DETERMINING THE POWDER THICKNESS

Advanced radiometric solution for real-time steel and powder control

WhitePaper

BERTHOLD

Introduction

Radiometric based mould level measurement is the dominating technology for measuring the steel level in continuous casting. A well-known drawback of radiometric mould level measurement in closed casting is its inability to determine the true position of the steel meniscus due to the uncertainty caused by the variable thickness of the lubricating powder layer on top.
The LB 6755 CONGAUGE detector overcomes this limitation by using a vertical stack of scintillating crystals instead of a single crystal. This configuration enables precise determination of both the actual steel level and the powder layer thickness, based on their different densities (figure 1). For statistical reasons, this advanced measurement takes a few seconds and requires processing by a specially developed algorithm.[1]

The influence of lubricating powder
All continuous casting machines need to be equipped with a mould level measurement system in order to stabilize the casting process to improve the quality of production, minimize steel defects and avoid undesired catastrophic events such as break-outs related to incorrect skin formation. The mould level is commonly controlled by the stopper position in the tundish or the casting velocity. The more accurate and faster the level measurement, the better the process control. For billets and small blooms the most commonly used and reliable solution is a nuclear gauge, that can be used in open or closed casting.
A nuclear gauge consists of a radioactive source working as transmitter and a radiometric detector working as a receiver to monitor the radiation that passes through the mould. The radiation is measured as a count rate that varies according to the filling conditions of the mould. The lubricating powder shields a part of the radiation, which falsifies the true position of the steel level. The steel level is controlled by using set-point values for count rate, which are calibrated by positioning a steel block inside the mould before casting. An unknown thickness of lubricating powder affects the meniscus height in an undetermined way. The possibility to control the powder thickness is therefore quite critical: on the one hand an adequate thickness is required to guarantee correct lubricating conditions, on the other an uncontrolled increase in the powder layer results in a depression of the meniscus position with consequent quality degradation. Even when automated powder feeding devices are used, careful calibration is required based on the casting conditions (steel grade, powder quality, superheat temperature, etc) and human supervision cannot be completely avoided.
The LB 6755 CONGAUGE detector developed by Berthold in cooperation with SMS Concast overcomes this limitation by offering the possibility of measuring the liquid steel level and the powder thickness at the same time, with an accuracy of a few millimeters. This feature can be used to stabilize the meniscus and to keep the powder thickness constant by combining it using an automatic powder feeding mechanism. Now it is possible to implement a closed control loop for powder addition, using a single sensor to measure the level of steel and powder.

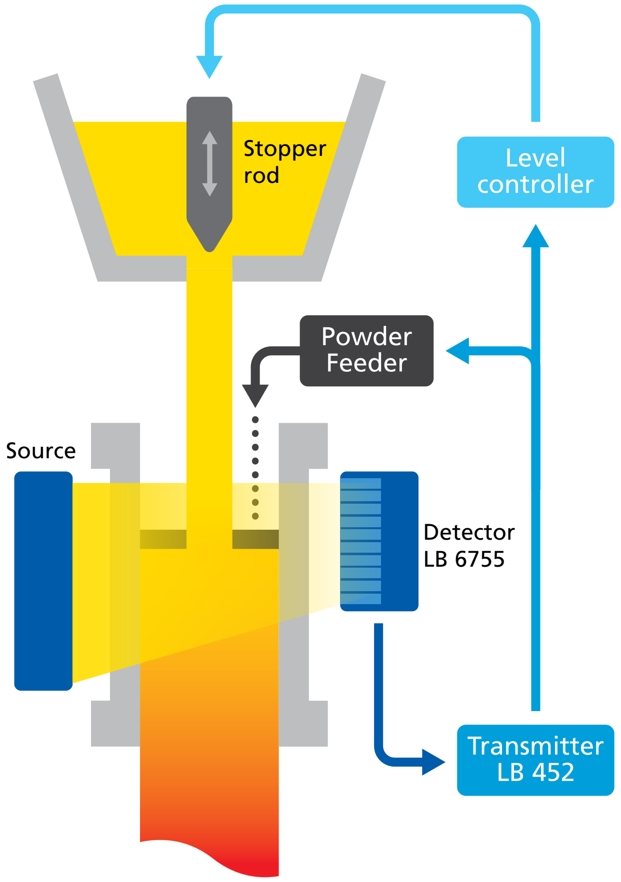

Figure 1 Principle of mould level measurement and mould level control

The sensor concept

All radiometric mould level sensors use scintillating material: when the high-energy photons (gamma radiation) resulting from the radioactive decay of the source reach the scintillator, it absorbs part of the radiation energy and re-emits it as a pulse of visible light (scintillation) that can be converted into electric pulses , which are read as a count rate. This count rate is dependent on the steel level inside the mould, since the steel prevents the photons from reaching the detector. A vertically extended radioactive source is used that usually covers a range of 150 – 200 mm, which us enough for both the start-up sequence and the working conditions. The source can be coupled to sensors with a small scintillating volume (a size of a few centimeters) or even to sensors with more vertically extended active volumes to achieve a higher sensitivity and longer level range.
The LB 6755 CONGAUGE detector uses ten vertically aligned scintillation crystals, enabling parallel readout of the count rates from each segment. The obtained count rates result in a vertical profile of radiation counts reaching the detector (figure 2).

The information recorded is a function of the different density values for liquid steel (~7.0 g/cm³) and dry powder (0.7 – 0.9 g/cm³) resulting in well distinct masking effects on the radiation photons crossing the mould (see figure 1). The steel almost stops any radiation while the dry powder allows the transmission of a considerable amount of radiation. This observation suggests that the vertical sampling of the radiation counting on an extended sensor could be used for the discrimination between the two materials, while a single crystal used for covering the same active volume does not allow the estimation of the thickness of the powder layer.

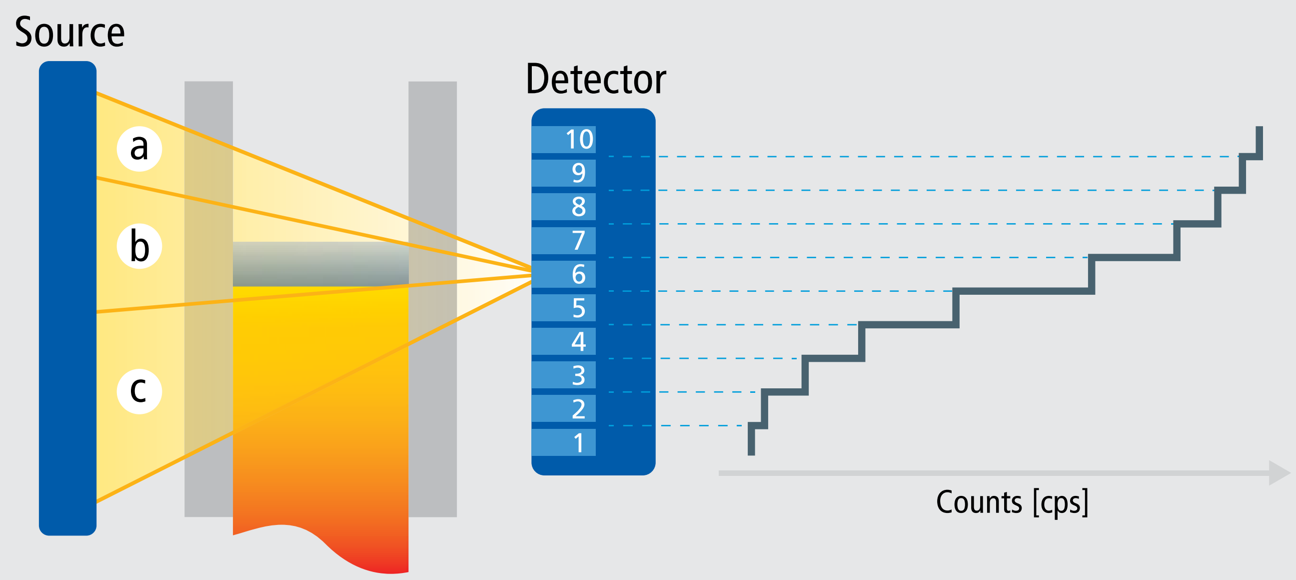

Figure 2 Shows a vertical stack of scintillating crystals in the detector. The left part shows the different areas of radiation that affect crystal No. 6. The count rate of this crystals is composed of three areas: Area (a) shows no attenuation, area (b) is mainly affected by powder and area (c) is strongly affected by steel. This composition of areas is different for every crystal, resulting in different count rates for each crystal. The right part of the figure shows the count rate profile as a result from the count rates of all 10 crystals at the current steel and powder level. The interface between steel and powder can thus be determined due to the different densities of the materials.

Impact of powder thickness on steel level accuracy

To illustrate the behavior of a single crystal compared to an array of crystals, figure 2 shows a comparison of count rates of two combinations of steel level and powder thickness inside a mould. The two configurations result in the same position of the steel level, which is calculated by the amount of total counts (statistical error taken into account) on the volume of the stack considered as a whole (stated as single crystal). This means that with the conventional design of a single crystal the two different configurations of steel and powder levels would be measured as exactly the same steel level. In reality the meniscus of the red configuration of steel level and powder height is lower than the blue configuration. The lower steel level is counterbalanced in counts by the presence of a much thicker powder layer. This shows the undesired effect of meniscus depression with powder increase/addition. In contrast, the count rate profiles gained by using an array of crystals (see figure 1) enable the detector to locate the interface between steel and powder (change of density) by processing the count rates from the profile into a true height of steel level and a thickness of the powder layer.

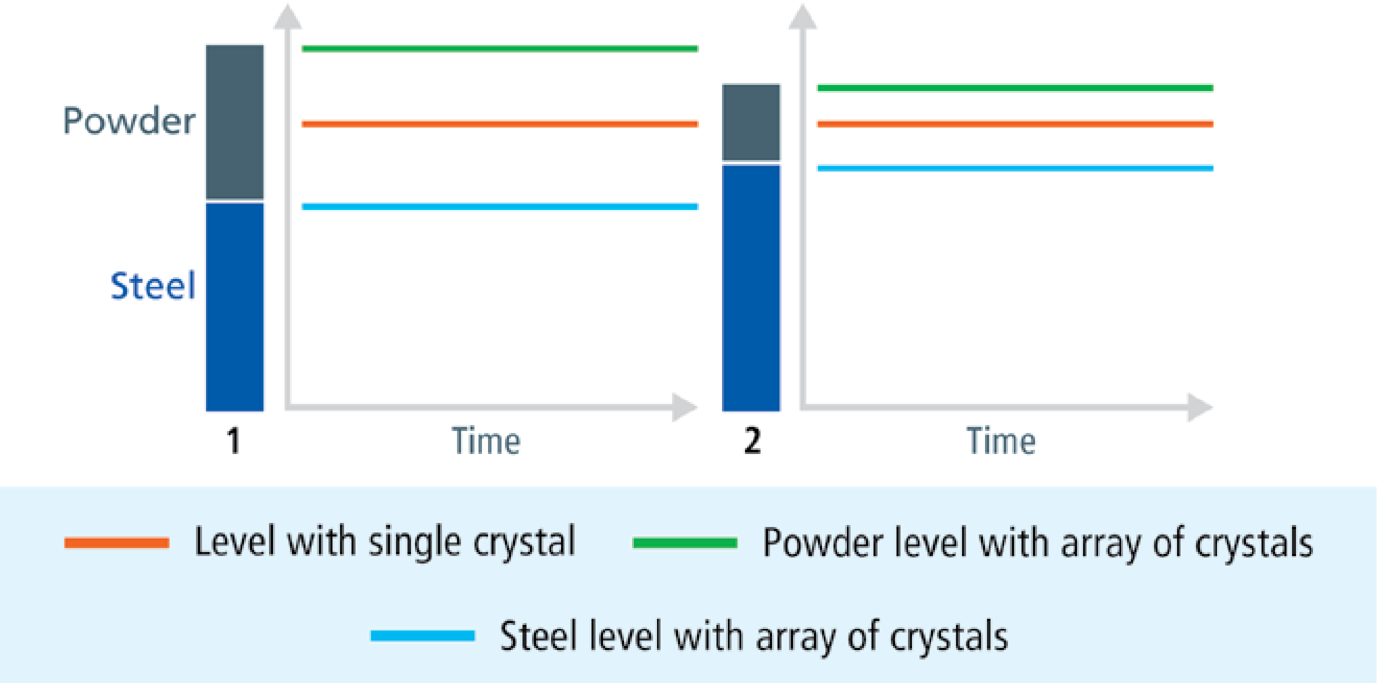

Figure 3 Shows a comparison of resulting steel and powder levels for two configurations of steel and powder. In comparison to the left configuration the right has a higher steel level and thinner layer of powder. For a single crystal the two configurations would give the same count rate reading resulting in the same measured steel level (orange line), since it is always a combination of the true steel level and the powder level. For the left configuration, the lower steel level is counterbalanced in counts by the presence of a much thicker powder layer. Using an array of crystals instead enables the detector to give an accurate reading of the true steel level (blue line) and the powder thickness (green line).

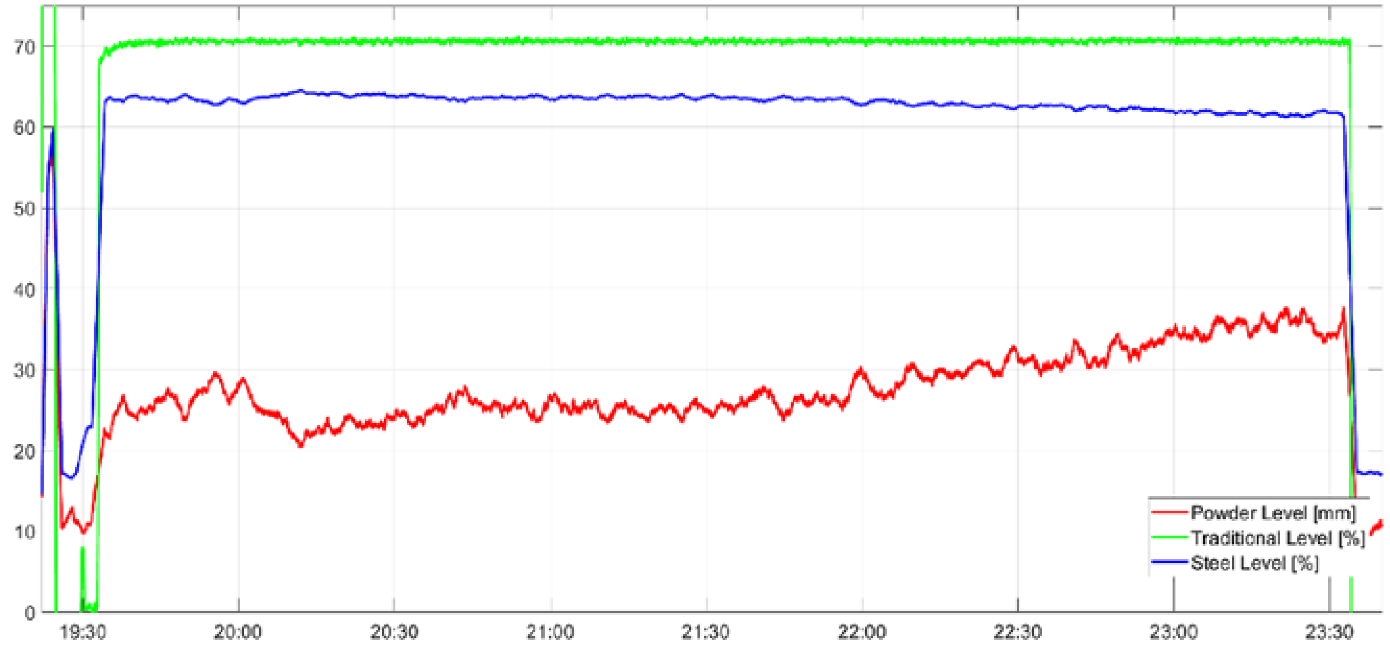

Figure 4 Shows a section of a data log of a LB 6755 CONGAUGE detector. The green line shows the traditional level reading [in %] of the fast signal (5 ms), being a combination of steel and powder. The blue line clearly shows the true steel level reading [in %], which is lower than the traditional level due to the effect of meniscus depression. The red line shows the layer of powder thickness [in mm]. Although the powder level rises, the real steel level (blue) stays stable

Description and operation of the detector

The LB 6755 CONGAUGE detector has 10 NaI crystals (see figure 5), which are stacked together. The choice of NaI as the scintillation material provides a good compromise between light yield, low hygroscopicity, reasonable cost and good spectral matching with silicon photo detectors. In addition, the LB 6755 CONGAUGE detector uses latest SiPM technology. Traditional detectors are using vacuum photomultiplier tubes (vPMT) with glass housing for collecting light, converting it to electrons and amplifying them. vPMTs have been used for many decades, but they are bigger in size than SiPMs, require a higher voltage, are sensitive to the magnetic field and have a risk of breaking if not handled with necessary care. SiPMs combine high mechanical robustness with immunity to electromagnetic stirrers and brakes.

The LB 6755 CONGAUGE detector provides two functions: The conventional function of calculating the steel level that is based on the sum of counts from each separate crystal. By adding the count rates the stack of crystals acts as one big crystal and it works with the same dynamic characteristics as the conventional detectors from Berthold with a cycle time of 5 ms. This ensures fast control of the steel level and integration with existing automation.

The additional function of a distinct parallel measurement of the true steel level and powder thickness is performed by the detector electronics in combination with the evaluation unit connected to the detector by using a sophisticated algorithm to process the different information from the separate crystals. To obtain adequate precision (2 – 3 mm), the count rates need to be integrated for at least a few seconds as the segmentation into 10 distinct crystals results in lower count rates per crystal. As a result the cycle time of the powder height signal is 250 ms. In combination with the LB 6755 CONGAUGE detector the evaluation unit LB 452 castXpert provides three analog and digital output signals: the conventional steel level and in addition the true steel level and the powder thickness.

Figure 5 Cutaway view of the LB 5755 CONGAUGE detector with 10 NaI crystals

Calibration process and fit algorithm

The fit algorithm works by means of a maximum likelihood estimation, where the likelihood is the product of the probabilities of each crystal collecting the recorded count rates. The count rate collected by a crystal is a function of two variables: the steel level (l), and the powder thickness (t), and has a statistical distribution. The combination (l, t) which maximizes the product gives the best estimation. In this estimation the use of more crystals reduces ambiguity and increases confidence in the results. The challenge is how to establish such two-variable probability distribution for each crystal: this is done by a calibration procedure, recording data with low statistics (so to reduce statistical error on the mean value to a negligible level) at known filling conditions of the mould.

This calibration procedure is comparable to the known procedure of positioning a steel calibration block before casting, where usually the two extreme conditions "Empty" and "Full" for the mould range are saved (as the response along the level range is supposed or verified to be linear). However, besides moving the calibration block to different positions around the working level, a calibration is required with different layers of aluminum plates with defined thickness simulating the powder within the range of the expected/desired thickness. The plates are slotted to reach a density like the density of powder.

This allows building a two-dimensional grid of reference values for each crystal, which finally permits a probability calculation as a function of the (l, t) values. This procedure must be performed once only for a given source-mould-detector geometry, to build up a sufficient dense grid for consistent interpolation between points. The number of calibration steps and the amount and thickness of the powder plates need to be defined by the customer to meet his casting habits. Lower positions for the level in the mould that are passed through during casting start must be controlled by the conventional integral signal as in this measurement area a faster response is required.

Conclusion

The use of a correctly sized array of scintillation crystals, as a substitution for a single large crystal offers new possibilities for the level control of liquid steel inside the mould for closed casting applications. By processing the information from the array of crystals using a sophisticated algorithm, it is possible to discriminate the true meniscus position of the steel and the thickness of the powder layer on top of it with a good level of precision in high speed. At the same time, simply summing the counts of all the crystals, the conventional level control signal is obtained and used for the fast mould level control system. The level of the lubrication powder is a parameter of major importance for process quality control: measuring it helps to avoid the well-known drawbacks of conventional radiometric mould level detectors, which estimate only a single combined level representing both steel and powder. The LB 6755 CONGAUGE detector measures the steel level and powder thickness using only one measuring device and at the same time allows the implementation of a closed control loop for an automatic mould powder feeding system. As of today more than 30 strands from customers all over the world are equipped with a CONGAUGE system. They report positive effects such as reduced number of breakouts, improved stability of mould level accuracy, improved powder thickness stability, improved billet quality level and higher efficiency in powder consumption.

[1] This article is based on the previously published article "New radiometric sensor for mould level measurement." M Fabrizioli, G Michelon, F dal Corso, E Borsato, S Fries, G Ney, R Nagy. Stahl und Eisen 135 (1), 39-47.

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