A Lorentz force flow meter for application at blast furnaces: design and calibration

Daniel Hernández1, *, Christian Karcher1 **, and André Thess1 ***

1 Institute of Thermomechanics and Fluid Mechanics, Technische Universität Ilmenau, PO Box 10 05 65, 98684 Ilmenau, Germany

A reference Lorentz force flow meter (LFF) has been developed to measure molten steel mass flow at the end of the runner of an experimental blast furnace. It works according to the principles of Lorentz force velocimetry [1] in which a static magnetic field interacts with a liquid metal stream. The magnetic field lines are generated by an arrangement of permanent magnets and penetrate the entire cross-section of the flow generating eddy currents and a total Lorentz force inside the melt. This force is proportional to the mass flow of the liquid metal and owing Newton’s third law, there is a counter force of the same magnitude acting on the magnet system which is connected to a load cell. For accurate flow rate measurements, a “dry and wet calibration” of the LFF needs to be performed [2].

1 Introduction

In metallurgic industry the in-situ measurement of the flow rate of metal melts is still an unsolved problem. Due to the chemical aggressiveness of high-temperature melts, classical measurement techniques such as fly-wheel, Pitot tube, and hot-wire probes cannot be used as these methods require mechanical contact with the melt. On the other hand, contactless optical methods fail due to the opaqueness of the melt. In this paper we present the design and the calibration of a non-contact electromagnetic flow rate measurement device called Lorentz force flow meter (LFF). The flow meter has been especially developed to record the flow rate of liquid steel during the tapping of a blast furnace in open channels. It works according to the principles of magnetohydrodynamics: when the electrically conducting melt crosses the field lines spanned by an externally arranged magnet system, eddy current are induced within the melt. The interactions of the eddy currents with the applied magnetic field give rise to the generation of Lorentz forces inside the fluid. These Lorentz forces tend to break the melt flow and are direct proportional to the flow rate. The following scaling relation presents the magnitude of this flow-braking Lorentz force \( F_L \) as a function of the mass flow rate \( \dot{m} \), the electrical conductivity \( \sigma \), and the strength of the imposed magnetic field \( B_0 \) [1]

\[
F_L \sim \dot{m} \sigma B_0^2
\]  

On the other hand, the electromagnetic interactions lead to an accelerating counter force of same magnitude acting on the magnet system. Hence, a Lorentz force flow meter basically consists of a magnet system and an attached force sensor. In order to record the flow rate, the magnet system is designed so that its field lines penetrate the entire cross-section of the melt flow.

2 Calibration facilities

To use this Lorentz force flow meter in industrial applications with a determined accuracy, a proper calibration of the flow meter has to be performed beforehand. To this aim, we perform a two-step calibration method consisting of a dry and a wet technique. In dry calibration the melt flow is modeled by a solid bar of known geometry and conductivity that is pulled at a controlled speed through the magnetic field. In a second step of wet calibration we take into account the influence of the dynamics of free-surface channel flow that is encountered in application. The two-step calibration is performed at the wet and dry LFF calibration facilities MITROKA and LITINCA respectively (Fig. 1) having as a test melt molten tin. Both calibration procedures are used to determine the characteristics of the flow meter.

3 Results

According to equation 1, the force signal measured with the LFF gives us the magnitude of mass flow of metal melt which passes through the magnetic field lines of the LFF. Additionally, after integrating this signal, we can easily calculate the
Fig. 1: In the dry calibration facility MITROKA a, the liquid metal flow is modeled by solid bars whose cross-section and electrical conductivity are known. They are moved through the magnetic field lines produced by an arrangement of permanent magnet (green) of the LFF at a controlled velocity. On the other hand, in the wet calibration facility LITINCA b, liquid tin is melted in the first furnace (red) and pumped into the runner by a metal pump (blue). The liquid tin is collected at the end of the runner by a second furnace (red) which sits on a weighting device (black). This device allows us to generate the cumulative mass signal during experiments which is afterwards compared with the signal of the LFF.

![Image of dry calibration facility MITROKA](image1.png)

![Image of wet calibration facility LITINCA](image2.png)

Fig. 2: Integral of the LFF signal a and of the weighting device b during the wet calibration of the LFF with the LITINCA at a constant liquid tin flow. Here, the signal of the LFF is slightly ahead than the one of the weighting device owing to the fact that the liquid tin passes first through the LFF that the second furnace. Both signals illustrate the cumulative mass signal of molten tin by two different methods and is clear to see the direct correlation between them. A constant slope in each of these two graphs corresponds to a constant molten tin mass flow as expected.

Amount of liquid metal that has flowed through the runner (cumulative mass). Figure 2 illustrates the comparison between the integral of the LFF and the cumulative-mass signal generated by the weighting device during a wet calibration experiment with the LITINCA. In this experiment, the mass flow and the inclination of the runner were maintained at the same value. The constant slope in this two curves verify the constant mass flow condition of the experiment and, by calculating the ratio between the one of the LFF and the one of the weighting device, we can easily determine the calibration factor $C$ of the LFF as follows:

$$ C = \frac{\dot{m}}{F_L} = \frac{25 \text{ kg/s}}{2.8 \text{ mV}} = 8.9 \text{ kg/s} \cdot \text{mV} $$

This calibration number is valid for the following influence parameters that are controlled for the experiment and affect the magnitude of the Lorentz force:

- Temperature of the liquid tin
- Inclination of the runner
- Cross-section and level of the flow

Acknowledgements The Lorentz force flow meter calibrations facilities used in this work were funded by the Deutsche Forschungsgemeinschaft DFG within the RTG Lorentz Force Velocimetry and Eddy Current Testing.

References