynamic relaxation method or the static relaxation method are two kinds of iterative calculation method for cycle. The force balance of all elements, the moment and all units are displaced within the small enough time step, the position and the microscopic movement of each cell are tracked, so as to show the whole object of studying of macroscopic motion law[3].

2.2. The simplification and establishment of three-dimensional geometry model
The loader bucket is usually welded by the front edge plate, bucket bottom wall, back wall, side edge, side wall, baffle and hinged ear plate, bucket adopts the four basic parameter method[4]. The bucket structure is determined. As shown in Figure 1. It is characterized by the ratio of parameters to show the "shape" of the bucket, which has the advantage of reducing the experience coefficient and simplifying the calculation of bucket parameters, in the case of not affecting the scraper resistance, some rounded corners and cutting edges are removed. The original rational experiment is carried out with the bucket model, which is based on the general similarity principle to realize the shoveling loading rule of the actual bucket.

Figure 1. The simplified shape of bucket

3. Establishment of discrete element simulation model

3.1. The selection of contact model and setting of contact parameters
In particle contact theory, contact model is an important basis of discrete element method. Its essence is the solid particles under quasi-static elastic-plastic contact mechanics analysis. The result of the analysis is obtained by contact model directly, and determining the size of the particles by force and moment. For different simulation objects, different contact models must be established, and there are usually six contact models. In this study, Hertz-Mindlin's non-slip contact model is selected to calculate force of the particles in EDEM. The theoretical basis of this contact model is the research results of Mindlin. In order to establish an accurate and appropriate simulation model, the simulation model should be set up correctly, the relevant literature and the previous production experience are summarized. The property parameters of the material are shown in Table 1, and the contact property parameters of the material are shown in Table 2[5-7].

| Material | Poisson Ratio | Shear Modulus (Pa) | Density (kg/m³) |
|----------|--------------|--------------------|----------------|
| Gravel   | 0.20         | 5e+07              | 2600           |
| Steel    | 0.30         | 7e+10              | 7800           |
Table 2. Material's contact attribute parameter table

| material       | coefficient of restitution | coefficient of static friction | coefficient of rolling friction |
|----------------|-----------------------------|--------------------------------|-------------------------------|
| gravel-gravel  | 0.5                         | 0.9                            | 0.15                          |
| gravel-steel   | 0.5                         | 0.4                            | 0.05                          |

3.2. Establishment of particle geometry model

There are various kinds of gravel particles in the real experiment, which is usually divided into five types: angle, slice, strip, square and middle type. In order to create accurate particle model, previous scholars used reverse engineering techniques to create CAD model of rock particles, the results of the granule model are in accordance with the actual gravel shape, it has high accuracy. Sphere is default particle shape in EDEM, if simulation experiment is carried out with spherical particles simply, there will be a big error, the simulation results are not accurate, thus creating the complex shape of particles in the study. As shown in Figure 2. The material heap model form basically is stacked in accordance with the Reposed Angle of the material. As shown in Figure 3.

Figure 2. The simulated model of rock particles
Figure 3. The model of rock

4. Analysis of drag loading resistance in EDEM

4.1. The loader bucket bucket model is established

In order to study the influence of the number of bucket teeth on the drag resistance. A simplified model of bucket tooth size is established. In order to ensure the accuracy of the simulation analysis, it is necessary to ensure the analysis of the single factor, the shovel is installed, shoveling loading trajectory has chosen a shovel crate, bucket simplified motion parameters are shown in Table 3, 7 tooth shoveling bucket model is shown in Figure 4 with material object, other bucket tooth number of simulation is in the same way.

Table 3. Simplified movement parameters of bucket

| velocity                      | 0s-2s | 2s-2.8s | 2.8s-4s |
|-------------------------------|-------|---------|---------|
| Horizontal velocity[m/s]      | 1.2   | 1       | 3       |
| The vertical speed[m/s]       | 0     | 1       | 0       |
| The angular velocity[rad/s]   | 0     | 1.5     | 0       |

Figure 4. The object picture of seven tooth shoveling loading material

4.2. Analysis of the drag load resistance of bucket with different bucket teeth

The bucket of different bucket teeth is used for material shoveling, and the drag pattern of different
bucket teeth is formed. As shown in Figure 5. In order to understand the resistance of different bucket teeth in the shoveling bucket during the whole process, the whole process of the shovel is divided into four regions. As shown in Figure 6.

![Figure 5. General drawing of resistance curve of different bucket tooth number](image)

![Figure 6(a). Phase 1 of inserting](image)

![Figure 6(b). Phase 2 of inserting](image)

![Figure 6(c). Phase 3 of inserting](image)

![Figure 6(d). Diagram of elevation phase](image)

I can see from the figure above:

1. In the process of shoveling, the drag resistance of the shovel will increase with the increase of the insertion distance, and the index distribution state will be presented.

2. In the 0cm-50cm section of the bucket insertion (as shown in Figure 6 (a)), the number of the bucket tooth has little impact on the drag resistance of the shovel. Within 50cm-200cm (as shown in Figure 6 (b)), the resistance will gradually increase with the increases of the insertion depth, and it will have certain volatility within a certain range. Within 200cm-240cm (as shown in Figure 6 (c)), the drag resistance of the bucket will increase, it can be seen that the maximum shovel-drag resistance of the bucket will appear at the moment when the shovel is about to be elevated, because the bucket will need to overcome the whole pile resistance.

The drag resistance of the shovel will become smaller and smaller in the elevating stage, showing the number of bucket teeth and the law of the shoveling resistance of the shovel(as shown in Figure 6(d)). This is mainly because the bucket is on the elevating process, heap scoops out gradually, the reaction between windrow gradually decreases, the inside material of the bucket goes toward the bucket inside for the loose area, the force of bucket tends to be stable, the outside material of bucket is under the action of its own gravity for outside slip zone, and becomes gradually stable.

3. By comparing the resistance curves of the shoveling load in Figure 5. It can be seen that the
maximum shovel-mounted resistance of the three-tooth bucket is higher than the others, and the maximum drag resistance of the toothless bucket is least, in addition, the comparison of full bucket rate is also carried out, and the quality can be compared indirectly through the shoveling load. The quality of the model bucket is shown in Figure 7, the shoveling quality of each model bucket is shown in Table 4.

![Figure 7. Shovel quality of model bucket](image)

**Table 4. Fill bucket rate of different bucket teeth shovel**

| bucket type | 0tooth | 3tooth | 5tooth | 7tooth |
|-------------|--------|--------|--------|--------|
| full rate/Kg| 3034.31| 3139.69| 3251.89| 3367.8 |

It can be seen from Table 4, the full bucket rate increases with the increase of the number of bucket teeth, and the full rate of 7 tooth bucket is the highest. In the study, the maximum drag resistance is calculated and the impact rate of the bucket teeth is not more than 9% on the maximum drag resistance. It can be seen from the combination of full bucket rate and shoveling load resistance, the 5 teeth has smaller drag resistance and higher full rate, which will be a good choice.

5. Conclusion
The analysis can be seen from the resistance of different bucket teeth. In the inserting phase, shoveling loading resistance would be increased with the increase of insertion depth and presents exponential distribution. The number of shoveling bucket tooth has certain influence on the changes of resistance, the number of bucket tooth has no influence on the drag resistance of the bucket during the elevating stage, and it is more suitable to choose the bucket model with 5 tooth uneven distribution.

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