# LOCAL LORENTZ FORCE VELOCITY USING SMALL-SIZE PERMANENT MAGNET SYSTEMS

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**Abstract**: Lorentz force velocimetry (LFV) is a contactless velocity measurement technique suited for electrical conductive fluids like liquid metals. This technique is based on the interaction of the melt flow with an externally applied magnetic field produced by a special arrangement of permanent magnets. These interactions result in the generation of a flow-breaking Lorentz force inside the melt which is proportional to the velocity of the flow. In the case of local Lorentz force velocimetry, the permanent magnet system is significantly small compared to the melt volume giving access to local velocity information.

## 1. Introduction

Measurement of local velocities or volumetric flow rate of liquid metals still presents a big challenge in metallurgic applications. As metal melts such as liquid steel are highly aggressive and opaque, flow measurement techniques providing mechanical contact between melt and probe as well as optical methods cannot be used. Recently, a non-contact electromagnet technique has been developed called Lorentz force velocimetry (LFV). Applying this technique, the electrically conductive moving melt interacts with an externally arranged magnetic field that is generated by a special arrangement of permanent magnets. Due to the principles of magnetohydrodynamics, eddy currents are generated within the fluid giving rise to Lorentz forces which are acting in the direction opposite to the flow. According to Newton's third law, there is a counter force of the same magnitude that acts on the magnet system. LFV is based on measuring this reaction force using a force sensor on which the arrangement of permanent magnets is mounted. The magnitude of this flow-braking Lorentz force $F_L$ depends on the electrical conductivity $\sigma$, the volumetric flow rate $Q$ or velocity $V$, and the strength of the imposed magnetic field $B_0$ according to the scaling relation [1]

$$F_L \sim \sigma\, Q\, B_0^2 \qquad \text{or} \qquad F_L \sim \sigma\, V\, B_0^2 \qquad (1, 2)$$

In case of flow rate measurement, the magnetic lines penetrate the entire cross-section of the flow (cf. Eq. (1)). On the other hand, in the case of local Lorentz force velocimetry (cf. Eq. (2)), magnets that are significantly smaller than the cross-section of the flow are of interest. It has been already demonstrated by Heinicke in [2] that by applying this technique it is possible to resolve the wake behind a small mechanical obstacle submerged in liquid metal flow. The present paper aims to extend these model experiments by using a novel arrangement of miniaturized permanent magnets resulting in both a higher resolution and a higher sensitivity of the measurement. Additionally, we provide measurement of both the streamwise force and the total moment acting on the magnet system by using a multi-degree-of-freedom sensor. Here, the force will provide information of the velocity and the torque information of the local velocity gradient. The model experiments are performed in the liquid metal loop GALINKA (fig 1) using the low-melting alloy GaInSn in eutectic composition.

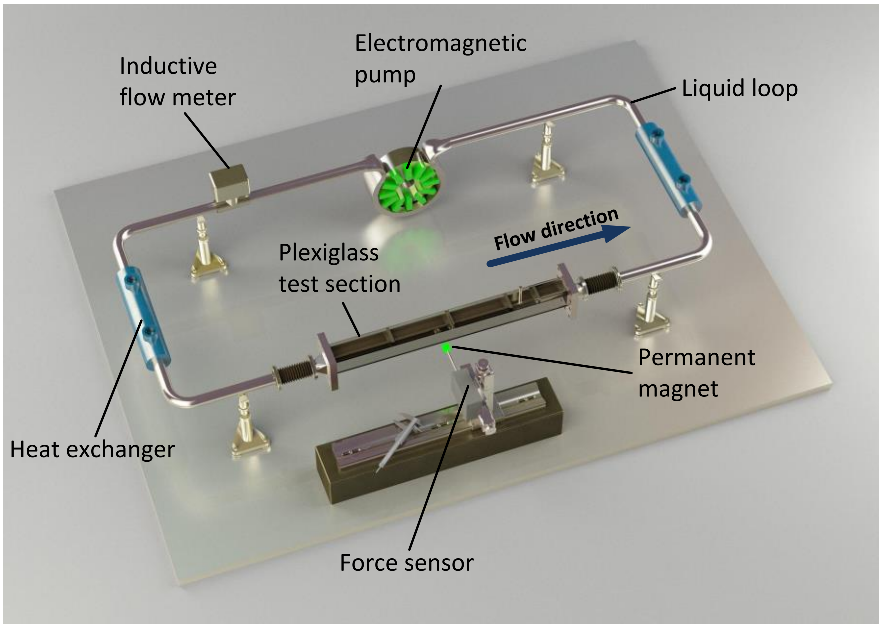


Figure 1: Experimental facility GALINKA. GaInSn in eutectic composition is pumped by a an electromagnetic pump and circulates in a loop made of stainless steel and a 50 mm x 50 mm plexiglass rectangular test section. Aside the test section, a permanent magnet is arranged and fixed to a force sensor.

## 2. Presentation of the problem

As explained before, LFV gives us the possibility of performing local velocity measurement in electrical conductive liquids. In order to do that, the volume of the liquid that interacts with the magnetic field has to be considerably smaller than the cross-section of the flow. This requirement is met when using miniaturized magnets characterized by a rapid decay of magnetic field strength with distance. According to this principle, in Ref. [2] a spatial resolution of 3 cm has been achieved by using a 10 mm cubic magnet. Using such set-up, detection of obstacles submerged inside the flow and the wake behind them could be achieved. However, if we decrease the size of the magnets, the measured force decreases likewise making its measurement a big challenge for currently existing force measurements devices. For example, a magnet-size parametric study has shown that clear force measurements using a 5 mm cubic magnet is not possible [3].

The current goal is not just to increase the spatial resolution of the force but also to have local information of the velocity gradient with an arrangement of small-size permanent magnet system (fig 2). For this purpose, the magnet system shall be attached to a multi-degree-of-freedom force sensor which is currently been developed in the A-2 project of the RTG Lorentz Force Velocimetry and Eddy Current Testing at Technische Universität Ilmenau [4]. In this proposal, the total streamwise force and net torque acting on the permanent magnet arrangement will be measured simultaneously having a local velocity as well as a local velocity gradient assessment respectively. Additionally and prior to validation experiments, the number, the magnetization direction and location of each magnet will be the results of an optimization procedure using the software Ansys Workbench, Fluent and Maxwell. Afterwards, the results of optimization would be validated in the experimental facility GALINKA (fig 1).

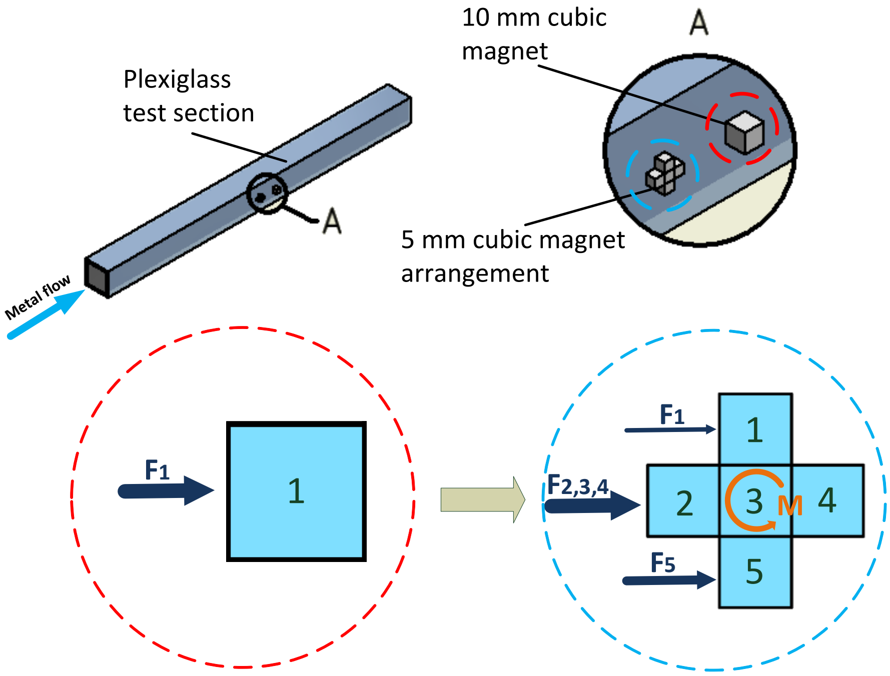


Figure 2: Proposal of replacement of a 10 mm cubic magnet with a 5 mm cubic magnet arrangement. For a better understanding, just the plexiglass test section, the old (10 mm cubic magnet) and the new (five 5 mm cubic magnet arrangement) magnet systems are shown *(top)*. In the current set-up, the force sensor is fixed to the 10 mm magnet and measures the streamwise force $F_1$. However, in the proposed model, the multi-degree-of-freedom force sensor is fixed to the magnet 3 which allow us to simultaneously measure the total streamwise force $\sum_{i=1}^{5} F_i$ and the net torque $M$, which are a local qualitative measurement of the velocity and its gradient respectively *(bottom)*. The magnet arrangement shown in this picture is for explanation purpose only. The number, the magnetization direction and location of each of the 5 mm cubic magnets will be determined by an optimization procedure.

We start our analysis on comparing the current and the proposed magnet systems by finding the imposed magnetic field that they produced on the liquid metal. As first approach, we will start with a permanent magnet system arrangement composed by three small magnets aligned to the direction to the flow. In fig 3 is shown the simulation of the magnitude of the magnetic field *Mag_B* of a 10 mm N42 cubic magnet and three 5 mm N42 cubic magnets inside a 50 mm x 50 mm rectangular duct using the electromagnetic field simulation software Maxwell 2014. The magnetization direction of each permanent magnet is constant and perpendicular to the flow and the distance between the surface of each magnet and the fluid is 5 mm. The results show that there is an increase of the spatial resolution of the magnitude of the magnetic field due to the oval-shaped magnetic field distribution. However, there is a decrease by a factor of approx. 1.8 of the maximum magnitude of the magnetic field in comparison with the 10 mm cubic magnet.

The next step is to perform validation experiments within GALINKA with the aim of comparing the spatial resolution of the force using the current and the proposed magnet systems. Additionally, we will continue with the optimization of the small-size permanent magnet system using the electromagnetic field simulation software Maxwell 2014. The magnetization direction, the number and location of 5 mm cubic magnets will be taken into account with the objective of maximizing the total Lorentz force acting on the magnet system.

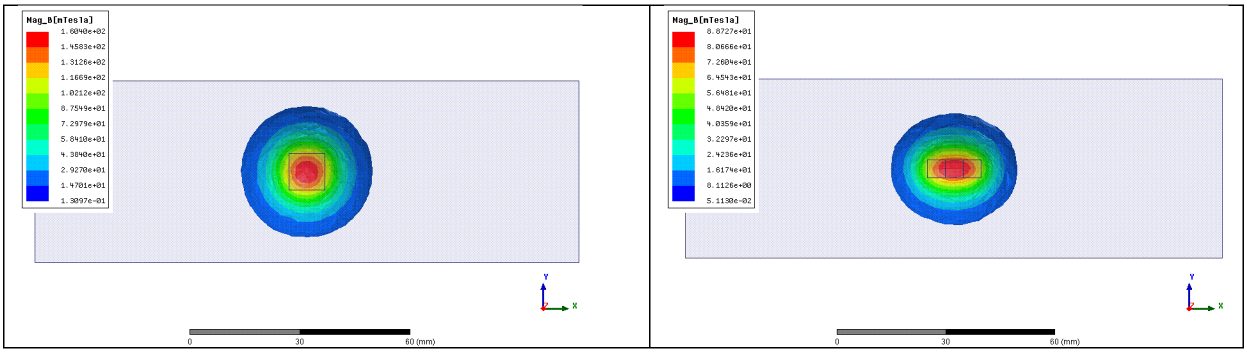

Figure 3: Magnitude of the magnetic field produced by a 10 mm N42 cubic magnet (*left*) and an arrangement of three 5 mm N42 cubic magnets (*right*) inside a 50 mm x 50 mm rectangular duct. The distance between the surface of the magnet arrangement and the liquid is 5 mm and the magnetization direction is perpendicular to the flow in each case. In this two magnetic field simulations, we can see that the magnetic field of the proposed magnetic arrangement has an oval-type distribution providing a higher spatial resolution of the force in the flow direction x with a decay of a factor 1.8 of the maximum value in comparison with the 10 mm permanent magnet. The simulations were performed using the electromagnetic field simulation software Maxwell 2014.

## 3. Conclusion

The oval-shaped magnetic field distribution of a 5 mm permanent magnetic system arrangement was compared with the current one of a single 10 mm cubic magnet used in local Lorentz velocimetry. The new magnet system presents the possibility of increasing the spatial distribution of the magnetic field in the streamwise direction, and therefore, an increase of the spatial resolution of the total Lorentz force. This enables us to increase the sensitivity of the local velocity measurement which is the main aim of this local velocity measurement technique for liquid metals. However, the maximum value of the magnitude of the magnetic field was 1.8 times lower. In order to reduce this difference, an optimization procedure of the 5 mm permanent magnet arrangement is proposed having as input variables the magnetization direction, the number, and the location of magnets; and as output, the total force acting on the magnet system will be considered.

## 4. References

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