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Expectable Forces of Lorentz Force Velocimetry in low conducting and slow flowing solutions by the use of high- T_c superconductors

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Abstract

To increase the resolution of a fluid flow measuring system based on measuring the Lorentz force in flow direction one possibility is to increase the flux density of the used magnet system. Therefore high temperature superconductors are considered. This contribution shows the possible improvements of such a system by trapping higher fields in the magnets and the optimization of the arrangement which was done by numerical simulations.

Key words: Lorentz force velocimetry, high temperature superconductor, electrolytes, salts, glasses

Introduction

The Lorentz force velocimetry (LFV) is a novel method for flow measurement of low conducting and slow flowing fluids [1]. In this application the velocity or the conductivity of a fluid is measured by the accelerating force on a strong magnet system generated by magnetic induced eddy currents in the fluid. Because of the contactless measuring this method can stand very hot and aggressive fluids like molten salt or glass.

In former phases investigations of permanent magnet systems were done. Here a Halbach array system based on NdFeB magnets was successfully used [2]. The measurement of the very small forces which are in μN range is done by an electromagnetic compensation system. This very sensitive system limits the weight of the magnet system to 1 kg so that there must be constructed an efficient system.

To generate higher eddy currents in the fluid and get a higher resolution of this application magnets with higher energy densities are necessary. A promising method is the use of high-temperature superconducting bulk materials (HTS) because of their very high energy density [3].

To get to know what Lorentz forces can be expected numerical simulations were done with variations of the trapped field in the HTSs. Also investigations on possible arrangements of several bulks were analyzed.

Modell

Based on the experimental setup the fluid volume which must be to consider has a quadratic cross section with sides of 50 mm and a length of 400 mm. Due to the low velocity of 5 m/s and the poor conductivity of 4 S/m the fluid profile is negligible disturbed by the magnetic field interaction and the magnetic field is not deformed by the induced secondary field and consequently for the modeling of the fluid a solid body approximation can be used [2]. The cylindrical HTS bulks are positioned symmetrical left and right of the channel with distance of 3 mm. Fig. 1 shows a Modell with normalized current density, y component of the magnetic flux density of the HTS bulks and the induced eddy currents (red arrows) by the use of a center line between bulk pairs.

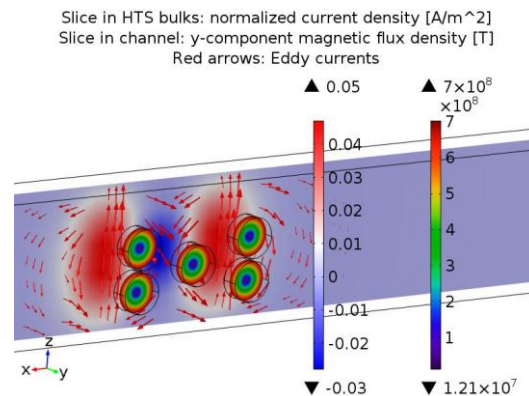


Fig. 1: Model of a five HTS bulk arrangement

Because of the almost linear depending magnetic flux density in perpendicular direction of cylindrical HTSs the bulks were simulated based on Bean's Modell with a radial depending current density $J_C(r)$ inside like Eq. (1).

$$J_C(r) = c \cdot r \quad (1)$$

By variation of the constant c the trapped field of the HTS bulks can be simulated for changes of their operating temperature and material properties.

Results

To estimate Lorentz forces of a superconducting magnet system the trapped field of commercial available YBCO bulk pairs with diameter of 46 mm and height of 17 mm was simulated from zero to 5 T which is the maximum generated field in our laboratory. As shown on fig. 2 the Lorentz force increases by two oppositely arranged HTS bulks with increasing trapped field. How the approximation of the graph indicates a quadratic behavior which agrees with the scaling law of Thess et. al. [1] at constant velocity and electric conductivity can be seen. By cooling these superconductors with liquid nitrogen at temperatures of 77 K a field of approximately 1 T can be trapped. It is reported that YBCO bulks are able to trap 5 T by cooling them down to the temperature range of 45 to 50 K [4]. With this magnetic flux density the resolution of the LFV can be increased by the factor of 25.

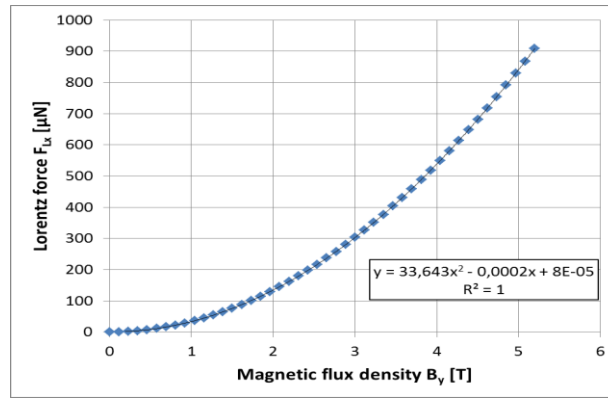


Fig. 2: Generated Lorentz force F_{Lx} in flow direction of HTS bulk pair with diameter of 46 mm and a distance of 56 mm depending on trapped field B_y at 5 m/s and 4 S/m of the fluid

Another way to improve the trapping behavior of HTS bulks is to irradiate them with neutrons [5]. Especially for small diameters of bulks trapped field can be increased dramatically. So a magnet system based on small improved HTS bulks could be arranged to work with liquid nitrogen at temperatures of 77 K which means resource saving and easier handling. For estimation of the potential of this idea HTS bulks with a diameter of 14 mm and a height of 6 mm were simulated with a trapped field of 1 T in different arrangements. Because of comparison and the limited mass m of the magnet system an efficiency factor e was defined as shown in Eq. (2).

$$e = \frac{F_{Lx}}{m} \quad (2)$$

Hereby it is possible to evaluate the magnet system in quantitative way. For a symmetric rectangular (fig. 3) and a rhombic (fig. 4) arrangement of four pairs of HTS bulks on each channel side with same magnetization direction the generated Lorentz force increases with increasing horizontal (y direction) and decreasing vertical (z direction) displacement. This leads to the point that for same magnetic directed HTS bulks one dimensional chains with a definite horizontal displacement would be the best magnet system. Such magnet systems are realizable with multi-seeded HTS bulks.

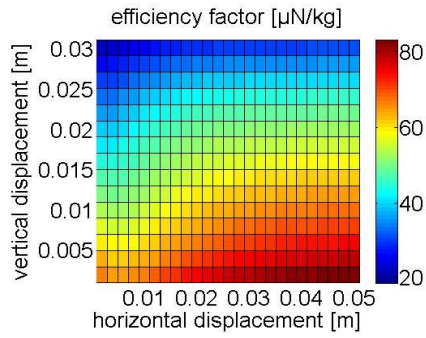


Fig. 3: Efficiency factor e of Lorentz force in channel direction of a symmetrical rectangular arrangement of four HTS bulk pairs with variation of horizontal and vertical distances

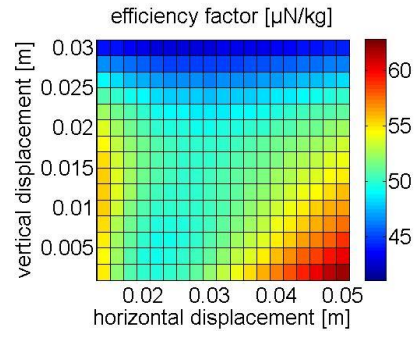


Fig. 4: Efficiency factor e of Lorentz force in channel direction of a symmetrical rhombic arrangement of four HTS bulk pairs with variation of horizontal and vertical distances

By using a HTS bulk system with different directions of magnetization it is possible to find optimal compact arrangements which are able to generate higher Lorentz forces. Fig. 5 shows the generated Lorentz forces of the symmetric rectangular system from figure 2 with an additional HTS bulk with opposite magnetization in the center. At this arrangement also the vertical displacement should be as small as possible. For the horizontal direction there is an optimum which depends on the bulk diameter.

For a symmetric rhombic arrangement with an additional HTS bulk in the center fig. 6 shows that there is an optimum for vertical and horizontal displacement. Although this arrangement is the smartest one it generates the relative to its weight the smallest Lorentz force. Concerning this results a by magnetization alternating one dimensional chain with defined horizontal distances is a promising configuration for magnet system of HTS bulk for the LFV.

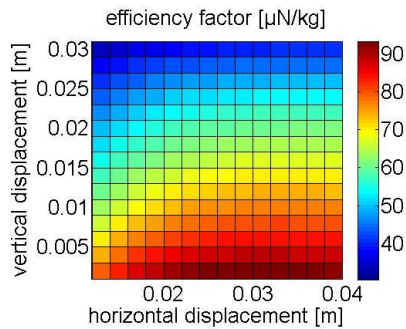


Fig. 5: Efficiency factor e of Lorentz force in channel direction of a symmetrical rectangular arrangement of four HTS bulk pairs with a opposite magnetized bulk pair in the center with variation of horizontal and vertical distances

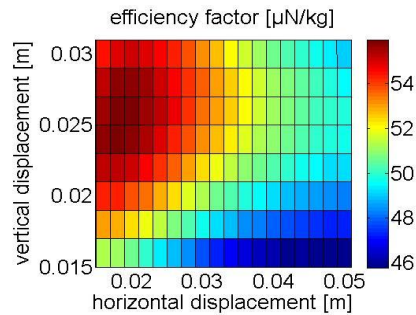


Fig. 6: Efficiency factor e of Lorentz force in channel direction of a symmetrical rhombic arrangement of four HTS bulk pairs with a opposite magnetized bulk pair in the center with variation of horizontal and vertical distances

For comparison a single HTS bulk pair with diameter of 47 mm and height of 17 mm at 77 K has an efficiency factor of $79.4 \mu\text{N/kg}$. This shows that already simple geometrical arrangements of improved HTS bulks have a 17.5% better efficiency factor which is $93.3 \mu\text{N/kg}$.

Fig. 7 shows the Lorentz force in channel direction of two adjoined bulk pairs (diameter 47 mm and height 17 mm) with same and opposite magnetization direction under variation of their horizontal distance at 77 K with a trapped field of 1.1 T. For same directed magnetization the generated force increases with distance until the influence of the HTS bulk pairs does disappear and the measured force will be twice of the force of one pair. For low distances the field in the middle of the two pairs superimposes so that there is a low field gradient between the HTS bulk pairs in the channel. Hence the induced eddy currents in the center of the channel are very low. For large distances there are two regions with strong eddy currents more and the Lorentz force increases.

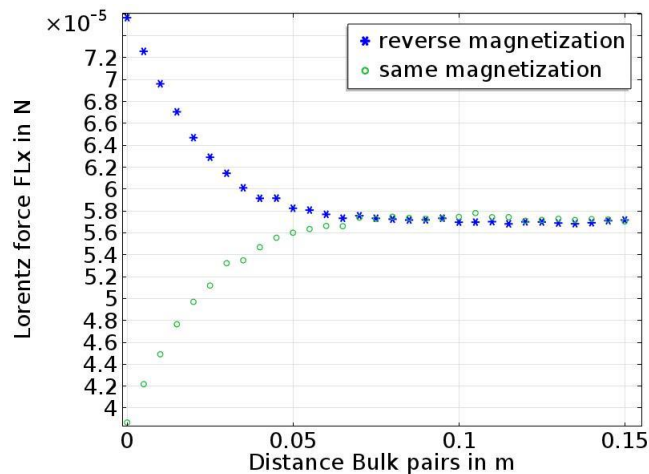


Fig. 7: Lorentz force of two HTS bulk pairs with diameter of 47 mm depending on the distance and magnetization direction

In case of one opposite magnetized HTS bulk pair at low distances the field gradient between the bulk pairs is very high so that the induced eddy currents in this region of the fluid are very high and highest Lorentz forces are generated. For increasing distance the force approaches to the double force of one HTS bulk pair. In the arrangement without a distance between the bulks the efficiency factor of this system amounts $105.1 \mu\text{N/kg}$.

Conclusion

The analyzed cases show that it is possible to generate higher Lorentz forces with optimized dimensions and arrangements of HTS bulks. Therefore systems with different magnetized HTS bulk must be used. To increase the resolution of the LFV dramatically by the magnet system the biggest effect will be achieved by cooling these materials below 77 K. In interaction with optimized dimensions and arrangements a strong magnet system based on HTS can be built. Future works will validate these numeric results with experiments and show the feasibility of such conditions with special designed cryostats.

Acknowledgment

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References

- [1] A. Thess, E. Votyakov, B. Knaepen, O. Zikanov (2007), *New Journal of Physics* 9, 299
- [2] M. Werner, B. Halbedel (2012), *IEEE Transactions on Magnetics* 48, No. 11, pp 2925-2928
- [3] B. Halbedel, M. Klaiber, M. Weidner, (2013), *Proceedings Workshop Elektroprozessstechnik, Ilmenau/ Ortsteil Heyda, 12.-13. Sept. 2013*
- [4] L. Prigozhin (1996), *Journal of Computational Physics* 129, pp 190–200
- [5] S. Gruss, G. Fuchs, G. Krabbes, P. Verges, G. Stöver, K.-H. Müller, J. Fink, L. Schultz (2001), *Applied Physics Letters* 79, No. 19, pp 3131-3133
- [6] M. Eisterer, S. Haindl, M. Zehetmayer, R. Gonzalez-Arrabal, H. W. Weber, D. Litzkendorf, M. Zeisberger, T. Habisreuther, W. Gawalek, L. Shlyk, G. Krabbes (2006), *Superconductor Science and Technology* 19, pp 530-536