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Journal of Computational Design and Engineering 4 (2017) 14–20

www.elsevier.com/locate/jcde

A computational methodology to calculate the required power in disc crushers

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Received 13 July 2016; received in revised form 29 August 2016; accepted 12 September 2016
Available online 15 September 2016

Abstract

This study aims to contribute to the estimation of power consumption in a disintegration process in disc crushers (fixed and mobile). The study covers the dynamic analysis of forces acting on the particles and the mobile disc. A detailed analysis of the resultant force on the particles was performed. Finally, the consumed power is calculated with the forces acting on the mobile disc. The calculated power is a key aspect in the design of disc crusher machines.

Keywords: Power estimation; Mill disc; Disc crushers; Disintegration process

1. Introduction

Disc crushers are widely used in the agricultural, wood, mining and chemical industries [1]. For example, the studies on the effects of milling on oil quality [2], the effects of different mechanical crushers in the process of olive paste [3], the studies on the influence of physical properties of seeds on shelling performance using a disc mill [4] are recent and important studies that suggest the need to fully understand the physics and mechanics in the design and performance of new types of disc crushers.

The relationship between energy consumption and product size in a disintegration process is the fundamental pillar of the theory of the disintegration process [5]. For that reason, it is important to obtain the power consumption, which is related to energy consumption in a time interval. Consequently, the estimation of the required power for disc crushers is essential in a fragmentation process.

Although there are theories that give an approximation of the energy consumption in a process of disintegration, currently, there is no a satisfactory and general one. Among them, the theory of Von Rittinger (1867), who believed that the required energy in the milling process must be related to the new surface produced during this operation. Another theory is the theory of Kick, who believes that the required energy for size reduction of two particles is proportional to the reduction in volume or mass of these particles [6]. It is also important to mention the theory called Bond Law, which states that the work required in a process of disintegration is proportional to the square root of the diameter of the particles produced [7]. These three proposed theories can be expressed in a single equation known as Walker Equation, which states that the energy required for size reduction of a material is proportional to the amplified n times size [8].

Another method describing a process of disintegration is "The Population Balance Equation", which is a mathematical description of how the distribution of particles according to their size changes depending on time [9]. It is worth mentioning that there are several commercial softwares which allow the estimation of the consumed power in a disintegration process. These softwares use numerical method which are based on the method of discrete elements [10], for example the software called Rocky.

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Peer review under responsibility of Society for Computational Design and Engineering.

http://dx.doi.org/10.1016/j.jcde.2016.09.003
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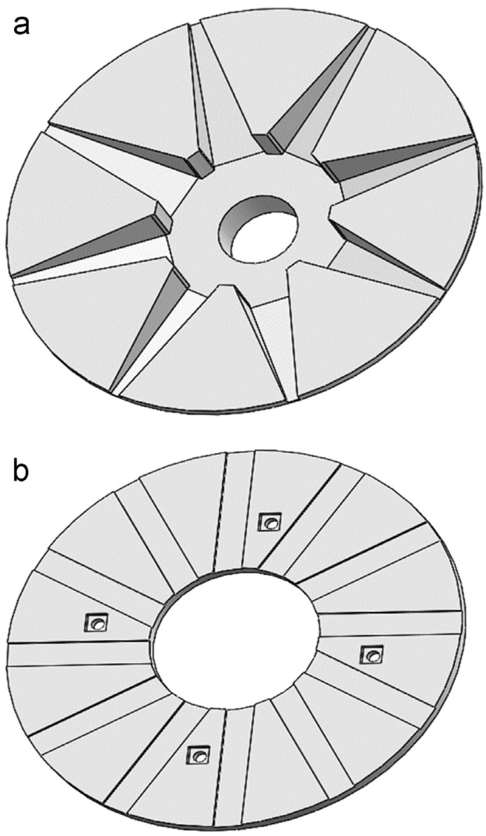

Fig. 1. Discs crushers, (a) mobile disc, (b) fixed disc.

In this study, a methodology to calculate the required power in a disintegration process is presented. This analysis considers relative movement between particles and disc crushers, which includes coriolis and centripetal forces. Worth mentioning that the disc crushers were designed by the authors of this paper.

2. Methodology

A disintegration process is closely related to the size reduction [11]. For this reason, it is necessary to analyze the size reduction through the disc channel.

2.1. Technical description of fixed and mobile disc

It is worth to mention that the discs were designed to mill sweet corn. Fig. 1 shows the discs used in this paper to evaluate the calculation methodology of required power during milling. The disc crusher of quadrangular channel is utilized in further discussions, see Fig. 1a. Its geometry was design to mill properly sweet corns. As it can be seen, the section is reduced as it approaches to the boundary of the disc, see Fig. 1. It is assumed that sweet corns are spherical and compact and as son them enter into the disc crusher the milling process starts. The number of channels of the disc depends of the volume of the first spherical body and they are used to guide the corn through all the milling process until the final process. The fixed disc has special channels, which have the function of cutting the corn while it is rotating in the channel of the mobile disc.

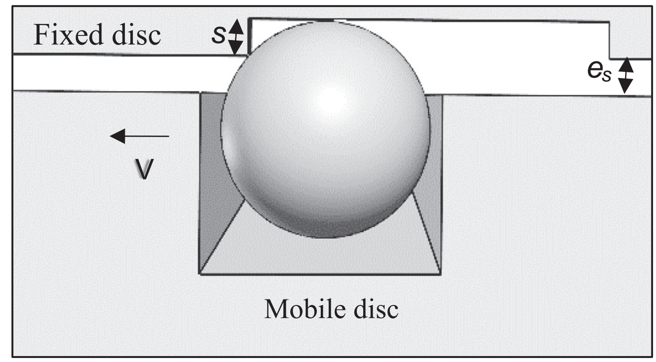

Fig. 2. Cutting process of the particle, "s" is the cut depth and "e_s" is the distance between the flat faces of the discs.

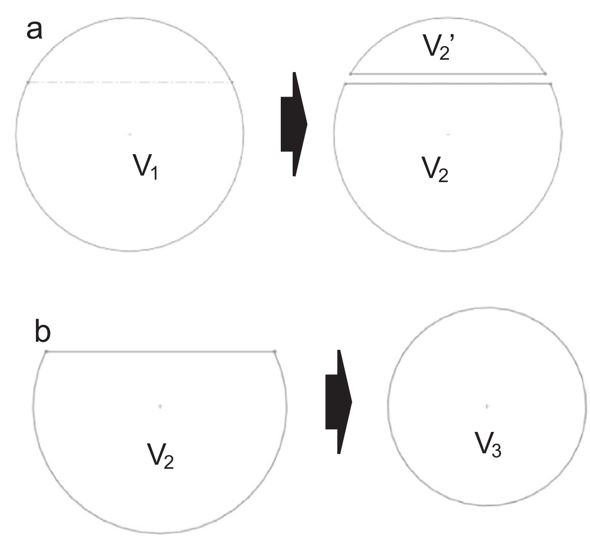

Fig. 3. The process of disintegration of the particle, (a) generation of new elements, (b) generation of the new sphere of volume V_3.

2.2. Methodology of calculation

It is considered that the product to be fragmented is a sphere, because the sphere is more compact and it has higher shear strength than other solids, consequently the method of estimation of power is conservative. The forces that normally act in a process of fragmentation are: compression, shear, impact and abrasion [12]. The present disc is designed to cut as shown in Fig. 2.

In each cut, the volume of the sphere V_1 becomes two elements V_2 and V_2'. The element V_2' is, in terms of volume, much lower than the element V_2; this is due to the fixed disc geometry, which ultimately determines the cutting depth. For purposes of calculation, it is assumed that the solid of volume V_2 becomes a new sphere of volume V_3, see Fig. 3.

To evaluate the power consumption in the disintegration process, it is necessary to evaluate the power consumption in each channel of the mobile disc, see Fig. 4.

To obtain the power on each disc channel, the forces $\vec{N}_1$ and $\vec{N}_2$, acting on the mobile disc, have to be calculated, see Fig. 5.