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New bulk – bulk superconducting bearing concept using additional permanent magnets

***Abstract**. The paper deals with an improved concept of the superconducting (HTS) magnetic bearing. This new solution depends on the application of additional permanent magnet rings placed below the bulk superconductors connected with the rotor. Calculations and measurements of the levitation force between the magnetized HTS and a coaxial MgB_2 hollow cylinder are reviewed, proving the validity of the concept of such a superconducting bearing.*

Streszczenie**. W pracy zaprezentowano zmodyfikowaną wersję nadprzewodnikowego (HTS) łożyska magnetycznego. To nowatorskie rozwiązanie polega na zastosowaniu dodatkowych pierścieni z magnesów trwałych umieszczonych poniżej masywnych nadprzewodników wysoko-temperaturowych umocowanych do wirnika. Przedstawione w pracy obliczenia oraz wyniki pomiarów sił lewitacji pomiędzy namagnesowanym HTS a cylindrem z MgB_2, potwierdzają zalety zaproponowanego rozwiązania. **(Nowa koncepcja łożyska nadprzewodnikowego wykorzystującego dodatkowe magnesy trwałe).

Keywords: levitation, superconducting magnetic bearings, high temperature bulk superconductors.
Słowa kluczowe: lewitacja, nadprzewodnikowe łożyska magnetyczne, masywne nadprzewodniki wysokotemperaturowe.

Introduction

All superconducting bearing has been mentioned in [1]. This paper deals with an improved concept for an HTS magnetic bearing. The main idea of a unique bulk-bulk superconducting rotary bearing design which uses superconducting bulks on both the rotor and the stator has already been reported in [2] and [3]. According to [2] cylindrical field source bulks are stacked and magnetized with alternating polarity, leading to the magnetic bearing of increased performance. This YBCO-MgB_2 bearing has been shown in Fig.1.

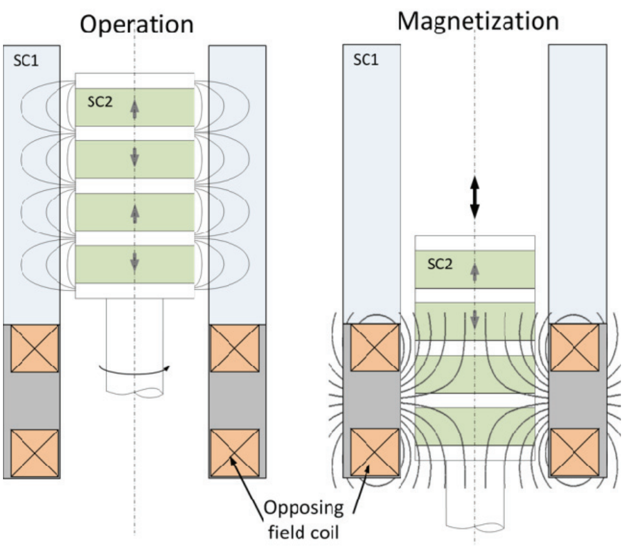

Fig.1. The bulk-bulk superconducting bearing [2]

The application of the magnetized (RE)BCO bulks instead of conventional permanent magnets leads to a significant increase in the levitation force density [2].

Problem formulation

The new solution of the HTS bearing depends on the application of additional permanent magnet rings placed below the lower YBCO bulk superconductor. These rings create additional axial and radial forces in the bearing system. PM rings can boost the force for the existing bearing design by providing a 'cushion' of magnetic field for the bottom YBCO bulk. The bottom YBCO bulk can be magnetized and cooled down in the absence of the external magnetic field of the PMs (zero field cooling) and then moved towards the MgB_2-PM system causing repelling forces. This diamagnetic levitation supports the force generation within the bulk-bulk superconducting bearing. The idea of the new HTS bearing has been depicted in Fig.2.

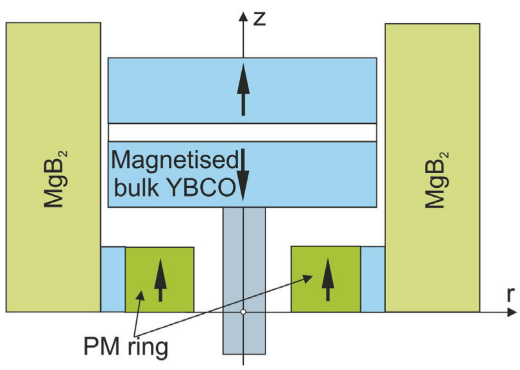

Fig.2. Fundamental structure of the novel bulk-bulk superconducting bearing using additional PM rings

The significantly higher force densities predicted for this new bearing design compared to the previous designs give it the potential to be suitable for applications, such as flywheel energy storage, where a higher load capacity can increase the energy stored.

Calculations

For the analysis of the configuration depicted in Fig.2 the trapped-flux calculation model ([1], [5]) has been applied. It means that the magnetic field from the cooling position is perfectly preserved inside the superconductor. The use of the finite-element method with vector potential formulation and Schwarz-Christoffel transformation method for the trapped-flux calculation method has been described in [5]. This method gives the estimation of maximum force which can be obtained in any arbitrary superconductor configuration, thus its application makes it possible to carry out a practical evaluation of such configurations.

Additional permanent magnets are placed within the MgB_2 ring before the initiation of the cooling process of the entire system. Figure 3 shows the exemplary field distribution in the initial position of the YBCO stack within the MgB_2 and in two positions of YBCO bulks moving towards the PM ring.

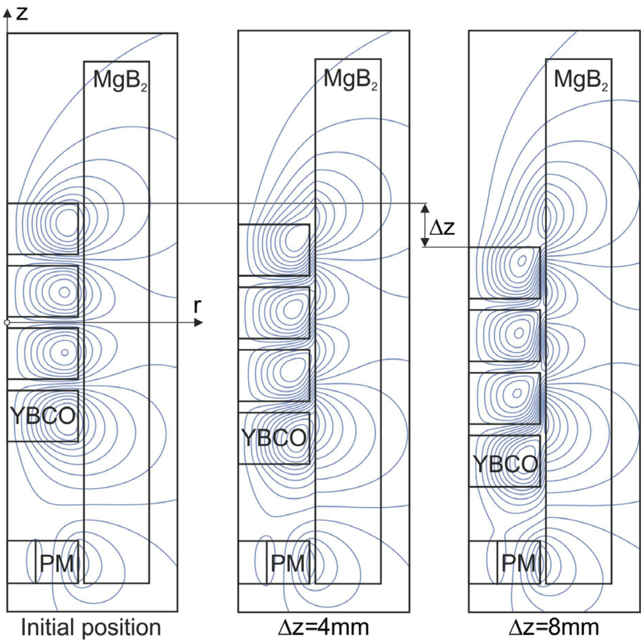

Fig.3. Field distribution within the HTS bearing for different positions of moving YBCO superconductors and permanent magnets placed within the MgB_2 hollow cylinder system (one half of the configuration). The magnetic field within the MgB_2 ring remains unaltered - the trapped-flux calculation model

Figure 4 shows the comparison between forces obtained in the analyzed HTS bearing for the YBCO excitation with and without additional permanent magnets (as referenced, the force obtained for conventional PM with B_r=1.4T excitation has also been shown).

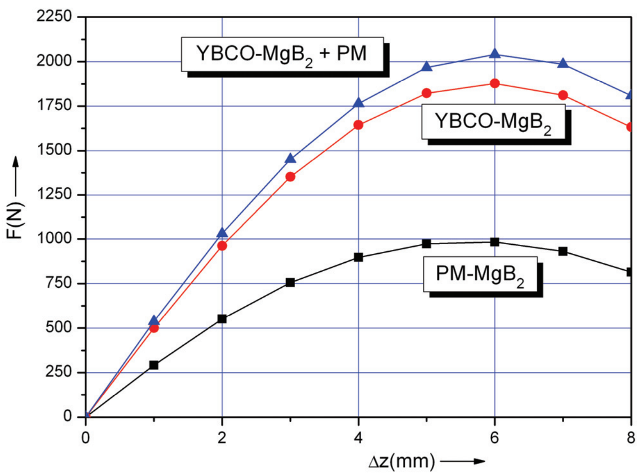

Fig.4. Axial force dependence vs. displacement of the YBCO stack. Remanence field of supporting PMs B_r=1.4T, critical current density of magnetized YBCO J_c=533A/mm^2

As can be seen in Fig.4, the application of additional magnets leads to an increase of the axial force in the HTS bearing of about 9% for the axial displacement of Δz=6 mm (exact geometrical dimensions of the bearing are given in [2]). In comparison to the conventional HTS bearing with the PM excitation, the increase of the supporting force equals about 100%.

Measurements

The configuration from Fig.2 was investigated experimentally. The measurement system has been depicted in Fig.5.

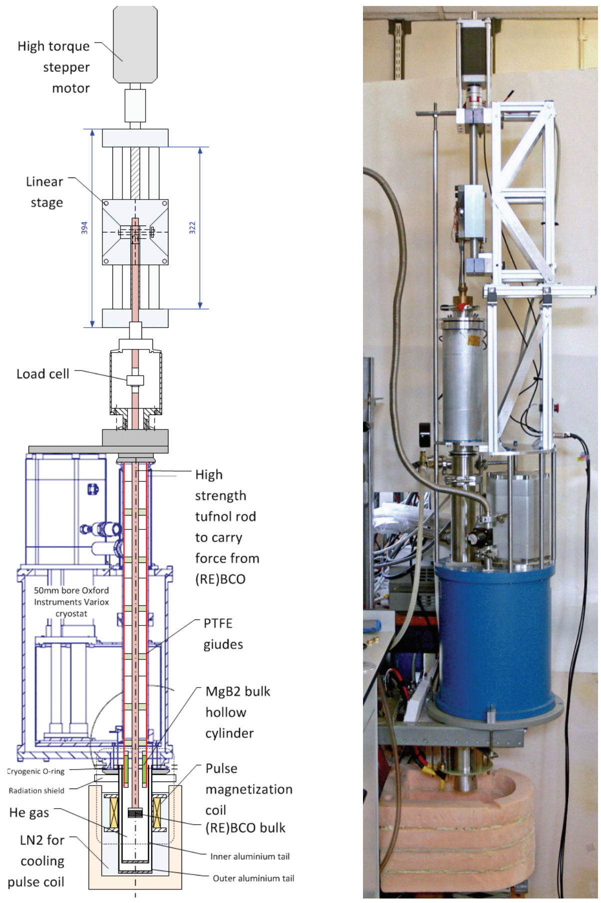

Fig.5. Measurement system for the examined HTS bearing. Based on a cryostat with a 50 mm bore and a 10T pulsed field coil. Magnetic force up to 1 kN can be measured

A unique levitation force measurement system has been constructed to allow investigation into pulsed field magnetization of superconducting bulks and forces between a magnetized bulk and another superconductor. Measurements are to follow after completion of the electronics, however all mechanical parts of the system including the pulse field coil have been completed. A photo and schematic of the system is displayed in Figure 5. The system is based on an Oxford Instruments cryostat which will allow bulks to be cooled down to 13 K via convection of helium gas. The magnetizing coil is able to deliver a pulsed field up to 10 T. If the MMPSC [6] procedure is used then it should be possible to trap fields over 3 T in a 25 mm diameter YBCO bulk. After magnetization of YBCO, it can be aligned inside an MgB2 cylinder (the linear stage allows large movement), before the system is cooled further to around 20 K. It is then possible to measure levitation force between the MgB2 and YBCO bulks up to 1 kN. The gap between the two coaxial bulks will be 1.75 mm. This small gap along with the high trapped field should easily allow a levitation force of 100 kg to be achieved as supported by the modeling predictions. The cryogenic and force demands on the bulks have required careful design of the system including the use of glass composites and non-magnetic stainless steel grades for the casings which hold the bulks. The system will be able to verify the bearing design proposed in this paper by using a PM ring, but will also be a more general tool for investigating pulse magnetization and forces between superconducting bulks. The full experimental results for the design presented will be reported in future.

Modifications to the fundamental structure

The main configuration of the proposed HTS bearing can still be modified in order to obtain higher levitation forces and stiffness. The most important factor for the force generation is the geometry of the additional field source, its size and position. The supporting permanent magnets can be placed outside the MgB_2 system. Figure 6 shows the field distribution in the initial position of the YBCO stack within the MgB_2 and in two positions of YBCO bulks moving towards the PM ring.

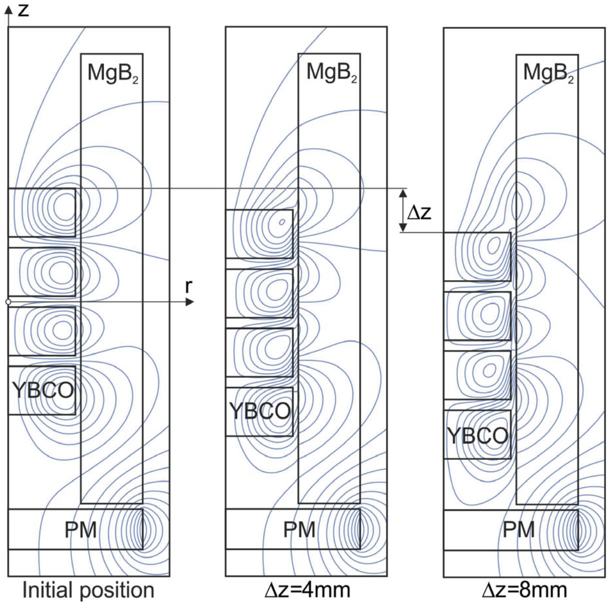

Fig.6. Field distribution within the HTS bearing for different positions of moving YBCO superconductors and permanent magnets placed outside the MgB_2 hollow cylinder system (one half of the configuration)

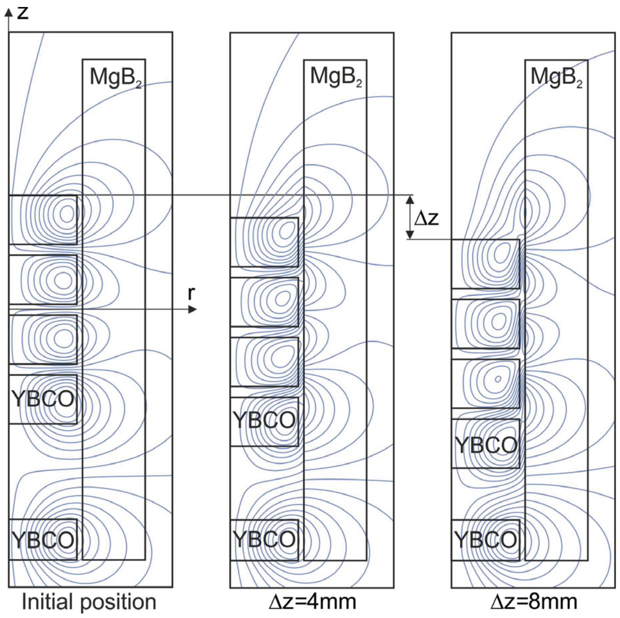

Fig.7. Field distribution within the HTS bearing for different positions of moving YBCO superconductors and additional YBCO superconductor placed within the MgB_2 hollow cylinder system (one half of the configuration)

Much better results can be obtained by using the magnetized YBCO ring instead of the PM ring. This additional YBCO ring should be magnetized in the same way as the main YBCO stack. Figure 7 presents the field distribution in the initial position of the YBCO stack within the MgB_2 and in two positions of YBCO bulks moving towards the additional YBCO bulk. As can be seen in Fig.7, the initial magnetic field caused by the magnetized YBCO stack and supporting SPM within the MgB_2 ring remains unaltered. This causes much higher levitation forces in the bearing compared to its conventional structure.

Conclusions

The paper presents a new idea for an HTS bearing and describes the methodology for evaluating the force within the superconducting field excitation system in superconducting bearing. Assuming the trapped-flux model to be valid for the HTS, the evaluation of the maximum force for different configurations has been analyzed. Calculations of the levitation force between the magnetized HTS and a coaxial MgB_2 hollow cylinder are reviewed, proving the potential of the new concept of a magnetized YBCO-MgB_2-PM bearing. The construction of a new experiment has been outlined which will be used to validate the design presented here. The new system will also be used as a more general tool for investigating force interactions between superconducting bulks for bearing applications. The results presented in this paper and proposed experiments lay down the foundations for a more general method of analysis and design of any practical configuration used in superconducting bearings. The limitations of permanent magnets have lead to a bearing design which instead relies on magnetized bulks due to the much higher flux density they can provide. However the results presented show that even for this design, permanent magnets can still have a valuable role in a bulk-bulk bearing and may be used to tune the force behavior of a bearing. In addition more generally a bulk-bulk bearing design does not necessarily have to rely solely on field cooling but can also use zero-field cooling with an additional field source to boost the force behavior of the system.

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