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ENTWICKLUNG EINER NEUEN DURCHFLUSSMESSTECHNIK ZUR VERMESSUNG ELEKTRISCH SCHWACHLEITFÄHIGER FLUIDE MITTELS LORENTZKRAFT ANEMOMETRIE

DEVEOPMENT OF A NOVEL FLOW RATE MEASUREMENT DEVICE FOR POORLY CONDUCTING FLUIDS USING LORENTZ FORCE VELOCIMETRY

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Abstract

This paper presents the experimental setup and the first measurement results of a novel device for flow rate measurement in poorly conducting fluids. The device relies on the technique of Lorentz force velocimetry (LFV) which has been intensively studied by Thess et al. [1]. The results of our investigation show for the first time the feasibility of LFV in fluids with a conductivity less than 10 Sm^{-1}. The resulting Lorentz force is in the order of magnitude of 10^{-5} N.

Introduction

Classical flow measurement methods are commonly used in various industries such as food industry or chemical industry. There are several well-known techniques available to accomplish the required measurement tasks. But in some special applications the fluids are extremely hot and aggressive and classical methods would not withstand the rough environment for a sufficiently long time, because the sensor in each of these techniques interacts with the surrounding fluid or with the pipe wall. Examples for these fluids include metal melts and acids.

This paper describes a novel contactless flow rate measurement technique to avoid these interactions. The basic idea of the innovative flow measurement device relies on the interaction between a magnetic field and the moving conducting fluid. This method is known as Lorentz force velocimetry [1]. When the conducting fluid moves through the magnetic field, a Lorentz force occurs which acts on the magnet system. Due to that, the magnet is used as a source as well as a sensor.

$$F_{Lorentz} \sim \sigma \cdot v \cdot B^2 \cdot V \qquad (1)$$

Equation (1) shows the scaling behaviour of the Lorentz force [1]. The Lorentz force depends linearly on the electrical conductivity (σ), the velocity of the fluid (v) and the measurement volume (V) in the channel. However, the magnetic field strength (B) has a greater influence on the Lorentz force due to the quadratic dependence.

It is a proven fact that LFV works well in fluids like metal melts because of the high electrical conductivity [1, 2 and 3], which is in the order of magnitude of 10^6 Sm^{-1}. For poorly conducting, aggressive and hot fluids, for example glass melts, the generated Lorentz force is very small. Consequently, the force measurement needs to precisely resolve the signal. Nevertheless, our long-term vision is to set up a highly reliable and accurate Lorentz force flowmeter (LFF) for industrial application.

Methods and Research Results

We investigate the feasibility of Lorentz force velocimetry for poorly conducting fluids. For this, we perform basic flow rate measurements in electrolytes of electrical conductivities less than 10 Sm^{-1}. Figure 1 shows the main components of the experimental setup. The channel (d) is filled with salt water with an electrical conductivity of about 4 Sm^{-1} at room temperature and flow velocities of up to 5 ms^{-1}. The magnet system (c) is equipped with high-energy magnets made of NdFeB with a magnetic remanence of $B \approx 1.4$ T and a coercivity of $H_c \approx 920$ kA/m. The mentioned magnet system is suspended on thin tungsten wires (b) resembling a pendulum which is mounted on a frame of aluminium profiles (a).

The Lorentz force causes a deflection of the magnet system which can be measured with a laser interferometer (e). The aluminium frame and the laser interferometer are mounted on a heavy granite block (f) with a mass of about 400 kg to suppress vibrations. The Lorentz force can be calculated from the dimensions of the pendulum and the measured deflection. These elements are crucial for measuring the Lorentz force which is expected to be in the range of $F_{Lorentz} \leq 10^{-5}$ *N*. Another important factor is the design of the cross section of the water channel which has been intensively studied by Werner et al. [4].

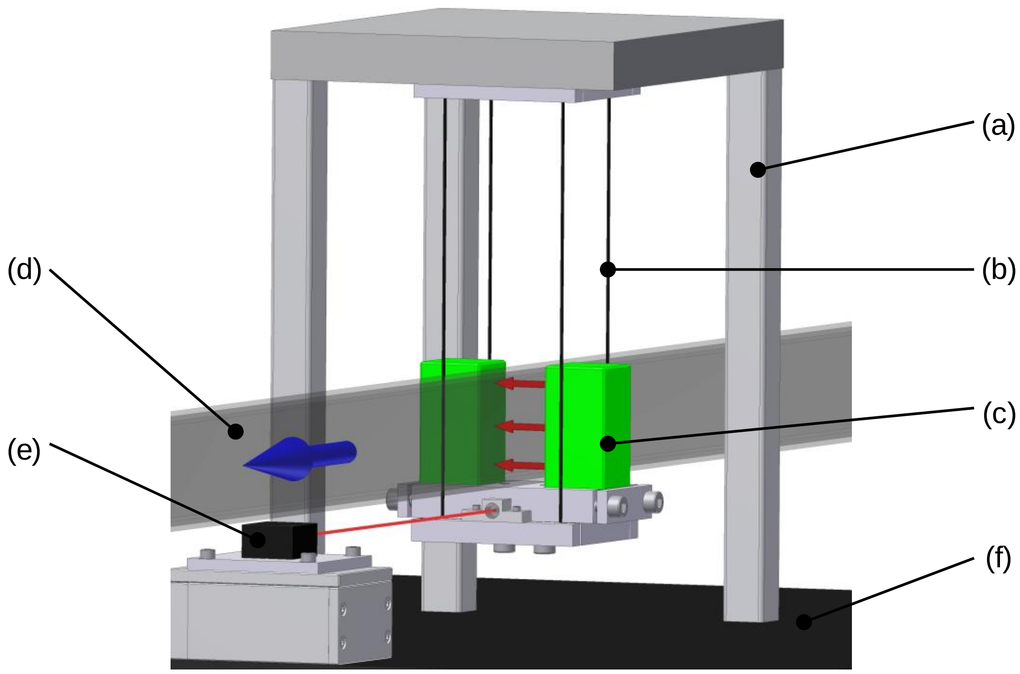

Fig. 1: The sketch of the main components of the experimental set-up.

The experiment has been performed with various fluid velocities and three different electrical conductivities of 2.3 Sm^{-1}, 4.0 Sm^{-1} and 6.2 Sm^{-1}. Figure 2 shows the results of the experiment with salt water. Instead of the very complex and time-consuming simulation with real fluids, the numerical simulations for comparison with the salt water experiment maintain the solid body approximation [4]. Except for the test series with 6.2 Sm^{-1} (diamonds), the measured values match the simulations well. Furthermore, it can be seen that there is a linear dependence of the Lorentz force on the flow velocity in both experiment and numerical simulation. This confirms the prediction of equation (1) that the Lorentz force scales with the flow velocity linearly. Furthermore, the test proves the feasibility of LFV for poorly conducting electrolytes.

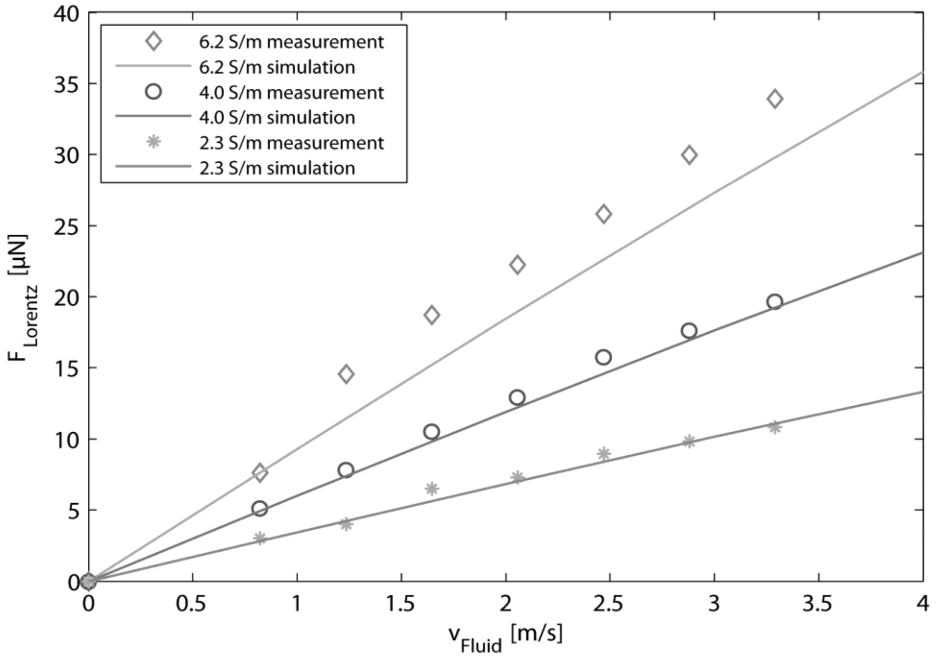

Fig. 2: The dependence of the generated Lorentz force on the velocity of the fluid.

Summary and Outlook

We have investigated the feasibility of LFV on poorly conducting fluids with a novel flow measurement device called Lorentz force flowmeter (LFF). We have shown that the LFF is suitable for measuring the flow rate in poorly conducting fluids like salt water. Here, the Lorentz force is in the order of $F_{Lorentz} \leq 10^{-5}\ N$. There is a linear behavior of flow velocity and Lorentz force, proving that the scaling law from equation (1) is also valid in poorly conducting fluids. Numerical simulations with a moving solid body have been performed. The simplified model using the solid body has proven to be a reasonable approximation. Even though the described setup is only preliminary and the model simplified, the results between measurement and simulation show a good agreement.

To perform more precise measurements a new series of tests with different conductivities and velocities is planned. A further step is the design and the commissioning of a new, improved fluid test channel that will allow to control the in-/ and outlet velocities within the measurement test section. Furthermore a measurement device based on the principle of electromagnetic force compensation will replace the mentioned measurement system. In addition to the new measurement device, a more sophisticated magnet system will be used.

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