

NONCONTACT ELECTROMAGNETIC FLOW MEASUREMENT IN ELECTROLYTES

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Summary Lorentz force velocimetry (LFV) is a noncontact electromagnetic flow measurement technique that is currently successfully applied for velocity measurements in liquid metals both in laboratory experiments and industry. However, up to now the application of LFV was restricted to conducting fluids with electrical conductivities of the order of 10^6 S/m such as are encountered in liquid metals. Here we demonstrate that LFV can be successfully extended to poorly conducting fluids (electrolytes) by using high-resolution force measurements.

INTRODUCTION

Measuring the velocity in liquid metals, glass melts and molten salts is a notoriously difficult problem because these materials are hot and aggressive. Lorentz force velocimetry [1]-[3] is a contactless technique for electromagnetic flow measurement which is based on measuring the force acting upon a magnet system interacting with the flow of an electrically conducting fluid. Whereas the development of LFV for liquid metals has evolved to the state where its application in aluminium production and steelmaking is imminent, the application of LFV to poorly electrically conducting fluids like molten salts or glass melts is still an open problem since the Lorentz forces are extremely small. The goal of the present communication is to demonstrate that LFV can be successfully applied to flow measurement in a model substance (salt water) with electrical conductivities as small as 2 S/m thanks to the application of high-resolution force measurement techniques. The basic principle of LFV is explained in Figure 1. When an electrically conducting fluid, for instance liquid aluminium or salt water, is exposed to the action of a magnetic field produced by a permanent magnet, eddy currents are induced in the fluid. The eddy currents and the magnetic field create a Lorentz force which brakes the fluid. Due to Newton's third law a force with equal strength but opposite direction must then act upon the magnet. LFV consists in measuring this Lorentz force and deducing the unknown velocity of the liquid from this force.

EXPERIMENTAL SETUP

We demonstrate the feasibility of LFV in weakly conducting liquids by setting up the experiment sketched in Figure 1. A turbulent flow of salt water with electrical conductivities in the range between 2.3 S/m and 6.2 S/m is set up in a channel with rectangular cross section. The flow is exposed to a non-uniform magnetic field created by a magnet system consisting of two identical blocks of NdFeB permanent magnets held together by an aluminium frame. The magnet system is attached to an aluminium frame by four tungsten wires with a diameter of 125 μ m and is free to oscillate as a pendulum. The horizontal displacement x of the magnet under the action of the flow is measured using a commercial laser interferometer with a corner cube mirror fixed to the pendulum. This interferometer has a resolution of 1nm. All parts of the experiment are attached to a non-ferromagnetic granite block which is in turn embedded in a box filled with sand in order to suppress vibrations coming from the environment. The mean velocity of the salt water flow is determined using an ultrasonic flowmeter.

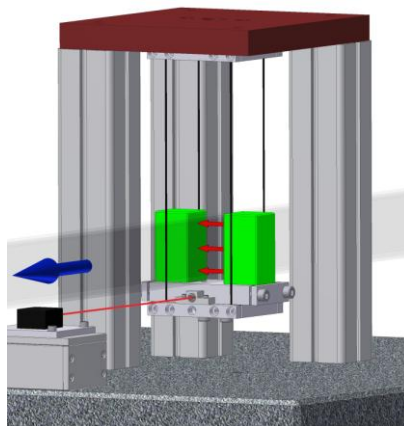


Figure 1 - Schematic of the apparatus used for contactless electromagnetic flow measurement in electrolytes: A turbulent flow of saltwater is exposed to the magnetic field generated by a lightweight permanent-magnet system hanging on a four-wire pendulum. The displacement of the pendulum is measured using an interferometer.

RESULTS

The results of the measurements are plotted in Figure 2. The experimental data show that the Lorentz force is an almost linear function of the mean velocity, as expected. The data also confirm that the slope of the function $F(u)$ increases with increasing electrical conductivity of the salt water. This demonstrates the feasibility of contactless electromagnetic flow measurement in a weakly conducting liquid. The validity of the experimental data is confirmed by the results of numerical simulations plotted as linear functions in Figure 2. Given the fact that the exact velocity profile is unknown, the numerical simulations are carried out under the assumption that a solid body with the same electrical conductivity as the salt water undergoes a translational motion with a velocity equal to the mean velocity of the liquid.

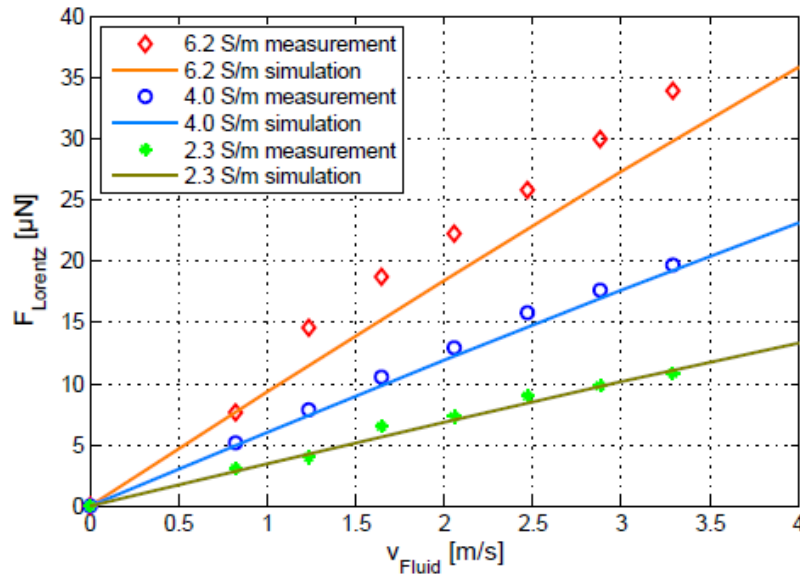


Figure 2 – Results of Measurements and Simulations: Lorentz force as a function of the volumetric flow rate of salt water with electrical conductivities 2.3 S/m, 4.0 S/m, 6.2 S/m as obtained from the experiments (symbols) and numerical simulation for solid body translation (lines).

SUMMARY AND CONCLUSIONS

We have demonstrated that LFV can be successfully applied to poorly electrically conducting fluids. We conclude that this proof of concept paves the ground for more accurate laboratory experiments with well controlled inflow boundary conditions as well as industrial applications in glass industry and possibly solar thermal power plants.

ACKNOWLEDGMENT

The authors gratefully acknowledge financial support from the German Research Foundation (Deutsche Forschungsgemeinschaft) for the Research Training Group (Graduiertenkolleg) “Lorentz force velocimetry and Lorentz force eddy current testing”. We thank Gerd Jäger, Jörg Schumacher, Ulrich Lüdtké and Artem Alferenok for useful discussions.

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