Simulation Study on the Scooping Trajectories of Loader Based on EDEM

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Abstract. This paper using DEM method to study the shovel scooping process of one time scooping, segregated scooping and composite scooping, finding a new bucket’s trajectories and with the minimum shovel scooping resistance. And combined one time scooping with vertical lifting and segmented shovel loading with horizontal insertion phase, In the same full bucket rate situation, through many times simulations and experiments, composite scooping trajectory was modified which was based on the influence degree of Trajectory on resistance. Then the revised maximum horizontal resistance during composite scooping was 11% lower than before correction and vertical resistance decreased by 9%. The research provided theoretical foundation and practical support for loader’s automatically scooping and intelligent resistance reduction.

1. Introduction
In recent years engineering machinery have been developed greatly under the thrust of modern market needs. The engineering mechanical performance is put forward to higher requirement, not only requires higher bearing capacity, longer lifespan, but also requires to decrease the operation cost and energy consumption. But classical loader still require the high energy consumption and load cost, especially shoveling with gravel, tyre serious wear and power consumption is too large because of larger scooping resistance, which influence the loader performance seriously and creates larger operation cost. In order to reaching to higher efficiency and saving energy, loader requires in the shortest time, with less energy consumption, to obtain larger bucket full rate, so it is necessary to study scooping resistance further.

When loader shovels material, the trajectory of bucket tip[1]is generally divided into three kinds, one time scooping, segregated scooping and composite scooping. In the field of the trajectory and resistance of loader, it has produced a lot of work and has great results. Gong Jie[2] has analysed of straight line and curve loading trajectory, and find the maximum scooping resistance in the straight trajectory is less than the maximum scooping resistance of the curve. Gong Jie, Bao JinFeng[3], found that the compensation calculation method of the scooping resistance has tracked in the desired precision trajectory.

2. The scooping trajectory planning and insertion resistance calculation
2.1 One time scooping
Loader advance horizontally, the bottom of the bucket insert into the bottom of the material pile, when loader inserted the depth of about 0.8 to 1.1(L+R), loader stopping to advance horizontally, then the
bucket hoisted. This kind of blade loading method is often used to shovel the discrete material. One time scooping, it is not require the driver too much, but the work resistance and energy consumption is very large, otherwise the loading efficiency is low and the bucket full rate is small.

![The T rajectories of Bucket Tip](image)

Figure 1 The Trajectories of Bucket Tip

The horizontal and vertical motion is to be simulation and study of the scoop process in the EDEM, because of the rotation axis can't to be defined continuous movement in the EDEM. The trajectory of bucket tip and the concrete dimension as shown in figure1.

2.2 Segregated scooping

Using one time scooping method, sometimes scooping resistance is too large. After the loader insert the material pile certain depth, then the movable arm ascend certain height, and then loader advance horizontally certain distance, then movable arm ascend to removed material pile. This loading method is Cumbersome, parts wear quickly, shorten the lifespan of devices.

2.3 Composite scooping

Loader advance horizontally, when loader inserted the depth of about 0.2 to 0.5(L+R), loader stopping to advance horizontally, then the bucket is incline hoisted, and then the movable arm ascend to removed material pile.

2.4 bucket insert resistance calculation

By the experience formula [4], bucket insert resistance of scooping the gravel pile:

\[ F = K_1 K_2 K_3 K_4 L^{1.25} \]  

Where \( B \) is the width of bucket, the dimension of bucket model is 42cm; \( L \) is insertion depth;

\( K_1 \) is the material block coefficient, the particle size of 15mm was 1;

\( K_2 \) is the material properties, the density of 2600kg/m^3 of the gravel is 0.1;

\( K_3 \) is the material pile height coefficient, the 80cm of material pile height is 1;

\( K_4 \) is the bucket form coefficient, it is closely related with the angle of inclination between the bucket floor and the ground:

\[ K_4 = \frac{K_4}{K_4'K_4''K_4'''} \]  

\[ K_4' = 1.05 + (\alpha_f + \alpha_0)/120 \]  

\[ K_4'' = 1.2 - 0.2B/R_0 + K_t \]  

\[ K_4''' = 0.83 + 0.0155\alpha_0 \]  

\( \alpha_f \) is the angle of inclination the front edge of the bucket, and the dimension of bucket model is 60 degree;

\( \alpha_0 \) is the angle of inclination between the bucket floor and ground, it generally [5-6] is 3 degrees to 7 degrees, this paper is to be chosen 5 degrees;

\( K_4'\) is the bucket floor and tooth influence coefficient;

\( K_4'' \) is the tooth influence coefficient, the coefficient of the toothless is 0.35;

\( R_0 \) is the bucket floor front edge effect coefficient, the dimension of bucket model is 42cm;
Based on the figure 1-3 and formula (1)-(5), the resistance can be calculated: one time scooping: F=1139.83; segregated scooping: F=1107.44 N; composite scooping: F = 824.38 N.

3. Simulation scoop process using the EDEM

3.1 Establishment of the simulation model

This paper based on the ZL30[^7] loader bucket, reduced according to the proportion of 14:1, bucket model is built, because of the EDEM software running memory is too big. The model of the bucket size and three-dimensional model is following:

| Parameter | Real bucket | Model bucket |
|-----------|-------------|--------------|
| L (cm)    | 560         | 40           |
| R (cm)    | 355         | 25           |
| D=L/R     | 1.58        | 1.6          |
| E₀ (°)    | 42          | 40           |
| B (cm)    | 600         | 42           |
| E₁ (°)    | 60          | 60           |

Through the experimental and looking up table, the required parameters[^8] is as follows:

| Material | Density/kg/m³ | Shear modulus/MPa | Poisson's ratio |
|----------|---------------|-------------------|-----------------|
| Gravel   | 2600          | 0.5               | 0.2             |
| Steel    | 7800          | 0.7               | 0.3             |

| Interaction         | Coefficient of restitution | Sliding friction coefficient | Rolling friction coefficient |
|---------------------|----------------------------|----------------------------|----------------------------|
| Gravel—gravel       | 0.5                        | 0.9                        | 0.004                      |
| Gravel—steel        | 0.41                       | 0.4                        | 0.01                       |
| Steel—steel         | 0.7                        | 0.2                        | 0.01                       |

3.2 Simulation using the EDEM

The bucket model import the EDEM, it can simulate three shovel loading methods. In order to eliminating the influence of the speed, the simulation speed is 0.65 m/s of all.

3.3 Contrast analysis of simulation and calculation results

In the three scoop methods, gravel particles in the bucket are: 46.53kg, 56.13kg and 45.67kg, which we can consider that the loading shovel quality is almost equal.

The data obtained from the simulation results compared with the calculated value:

| The maximum insert resistance | The results of the simulation (N) | The results of the calculate F(N) | Error | η % |
|-------------------------------|-----------------------------------|----------------------------------|-------|-----|
| one time scooping             | 1238.39                           | 1337.64                          | 7.4   |     |
| segregated scooping           | 1026.13                           | 1107.44                          | 7.3   |     |
| composite scooping            | 872.83                            | 824.38                           | 5.6   |     |
Through the comparison, we can find that the calculated results of the inserting resistance and simulation values of inserting resistance are anastomotic, the error less than 7.5%, it shows that the simulation is feasible.

Exporting the simulation results of the horizontal component and vertical component, we can see the changes of loading resistance.

Figure 2 The Level and vertical Force of the three Scooping Way

Through the diagram2, the bucket scoop the same quality gravel material, one time scooping method with the maximum resistance, composite scooping method with the least resistance. The level resistance by composite scooping is 0.7 times that of one time scooping and is 0.85 times that of segregated scooping method. One time scooping method with the maximum resistance, composite scooping method with the least resistance. The vertical resistance by composite scooping is 0.7 times that of one time scooping and is 0.85 times that of segregated scooping method.

4. the modification of the compound shovel loading method
In order to reducing the resistance, saving the energy consumption and improving the operating efficiency of the loader, the general use of composite scooping method. But for the playing fully to the role of the traction pull of the loader, the loader in the composite scoop should always keep moving forward, therefore composite scooping method in the third stage(a vertical lifting stage) can not completely perpendicular to movement. So the composite scooping method is not the ideal trajectory of the bucket tip.

The composite scooping trajectory is modified: in the first stage the bucket inserts into the material pile deeper. In the second stage the scooping trajectory remains parallel material pile bevel. In the third stage the vertical line correct for oblique line. In order to ensuring the same bucket fill rate, it is request that the area of the bucket tip trajectory surround the material heap will be equal the modified trajectory surrounded the material heap. The dimensions of modified trajectory as shown in Figure 3.

Figure 3 The Trajectories of Revised Composite Scooping

After the simulation scooping completed, the quality of inside the bucket of gravel is 46.8 kg, and it can be thought the same bucket full rate.

The data obtained from the simulation results compared with the experiment value:

The date of the simulation is exported as following:

Contrast analysis diagram 2 and 3, the horizontal resistance decreased from 872N to 714N, it reduces by 11%, the vertical force decreased from 644N to 586N, it reduces by 9% in the corrected composite scooping method, it shows the effectiveness of correction.
5. Conclusion
This paper made a visual simulation research on loading resistance of the loader shovel by a discrete element method (DEM). By comparing one time scooping, segregated scooping and composite scooping method with three shovel resistance when scooping, illustrates under the same condition that the bucket is full rate, one time scooping method with the maximum resistance, composite scooping method with the least resistance. Under the condition in this paper, the level resistance by composite scooping is 0.7 times that of one time scooping and is 0.85 times that of segregated scooping method; the vertical force by composite scooping method is 0.77 times that of one time scooping and is 0.88 times that of segregated scooping method. The feasibility of the study is also proved through the theoretical calculation.

Therefore, combined one time scooping with vertical lifting and segmented shovel loading with horizontal insertion phase, modified composite shovel loading trajectory, especially amended the vertical lifting to oblique upward. Loader shovel loading using the revised composite blade method with shovel loading, the resistance is least. Revised composite scooping in the first paragraph insert phase (horizontal) maximum insert depth is in scope of the 0.65(L + R) - 0.88 (L + R), the second paragraph (parallel to the stock pile inclined upward stage) biggest hoisting height is in scope of 0.85 (2 R) - 2 R, the scooping resistance is least. This reduces drag shovel rubble when loading operation in order to achieve high efficiency and energy saving and automatic shovel loading provides a theoretical basis. Then the revised maximum horizontal resistance when composite scooping was 11% lower than before correction and vertical resistance decreased by 9%. The research provided theoretical reference for loader’s automatically scooping and intelligent resistance reduction.

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