Minerals Engineering 62 (2014) 2–8

Contents lists available at ScienceDirect

Minerals Engineering

journal homepage: www.elsevier.com/locate/mineng

Evaluation of the applicability of ultrasonic velocity profiling in conditions related to wet low intensity magnetic separation

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ARTICLE INFO

Article history:
Available online 18 September 2013

Keywords:
Iron ore
Magnetic separation
Process instrumentation
On-line analysis
Fine particle processing

ABSTRACT

The internal material transport and selection processes of the wet low-intensity magnetic separators (LIMS) are poorly understood; this calls for improved measurement techniques. In this work an ultrasonic velocity profiling (UVP) technique for measuring how material flow velocity varies with penetration depth is presented. A measurement depth of just a couple of centimetres would greatly improve the understanding of the separation process in a LIMS.

When applied to flows of mineral suspensions with high volumetric solids concentration, similar to those in the separators, UVP is unique in combining:

- Non-intrusive measurements.
- Operates using just one sensor element (transducer).
- Relatively good spatial resolution.
- Penetrates opaque suspensions.
- Fast sampling rate.

Here, flows are studied in a rectangular duct (50 × 75 mm). Using magnetite suspensions, measurement through the whole depth of 50 mm is made with good accuracy. Velocity profiles are presented for solids concentrations of 5% and 9% solids by volume (20% and 36% by weight). Even at 9 vol% solids it is possible to reach a penetration depth of more than 25 mm.

1. Introduction

The wet low-intensity magnetic separator (LIMS) is the workhorse for winning of fine ferromagnetic particles from ore pulps; despite this the internal workings of the machine are poorly understood. Also, as experienced by the industry, when pushed to higher capacities and with higher concentrate quality demands, it has started to show some limitations. To increase the understanding of this problem the use of computer simulations were attempted by Lejon Isaksson (2008). One conclusion was that trustworthy simulations need measurements for validation. The maximum depth of a full size separator tank is about 100 mm, but to verify simulations a measurement depth of just a couple of centimetres would suffice.

1.1. Magnetic separation

The wet LIMS (Fig. 1) consists of a rotating non-magnetic drum with a number of internally fixed magnets arranged with alternating polarity. The rotating shell is partially submerged in a tank into which the suspension of ferromagnetic material is fed. The magnetic portion of the feed material is attracted towards the drum surface and then carried through the alternating magnetic field and out through the concentrate discharge. The history and physics of wet LIMS is described in more detail by Parker (1977).

The amount of research done on wet LIMS is limited, but some has been published, for example Lantto (1977a,b) investigated how various factors influenced the performance of wet LIMS for a titaniferrous magnetite ore. Some of the factors investigated were the number of separation stages, the magnet assembly design, tank design, pulp density and magnetic flocculation. It was found that magnetic flocculation had central significance for determining the separation result. Rayner and Napier-Munn (2003) combined empirical advice and experimental trials to develop process models for wet drum magnetic separators. Also here, magnetic flocculation was shown to play a central role. A model to predict loss of magnetic material was presented where the loss depended upon a first order flocculation rate and the residence time within the separation zone. Even though this work was aimed at wet drum magnetic separators used for dense medium recovery, much of the theory should also be applicable to concentration of magnetite.

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http://dx.doi.org/10.1016/j.mineng.2013.08.005

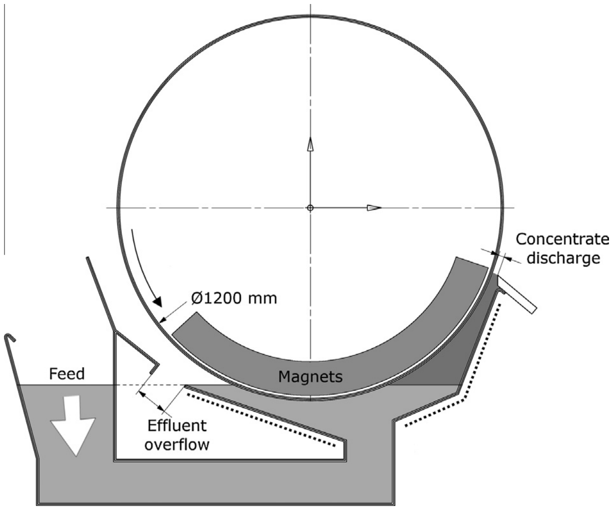

Fig. 1. Cross section of wet LIMS of counter-current type (design by Metso, www.metso.com). Dotted lines indicate walls of special interest for mounting of sensor for flow velocity measurements.

Recently Dworzanowski (2010) described, from a general point of view, how the various designs and operating variables interact, how they affect performance and also provides guidelines on operation. Factors given high importance included tank design, magnet assembly configuration, feed preparation, feed rate, level control and drum/tank distance.

Generally, one of the challenges of optimizing LIMS is the balance between attracting too much material, and thus getting mixed grains of low grade in the concentrate, and attracting too little material and losing the very fine (liberated) magnetic fraction to the tailings. This is where understanding the limitations of LIMS and the mass transfer of material within a LIMS could help in circuit configuration and processing to maximize the overall magnetite recovery.

To gain a deeper understanding of the process of wet LIMS, measurements of internal particle flow are needed. To obtain good quality data the following specification was set up:

1. The sensor is required to operate from one direction only, this since the separator design allows physical access to the flow from only one side (dashed lines in Fig. 1).
2. A technique capable of penetrating an opaque and attenuating suspension is required.
3. Some degree of spatial resolution is needed to interpret the results.
4. A non-intrusive technique is preferred since the best results are obtained if the flow is not disturbed. Also the internal environment could be very harsh on equipment.
5. Information about both flow speed and suspension concentration variations is desired.

2. Method

To meet the specifications listed above an ultrasonic flow velocity measurement method was chosen. These techniques are (almost) non-invasive quantitative techniques capable of operating in opaque fluids. There are three main categories of ultrasonic flow velocity measurement methods; transit time, Doppler-based and speckle correlation techniques. Most of these methods originate from the field of medicine or navigation but have in more recent years found many other applications. Hein and O'Brien (1993) made a review summarizing these developments.

In transit-time flow measurement systems two ultrasonic transducers operate by alternately transmitting and receiving bursts of sound energy between them. The difference in measured transit time is directly proportional to the velocity of the liquid in the pipe. Transit-time techniques measure the bulk flow velocity. However, transit-time techniques cannot be used in the current target application since they require sensors on two sides of the flow.

Ultrasonic Doppler flow meters employ the frequency shift (Doppler Effect) of an ultrasonic signal when it is reflected by suspended particles or gas bubbles in motion. Doppler based methods measure the motion of the particles. This technique is used for example by Takeda (1986), Wiklund and Stading (2008), Chemloul et al. (2009) and Hunter et al. (2011).

Speckle correlation techniques track the movement of particles or local density variations in a suspension. A visualization of particle distribution in turbulent suspension flows can be found in Wood et al. (2005). Short ultrasonic pulses are generated and these create backscatter waves, which are sampled and run through a cross-correlation process to extract a time delay. From this delay the particle displacement and velocity can be calculated. This technique is computationally demanding, but since the generally available computing power increases, this limitation rapidly diminishes. Already Dotti et al. (1976) used an ultrasonic cross-correlation technique to measure blood flow.

Related methods include the use of arrays of sensors to acquire a 2D profile; cf. Sandrin et al. (2001), Manneville et al. (2001) and Carlson and Ing (2002), and the use of similar (or the same) equipment to measure slurry density and solids concentration; cf. Bamberger and Greenwood (2004) and Furlan et al. (2012).

2.1. Ultrasonic velocity profiling

To develop a method capable of operating in the demanding environment of a wet LIMS tank a variant of the speckle correlation technique was selected. The method, here called ultrasonic velocity profiling (UVP), uses an ultrasound transducer to track particle motion in the flow. The transducer first transmits a short pulse and is then used as a receiver to record the backscattered signal (echo). This backscattered signal contains information about the particles in the flow.

By acquiring two backscatter signals closely spaced in time and then cross-correlating them it is possible to follow the movement of particles. By dividing the backscatter signals into short segments and cross-correlating them piecewise it is possible to obtain information on how this movement varies with position. The distance travelled by the particles are related to the time delay (lag) corresponding to the strongest correlation. Since the time between the two backscatter signals is known it is possible to calculate particle velocity. The transducer inclination angle (θ) is used to project the measurements on the direction of flow. The method is described in more detail in the signal processing section.

During signal processing it is assumed that the volume responsible for measured backscatters at each time, the interaction volume (IV), is of negligible size. In reality the volume is finite. Jorgensen et al. (1973) describe the IV as flat drop shape, but here it is sufficient to treat the IV as a flat cylinder, see Fig. 2. Close to the transducer the diameter of the IV (d) is assumed to be identical to the transducer diameter and the diameter then increases as the pulse diverges (with divergence angle α). The height (h) of the IV is related to the pulse duration and the speed of sound. Note that the interaction volume is a theoretical concept, in reality there is no distinctly defined border between affected and unaffected suspension.

Due to the finite volume of the IV, velocity profiles measured using UVP can become distorted in the vicinity of channel walls. With the current setup approximately 5 mm from each wall is