Some Considerations on the Parameters Selection of DEM Simulation for Tumbling Ball Mills

Guoming Hu, Yu Liu, Muqun Liu and Hui Wan

Department of Mechanical Engineering, Faculty of Engineering, Wuhan University, Luojia Hill, Wuhan, 430072, China

Introduction

Grinding is an important operation in mineral processing. The power consumed by grinding accounts for 2.8%~3% of the world power. The tumbling ball mill is the major equipment for grinding, which involves so intricate parameters needed to be determined that this difficulty prohibits further research by a theoretical or experimental method.

Mishra and Rajamani [1] applied the Discrete Element Method (DEM) on motion analysis of tumbling ball mills. They studied the dynamics of the ball media of tumbling ball mills, and established the simulation model of the charge motion. Kano *et al.* [2] and other researchers [3, 4] contributed a lot to the DEM solution and its applications in tumbling ball mills. Because of the availability of microscopic observation of the charge motion in tumbling ball mills, DEM is widely used.

Linear-spring dashpot model is one of the major contact models of the dynamics DEM simulation for the tumbling ball mill. Due to its simplicity in calculation, the linear model is widely used. However, there is no standard for reference to identify the parameters. Therefore, this paper focuses on the selection of parameters for the linear-spring dashpot model.

The contact model and its parameters

The contact model

As shown in Fig. 1, the ball media in tumbling mills are identified separately, and they are allowed to overlap at the contact points. The interactive forces in the normal and tangential directions among balls at the contact points are given by:

$$\begin{cases} F_n = K_n U_n + C_n \dfrac{dU_n}{dt} \\ F_s = \min\left(\left|K_s U_s + C_s \dfrac{dU_s}{dt}\right|, \mu F_n\right) SIGN\left(K_s U_s + C_s \dfrac{dU_s}{dt}\right) \end{cases} \quad (1)$$

where F is the interactive force, U is the displacement at the contact point, and K, C and μ are the stiffness, the damping coefficient and the friction coefficient, and the subscripts n and s represent normal and tangential directions, respectively.

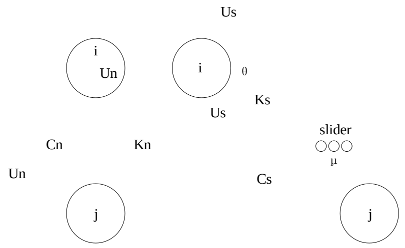

Fig. 1. Contact model between two interactive balls

Contact stiffness

In simulation, the maximum normal overlap during the collision can not be too large, unless it is unrealistic, and the time step can not be too small, unless it results in large quantity calculations and low efficiency. We establish equation according to the maximum overlap condition:

$$(mg+\sqrt{m}\sqrt{mg^2+K_n v_0^2})/K_n=\lambda d \quad (2)$$

where λ is overlap (Cleary *et al.* [4] took it as 0.1%~1%), d is the diameter of the milling ball, v_0 is the initial collision velocity. The normal stiffness is

$$K_n = m(2\lambda g d + v_0^2)/\lambda^2 d^2 \quad (3)$$

The tangential stiffness can be obtained from the principles of mechanics of material:

$$K_s/K_n = 1/2(1+po) \quad (4)$$

where po is the Poisson's ratio.

Damping constant

Damping is usually identified by the coefficient of restitution e:

$$C = -2\ln e\sqrt{km}/\sqrt{\ln^2 e+\pi^2} \quad (5)$$

where $m = m_1 m_2/(m_1+m_2)$. Substituting Eq. (4) into Eq. (5), the normal damping constant is expressed as:

$$C_n = -2\ln e\, m v_0/\sqrt{\ln^2 e+\pi^2}\,\lambda d \quad (6)$$

Combining Eqs. (4), (5) and (6), the tangential damping constant is given by:

$$C_s = -\frac{2\ln e}{\sqrt{\ln^2 e+\pi^2}}\frac{mv_0}{\lambda d}\sqrt{\frac{1}{2(1+po)}} \quad (7)$$

Coefficient of friction

It is assumed that the ball is at the lowest position of the mill and has synchronized motion with the shell of the mill initially. When $\alpha \geq \alpha 1$, $P_s = \mu P_n$, we obtain:

$$\alpha_1 = \arcsin\frac{\mu r\omega_0^2}{\sqrt{1+\mu^2}\,g} + \arctan\mu \quad (8)$$

$$\omega = \sqrt{e^{2\alpha\mu}c(1) + \frac{2g(\cos\alpha - 2\mu^2\cos\alpha + 3\mu\sin\alpha)}{r(1+4\mu^2)}} \quad (9)$$

where g is the acceleration due to gravity, P_n is the support force of the mill, P_s is the friction force that the mill put on the ball, $c(1)$ is a integral constant. We can see from Eq. (8) and

Eq. (9) that the angles in 2nd, 3rd and 4th position is relevant to the coefficient of friction which needs to be chosen according to the realistic situation in the simulation.

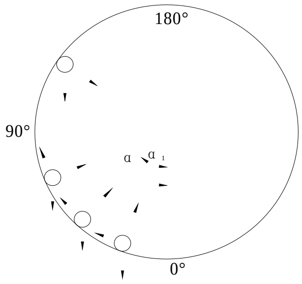

Fig. 2. Force analysis of one ball at different positions in mill.

Results and discussion

Discussion about the parameters

We can see from Eqs. (3), (4), (6) and (7) that the stiffness and damping coefficient are both relevant with the initial velocity of the ball. Considering that the range of the diameters from the laboratory mill to the industrial mill are from 0.15 to 5.5m, we obtain the values of v_0, stiffness and damping coefficient in both normal and tangential directions, which are shown in Table 1.

Table 1. Limits of variation of simulation parameters

Mill diameter	0.15-5.5 m
v_0	1..638-9.921 m/s
Normal Stiffness	3.318×10^6-1.214×10^8 N/m
Tangential Stiffness	1.327×10^6-4.856×10^7 N/m
Normal damping coefficient	240.15-1454.18 N s/m
Tangential damping coefficient	151.89-919.71 N s/m

From Eq. (8), we can see that α_1 is related to both the coefficient of friction and the velocity of the mill. When the velocity of the mill is identified, α_1 changes with the coefficient of friction, shown as Fig. 3(a). $\alpha = 90°$ is the critical point when the ball does cascading or cataracting movement. Fig. 3(b) shows that different coefficient of friction required in which the ball reaches the critical position at different velocities of the mill.

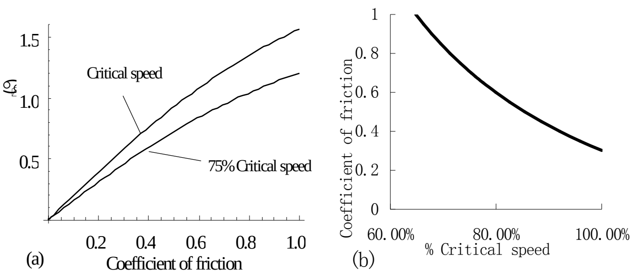

Fig. 3. (a) α_1 vs. coefficient of friction when the rotational speed is given; (b) the rotational speed vs. coefficient of friction as the particle reaches $\alpha = 90°$.

Simulation results

Fig. 4 compares the maximum elevated heights fron theoretical analysis with that from DEM simulation when the coefficient of friction is 0.05, 0.4, and 0.8 respectively. We can see from Fig. 4 that the stimulation results approach to that from the theoretical analysis.

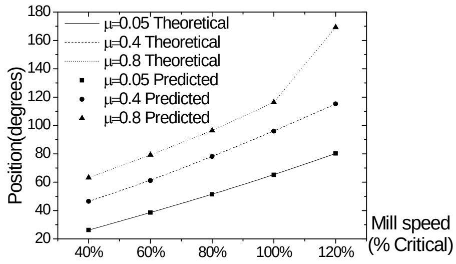

Fig. 4. Comparison of the maximum elevated heights of ball media between theoretical analysis and DEM simulation.

Conclusions

This paper analyzed the parameters of the linear-spring dashpot model, deduced the expressions of contact stiffness and damping constant. In the case of a single ball which was initially set in the lowest position of the mill and make synchronizing motion with the mill, we studied the synchronized height and the maximum elevated height so as to testify the possible existing relationship between the elevated height of the ball and the friction coefficient. The simulation of the movement of a single ball was performed. Finally, we compared the value of the maximum elevated height predicted with the theoretical analysis. The results show that the method by which the parameters could be determined is feasible.

Acknowledgements

The authors are grateful for the financial support by National 863 Project of China Grant # 2007AA04Z128.

References

1. Mishra B.K., Rajamani R.K., Motion analysis in tumbling mills by the discrete element method. KONA 1990; 8:92-98.
2. Kano J., Chujo N., Saito F., A method for simulating the three-dimensional motion of balls under the presence of a powder sample in a tumbling ball mill. Advanced Powder Technol 1997; 8(1):39-51.
3. Mishra B.K., Rajamani R.K., The discrete element method for the simulating of ball mills. Appl. Math. Modelling 1992; 16:598-604.
4. Cleary P.W., Morrisson R., Morrell S., Comparison of DEM and experiment for a scale model SAG mill. Int. J. Miner. Process. 2003; 68:129-165.