Research Journal of Applied Sciences 9 (11): 869-873, 2014
ISSN: 1815-932X

The Application of EDEM Software for Design Parameters Calculation of a Ball Mill Lining

Vasily S. Bogdanov, Pavel A. Khakhalev, Nikita E. Bogdanov and Alexey Ju. Gavrunov
Belgorod State Technological University Named after V.G. Shukhov,
Kostyukova Str. 46, 308012 Belgorod, Russia

Abstract: The study describes the study of the effect of liners height and step in ball mills which has been conducted using EDEM Software by DEM Solutions. Digital models of ball mill liners with various profiles using the NX CAD Software by Siemens PLM Software have been built. EDEM Software has been used to calculate kinematic and energetic parameters of a grinding media. The graphic and digital models of grinding media motion have been prepared their comparative analysis has been conducted; the rational operation mode of the mill has been showed. The properties of materials that a lining and grinding media are made have been considered when calculating the motion of grinding media. The interaction between grinding media and the lining has been characterized by coefficients of restitution, static and rolling friction and by variable height of the lifters, step of the lifters and rotation frequency of the mill drum.

Key words: Ball mill, grinding media, lifter lining, discrete element method, digital model analysis

INTRODUCTION

While designing ball mills as well as during their lifetime companies strive to achieve the highest performance of theirs operation. Any design is inextricably linked with calculations, experiments, rational selection of parameters and modes of grinding process (Kryukov, 1965). Today, we cannot speak about a design of modern equipment without a huge computing capabilities of computer technology (Bogdanov *et al.*, 2012).

It is well known fact that there are many software products that help an engineer to realize ideas and to release a finished product to the market as soon as possible. In this study, EDEM Software has been used representing a multi-purpose discrete element modeling tool designed for the simulation and analysis of industrial particle handling and manufacturing operations. It utilizes the simplified theories of Hertz and Mindlin which help approximate the contact interaction between particles when calculating simulations (Austin and Bagga, 1981; Bogdanov and Khakhalev, 2014; King, 2001; Kalala *et al.*, 2005; Mindlin, 1949; Mishra and Rajamani, 1992).

The purpose of the study is a determination of rational design parameters of the ball mill and achievement the maximum efficiency of grinding media movement when operating.

METHODS

The milling chamber with lifter liners represent a complex geometry. To build a Digital Model of a mill chamber for a subsequent calculation we used the NX CAD by Siemens PLM Software. Totally, nine models were created using various steps p of lifter lining and height h). The scheme of the mill section is shown on Fig. 1.

The digital model of a mill was imported to EDEM Software using a universal Parasolid format. The virtual simulation was created with original data, presented in Table 1.

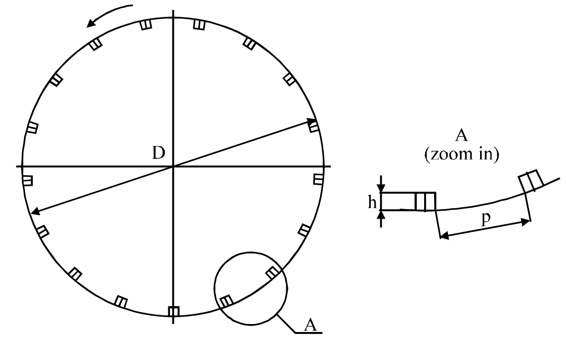

Fig. 1: Section of the mill used in the digital model (D: mill diameter, h: height of the lifter, p: step of the lifter)

Corresponding Author: Vasily S. Bogdanov, Belgorod State Technological University Named after V.G. Shukhov, Kostyukova Str. 46, 308012 Belgorod, Russia

The material properties of the balls and the lining were considered as well (Table 2). Interaction of grinding media was characterized by the following parameters coefficients of restitution, static friction and rolling friction (Table 3).

Totally, there were twenty-seven computational experiments. Variable parameters were: height of the lifters lining (h = 40 mm, 80 mm and 96 mm) step of the lifters lining (p = 3.d_b, 6.d_b and 9.d_b) and rotation frequency (n = 0.7·n_{max}, 0.76·n_{max}, 0.8·n_{max}. According to the pre-calculations the critical speed was n_{max} = 26.97 rpm (Bogdanov *et al.*, 2012). EDEM Software was able to obtain results in different ways: graphs and histograms, visual assessment of particles motion to export data to a spreadsheet. The package has a separate module for post-processing of data-EDEM Analyst module (Elcov *et al.*, 2011).

Table 1: Conditions used in the simulation

Variables	Values
Mill diameter (D, m)	2.6
Ball diameter (d_b, mm)	80.0
Weight of grinding media (m, kg)	6264.0
Mill filling (%)	30.0

Table 2: Characteristics of the materials

Variables	Material of grinding media (Steel (ShH-15))	Material of lining (Steel (G13H2L))
Poissons ratio	0.25	0.25
Density (kg/m^3)	7800	7800
Shear modulus (MPa)	200000	200000

Table 3: Parameters of grinding media interaction

Variables	Steel (G13H2L) to (ShH-15)
Coefficient of restitution	0.555
Coefficient of static friction	0.500
Coefficient of rolling friction	0.020

Values of kinetic energy of the grinding media with variable height of lifters lining at different rotation frequency were considered in simulations (Table 4). Step of the lifters is constant, p = 3.d_b.

With increasing rotation frequency from 0.7.n_{max} to 0.8.n_{max}, kinetic energy E_K of the grinding media for any value of the lifters height increases. However, at the height of the lifters lining h = 80 mm there is a declination of kinetic energy comparative to h = 40 mm or with h = 96 mm at any frequencies. Thus, when rotational speed of the drum near 0.7.n_{max} kinetic energy is reduced about 21-22% when it goes to 0.8.n_{max} the energy drops on 32% comparative to h = 40 mm.

The grinding media operation mode depending on the rotation frequency and the height of the liners was analyzed visually (Fig. 2-4). The color of the grinding

Table 4: The total value of kinetic energy of balls in the mill at different rotation frequency and height of the lifters

lining Rotation frequency, n (fraction of critical speed)	Height of the lifters h (mm) 40	80	96
0.7.n_{max}	13360	10360	13280
0.76.n_{max}	15910	11900	15100
0.8.n_{max}	18100	12250	16200

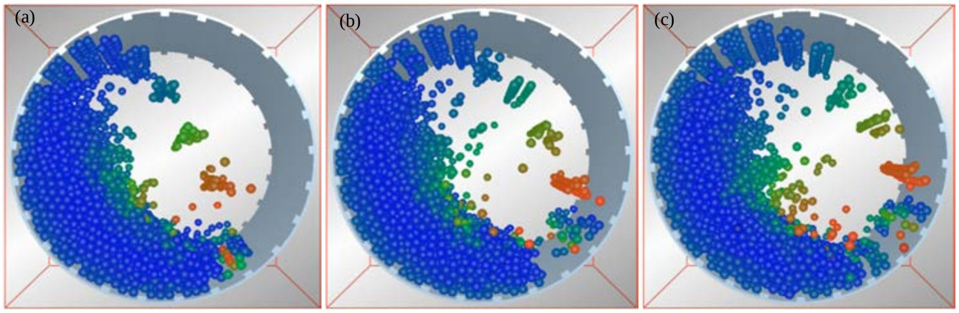

Fig. 2: Grinding media profile motion with the height of the lifters h = 40 mm; a) 0.7.n_{max}; b) 0.76.n_{max} and c) 0.8.n_{max}

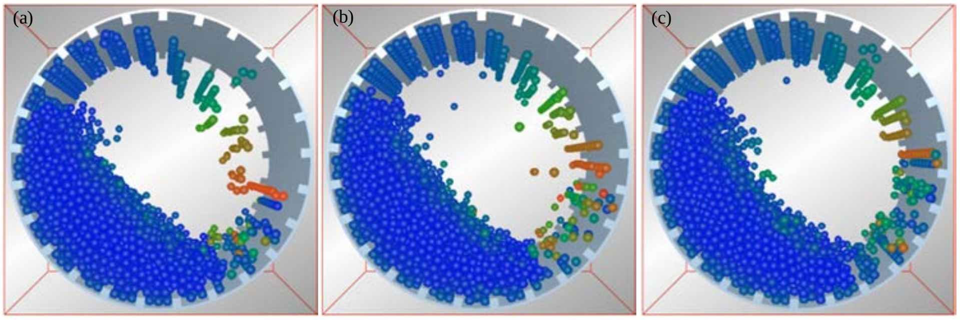

Fig. 3: Grinding media profile motion with the height of the lifters h = 80 mm; a) 0.7.n_{max}; b) 0.76.n_{max} and c) 0.8.n_{max}

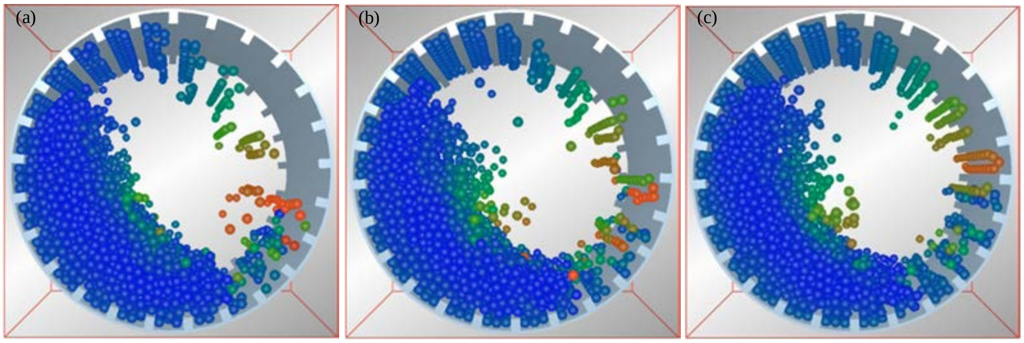

Fig. 4: Grinding media profile motion with the height of the lifters h = 96 mm; a) 0.7.n_{max}; b) 0.76.n_{max} and c) 0.8.n_{max}

media is different according to kinetic energy possessed by each ball designated in: red maximum kinetic energy, blue the minimum.

For the mill with height of the lifters h = 40 mm, it is advisable to select the rotation frequency equal to 0.7.n_{max}. A large number of balls with maximum kinetic energy is observed at 0.8.n_{max} but at such frequencies the grinding media fall on the lining and it begins wear quickly which is not desirable (Fig. 2).

By increasing the height of the lifters (Fig. 3-4) a throwing more grinding media to the lining in the mill at any frequencies is observed which directly leads to a reduction of its operational period. This mode of grinding media motion is not recommended, therefore, lifters height does not provide a required efficiency of a grinding process.

The visual analysis of the grinding media motion (Fig. 2-4) shows that the highest efficiency of the grinding process is provided by the height of the lifters equals to 0.5.d_b (40 mm) the step of the lifters equals to 3.d_b and the rotation frequency equals to 0.76.n_{max}. The comparative visual analysis of the grinding media motion (Fig. 2-4) shows that the highest efficiency of the grinding process is provided by the height lifters equal to 0.5.d_b (40 mm) lifters step equals to 3.d_b and rotation frequency equals to 0.76.n_{max}.

Further, the alteration of kinetic energy of the grinding media affecting the step of the lifters lining and rotation frequency was considered (Table 5). The height of the lifter is constant, h = 40 mm.

The kinetic energy of grinding media reduces when increasing of the step of the lifters at any rotation frequency (Table 5). Thus, kinetic energy of the falling balls in step lifters lining p = 6.d_b is 9-11% and for p = 9.d_b is 11-13% compared to p = 3.d_b.

It can be concluded that kinetic energy of the grinding media E_K decreasing at any rotation frequency of a mill chamber when increasing the lifters step during the data analysis.

Table 5: The total value of the kinetic energy at different rotation frequency and step of the lifters

Rotation frequency (n) (fraction of critical speed)	Step of the lifters (p) 3.d_b	6.d_b	9.d_b
0.7.n_{max}	13360	12105	11900
0.76.n_{max}	15910	14150	13930
0.8.n_{max}	18100	16200	15900

The visual analysis of the grinding media motion (Fig. 2-4) shows that the highest efficiency of the grinding process is provided by the height of the lifters equals to 0.5.d_b (40 mm) the step of the lifters equals to 3.d_b and the rotation frequency equals to 0.76.n_{max}.

When increasing the mill rotation frequency at every step between lifters kinetic energy of the balls increases. This is obvious and confirms the adequacy of the computational model. For example by increasing the rotation frequency of the mill by 15%, the kinetic energy of the balls increases by 36%.

The motion of the grinding media with the step of the lifters p = 6.d_b is shown at Fig. 5, suggests that the most effective grinding media operation is observed at the rotation frequency n = 0.76.n_{max}. When n = 0.76.n_{max} the grinding media begin to fall off the lining that significantly reduces its operating characteristics and makes its use impractical.

The grinding media motion in the mill chamber with steps of the lifters p = 9.d_b and only at n = 0.76.n_{max} contributes to the rapid wear of the lining because up to 20% of the grinding media falling from a great height on the flat lining (Fig. 6).

The distribution of the balls in the mill and kinetic energy at height h = 40 mm and step of the lifters p = 3.d_b at different rotation frequencies were analyzed (Fig. 7).

The number of balls with kinetic energy E_K<6 J is bigger in the mill chamber when n = 0.7.n_{max}. The number of balls with E_K = 8-16 J observed at the rotation n = 0.8.n_{max}. Only 10% of the grinding media have a maximum kinetic energy equals to 38 J.

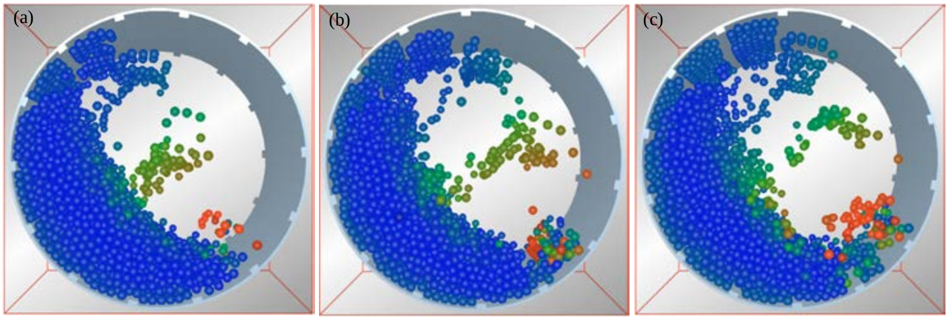

Fig. 5: Grinding media profile motion with step of the lifters p = 6.d_b; a) 0.7.n_{max}; b) 0.76.n_{max} and c) 0.8.n_{max}

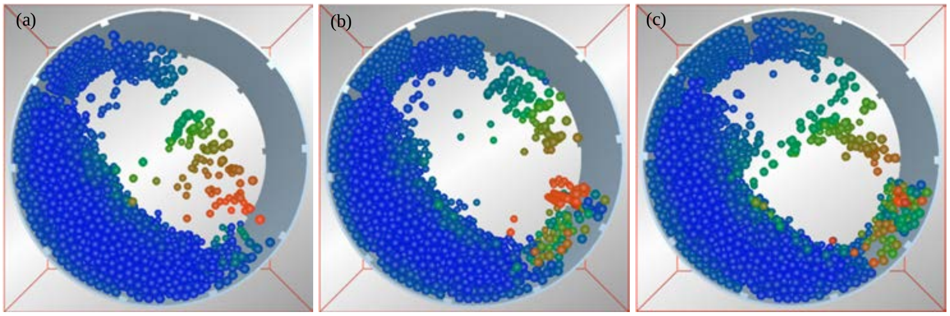

Fig. 6: Grinding media profile motion with step of the lifters p = 9.d_b; a) 0.7.n_{max}; b) 0.76.n_{max} and c) 0.8.n_{max}

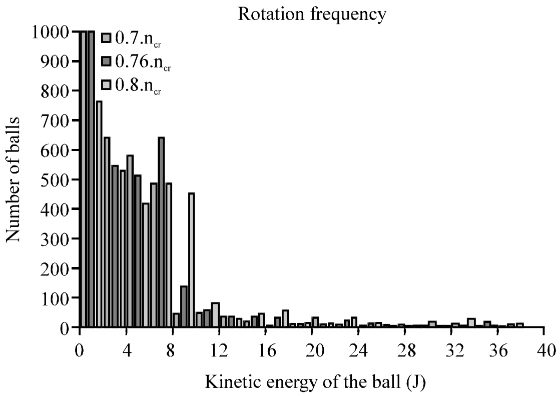

Fig. 7: Histogram of balls distribution in the mill corresponding to a certain range of kinetic energy

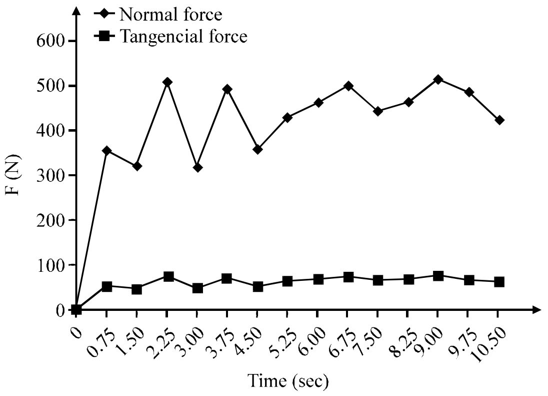

Fig. 8: Normal and tangential components of the force of collision of the ball

Figure 8 shows the graph of the values of the tangential and normal component of the force of collision of the ball at the point of incidence. Normal force of the collision in a steady motion of the grinding media is on average about 480 H and tangential is 80 N that is 6 times less. This shows the prevalence of an impact grinding mode and confirmed by a character of grinding media motion represented in Fig. 2 which proves the adequacy of the computational model. It can be stated that a grinding took place because of the impact forces (Fig. 2) and it proves a high level of the simulation model adequacy.

Kinetic energy of the grinding media in the mill chamber with rotation frequency equals 0.76.n_{max} is 13 kJ and the potential is 23 kJ that is 35% less (Fig. 9). The velocity of balls movement in this mode with rotation frequency (n = 0.76.n_{max}) is 2 m sec^{-1} and angular is 1.75 rad sec^{-1} (Fig. 10).

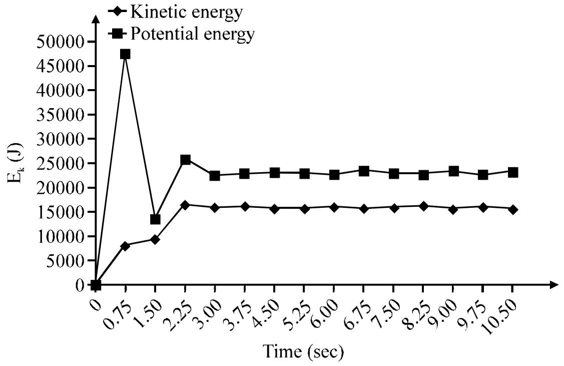

Fig. 9: Kinetic and potential energy of the ball

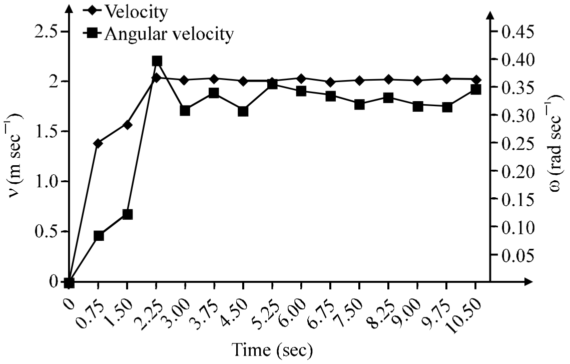

Fig. 10: Linear and angular velocity of the ball

CONCLUSION

The calculations has allowed to study the kinetic energy depending on the height and step of the lifters lining at different rotation frequency in the mill chamber (Makokha and Moys, 2006; Tavares and de Carvalho, 2009). Visual evaluation of grinding media movement finally allowed to make the conclusions about the movement of balls in the mill chamber.

The results fully meet the previously obtained by D.K. Kryukov, V.A. Olevskii and others (Kryukov, 1965; Olevskij, 1963). Presented methodology here in the article for calculating parameters of the lining the height and step of the lifters at each section of the mill chamber. Modeling software utilizing discrete element analysis enables fully explore the nature of the motion of particles in the mill and the resulting data can be used to make a decision on changing the geometric parameters of the linings.

Finally, when designing the profile of the lining and predicting of a mode of motion of grinding media it will be advisable to consider the size, physical and mechanical properties of the crushed material and the kinetics of the milling process.

ACKNOWLEDGEMENT

The experiments were conducted in PLM/CAD/CAE-laboratory in Belgorod State Technological University Named after V.G. Shukhov.

REFERENCES

Austin, L.G. and P. Bagga, 1981. An analysis of fine dry grinding in ball mills. Powder Technol., 28: 83-90.

Bogdanov, V.S. and P.A. Khakhalev, 2014. Design technique for energy-changing linings in ball drum mills. Bulletin of State Technological University, No. 1, pp: 67-71.

Bogdanov, V.S., R.R. Sharapov and J.M. Fadin, 2012. Basis of Calculation of Machines and Equipment of Building Materials and Products. TNT, Staryy Oskol, Russia, Pages: 688.

Elcov, M.J., O.A. Timofeeva and A.A. Kozlov, 2011. Research of efficiency modes ball mills, depending on the design parameters in the software EDEM. Belgorod, Energy-saving technological systems and equipment for the production of building materials. Bulletin of State Technological University, pp: 96-101

Kalala, J.T., M.M. Bwalya and M.H. Moys, 2005. Discrete Element Method (DEM) modelling of evolving mill liner profiles due to wear. Part I. DEM validation. Miner. Eng., 18: 1386-1391.

King, R.P., 2001. Modeling and Simulation of Mineral Processing Systems. Elsevier, Oxford, ISBN: 9780750648844, Pages: 403.

Kryukov, D.K., 1965. Lining of Ball Mills. Mashin, Moscow, Pages: 184.

Makokha, A.B. and M.H. Moys, 2006. Towards optimizing ball-milling capacity: Effect of lifter design. Miner. Eng., 19: 1439-1445.

Mindlin, R.D., 1949. Compliance of elastic bodies in contact. J. Applied Mech., 16: 259-268.

Mishra, B.K. and R.K. Rajamani, 1992. The discrete element method for the simulation of ball mill. Applied Math. Model., 16: 598-604.

Olevskij, V.A., 1963. Grinding Equipment of Concentrating Plants: Casebook on Structures, Calculation and Operation of Ball and Rod Mills. Gosgortehizdat, Moscow, Pages: 448.

Tavares, L.M. and R.M. de Carvalho, 2009. Modeling breakage rates of coarse particles in ball mills. Miner. Eng., 22: 650-659.