Novel design principles for electromagnetic flow metering (MIF), based on permanent magnets.

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1. Introduction

Magnetic inductive flow metering is a well established method for measuring the flow rate of aqueous fluids. Among the main advantages are smooth inner walls of the measuring tube without any obstacles or dead space and the absence of any dependence on physical fluid parameters like temperature, viscosity, pressure and density. One of the drawbacks of commercially available systems is the necessity of using time dependent magnetic fields which require a considerable amount of power. Up to now battery driven devices have become known only relying on the drastic reduction of the magnetic field in order to save power. Unfortunately this is accompanied by a corresponding reduction in sensitivity.

In the present article we will show novel design principles allowing the application of extremely strong permanent magnets in combination with signal coupling across insulating surfaces, which essentially means capacitive signal coupling. This gives rise to new high resolution systems with almost no power consumption which open up a whole number of exciting application fields not accessible until now. These range from micromechanical devices to energy autonomous sensor networks.

2. Experimental Area

Resident at Kiel University of Applied Sciences the Research and Development Center FH Kiel (Ltd) realizes innovative development projects, close to the faculties of the University.

A main topic of the actual projects is the fundamental research on electromagnetic flow metering (MIF), based on permanent magnets.

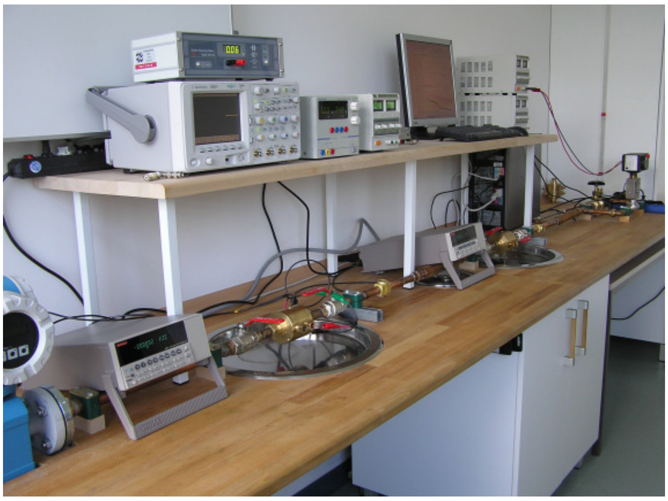


figure1

Especially for this project a testing environment (*figure 1*) has been designed and realized. This construction enables an individual adjustment of the flow rate and temperature. The closed circuit also allows tests in different kind of fluids.

Two measuring-places (*figure 2, 3*) with variable pickups are integrated into the system. Passive and active sensor-elements can be mounted in this way. A flexible connector design allows easy signal access.

figure 2

Alternatively it is possible to connect external electronics for supply or signal processing (*figure 3*).

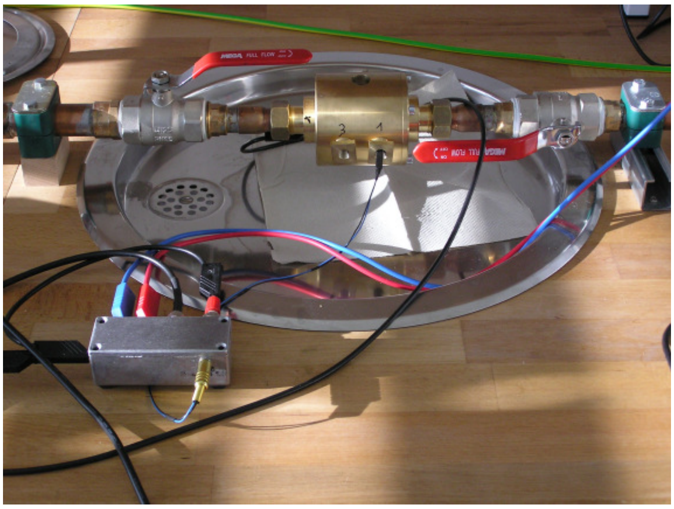


figure 3

Central part of the experimental unit is a cylindrical core with an integrated magnetic circuit supplied by permanent magnets (*figure 4*) and appropriate bores to accept up to four sensors per unit. These may be used for single or differential measurements in two measurement paths of opposite field direction (*figure 5*).

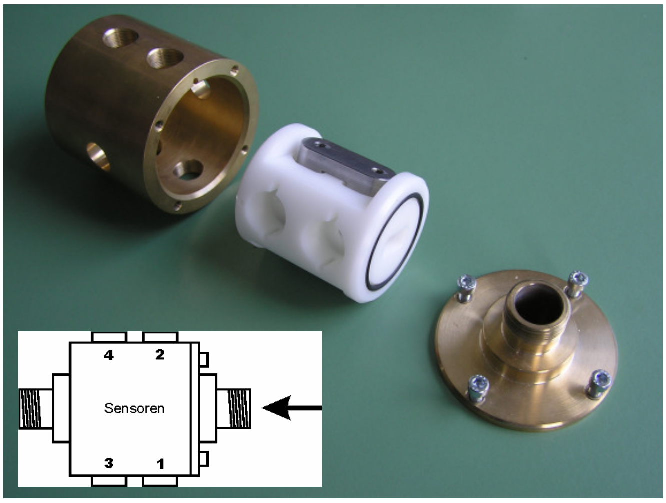


figure 4, 5

3. The Principle of Electromagnetic Flow Metering (MIF), based on permanent magnets.

The operational principle is based on Michael Faradays law of induction. It describes the voltage induced into an inductor of length L moved with the velocity v through a magnetic field of the induction B.

$$U_o = v \bullet B \bullet L$$

Uo = induced voltage (vector)
B = magnetic flux density (vector)
L = effective length of the magnetic field
v = speed of movement (vector)

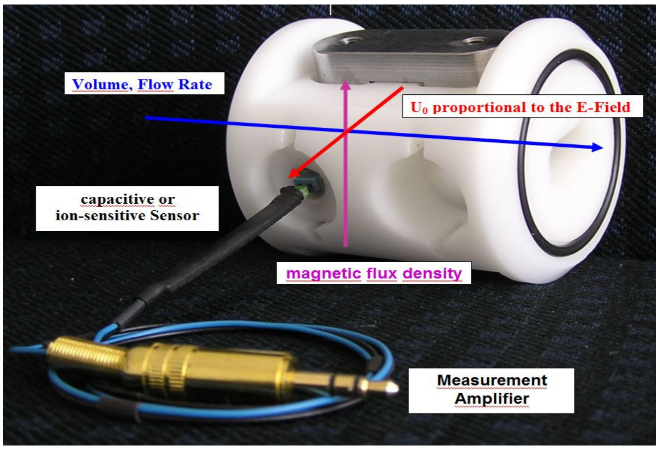


figure 6

Permanent fields (about 0.5 T) which are one to two orders of magnitude higher compared to those from conventional electromagnetic systems (see Fig. 8) result in very high signal resolution.
Due to the system symmetry disturbing signals may be removed by differential measurements.
(*figure 7*)

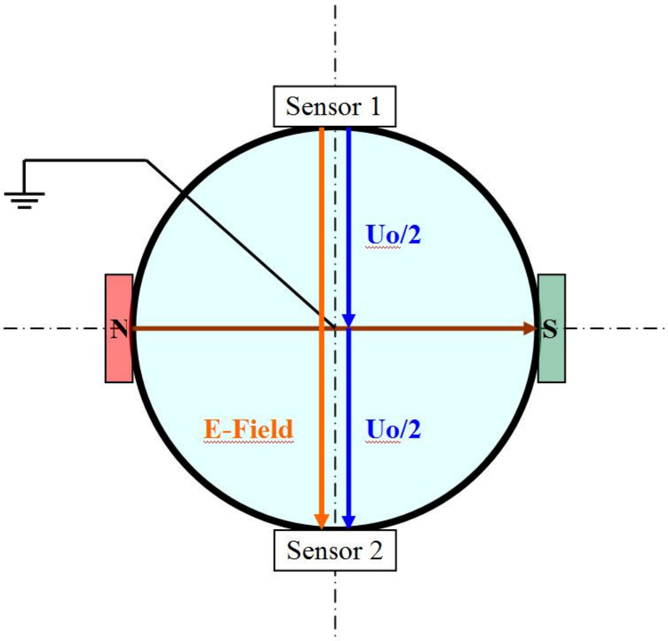


figure 7

The diagram (*figure 8*) shows the symmetric distribution of flux density.

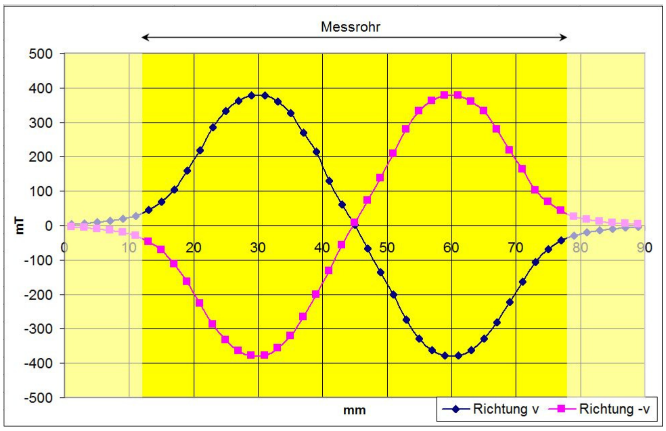


figure 8

4. Signal Coupling

All signal coupling out of the fluid or into the fluid has to pass the interface between fluid and inner wall of the measuring tube. Besides the induced signal U_0, double layer voltages U_{D1} and U_{D2} will be coupled to sensors. (*figure 10*)

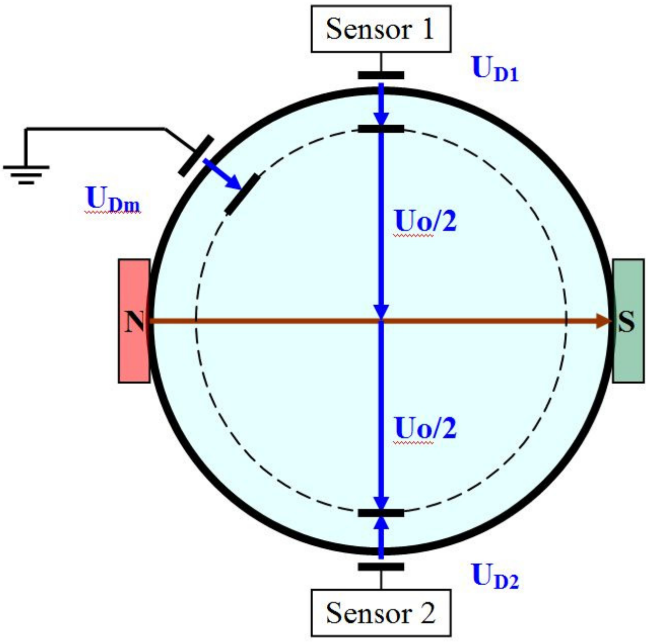
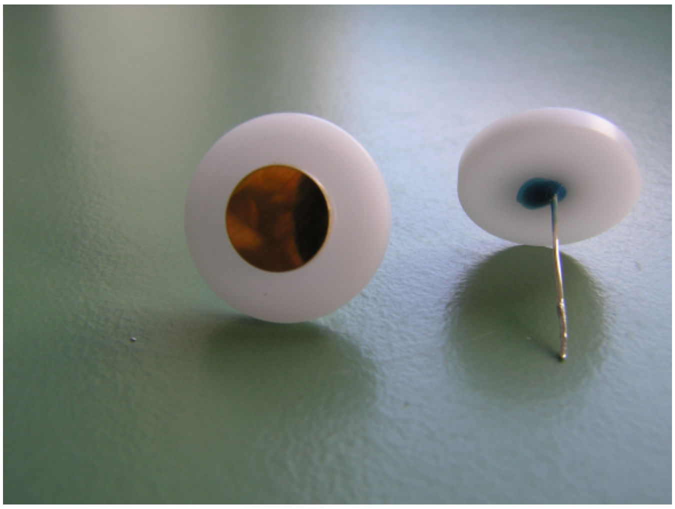


figure 10

One of the main objectives of our research work is the study of these double layer voltages. Only interfaces with stable double layer potentials are qualified for practical use. According to our investigations insulating surfaces sufficiently meet these requirements as will be shown by the following results of measurements.

5. Galvanic Sensors

First orienting system tests have been performed with galvanic sensors to study the basic system behaviour. Galvanic sensors of different materials (stainless steel, brass, gold, platinum) and geometric forms (*figures 11, 12, 13*) helped to study, interpret and understand the influence of the double layer voltages.



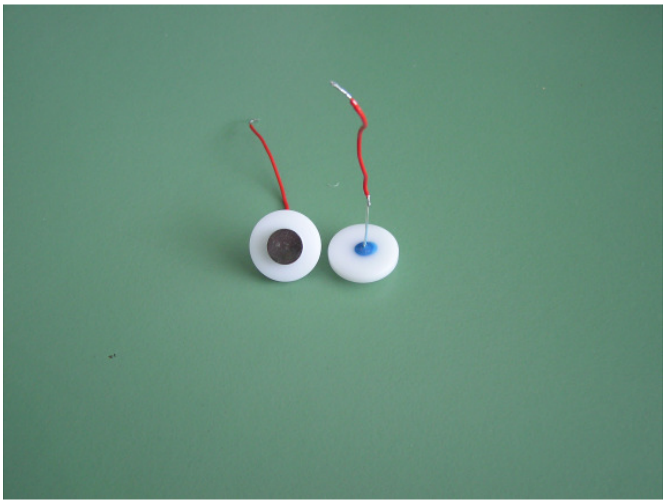


figure 11, 12, 13

The investigations have been focused on drift phenomena.

All galvanic sensors exhibit strongly floating double layer potentials caused by electrochemical and electrokinetic effects. As an example Fig. 14 shows the electrode potentials of the single electrodes of a pair of electrodes made from stainless steel with respect to ground. Obviously it is difficult to separate the induced signal from these single tracks. Taking the difference of these signals however as this has been done in Fig. 15 almost eliminates drift and electrokinetic phenomena and clearly shows the induced signal received from the flow switched between zero and a constant flow rate.

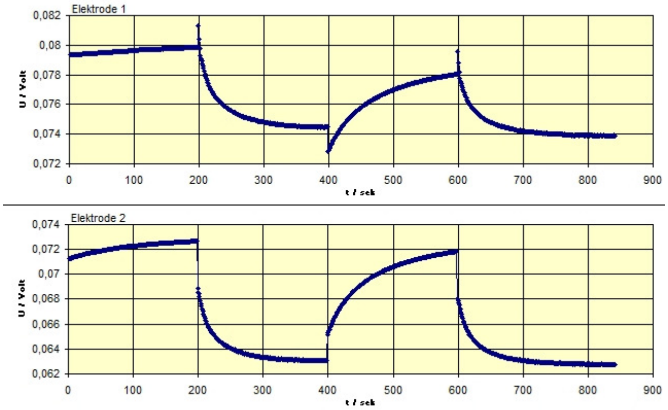


figure 14

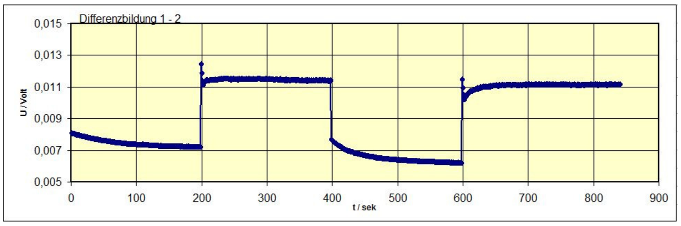


figure 15

On insulating surfaces double layer potentials are much more stable so that a considerable improvement has to be expected. In the following we show results.

6. Capacitive Sensors

Compared to galvanic electrodes the double layer potentials of capacitive elements as shown in Fig.'s 16 and 17 tend to be smaller and much more stable (see Fig.'s 18, 19).

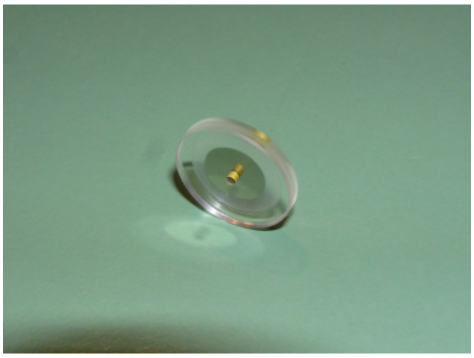


figure 16

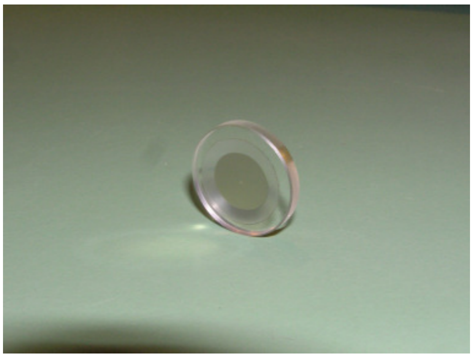


figure 17

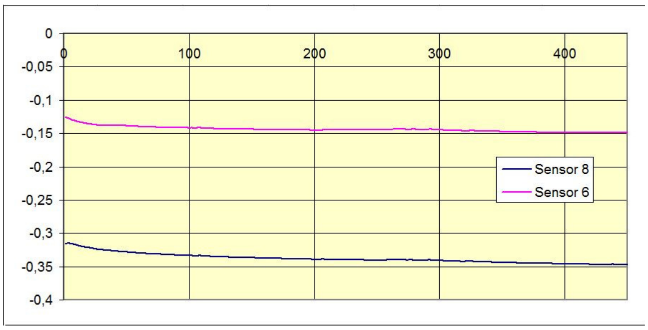


figure 18

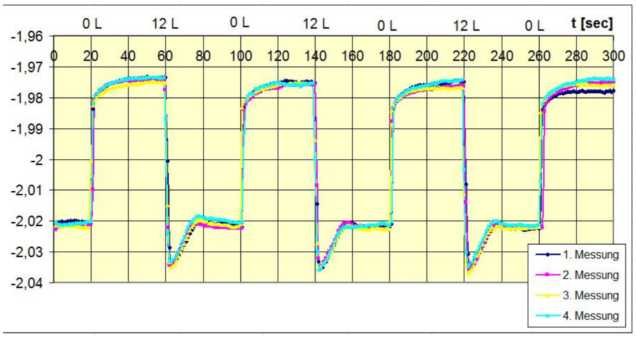


figure 19

As a result in combination with the very high permanent magnetic field we arrived at the resolution shown in Fig. 's 20, 21. They clearly show the peculiarities of our test stand with its oscillating behaviour when switching the flow rate. Detailed investigations showed a resolution capability with respect to the flow velocity of less than 1 mm/s and a linear output up to more than 2 m/s which corresponds to a dynamic ratio of more than 1000. Long time drift measurements gave results of less than 1µV/s.

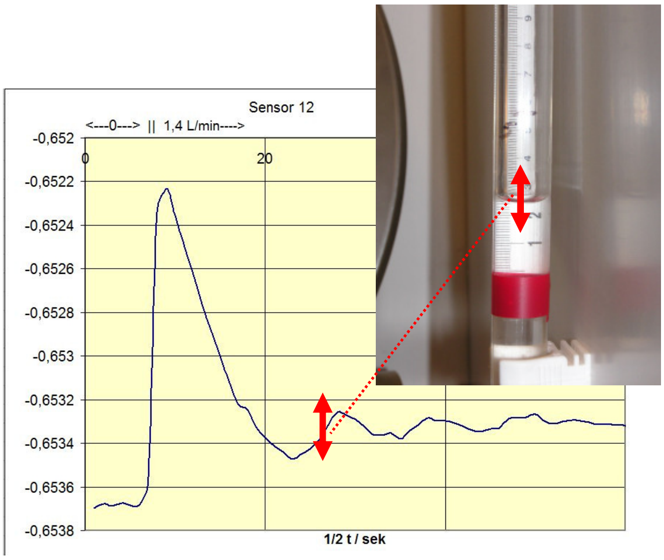


figure 20, 21

Although these results are preliminary they may be considered as very encouraging towards the realization of a completely new generation of magnetic inductive flow meters.

7. Conclusions

The magnetic inductive flow measurement presented uses a permanent magnetic field as opposed to an alternating magnetic field used in commercial devices. In conjunction with the capacitive signal coupling, this new technology promises an extremely compact sensor design with minimal energy consumption, such that mains-independent operation is possible. Nevertheless, all the known advantages of MIF are retained: smooth inner tube without additional pressure drop, measurements irrespective of the temperature, viscosity, pressure, density and largely regardless of the flow profile. Compared with conventional MIF, the use of state-of-the-art magnetic materials made from inter-metallic compounds with elements from the group of rare earths permits magnetic fields that are higher by one order of magnitude. This benefits the measuring accuracy directly.

- Permanent magnets permit mains-independent operation
- Capacitive signal decoupling prevents corrosion problems
- Extremely compact design with high magnetic field
- New fields of application from microsystems technology to fluids of very low conductance
- All-purpose use
- Reduction of installation and maintenance costs