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Mechanical characterization of journal superconducting magnetic bearings: stiffness, hysteresis and force relaxation

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Abstract. Superconducting magnetic bearings (SMBs) can provide stable levitation without direct contact between them and a magnetic source (typically a permanent magnet). In this context, superconducting magnetic levitation provides a new tool for mechanical engineers to design non-contact mechanisms solving the tribological problems associated with contact at very low temperatures. In the last years, different mechanisms have been proposed taking advantage of superconducting magnetic levitation. Flywheels, conveyors or mechanisms for high-precision positioning. In this work the mechanical stiffness of a journal SMBs have been experimentally studied. Both radial and axial stiffness have been considered. The influence of the size and shape of the permanent magnets (PM), the size and shape of the HTS, the polarization and poles configuration of PMs of the journal SMB have been studied experimentally. Additionally, in this work hysteresis behavior and force relaxation are considered because they are essential for mechanical engineer when designing bearings that hold levitating axles.

1. Introduction

Superconducting magnetic bearings (SMB) are used in applications such us in flywheels [1] or Maglev devices among other devices [2–7]. The lack of contact, the extremely low friction and energy losses and the absence of wear are some of the outstanding characteristics that make this kind of bearings interesting for the mechanical engineer [8].

The mechanical interaction between magnets and superconductor has been previously deeply analyzed [9–12]. There are some models that are useful to describe this interaction and that can be applied in finite elements programs as it is commonly used in mechanical engineering [13,14]. Although these models can be very useful for static loads calculations, they are still limited when dynamics are transient effects are taken into account. Hence the real experimentation of SMBs design is still necessary.

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Among superconducting bearings, journal bearings have been typically considered in order to bear high axial and radial loads. For most configurations in the literature, a superconducting journal bearing is composed by a ring permanent magnet (PM) levitating over a disk superconductor (SC).

In the FP7 MAGDRIVE project, superconducting magnetic bearings will be used in order to support a novel magnetic harmonic drive where there is no contact between any of the moving parts. As part of this research, a study of different journal superconducting bearings under field cooling conditions has been carried out. Relevant parameters such as the stiffness, the hysteresis or the force relaxation has been characterized using a specifically designed and built test bench.

2. The MAGDRIVE FP7 project

The objective of this FP7 project is to design and build a harmonic drive able to work under cryogenic conditions, with an extremely low friction, long life time and no wear, figure 1. The drive will not use any lubrication and will be free of wearing. This harmonic drive will achieve a great reduction ratio, being based on a non-contact interaction between permanent magnets and soft magnetic materials. In addition, the whole prototype will be supported by High-Temperature SMB intended not only to bear the weight but also to radially stabilize the magnetic harmonic drive core.

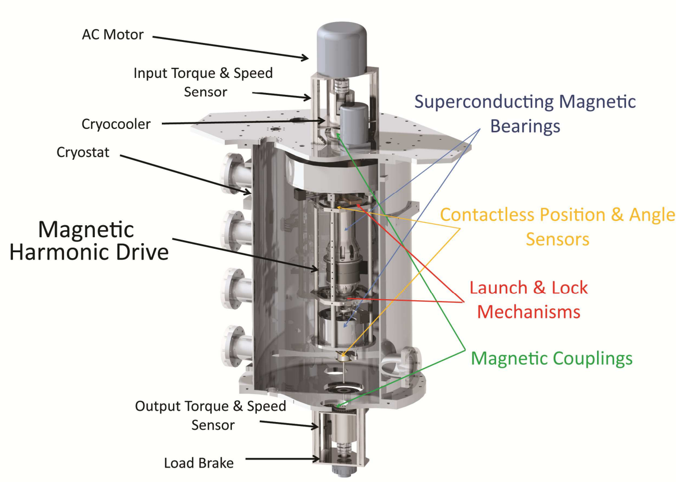

Figure 1. In this case simply justify the caption so that it is as the same width as the graphic.

3. Experimental set-up

In order to characterize the axial and radial stiffness of the SMBs, a dedicated test bench has been designed and built. The bench, shown in figure 2, is mainly composed of a metallic structure made of aluminum (1) which fixes the PM in position. Due to the magnetic properties of the aluminum alloy used, low magnetic interaction with the PM and the SC is assured. In addition, the superconductors are placed and fixed inside a LN2 vessel (2) and the last assembled onto a motorized lab-jack from Thorlabs, model L490MZ (3). This lab-jack stand is intended to modify the gap (Z axis) between the PM and the SC with extreme accuracy (about 5μm) within a stroke about 55 mm. The lab-jack stand is assembled onto a linear slider (4) from Igus able to modify the radial distance between the centers of the SC and the PM (X axis). This slider is controlled in a close-loop using the position signal from a laser triangulator from Microepsilon model ILD 1402-50. In summary, overall repeatability in the radial and axial position has been estimated to be better than 100 μm.

The radial and axial forces between the PMs and the SCs have been measured by using two load cells (5) from SENEL, model SX-1, C3 precision category. They were installed at either side of the T bar that supports the PMs as shown in figure 2. Finally, all the electronic systems are connected to a PC and data acquisition is synchronized using Labview.

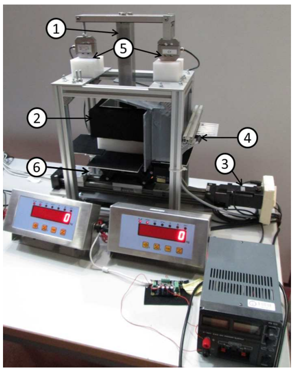

Figure 2. Test bench. 1) T bar, 2) LN2 vessel, 3) lab-jack stand, 4) linear slider 5) laser position sensor and 6) load cells.

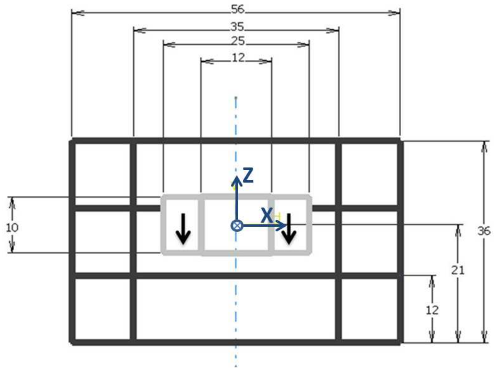

Figure 3. Journal bearing design: grey lined PM and black lined SC.

4. Results and discussion

The superconductors were field cooled using liquid nitrogen (LN2) at ambient pressure (≈ 77 K). The permanent magnets were also immersed in LN2 to assure little variation on the forces measured as a consequence of changes in the magnetization of the permanent magnets due to variations of their temperature (see force relaxation chart). After cool down the bearing, figure 3, the relative axial and radial position of the permanent magnet with the superconductor is modified.

4.1. Levitation and radial force: Hysteresis

Hysteresis in SMB is a very relevant parameter that must be taken into account when designing a SMB. It not only affects the levitation but also the radial force. Hysteresis for both motion direction in a simple journal bearing is plotted in figure 4 and 5. Additionally, note that the levitation force start to decrease when the axial displacement is about half the height of the PM, figure 4 and 5.

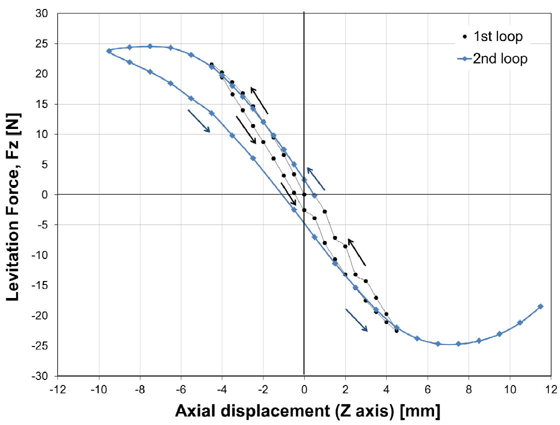

Figure 4. Lift force versus axial displacement.

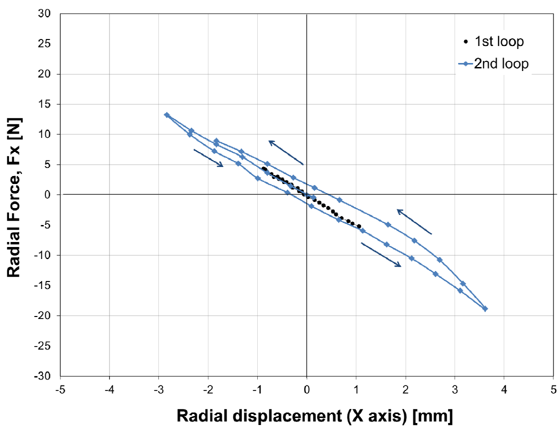

Figure 5. Radial force versus radial displacement.

4.2. Force relaxation

The force relaxation is the drop in the levitation or radial force with time after a relative motion between a permanent magnet and a field cooled superconductor happens. It must be carefully considered when designing a SMB. The relaxation of the levitation force for an axial displacement of

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- 4 mm from the FC position is shown in figure 6. For this design, the stable final lift force is 4% smaller than the initial one.

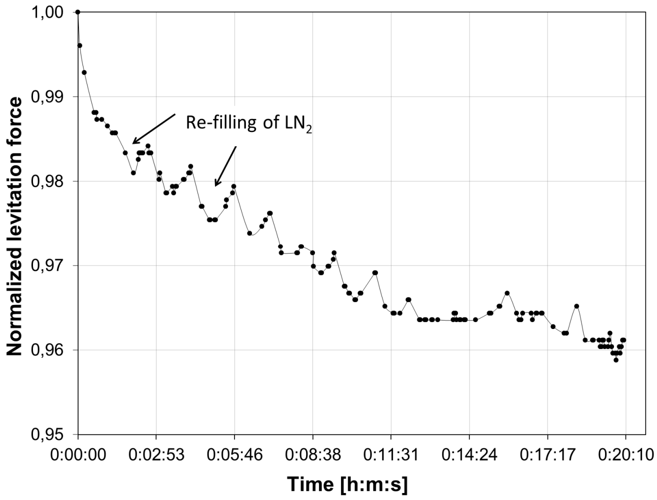

Figure 6. Levitation force in respect to time.

5. Conclusions

According to the experimental results obtained from the tests developed in MAGDRIVE FP7 project, a journal SMB will be designed to bear the weight and to compensate the radial instability of the MAGDRIVE core. Important parameters such us the hysteresis and the force relaxation have been analyzed. Finally, thanks to the relevant tribology advantages of SMB and due to the lack of contact they provide, the viability of a cryogenic-suitable magnetic harmonic drive with absolutely no contact between moving parts is expected to be demonstrated.

6. Acknowledgements

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