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A preliminary model of high pressure roll grinding using the discrete element method and multi-body dynamics coupling

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ABSTRACT

The HPGR is properly regarded as one of the most important recent developments in the field of size reduction. This success is mainly associated to its improved energy efficiency, grinding capacity, lower sensitivity to grindability variations and higher metal recovery in downstream processes compared with conventional grinding technologies such as ball mills and cone crushers. It comprises two counter-rotating rolls mounted on a sturdy frame, one of which is allowed to float and is positioned using hydraulic springs. Comminution in the HPGR is largely determined by the pressure exerted on the bed of particles by the hydraulic system. The paper describes how the coupling of the multi-body dynamic simulation with the discrete element method can be effectively used to describe the performance of the HPGR. The model considers important variables, including the HPGR rolls geometry and design, the hydraulic spring system start-up parameters and the material loading response, to describe key operational outputs as material throughput, operating gap and roller pressure distribution. The preliminary version of the model has been used to demonstrate qualitatively the effect of material properties on the operating gap, the pressure and the energy consumption of a laboratory-scale HPGR. Predictions using the model have been compared to those from phenomenological models, showing good agreement, but also limitations in the DEM approach with the current simple particle replacement model to predict the working gap at high initial nitrogen pressures.

1. Introduction

Compared to the more traditional crushing and grinding technologies, many of which in use for more than a century, High Pressure Grinding Rolls (HPGR) may be regarded as a recent development, given its patent from the 1980s by Professor Klaus Schönert (Schönert, 1988). Since their introduction, HPGRs have been widely used in cement industry which still has the majority of the industrial units in operation. The proven success in the cement industry has been attracting the mineral industry's attention for many years (Aydoğan et al., 2006). Nevertheless, their application in the mining industry has been growing steadily for the last 10 to 15 years, first in the preparation of diamond and iron ores and, more recently, with the improvements in the rolls wear resistance, also in gold, platinum and copper ores (Morley, 2010). The major benefits supporting this trend are better energy efficiency, improved grinding capacity, less sensitivity to ore grindability fluctuations, and ability to induce grain boundary fracturing and to reaching higher metal recovery in downstream processes such as heap leaching and flotation (Rosario and Hall, 2010).

The High Pressure Grinding Rolls comprises a pair of counter-rotating rolls mounted in a sturdy frame (Fig. 1). Material is fed to the HPGR by means of a chute usually mounted directly above the gap between the rolls. Feed particles are usually fine enough to be gravity fed into the HPGR, where the nip angles of the particle and the internal friction of the bulk of the material mass are sufficient to continuously draw the material through the rolls. The HPGR breaks particles predominantly autogenously inside the compression zone by the mechanism of interparticle breakage, unlike other comminution devices such as ball and rod mills. Comminution performance is largely determined by the pressure in the compression zone, with operating pressures varying in the range of 50–150 bar, reaching values as high as 180 bar (Morley, 2010).

In the machine the feed material is compressed between two counter-rotating rolls, in which one of the rollers rotates on a fixed axis while the other is allowed to move horizontally. The moveable roll is forced up against the material by a hydraulic oil cylinder system. Depending on the manufacturer, this oil pressure transmits, either through two or four pistons, the grinding force over the cross-section of the diameter of the rolls where the bed of particles is formed. The amount of material in the gap, or compression zone, may be manipulated to a limited degree to result in optimum operating conditions, but generally, it is a

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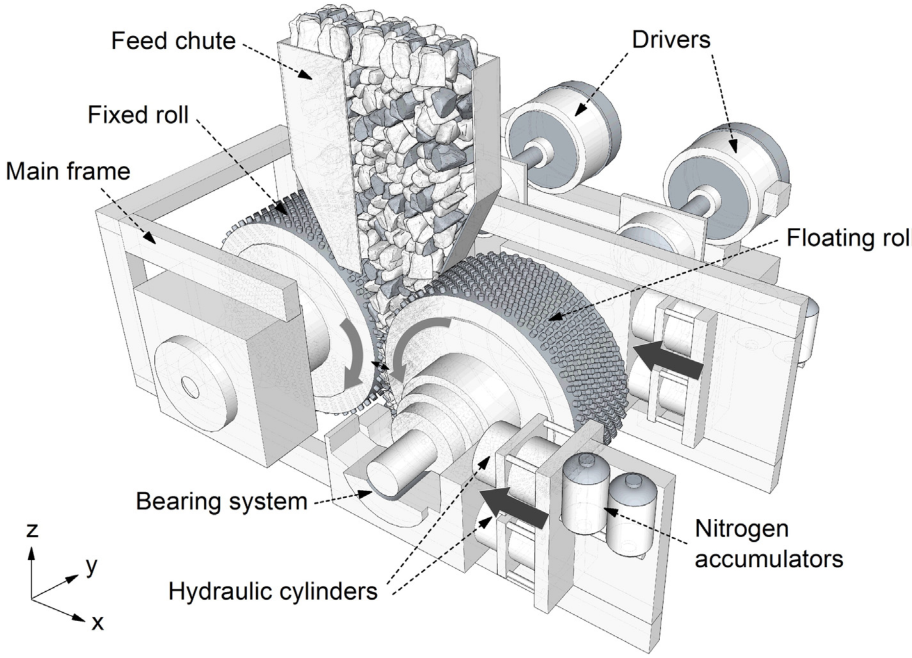

Fig. 1. Schematics of the HPGR.

characteristic of the feed ore, the roll diameter and its surface characteristics (Daniel and Morrell, 2004).

Simulation is a very powerful tool for both improving comminution equipment design and operation, since it allows comparing what-if scenarios with no cost associated with physical prototypes or with loss of production, respectively. Evidently, the usefulness of these simulations depends on the fidelity of the mathematical models of the unit operations. In spite of being a comparatively young technology, a number of worthwhile attempts (Schönert, 1988; Austin et al., 1993; Daniel and Morrell, 2004; Torres and Casali, 2009; Dundar et al., 2013) have been made to describe the performance of the HPGR either with empirical or phenomenological models. These models have been used to describe the effect of the main operating and design variables on the HPGR throughput, the product size distribution and the power consumption, being useful for both improving operation and design. However, these models rely heavily on experimental data from both pilot and industrial units and also are limited in their ability to predict the effect of variables in the hydraulic system on the HPGR performance. Such approaches have limited or no ability to help understanding the pressure distribution along the axis of the rolls and the edge effect, the skewing of the rolls and the relationship between the apparent pressure applied by the rolls and the buildup of pressure within the bed.

Important advances in modeling of size reduction operations have been made in recent years using the discrete element method (DEM) (Weerasekara et al., 2013). In the case of the HPGR, the application of the method is particularly challenging, given the intense particle-particle interactions during compression, besides the displacement of the movable roll in response to the hydraulic system and the bed particle characteristics.

The piston and die press provides a convenient and versatile tool for the study and analysis of the absorption, dissipation and utilization of grinding energy, size spectra of the ground products and virtual cessation of further size reduction at high pressures. Several studies have been made to study compression of particle beds in a piston-and-die press using DEM (Kou et al., 2001; Khanal et al., 2007). However, the first attempt to apply this type of simulation to gain insights into HPGR performance was made by Djordjevic and Morrison (2006), who simulated compression of a particle bed consisting of unbreakable spheres using PFC3D®. They demonstrated, for instance, that the thickness of the particle bed should not be very large – in terms of the number of layers of particles – in order to maintain energy-efficient operation. In spite of the similarities between the HPGR and the piston-and-die system, the operation of the continuous machine results in significant differences in performance, given the introduction of shear and to the different boundary effects. Luckily, advanced DEM codes allow the user to represent equipment geometry as tessellated surfaces of a 3D CAD model with the kinematics of the meshed geometry defined in the simulation, making it possible to predict interaction between particles and the rotating rolls in an HPGR. This was used by Quist and Evertsson (2012) to simulate the operation of a pilot scale HPGR using the software EDEM® considering unbreakable particles and fixed rolls. This study predicted the non-uniform axial pressure profile along the roll length and demonstrated the effect of cheek plates on this distribution of pressures. In these simulations, however, the rolls were assumed to occupy fixed positions, which is the case of conventional roll crushers, not HPGRs.

When the bulk material properties change as result of contact between the particles and the equipment, such as particle attrition and breakage in comminution processes, then the dynamic response of the equipment must be accounted for as it affects the efficacy of the simulation using DEM. Multi-body dynamics (MBD) simulation of comminution equipment requires application of transient loading to the equipment components in order to predict the machine kinematics, which changes according to the loading characteristics.

In the case of the HPGR, the aperture between the rolls or working gap is a key variable that defines its operation but it is not directly controllable, since it is an outcome of the interaction between the particle bed and the setting of the hydraulic system. This type of coupling has been implemented in Metso's DEM simulator (Herbst et al., 2011) and applied to simulate the HPGR. Recently, Cleary and Sinnott (2014) modeled the HPGR taking into account the dynamics of the roll movement as a result of the balance between the pneumatic force and the bed response, even describing particle breakage using the particle replacement method (Delaney et al., 2015). Unfortunately, these publications do not present details on the implementation of the floating roll model and neither use software that is available commercially. Edwards et al. (2013) proposed a coupling interface for the EDEM® physics co-simulation with equipment dynamics that can be used in such application.

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