Structure Optimization Design of Screw Conveyor based on EDEM

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Abstract: Screw conveyors are widely used in the transportation of various media in the industry because of their simple structure and low cost. However, some special powders are prone to accumulation during transportation due to their low density, large angle of repose, and poor fluidity, resulting in low transportation accuracy and unable to meet actual working conditions. In this paper, the discrete element method is used to simulate and analyze the powder transportation. The three-dimensional model of the screw conveyor is established and imported into the EDEM software for simulation simulation. The key parameters of the screw conveyor are screw inner diameter, pitch and speed as design variables. Hand in the experiment, and get the optimal solution of the variable parameters through the experimental results.

1 Introduction

As a traditional manufacturing technology, compared with other metal forming methods, casting technology has many advantages, especially in the aviation industry. For example, the casting method is not limited by the size of parts to a large extent, wall thickness and shape complexity, and it has an irreplaceable position in the aviation industry because of the adaptability and low cost of materials. Screw conveyor is a kind of mechanical and electrical equipment for continuous transportation, and there is no traction force. The utility model has the advantages of simple structure, easy disassembly and replacement, and high feeding precision. It is suitable for conveying powdery, granular and other materials, so it is widely used in casting, chemical industry, metallurgy and other industries. Yu Shuhao et al used discrete element method to study the influence of screw shaft diameter on the conveying performance of screw conveyor [1]; Luo Sheng et al explored the influence of screw feeder with different pitch and inner and outer diameter on conveying capacity and optimized the quantitative screw feeding process [2]. Zhang Donghai of Dalian University of Technology uses genetic optimization algorithm to establish the mathematical model of parameter feeder, and puts forward that the influencing factors of material transportation include filling rate and pitch [3]. In this paper, the discrete element software EDEM is used to simulate and analyze special auxiliary materials. Through the orthogonal test,
the effects of the inner diameter, pitch and speed of the screw conveyor on the conveying capacity are discussed, and a set of optimal solutions are obtained.

2 Parameter selection of screw conveyor

2.1 Theoretical formula calculation
In the whole design of the screw conveyor, the calculation and selection of the screw diameter is the key of the screw conveyor, which directly affects the conveying performance of the screw conveyor. Because the influence of the gap between the outer diameter of the spiral blade and the inner wall of the gun barrel on the spiral flow rate is negligible, according to the empirical formula (1):

$$Q = \frac{47D'Sn\beta\psi}{\gamma}$$

Then

$$D = \sqrt[4]{\frac{Q}{47\beta Sn\psi}}$$

In Formula (1):
- $Q$ — Transport flow (g·h$^{-1}$);
- $\beta$ — Inclined transport coefficient;
- $D$ — Outer diameter of spiral blade (cm);
- $S$ — Screw blade pitch (cm);
- $n$ — The speed of the screw shaft (r·min$^{-1}$);
- $\psi$ — Filling coefficient of material;
- $\gamma$ — Material capacity (g·cm$^{-3}$).

2.2 Basic parameter selection
According to the parameter characteristics of inorganic powder and the actual working conditions, by consulting the relevant parameters of auxiliary materials, the horizontal screw conveying device is adopted in this experimental design. The inclined conveying coefficient $\beta$ is 1, the filling coefficient of the material is $\psi=0.33$ [5-6], the material capacity is $\gamma=0.5$ g·cm$^{-3}$, the screw shaft speed is 100 r·min$^{-1}$; the conveying capacity is $Q=100$ g·h$^{-1}$.

Among them, the strength of the material and the actual production efficiency are needed to determine the pitch of the spiral. Too large or too small will affect the conveying accuracy, which can usually be calculated according to the following formula:

$$S = KD$$

For standard conveyors, $K$ is usually 0.8-1.0; $K \leq 0.8$ when inclined or conveying materials are poor; and $K$ is 0.8-1.0 when horizontal layout. The hollow shaft is usually used in the inner shaft of the screw conveyor in order to save material and reduce the weight. In addition, the diameter of the inner shaft of the screw also has a certain influence on the rising angle of the screw conveyor blade. Under the condition of determining the outer diameter and pitch of the spiral blade, the helix angles corresponding to different inner shaft diameters are different. According to the relevant literature [5], the size of the spiral shaft diameter is related to the value of the spiral blade. The general formula for calculating shaft diameter is:

$$d = (0.25 - 0.4)D$$

2.3 Parameter information of screw conveyor
Based on the selection of the parameters of the screw conveyor mentioned above, the outer diameter of the screw blade $D=87.2$ mm can be obtained from the formula (1). $K=0.7$ is selected in the design of spiral pitch and $d=0.4D$ is selected in the design of spiral shaft diameter. The specific parameters and selected values are shown in Table 1.
Table 1. Basic parameters of screw conveyor

| Parameter information                  | Numerical value/mm | Selected value/mm | Corrected flow/ g·s⁻¹ |
|----------------------------------------|--------------------|------------------|-----------------------|
| Outer diameter of spiral blade /D      | 87.2               | 90               |                       |
| Diameter of spiral shaft /d           | 34.88              | 35               |                       |
| Pitch /S                               | 61.04              | 60               | 110.0 g·s⁻¹           |

3 Simulation of screw conveyor by discrete element method

3.1 Brief introduction of discrete element method

In 1971, American professor Cundall P. A. put forward the discrete element method, which is based on the theoretical basis of molecular dynamics. Discrete element method plays a very important role in the field of particle dispersions and geotechnical fields [7-9]. The discrete element model technique can be used to study the interaction mechanism between powder and screw and the flow state of powder. The flow and speed changes of the screw conveyor are observed through post-processing, the motion trajectory of simulated particles is monitored in real time, and the structural rationality of the screw conveyor is analyzed.

3.2 Orthogonal variable setting

Orthogonal experimental design is also called orthogonal design, which is a design method to study many factors and levels. The orthogonal experiment can not only select the representative experimental combination in the experimental area, but also analyze the better parameter combination in the range method [10-11]. From the formula (1), it can be known that the flow rate of the screw conveyor is related to many factors, and formula (2) gives the relationship between the pitch and the outer diameter of the blade. By using the conventional design, it can be considered that the outer diameter of the blade can be expressed by pitch. In order to achieve the purpose of reducing the complexity of the experiment. Therefore, in this experiment, the pitch, shaft diameter and speed of the spiral blade are used as design variables, and the orthogonal design group is simulated and analyzed by EDEM to obtain a set of optimal solutions. The orthogonal design table is shown in Table 2:

| Factors | Screw blade pitch/mm | Shaft diameter /mm | Rotational speed /rpm |
|---------|----------------------|--------------------|-----------------------|
| 1       | 40                   | 30                 | 80                    |
| 2       | 60                   | 35                 | 100                   |
| 3       | 80                   | 40                 | 120                   |

As the three-dimensional modeling ability of EDEM software is limited, this paper builds the three-dimensional model of screw conveyor through Solidworks, which mainly includes three parts: feed port, helical body and housing, as shown in figure 1.
Based on the above theoretical basis, the overall size of the screw conveyor is determined, and nine groups of three-dimensional models of the screw conveyor are constructed by Solidworks. The horizontal parameter dimensions are shown in Table 3.

Table 3. Parameter design table of screw conveyor for orthogonal experiment

| Serial number | Pitch L/mm | Shaft diameter d/mm | Rotational speed n/min |
|---------------|------------|---------------------|------------------------|
| 1             | 40         | 30                  | 80                     |
| 2             | 40         | 35                  | 100                    |
| 3             | 40         | 40                  | 120                    |
| 4             | 60         | 30                  | 80                     |
| 5             | 60         | 35                  | 100                    |
| 6             | 60         | 40                  | 120                    |
| 7             | 80         | 30                  | 80                     |
| 8             | 80         | 35                  | 100                    |
| 9             | 80         | 40                  | 120                    |

3.3 EDEM Simulation Environment Settings

The particle size of the powder is small, in order to minimize the simulation error and obtain reasonable and effective simulation time, according to the national standard GB/T 16913.5-1997 and consulting the relevant domestic and foreign references, the discrete element simulation parameters of powder particles and stainless steel are determined. Finally, the intrinsic parameter of the simulation experiment is set as the density of inorganic powder. Its value is 1500 $\text{kg m}^{-3}$, which is three times larger than the actual powder density, the shear modulus is $6.0 \times 10^7$ Pa and Poisson's ratio is 0.2. The self-properties of stainless steel and the contact parameters of powder are shown in Table 4 [12-16].

Table 4. material property sheet

| Simulation parameters | Numerical value |
|-----------------------|-----------------|
| Shear modulus of inorganic powder/Pa | $6.0 \times 10^7$ |
| Poisson's ratio of inorganic powder | 0.2 |
| Stainless steel density/ $\text{kg m}^{-3}$ | 7800 |
| Shear modulus of stainless steel/Pa | $7.0 \times 10^{10}$ |
| Stainless steel Poisson's ratio | 0.3 |
| Inorganic powder-inorganic powder recovery coefficient | 0.2 |
| Static friction coefficient between inorganic powder and inorganic powder | 0.65 |
| Rolling friction coefficient between inorganic powder and inorganic powder | 0.23 |
| Inorganic powder-stainless steel recovery coefficient | 0.2 |
| Static friction coefficient of Inorganic Powder-stainless Steel | 0.72 |
| Rolling friction coefficient of Inorganic Powder-stainless Steel | 0.25 |

In the pre-processing setting, the particle model adopts the soft sphere model, the particle generation mode is Dynamic, and the material with a mass of 2 KG is generated by fast filling, the simulation step is set to 0.05s, and the simulation time is 15s.
4 Data analysis
The flow rate and speed of the screw conveyor are important indicators to evaluate its performance. After the simulation, the flow rate in the conveying process is monitored in real time by the flow sensor in the post-processing interface, and the monitoring position is set at the exit of the screw conveyor. The simulation results of each level are shown in figure 3: (figure X-Y-Z: pitch: X; screw inner diameter: y; speed: Z)
Through the monitoring of the flow sensor at the outlet of the screw conveyor, the conveying time-mass curve of each level is obtained, as shown in figure 4:

(a) 40-30-80
(b) 40-35-100
Figure 4. Transport time-quality diagram at each level
According to the above data, the conveying flow of each group of screw conveyor is obtained. Because the powder density is enlarged by 3 times in simulation, the flow value is reduced by 3 times in statistical analysis (Table 5).

Table 5. conveying flow of screw conveyors at all levels

| Group number | 1  | 2  | 3  | 4  | 5  |
|--------------|----|----|----|----|----|
| Flow/ g·s⁻¹  | 43 | 56 | 69 | 87 | 86 |

The above data are analyzed by orthogonal design, and the mean response is shown in Table 6.

Table 6. mean response table

| Horizontal  | A (Pitch) | B (Shaft diameter) | C (Rotational speed) |
|-------------|-----------|--------------------|----------------------|
| 1           | 167.0     | 231.0              | 262.0                |
| 2           | 275.3     | 259.3              | 282.7                |
| 3           | 357.7     | 309.7              | 255.3                |
| Delta       | 190.7     | 78.7               | 27.3                 |
| Rank        | 1         | 2                  | 3                    |

The mean main effect diagram is shown in figure 5.

5 Conclusion

(1) With the increase of the speed of the screw conveyor, its conveying capacity also increases, but if the speed is too high, the phenomenon of particle extrusion and accumulation will also increase, the centrifugal force will increase, and the powder will not be carried stably.

(2) The range of A (pitch) and B (screw inner diameter) in the mean response table is larger, indicating that the screw pitch and screw inner diameter have great influence on the flow transportation. Among them, the increase of pitch significantly improves the conveying flow value. Therefore, in order to improve the conveying effect, choosing a reasonable pitch plays a significant role.

(3) It can be seen from Table 6 that screw pitch level 3 (80 mm), screw diameter level 2 (35 mm) and speed level 2 (100 rpm) are the best choices for determining screw conveyor parameters.
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