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Calibration of a Lorentz force flowmeter

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Manuscript

A Lorentz force flowmeter is a contact- free device for measuring flow rates in electrically conducting fluids like high-temperature metal melts. To determine the flow rate a Lorentz force flowmeter (LFF) measures the acceleration force (the so-called Lorentz force) acting on a magnet system caused by the melt flow passing a stationary magnetic field. To obtain accurate results in operation a proper calibration of the measuring device is absolute indispensable. The main goal of this work is to develop an overall calibration procedure for LFF prototypes that shall be used in the production line of secondary aluminum. To reach this goal the calibration is divided into two parts: dry calibration and wet calibration.

The aim of the so-called dry calibration is to model turbulent free-surface liquid aluminum flow in a launder -typically encountered in application- by the laboratory-controlled movement of a solid bar with well-defined geometries. On the other hand, wet calibration will model the liquid aluminum flow by lower melting liquid tin flowing through a reference channel. By that, at moderate temperature, we can investigate the effects of the special flow situations met in application. Figure 1 shows the dry calibration set up. The test bars are mounted on the linear drive which provides a uniform speed in the range of 3cm/s up to 20cm/s. For each bar speed the generated Lorentz force is measured and evaluated. The estimated uncertainty of measurement is about 3%. Although this setup is referred to as “gold” experiment because of the traceability to national mass standard, it cannot cover all details needed to set up a proper calibration for application in aluminum industry. It cannot model hot turbulent fluid flow characterized by a free-surface and variable levels. This will be taken into account during wet calibration. The aim of the coupled wet and dry calibration is to get a standard LFF. Once a standard LFF is calibrated, it is possible to calibrate all other LFFs of the same type by dry calibration only and recalculate the parameters for wet calibration.

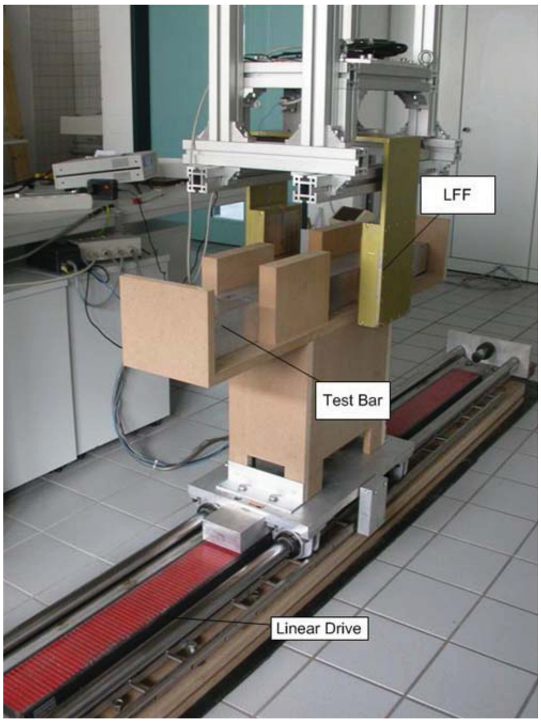

Figure 1: Dry calibration experiment

The wet calibration is performed in the liquid tin calibration facility LiTinCa which is recently set up. In this experimental set up pure tin is melted in a bale out furnace. The liquid tin is transferred by liquid metal pumps in a reference channel which models the launder used in aluminum industry. In the middle of the launder the LFF to calibrate is mounted. The reference channel can be inclined from 0,5° up to 5°. Thus, we can adjust the fluid velocity produced by gravity. The level of the liquid tin free-surface flow is measured by a special level meter for launder systems. Given the dimension in the launder, we can get the cross section of the fluid flow. After having passed the channel, the liquid tin is collected in a second furnace placed on top of a weighing device that records the time-dependent mass flux. With this information we can produce a mass flux signal by the LFF. Afterwards the launder is inclined in the opposite direction. A second

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liquid metal pump will drive the flow back in the melting furnace. Of course, this run can be also used for calibration of the LFF. Beside the signal of the LFF and the mass signal of the scale, the temperature of the tin, the level of tin in the launder and the inclination of the launder as well as the pump rotation speed is measured and protocolled. We expect LiTinCa to measure with an overall uncertainty of below 3%.

In the following we show results of the dry calibration procedure only. To evaluate the influence of the cross section of the metal bar and thus the influence of the launder form, a bar with round cross section is evaluated. We observe a linear behavior of the Lorentz force- velocity characteristic. Furthermore we test some bars made of E-Cu 58. From the results shown in Figure 2, we observe an almost linear dependence of the measured force on the velocity of the reference bar. This linear behavior is in good agreement with theory and simulations done with Maxwell and Comsol. The graph also shows that the force produced by a cylindrical bar of diameter 100mm is about the same as the rectangular bar with height 80mm and width 100mm because of having about the same size of the cross section in the magnetic field. This means that the produced force is directly proportional to the cross section in the magnetic field, but there is a highly nonlinear dependence on the height of the reference bars [3]. The results presented in Figure 2 were obtained with maximum magnetic Reynolds numbers of $Re_m = 0.54$. This parameter is defined as $Rem= \mu\sigma vL$, where μ is the magnetic permeability, σ is the electrical conductivity of the bar, v is the pulling speed, and L is the characteristic length of the bar. Within these magnetic Reynolds numbers the theory provides a linear characteristic of Lorentz- force vs. velocity of the fluid, as the secondary magnetic field induced by the generated eddy currents remains small compared with the externally applied magnetic field.

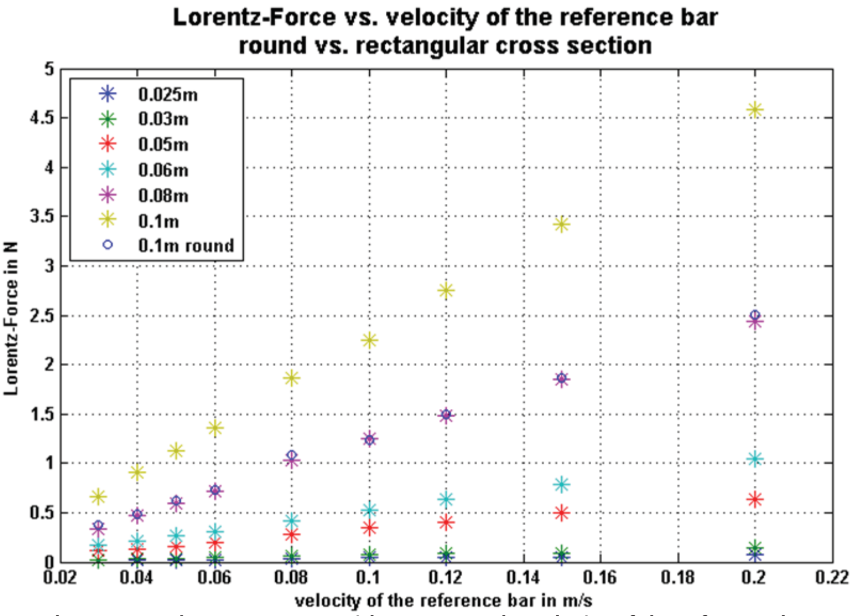

Figure 2: The measured Lorentz- Force with respect to the velocity of the reference bar. Comparison between round and rectangular cross section

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