SIMULATION STUDY ON THE INFLUENCE OF VARIABLE FREQUENCY AND INPUT QUANTITY ON FEEDING ABILITY OF VIBRATORY FEEDER

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Abstract: To explore the influence of variable frequency and input quantity on feeding ability of vibratory feeder, taking the actual vibratory feeder as a prototype and actual feeding process for reference, vibrating feeding process of coke dry quenching vibratory feeder was simulated based on the discrete element software EDEM. Simulation results show that filling rate of feed trough and feeding adjustment ability are all influenced by frequency and input quantity, which affects feeding ability and material flow unobstructed. With double amplitude of 3.5 mm, frequency tuning range of 25 Hz - 35 Hz, input quantity at the range of 140t/h - 190t/h, the material flow is unobstructed, and the feeding capacity has adjusting ability of 50t/h. Then the limit feeding capacity is 137t/h, when the minimum vibration ability is simulated without plugging. Compared with the limit feeding ability of industrial test of 130 t/h, the error is 5.4%, which indicates that the simulation is effective and credible. All works will provide a useful theoretical reference for coke dry quenching vibratory feeders on accurate quantification of feeding ability.

KEYWORDS: Variable Frequency; Input Quantity; Vibratory Feeder; Feeding Ability; Filling Rate; Discrete Element Method

1. INTRODUCTION

Coke dry quenching vibratory feeders are the core equipment of coke dry quenching production line for the feeding operation of coke dry quenching. The vibrating feeder made by a heavy industry Co., Ltd is GZD type inertial feeder beyond the resonance region (see Fig.1). When the feeder appears feeding obstructed, and the material is blocked at feed inlet in severe blocking, it will cause the material can't be delivered unobstructed as feeding adjustment in production. Above - mentioned phenomena is due to large input quantity or insufficient energy supply making a big filling rate of material trough. Therefore, the parameter of input quantity and frequency of energy supply have a greater influence on feeding ability, which needs to be discussed in detail. Not only does feeding ability of vibratory feeder refer to the adjustability of feeding capacity and unobstructed material flow for continuous operation under fixed input quantity, but also it is an important index, which measures feeding ability of the feeder.

Discrete Element Method (DEM) is a numerical method which analyses the physical properties, particle size, shape and motion of granular materials, such as transient, wave, collision and other mechanical characteristics as well as motion law (Kruse. D, Lemmon. R, 2005, Xiong L X, et al., 2019, A. Karrech, D. Duhamel, 2008). Scholars at home and abroad use the discrete element method for granular material vibration screening (Li J, Webb C, Pandiella S S,
et al., 2003, Jiao H G, Zao Y M, Wang Q Q., 2006, Mukherjee A K, Mishra B K., 2007), mixing (Gao W, Liu L, Liao Z, et al., 2019) and crushing and grinding (Orozco L F, et al., 2019) etc., make a lot of research and has made great achievements. There is much research on vibratory feeder by the relevant scholars (Lim, G. H., 1993, Du, W.Y., 2001, Umbanhowar Paul, Lynch Kevin M., 2008), but not much attention has been paid to using the discrete element method to analyze the material movement of the vibratory feeder, especially for feeding ability of feed trough with residual material is lack of research; and under the continuous frequency conversion, the study of feeding ability is still vacant.

In this article, the three-dimensional discrete element method is used to simulate feeding process of coke dry quenching vibratory feeder, and analyze motion law of material flow as well as feeding ability of the feeder, when there are frequency conversion and input quantity change. At the same time, combined with industrial test of actual feeder, the correctness and validity of the simulation results are verified. The work done above will provide beneficial theoretical references for the exact quantification of feeding ability of GZD type coke dry quenching vibratory feeders.

2. WORKING PRINCIPLE AND FEEDING THEORY OF VIBRATORY FEEDER

2.1. Working principle of vibratory feeder

GZD-2580×1200 type feeder is an inertial linear vibration feeder beyond resonance region. The concrete structure as shown in Fig. 1, the vibratory feeder consists of former spring group 1, latter spring group 2, feed box 3, and motor vibration exciter 4. The dimensions size of this feed box is 2580×1200×1280, and geometric model is shown in Fig. 2. Equipped with eccentric block in every vibration motor, the eccentric mass of the eccentric block produces centrifugal force, when two vibration motor are working. Centrifugal force produced by the two vibration motors through decomposition and synthesis, then it produces an exciting force F shown in Fig. 1, and the exciting force F is a harmonic force. The exciting force F provides the power for feeder body vibration and particles flow movement. The amplitude and frequency of harmonic force affect the change of the material flow, and then affect the feeding ability.

Fig.1. Structure of vibratory feeder

Fig.2. Geometric model of feed box

2.2. Feeding ability of vibratory feeder

According to relevant literature (Liu Shunping, 2005), the feeding ability of vibratory feeder can be expressed as:

\[ Q = 3600BHv_0\gamma \phi \]  

(1)

Where, \( Q \) represents feeding ability, t/h; \( B \) represents trough body width of feed trough, m; \( H \) represents trough body height of feed trough, m; \( \gamma \) represents material bulk density, t/m3; \( \phi \) represents material filling rate in the trough solid; according to 0.6 to 0.8, granularity is big or small to select, the big particle size selects small value; the small particle size selects big value; \( v_0 \) represents material conveying speed when the trough solid being placed horizontally, m/s.

When trough body is placed horizontally, the
material conveying speed can be expressed as:

\[ v_i = \eta m \frac{g n}{2 \rho f} \cos \beta \]  

(2)

Where \( \eta \) represents feeding efficiency, it can be selected as 0.8; \( m \) represents inclined angle coefficient of trough body; \( \beta \) represents cycle coefficient, which is related to material motions in the trough body; \( g \) represents acceleration of gravity, 9.81 m/s\(^2\); \( f \) represents vibration frequency, Hz; \( \beta \) represents vibrating direction Angle \( \beta \), which is usually selected at a range of 20\(^\circ\) to 25\(^\circ\); \( n \) represents material jumping coefficient, which is the ratio of throwing materials time to vibration period of the feeding trough body, and it can be selected at a range of 0.7 to 0.9.

The formula (1) and (2) belong to empirical formulas, which make great contribution to the design of feeders. However, the filling rate \( \varphi \) of the material inside trough solid is variable, when there is residual material in feed trough, with leading to the feeding trough solid height \( H \) to vary, so it is difficult to calculate feeding capacity. Then the formula (1) and (2) is not suitable for the calculation of feeding adjustment, when there is continuous variable frequency.

3. NUMERICAL SIMULATION AND ANALYSIS OF GRANULAR FLOW

3.1. Mathematical model of particle collision

Discrete element software EDEM is based on the Newton's second law to write, meanwhile particle motion is achieved through the process of touching and collision each other as well as looseness, etc. Known from analysis of the stress, Particles in motion are mainly affected by their own gravity, force, normal force \( F_n \), tangential force \( F_t \), tangential torque \( T_t \), and Coulomb friction torque \( T_r \). As shown from the literature (Zeilstra C, et al. 2008, Zhu, H. P. et al. 2008), the effects of interstitial air can be safely ignored, when granular matters are relatively large (> 1 mm). The motion equations of each particle \( i \) (mass \( m_i \), moment of inertia \( I_i \)) is provided by Newton’s second law as follows:

\[ m_i \frac{dV_i}{dt} = m_i g + \sum_{j=1}^{n_i} (F_{x,i,j} + F_{y,i,j}) \]  

(3)

\[ I_i \frac{d\omega_i}{dt} = \sum_{j=1}^{n_i} (T_{v,i,j} + T_{e,i,j}) \]  

(4)

In equations of (3) and (4), \( V_i \) and \( \omega_i \) are the velocity in m/s and the angular velocity in rad/s of particle \( i \) respectively, whereas \( g \) is the acceleration of gravity in m/s\(^2\). The normal force, tangential force, tangential torque, and Coulomb friction torque can be calculated using the basic principle of the discrete element method (Li, J., Webb, C., Pandiella, S.S. Campbell, G.M., 2003, Oda M, Iwashita K, Kakiuchi T, 1997).

3.2. Simulation parameter settings

Referring to contact collision model selected about vibration numerical simulation (Zhao L L, Liu C S, Yan J X, et al., 2010), this paper uses Hertz - Mindin (no slip) model of numerical simulation. The particles of the coke dry quenching is considered to be round ball shape (Being different from vibratory screening, the particle shape does not have much effect on macroscopic analysis of feeding amount). We choose the coke dry quenching particle's average diameter of 60 mm, and consider the actual situation, so we set the physical parameters of the material of coke and trough based on relevant literature (Hu Guoming, 2010) as shown in Table 1. Firstly, the trough model of the GZD type vibrating feeder is completed by SolidWorks software and then translated into the EDEM as shown in Fig. 2. The different vibration mode of the feeding trough can be realized through setting vibration parameters of the feeding trough. According to actual input quantity to set feeding velocity of particle plant and simulation time as well as time step length required, when particle flow is stable, the simulation of the movement of the coke particle in the feeding trough is completed. Figure 3 is the feeding process simulation of the GZD type vibrating feeder.
The movement process of dry coke quenching particle swarm in the feeding trough is very complex. As the vibration of the trough surface and the collisions of the particle between surrounding particles, the material takes on a movement form, which is similar to fluid in the trough. When the bottomed particles are leaping, material under the feed inlet appears as a vortex flow state, and the upper layer of particles at the outlet presents a similar landslide mud-rock flow form, as shown in Fig 3 (a). When bottomed particles fall back, particles under the feed inlet end still presents as vortex flow, the upper particles at material outlet end become a state as the curled-up debris flow, as shown in Fig. 3 (b).

Feeding process of the coke dry quenching particles in vibrating feeder is simulated as shown in Fig. 4. When there is smooth feeding, the filling rate of feeding trough is small, and the coke dry quenching particles is fed uniformly along the feeding trough surface under the vibrating effect of rough surface as well as trough frame to form a smooth flow of material, as shown in Fig. 4(a). When input quantity of material particles exceeds the processing capacity of the GZD type dry quenching vibrating feeder, the coke dry quenching particles will be piled up continuously inside the trough. When it reaches a certain time, accumulation of particles in the trough can affect the input quantity of feed inlet, and then a phenomenon of plugging material appears, as shown in Fig. 4 (b).

### Table 1. Physical parameters of materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Density (Kg/m³)</th>
<th>Restitution coefficient</th>
<th>Static friction factor</th>
<th>Rolling friction factor</th>
<th>Poisson's ratio</th>
<th>Shear modulus/Pa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coke</td>
<td>500</td>
<td>0.5</td>
<td>0.8</td>
<td>0.1</td>
<td>0.3</td>
<td>2.3×10⁷</td>
</tr>
<tr>
<td>Trough</td>
<td>7850</td>
<td>0.5</td>
<td>0.5</td>
<td>0.1</td>
<td>0.3</td>
<td>7.99×10¹⁰</td>
</tr>
</tbody>
</table>

**Fig. 3 Particle vector velocity field**

- (a) t=3s
- (b) t=20s

**Fig. 4. Feeding process simulation of GZD vibratory feeder**
3.3. Influence of input quantity on filling rate and feeding ability

Filling rate is an important indicator that measures particle motion to be unobstructed inside material conveying machinery, which is widely cited in ball grinding mill and material mixing machine (MAGNO R R RITA V G D S, CAMILO C D S., 2002). In the analysis, the filling rate of material in the trough influences feeding speed and joining vibration mass of the feeder. If there is excessive accumulation of material in the trough, it will result in the granule motion space to reduce, and the vertical average velocity of the granule flow decreasing, meanwhile it will reduce the regulation performance of feeding amount, which makes the feeding ability decline. Besides that, it will cause increased material vibration mass and energy consumption of vibration motor under the same vibration parameters (Pacurar Razvan, Balc Nicolae, Berce Petru, et al., 2008).

The filling rate of the material in the trough can be expressed as:

\[
\varphi = \frac{V_p}{(1 - \varepsilon)V_f} \tag{5}
\]

Where \(\varphi\) is material filling rate of the inside of the trough; \(V_p\) is material particle volume inside the trough, m³; \(\varepsilon\) is void ratio, and it is the rate of void volume to powder filling volume; \(V_f\) is material trough volume, m³.

According to the actual situation, we simulate the feeding process of the coke dry quenching under the following conditions, which is the double amplitude 3mm in length, exciting frequency of 35Hz, vibration direction Angle of 21°, trough dip angle of 6°and the input quantity of the feed inlet of respectively 140, 150, 160, 170, 180, 190 t/h. Figure 5 shows the filling rate of the material inside trough under the effect of the different feeding quantity.

![Fig.5. Filling rate curve with different feeding quantity of material trough](image)

From the simulation result, we can find that the materials of the feed trough is less, when the GZD type coke dry quenching vibrating feeder is with double amplitude of 3mm, vibration frequency of 35 Hz, and input quantity for 140 t/h. At this time, the filling rate of the material is 0.597, and the material is easy to achieve a lot of forms of motion, such as collision, loosing, layering and flowing under the action of the feeding box. The longitudinal velocity of material flow is fixed in 0.285m/s, and a relatively stronger feeding capacity can be achieved. With the increasing input quantity, the material is continuously accumulated inside feed trough. When input quantity is at a range of 150-180t/h, the fill rate of the trough can be respectively 0.658, 0.691, 0.754, and 0.786. When the input quantity is 190t/h, we can get the fill rate as 0.826 from Fig.5. Under this situation, the feed inlet accumulates too much material so that the materials can not glide smoothly, then the plugging phenomenon is seen in feed inlet, and the longitudinal velocity slows down to 0.162m/s.

3.4. The influence of continuous frequency modulation action on feeding ability

In the practical production, GZD type coke dry quenching inertial linear vibrating feeder achieves its variable amplitude via adjusting the angle of the two eccentric blocks, so the variable amplitude can not be continuous, but frequency
converter can be adopted to achieve continuous frequency modulation and adjust the velocity of material flow to control the feeding process.

According to the actual situation, under the condition of vibration direction Angle of 21°, trough dip angle of 6° and the double amplitude 3mm or 3.5mm in length, we get the effect from the different vibration parametric combination on the longitudinal feeding speeding and feeding flow smoothly under the continuous effect from high frequency to low frequency, from 35Hz to 25Hz. Tab.2 shows the average longitudinal speed of material flow in different frequency band, when there are different amplitude and feed quantity. When it is affected as long as 20s at each frequency, it becomes sufficient stability. And Fig.5 shows the longitudinal velocity changing curve, when the particles are affected under constant amplitude and a continuous changing frequency.

Table 2. Longitudinal average velocity of material flow with combined-parameters/ (m/s)

<table>
<thead>
<tr>
<th>Double amplitude /mm</th>
<th>3</th>
<th>3.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency/ Hz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>35 Q=190t/h</td>
<td>0.219</td>
<td>0.263</td>
</tr>
<tr>
<td>33 Q=180t/h</td>
<td>0.199</td>
<td>0.248</td>
</tr>
<tr>
<td>31 Q=170t/h</td>
<td>0.184</td>
<td>0.230</td>
</tr>
<tr>
<td>29 Q=160t/h</td>
<td>0.172</td>
<td>0.215</td>
</tr>
<tr>
<td>27 Q=150t/h</td>
<td>0.161</td>
<td>0.206</td>
</tr>
<tr>
<td>25 Q=140t/h</td>
<td>0.151</td>
<td>0.199</td>
</tr>
</tbody>
</table>

From Table 2 and Fig.6, we can get the information that, the GZD type coke dry quenching vibrating feeder has a larger longitudinal velocity, which means feeding smoothly at a range of 35-25Hz frequency from high to low, and there are the following other parameters: double amplitude of 3.0mm, vibrating frequency of 35Hz or 32Hz, affected time as long as 120s and input quantity of 190t/h -140t/h. When the input quantity is 170t/h and the frequency is 31Hz, the longitudinal average velocity is 0.184m/s as shown in Table 2. At the same time, the fill rate is 0.886. A blockage obviously occurs as shown in Fig.4b. Being affected at 29-25Hz, the average velocity is respectively 0.172 、0.161 、0.151m/s. Though the input quantity reduces, the fill rate is constantly increasing, so the blockage still exists. When the 3.5mm double amplitude is chosen, the material flow is smooth without blocking.

![Fig.6 particle longitudinal velocity curve with continuous frequency modulation](image)

This shows that the residual material in feed trough before frequency adjustment influences the material flow velocity after frequency adjustment, when the frequency is continuously changed from high to low; and it comes into being a blocking. And from the simulation result, we can find that a proper increase of the amplitude can effectively eliminate the blocking.

4. LIMITED FEEDING ABILITY SIMULATION AND EXPERIMENT VERIFICATION

Because of the approximate closed-form framework-trough structure of the GZD type coke dry quenching vibrating feeder; too large of the input quantity leads to overmuch material accumulation in the trough, especially at the feed inlet; and the overmuch material accumulation affects feeding, for material flow is not smooth; meanwhile it influences the material to slide down; hence, we discuss the situation that the vibrating feeder shows a smallest vibrating ability. When the feeding ability comes smallest, that is a double
amplitude of 3.0mm, frequency of 25Hz, vibrating direction angle of 21°, the feeding surface angle of 6°, so the feeding ability with smallest vibrating capacity obtained from the simulation is shown in Tab.3.

Table3. Simulation parameters with the minimum vibration ability

<table>
<thead>
<tr>
<th>Double amplitude /mm</th>
<th>Frequency /Hz</th>
<th>Longitudinal average velocity /(m/s)</th>
<th>Feeding amount /(t/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>25</td>
<td>0.164</td>
<td>137</td>
</tr>
</tbody>
</table>

We do an industrial experiment at the production factory of Qinhuangdao Qin Ye Heavy Industry Co., Ltd. The GZD type coke dry quenching vibrating feeder adopts the following parameters: double amplitude of 3.0mm; frequency of 25Hz; vibrating direction angle of 21°; feeding surface angle of 6°; the largest feeding ability of 130t/h; and the error with the simulation result is 5.4%, which shows that the result is valid and basically correct.

5. CONCLUSIONS

In this paper, the following conclusions are obtained through simulation and research.

(1) The feeding ability of vibration feeder increases along with the increasing of vibrating frequency, and decreases along with the increasing of the input quantity. The smaller the vibrating frequency and the larger the input quantity, the greater the accumulation of material in groove increased, then the fill factor becomes larger and the velocity of the material flow reduces, thus adjustment quantity of the material flow is influenced, and it will block easily. When the frequency comes larger and the input quantity comes smaller, the contrary is the case.

(2) For the GZD type coke dry quenching vibrating feeder, when it is under double amplitude of 3.0mm, frequency of 25Hz, then the vibrating ability is the weakest, so that the remnants of the material in the trough comes larger, and a plugging material phenomenon occurs easily. With following parameters, the double amplitude of 3.5mm, a frequency range of 25Hz-35Hz and an input quantity of 140t/h-190t/h, it feeds material smoothly with frequency adjustment and has a regulating capacity of 50t/h.

(3) From the comparison between the numerical simulation result and the industrial test result, we find that the error stays at 5.4%. It shows that the result is valid and basically correct.

REFERENCES


