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Influence of charge type on measurements with an in-mill sensor

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ABSTRACT

The process of grinding is complex with many factors affecting the result. As the composition of the ore fed to the concentrator varies, implying changes in grindability, the optimal operation conditions for a pebble mill will also vary. In an attempt to increase the understanding of charge dynamics, a series of statistically planned experiments were done in a pilot-scale pebble mill with differing charge types. This pebble mill is equipped with an in-mill sensor, which measures the deflection of a single lifter as it passes through the mill charge. The experimental setup was a factorial design with two factors; two levels of magnetite pebbles content and three different size distributions. The experiments show that there is an advantage to keep the magnetite pebbles proportion as high as possible. This will increase the power consumption and maximum deflection of the lifters, but at the same time increase the production of <45 μm material, the grindability and the pebbles consumption. A pebble size fraction 10–35 mm improves the grindability the most and the amount of <45 μm material. It is strongly suggested that the 10–35 mm and 100% magnetite pebbles fraction should be tested in a larger scale pebble mill to confirm these findings.

1. Introduction

In the North of Sweden, Loussavaara Kiirunavaara AB (LKAB) mines iron ore, mainly magnetite, and provides the steel industry with upgraded iron ore products. To maintain high production rates in the pellet plants, a steady flow and even quality from the concentrating plants are necessary.

The composition of the pebbles to LKAB's full-scale pebble mills vary. It depends on the availability of pebbles from the autogenous mills in the previous process step. When there is a lack of magnetite pebbles from the primary mill, either extra gangue pebbles will be added to the pebble mill, or a larger size fraction of magnetite pebbles has to be used. Therefore, it is of interest to find out how the different pebble mixtures affect the grindability of the pebble mill. It is also of interest to find out how the different pebble size fractions affect the product size.

Grindability is not a new concept, just a way of coupling the supplied grinding energy to the output of a desired particle size interval. However, it is dependent on the ore type and its composition. Fahlström (1974) used grindability defined as lbs. <325 mesh pro kWh, in comparing scale-up and grinding techniques for the Aitik ore. Jackson (1964) used tons <200 mesh pro horsepower-day in describing autogenous grinding in South Africa. In South Africa today, it seem more common to use an inverted form of grindability, i.e., to calculate the kWh pro ton of <75 μm material as done by Keshav et al. (2011). In Sweden, another approach is nowadays common, and that is to use grindability (G) defined as kg freshly produced <45 μm pro kWh grinding energy, cf. Eq. (1). The reason for selecting 45 μm as the defining size is that it is the smallest standard sieving size in most concentrators producing pellet feed or flotation feed.

$$G = \frac{(\%\mathrm{OUT} - \%\mathrm{IN})}{100} \cdot \frac{M}{P} \tag{1}$$

where %OUT and %IN are the %<45 μm in the product and feed respectively, M is the mass flow of solids in kg/h and P is the net mill power in kW.

The process of grinding is complex with many factors affecting the result, foremost the ore's mineralogical and physical properties. The composition of the ore to a concentrator varies over time, meaning that the grindability changes, which in turn leads to varying optimal operating conditions for the mill. Already Fahlström (1962) showed that the size distribution of the ore feed strongly affect the grinding result of an autogenous/pebble mill.

There is a lack of knowledge of events occurring in a mill and the inside of the mill is too harsh for direct in-mill measurements. Instead, different methods indirectly measuring the dynamics are used to increase the understanding. Campbell et al. (2001) measured vibrations with sensors placed on the shell of the mill. Kiangi and Moys (2008) used an inductive sensor inside the mill to get information. Pax (2001) used an acoustic method to get data.

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Clermont and de Haas (2008) presented SensoMag, a sensor from Magoutteaux.

Another type of sensor is used in the experiments presented here. The chosen sensor is the Continuous Charge Measurement (CCM) system developed by Metso Minerals. The main advantage of this sensor is that it directly measures the deflection of a bendable lifter, and that the deflection may be directly calibrated to the force acting on the lifter. It has been shown by Tano (2005) to have a fast response time for varying process conditions, and that it is reliable and has good reproducibility.

To learn more about the milling process, a series of statistically planned experiments were done and process data collected. To observe the changes inside the mill, the Metso Minerals CCM system was used. The test setup was a factorial design with two factors. Two different levels of magnetite pebbles content were investigated, 50% and 100%. In addition, three different pebble size distributions were tested, 0–35 mm, 10–35 mm and 20–35 mm.

2. The experimental setup

The necessary experimental data were obtained from a pilot mill at the LKAB R&D facility at Malmberget, Sweden. The mill has a diameter of 1.4 m and is 1.6 m in length. It has a rubber lining and 12 rubber lifters installed. The lifters are 10 × 10 cm with a face angle of 45°. The mill is a grate-discharge mill with open area of ~10%. The mill is fully instrumented and under process control with the following parameters continuously measured: motor power, mill feeders, mill weight, mill water addition, and the parameters from the CCM system.

The CCM system from Metso Minerals consists of a strain gauge detector embedded in one of the rubber lifters, see Fig. 1. When the lifter comes in contact with the charge it bends backwards, the strain gauge mounted on the leaf spring converts the deflection to an electric signal. The signal is amplified, filtered and transmitted to a computer (Dupont and Vien, 2001). The speed, charge level, toe-, shoulder- and charge angles and a deflection curve are continuously updated in the CCM program while the CCM is in operation.

The signal from the CCM system contains a large amount of information and is of great value when conducting and evaluating experiments. Seen in Fig. 2 is a typical deflection profile. Other information can be obtained from the signal, such as the calculated mill volume occupied by the charge.

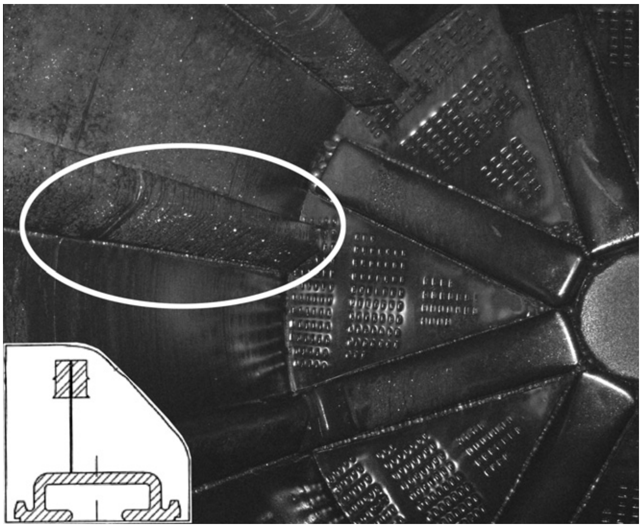

Fig. 1. A cross section of the rubber lifter with at strain gauge detector embedded and a view inside the mill with the lifters.

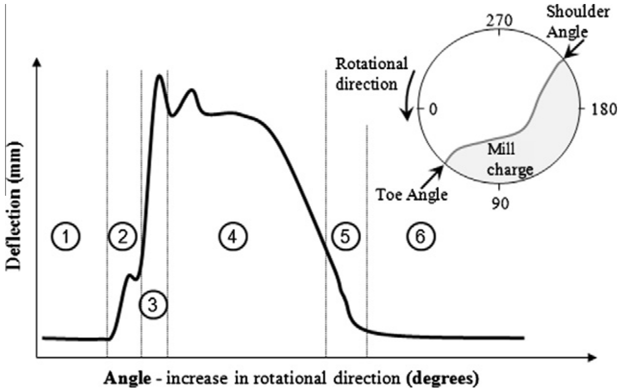

Fig. 2. A simplified view of a typical deflection signal of one revolution from the CCM system.

The deflection curve starts at 0° when the lifter is horizontal with only a velocity in the downward vertical direction, section 1. When it reaches the charge in the toe area there is rapid increase of deflection, section 2. Turbulence in the toe area can be seen as a small bump in the beginning of the toe area, but it might also be a slurry-pooling phenomenon. The maximal deflection often occurs around the bottom of the mill, section 3. Shockwaves from the other lifter impacts can be seen as the lifter moves through the charge, section 4. As the lifter continues and reaches the shoulder area, the deflection decreases, section 5. In section 6, the lifter has cleared the charge.

2.1. Experimental conditions

The feed to the mill was a magnetite feed with a d_{50} of ~70 μm, with 36% <45 μm and a solids density of 4.8 tonne/m^3. The feed rate was kept constant at 0.85 tonne/h.

The pebble feed was either of three size fractions: 0–35 mm, 10–35 mm and 20–35 mm and the pebbles were either a mix of 50% by volume of magnetite pebbles (bulk density 3.0 tonne/m^3) and gangue pebbles (bulk density 2.4 tonne/m^3) or 100% magnetite pebbles. The pebbles emanated from an autogenous mill at the Kiruna concentrator. This is the primary mill and it is equipped with pebble ports in the grate. The pebbles are sent either to the secondary pebble mill or to a pebble crusher before being recirculated to the primary mill. Pebbles for the tests were collected from the stream to the pebble crusher. These test pebbles then undergone dry magnetic separation on a belt separator. The magnetic and non-magnetic pebble products were dry screened to produce batches of 10–35 and 20–35 mm fractions of magnetite and gangue pebbles. The 0–35 mm fractions are the magnetic belt separator products without any further treatment. The pebble test fractions were then sent to the pilot plant at Malmberget.

At the pilot plant, the mill was filled with the desired pebble charge composition for each test. In the case of the magnetite–gangue pebble mix, it was accomplished by taking equal amounts by volume from each type of pebbles. The pebble feed rate was varied to keep the mill filling degree constant and the charge level was monitored by the CCM system. Pebble feed rate varied between 0.14–0.6 tonne/h, a lower feed rate for the gangue pebbles mix.

Each test point was run with an initial stabilisation period of ~2 h, followed by measurements during one hour. The mill was completely emptied when changing charge size fractions or composition. Due to the short test times, any changes to the charge are considered contained in the experimental errors.