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Analysis of simulation result by digital filtering technique and improvement of hammer crusher

Sokgun Hong *, Songgu Kim

Faculty of Mining Engineering, Kim Chaek University of Technology, Pyongyang, Democratic People's Republic of Korea

A R T I C L E I N F O

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A B S T R A C T

This paper presents a method evaluating in numerical value the magnitude of vibration component contained in the rotor angular velocity of a hammer crusher and a new structure to remove them. In the hammer crusher, while rotating by the rotor, hammers are swinging around their pivots simultaneously. This swinging gives effect on the motion of the rotor, making vibration component contained in the rotor angular velocity. By simulating the rotating process of the hammer crusher, the rotor angular velocity and motor power are obtained, and by using the digital filtering technique, a method is developed to evaluate its magnitude in root mean square value by extracting vibration component contained in this simulation result. With this evaluating method is evaluated the simulation result on the motion process of various structures to find out a new structure model of very little value of vibration components in angular velocity and motor power.

1. Introduction

Comminution is an essential part in preparing raw materials in a lot of production processes, consuming a great amount of energy. With the development of economy, the demand for various kinds of metal and non-metal mineral materials and building materials is increasing as time goes by, increasing rapidly the amount of materials to be crushed. It further increases the amount of energy consumption, leading us to conduct an ever-deepening study how to reduce the energy consumption.

The structure of the hammer crusher is simpler than other types of crushers such as jaw crusher and cone crusher (Ajaka and Adesina, 2014). And it is high in crushing efficiency and low in energy consumption with strike crushing as main mode. It also has been known to be safe in crushing relatively high-strength and tough materials thanks to the connection structure of hammer hinging the rotor. With these advantages it finds its wide application in many fields including mineral mining and metallurgy.

Fengnian et al. (2003) studied the energy model of a hammer mill to obtain a crushing model with dynamic internal recirculation by combining breakage classification function, screen classification function and breakage distribution function. The model was validated using the independent experimental data of single coal tests with the laboratory scale hammer mill and full operation audit data of an industrial hammer mill. The outcome of the energy-based swing hammer mill model is the capability to simulate the mill configurations and operating conditions on product size distribution. The model can be used to select the machine settings required to achieve a desired product. Austin (2004) considered that the power of hammer mill varies approximately proportional to the hammer speed cubed and then studied the relation between the power consumption and the product size distribution in consideration of the repeated strike of the hammer on the solid material which is not crushed at one strike.

Dey et al., 2013 studied on the comminution of coal and iron ore materials to investigate the comminution features of the hammer mill. The effect of the feed rate and the rotor speed on the mill efficiency in terms of reduction ratio, energy expenditure was investigated. The hammer mill products were observed to exhibit Rosin–Rammler type size distribution. A high rotor speed with a low to moderate feed rate was found to give better performance of the mill. It was suggested that the quantity of fines generated in the mill can reflect the degree of attrition in the mill which is an indirect measure of the mill wear.

Djordjevic et al. (2003) simulated the particle movement and calculated the velocity and energy distribution of collision in two types of impact crusher by applying the DEM technique: the vertical shaft crusher and the horizontal shaft mill. Experimental data of the hammer mill were used to verify the DEM simulation results. Upon the DEM procedures being validated, a detailed simulation study was conducted to investigate the effects of the machine design and operational conditions on velocity and energy distributions of collision inside the milling chamber and on the particle breakage behavior. The study on the hammer crusher based on the DEM technique was further developed by Sinnott and Cleary (2015). They simulated the flow of materials and the breakage by using the DEM replacement breakage model, which

* Corresponding author at: P.O. Box: 60, Kyogu, Pyongyang, Democratic People's Republic of Korea.
E-mail address: hsg6351@star-co.net.kp (S. Hong).

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Cleary (2001) put forth and Cleary and Sinnott (2014) supplemented, thus obtaining detailed results such as energy prediction, the product size throughput rate and wear.

As mentioned above, the previous works were mainly focused on improving the operation of the hammer crusher, in particular, those concerned with energy consumption, distribution of the product size and wearing, considering that the structure is very simple. However, this paper shows a need to focus on the structure.

A hammer crusher consists of a rotor and hammers. The hammers are hung on the pivots fixed on the rotor and can swing freely. The rotor is rotated through a belt-driven system by an electric motor. While the hammer crusher is working, feed materials drop into the crushing chamber to be shattered by the high-speed hammers. During the impact the hammers pass some of their kinetic energy over the materials to be shattered. The hammers lose their kinetic energy as much as that consumed in shattering materials and that shattered materials newly possess. But, unlike the rotary crusher with hammers fixed on the rotor, because of the connection structure of hammer hinging the rotor, the loss of energy from the collision does not directly affect the rotation velocity decrease of the rotor, but first causes velocity decrease (backward swinging) of the hammers, giving effect on the rotor to decrease the rotor angular velocity. In other words, that is regarded as buffering effect. The feed materials are not always the same kind; in some cases relatively massive and tough the materials, even some hardware difficult to be crushed. In this case, the collision between the hammers and these materials may be regarded as elastic one. So the hammers can't crush these hard materials, with the backward swinging angle of the hammers increased, which plays an important role in protecting the crusher.

However, the hinged structure of the rotor and the hammers has somewhat negative effect on the dynamic characteristics of the hammer crusher. Once the rotor starts rotating, the hammers also do along the rotor, swinging around their pivots simultaneously. Although the hammers are pushed further away in the circumferential direction by centrifugal force as the rotor angular velocity increases, they still swing backward and forward around hammer pivots due to the inertial mass and the hinged structure of hammers. And in crushing process there constantly occurs collision of the hammers with the materials, breaking down the stability of hammers and making their swinging stronger. Thus, such a motion characteristics of hammers continuously affects the rotor angular velocity to be instable with its stronger vibration. It causes the noise increase, and power consumption increase and bad effect on the power system with unstable motor power. Therefore it is of theoretical and practical significance to ensure protection of the hammer crusher from overload, the advantage of it, and to decrease the vibration component included in the rotor angular velocity.

In this paper presents a method of simulating the dynamic motion process of the rotor in the hammer crusher to evaluate the intensity by extracting with digital filtering technique the vibration component contained in the simulation result. And on the basis of analyzing and evaluating various structures of simulation results in this way, it finds out a new structure to improve its dynamic characteristics by decreasing the vibration component included in the rotor angular velocity.

2. Simulation of kinetic system of hammer crusher and analysis of the result

2.1. Simulation of kinetic system of hammer crusher

MSC.visualnastran software in MSC is used for simulation of kinetic process of the hammer crusher. Using this software makes it easy to make a model machine and set conveniently the force and the moment. It can be applied in combination with MATLAB which provides good control of machine and analysis of its features.

In order to visually derive natural physical characteristics of the kinetic system of the hammer crusher, friction is ignored. One of the important things in modeling to study on the effects of factors on a certain object is to simplify the model to clearly identify the characteristics of factors to be considered. The closer the model is to practical reality and the more factors are considered, the more difficult it is to identify the effect of individual one on the object due to the intervention. For example, if the more factors such as friction in linking parts and resistance caused by fluid dynamic phenomenon when hammers are rotating are added in modeling, the target factor, a proper physical characteristics in kinetic system consisting of crushing mechanism may be hidden by them and not be observed clearly. Thus, in studying on modeling, it is significant to make the model as simple as possible and find out a shortcut for achieving its goal, which is one of good studying methods to shorten the studying time to find out the solution by analyzing easily. From this viewpoint, the friction in linking part and the resistance caused by fluid dynamic phenomenon when hammers are rotating are ignored in this model.

Fig.1 shows a MSC.visualnastran model for the conventional hammer crusher described before.

As shown in Fig. 1, the model consists of a rotor, four hammers and a belt pulley. Motor constraint is given to the belt pulley, belt constraint between the pulley and the rotor, revolution joint constraints to the rotor and to the linking axis between the rotor and the hammers. In Fig. 1, ω is rotor angular velocity.

Moment of the motor is transferred to the rotor through the belt constraint. Then the rotor rotates around its axis with the hammers linked to the rotor by the revolution joint constraints. The faster is the rotor angular velocity, the greater is the centrifugal force causing hammers to pull out in the direction of centrifugal force. On condition that the materials to be crushed have been not provided yet, onto the motor given is the load by inertia moment of the rotor and pulley, the load caused by the varied angular velocity due to hammers' swing and the load by the frictions. When the materials to be crushed are provided, the load from collisions of hammers and materials is more added. This load should be balanced with the moment of the motor dynamically, thus, the motor power can be calculated by multiplying the moment of the motor by the angular velocity of the pulley with motor constraint. So, in this model calculated and analyzed is the rotor angular velocity and the motor power with respect to time.

Parameters used in simulating the model are given in Table 1.

When $t = 0$, an initial rotation angle and an initial rotor angular velocity are $\varphi_1 = 0°$ and $\dot{\varphi}_1 = \omega = 0$ respectively, initial rotation angles and initial rotation angular velocities of the hammers are $\varphi_2 = 0°$, $\varphi_3 = 270°$, $\varphi_4 = 180°$, $\varphi_5 = 90°$, $\dot{\varphi}_2 = \dot{\varphi}_3 = \dot{\varphi}_4 = \dot{\varphi}_5 = 0$ respectively.

On the basis of the data on 15 kw asynchronous motor, moment of the motor with respect to slip ratio is:

$$M = \frac{194.7s}{0.314^2 + s^2}, \text{[Nm]}$$

where M is moment of the motor and s is the slip ratio.

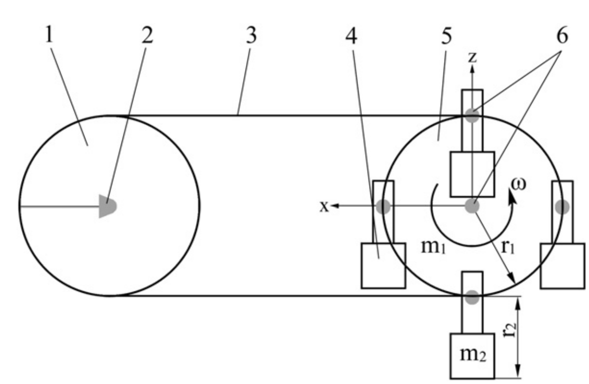

Fig. 1. MSC.visualnastran model of the hammer crusher. The hammers swing freely around the pivots fixed on the rotor. 1-pulley, 2-motor constraint, 3-belt constraint, 4-hammer, 5-rotor, 6-revolution joint constraint.