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Advances in Magnetic Flow Metering: A Clamp-on Device

Leonhard Schmieder[1], Peter A. Koss[1]
[1] Fraunhofer Institute for Physical Measurement Techniques IPM, Georges-Koehler-Allee 301, 79110 Freiburg im Breisgau, Germany
Leonhard.Schmieder@IPM.Fraunhofer.de

Summary:

This study presents advancements in a clamp-on flow metering apparatus based on the magnetic flow metering procedure, with a focus on its non-invasive capabilities for the measurement of fluid flow across diverse pipe materials. The proposed metering methodology leverages novel optically pumped magnetometers (OPM), facilitating precise flow detection without disturbing the fluid dynamics of the system. We provide a detailed description of the essential components, including the pre-polarization magnet and the low-field nuclear magnetic resonance (NMR) region for signal preparation. This research represents a pivotal contribution to the ongoing evolution of the magnetic flow metering procedure, advancing its readiness for industrial application.

Keywords: Flow Metering, Non-Invasive, Quantum Sensing, Clamp-On, Magnetometry, NMR

Motivation

Clamp-on flow metering devices have emerged as crucial tools in the process industry, offering a non-invasive and efficient means to measure fluid flow. These devices provide significant advantages over traditional flow measurement techniques, including ease of installation, minimal maintenance requirements, and the ability to measure a wide range of fluid types without disrupting the flow or requiring system shutdowns [1, 2]. As industries strive for greater accuracy and reliability in their processes, the integration of clamp-on flow meters can enhance operational efficiency and reduce costs.
Our newly invented magnetic flow metering procedure [3, 4], which allows for a non-invasive flow detection with novel optically pumped magnetometers (OPM) through steel and plastic pipe materials [5], is constantly developed further to reach its full potential eventually [6]. In this article, we will outline our latest research achievements related to a clamp-on flow metering device based on this magnetic flow metering procedure. By leveraging the advantages of clamp-on technology described above, this method is particularly well-suited for non-invasive flow measurement, paving the way for its industrial applications.
The aim of our research presented is to develop clamp-on versions of the devices required for magnetic flow metering and to evaluate their performance against a stationary laboratory setup

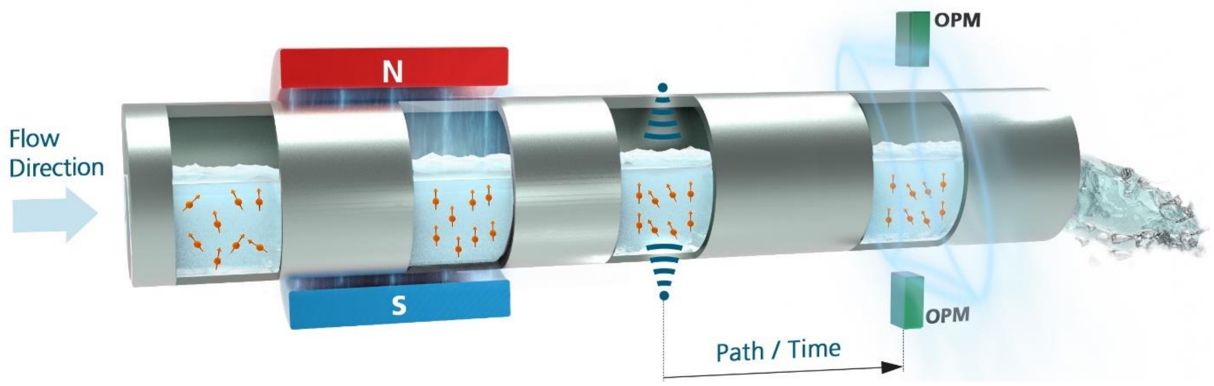

Fig. 1. Time-of-flight based measurement of a flow velocity. a) The fluid is magnetized by a strong magnet. b) A short and resonant RF pulse is applied to the fluid which creates a “notch” in a magnetized background. c) This notch is monitored by OPM downstream. The flow velocity is simply given by path over time where the timing information is given by the creation and detection of the notches.

and a commercial flow meter. The essential clamp-on devices include a pre-polarization magnet, a low-field nuclear magnetic resonance (NMR) region for signal preparation, and a magnetic shield that houses an optically pumped magnetometer (OPM) for signal detection. Although essential for the final apparatus, the OPM housing design is not yet complete at the time of this proceedings release; however, it is described in as much detail as possible.

Materials and Methods

Fig. 1 provides a schematic overview of the magnetic flow metering procedure. Short radiofrequency pulses are applied to a magnetically prepolarized fluid. The local changes in the magnetic background field, detected by magnetometers positioned downstream, serve as timestamps for measuring the flow velocity in a time-of-flight fashion.

The design principle for the clamp-on Halbach magnet is shown in Fig. 2. The pre-polarization magnet is modelled after the research on clamp on magnetic systems in [7]. There, a new magnetic orientation design of a Halbach magnet allows for a forceless opening and closure of the magnet system, which is crucial for a simple operation in the field.

The RF interaction region and the detection region where the OPM is located must be magnetically enclosed to eliminate stray fields. To construct a clamp-on magnetic enclosure a press-on design of two half shells of mu metal around the pipe is used. Pressing the shells together ensures the connectivity of the mu-metal enclosure components. Separate enclosures are constructed for each region. The RF enclosure contains a built-in coil system to maintain a constant magnetic background field necessary for RF pulsing. Additionally, a clamp-on RF coil is fabricated using PCB manufacturing techniques.

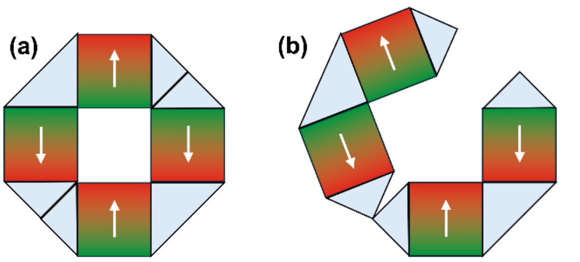

Fig. 2. Schematic arrangement of a clamp-on Halbach magnet with magnet orientation in open (a) and closed (b) depiction. The opening geometry allows for force free access. Image adjusted from [7], Fig. 3.

Results

The design of the clamp-on Halbach magnet is shown in Fig. 3. This magnet system is operated

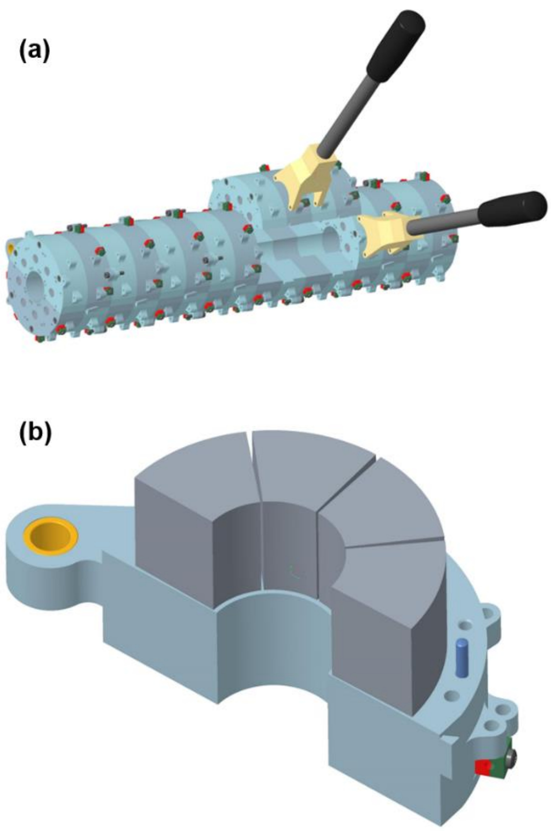

Fig. 3. Clamp-On Halbach system. In (a), a total view with opening levers is depicted. It consists of half shells which house trapezoid neodymium magnets. In (b), a close-up of a half shell is shown. The housed magnets are shifted outwards for an overview. The yellow ring is the hinge cylinder.

using two levers mounted on the exterior of the neodymium magnet housing. By pulling the levers apart, the half-shell magnet housing opens, allowing for effort-less deinstallation from the pipe due to the magnet's orientation. The magnetic field inside the Halbach system points perpendicular to the symmetry axis as the example shown in Fig. 2. The magnet system measures 416 mm in length and 86 mm in diameter. The modular construction enables the adjustment of the polarization length by adding or removing half shells from the magnet system.

The design of the RF magnetic enclosure is shown in Fig. 4. It has two layers mu metal pressed-on perpendicular to the symmetry axis and screws on both sides lock the layers into place. The enclosure measures 283 in length, 135 mm in diameter and has a simulated shielding factor on the order of 10^3. The inner coil system for RF pulsing and background field generation cannot be shown at the current development stage. The enclosure is manufactured by Sekels GmbH, Germany.

Although having more layers of mu metal and, thus a higher shielding factor, the magnetic enclosure for the OPM is manufactured in a similar

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fashion as the RF magnetic enclosure but without a coil system in plan.

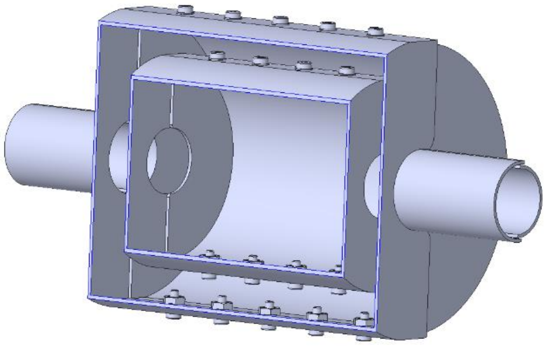

Fig. 4. Cross-sectional view of the clamp-on design for the interaction region enclosure. The magnetic field and RF coils are not depicted. The flow pipe is intended to run horizontally. Image provided by Sekels GmbH.

Discussion

This study presents advancements in clamp-on magnetic flow metering technology, emphasizing its non-invasive capabilities for measuring fluid flow in various pipe materials. By employing OPM, our method enables precise flow detection without disrupting the fluid dynamics, which is crucial for maintaining operational efficiency in industrial applications.

Our findings indicate that the clamp-on device, particularly the Halbach magnet design, allows for easy installation and removal, thus minimizing downtime. This reinforces the potential of our system to enhance measurement reliability while reducing maintenance needs.

The research contributes to the ongoing evolution of magnetic flow metering technology, showing promise for broader industrial applications. Continued development will focus on designing the OPM magnetic enclosure design and field tests when the apparatus is ready.

In conclusion, our clamp-on magnetic flow metering solution represents a pivotal step toward the industrial use as more efficient, accurate, and non-invasive flow measurement systems, aligning with the industry's increasing demands for sustainability and operational efficiency.

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