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Effect of the magnet insertion on the performance of a superconducting pump

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ABSTRACT

For medical and semiconductor fabrication lines, an ultra-clean and impurity-free environment is often required. In order to realize such a contaminant-free environment, it is desirable to employ a completely non-contact rotating mechanism. Such a non-contact rotation is possible by using a combination of permanent magnets and bulk superconductors. Furthermore, it is necessary to rotate a superconducting pump stably for practical applications. With the aim of increasing the stiffness of rotational parts, we placed a permanent magnet at the bottom such that the superconductors are sandwiched by top and bottom magnets. It was confirmed that the stiffness could surely be improved by arranging lower permanent magnets.

1. Introduction

Centrifugal liquid pumps are industrially used today to give energy to the liquid by the rotation of the impeller, which is converted to the pressure for efficiently pumping liquid like water [1].

Contaminant-free environment is often desired for the fabrication lines in medical and semiconductor fields [2]. In a conventional liquid pump, the motor and the impeller are connected with the shaft, for which the generation of wear particles from the bearings is unavoidable. Hence, there is always a risk of the contamination of impurities in the final product. Therefore, it is desirable to rotate the impeller in a completely non-contact mode. We can achieve stable levitation using a combination of permanent magnets and bulk RE–Ba–Cu–O (RE: rare earth elements) superconductors [3–6], which can be used for non-contact pumping [2]. Here the impeller containing PM circuit can be levitated stably and rotated without contact.

The advantage of such a superconducting pump is that it has no mechanical contact in order to drive the rotating unit. Thus, the liquid feed in a clean environment is possible without generating contaminant impurities [2].

For engineering applications, it is necessary to rotate the pump stably at a rotational speed of about 3000 rpm [1]. For the design of industrial machines, it is necessary to accumulate the basic data such as repulsive forces, stiffness, and torque. In general the rotation device has a so-called critical rotation speed, at which rotation becomes unstable due to the presence of a resonance frequency. When the stiffness is small, the impeller without contact will fly away at a critical rotation speed.

With increasing the magnetic field, the stiffness becomes large due to stronger pinning forces [7]. When the fields that interact with bulk superconductors are increased, the total pinning forces that stabilize the rotation will be increased. Hence, we placed a permanent magnet at the bottom in addition to a top magnet with the aim of increasing the stiffness. Thereby, we anticipated that more field lines interact with the superconductors, which enables us to achieve more stable rotation. We then studied the rotational characteristics of previous permanent magnet and the effects of arranging the lower permanent magnet.

2. Experimental

Fig. 1(a) shows a schematic illustration of a non-contact superconducting pump conventionally designed [8]. The top Fe–Nd–B permanent magnet circuit 200 mm in diameter and 15 mm in thickness is levitated with seven bulk Y–Ba–Cu–O superconductors 37 mm in diameter and 14 mm in thickness prepared by the top-seeded melt-growth process [9]. A pre-sintered Y–Ba–Cu–O pellet (a mixture of $YBa_2Cu_3O_y$ and Y_2BaCuO_5 in a ratio of 5:2) was heated

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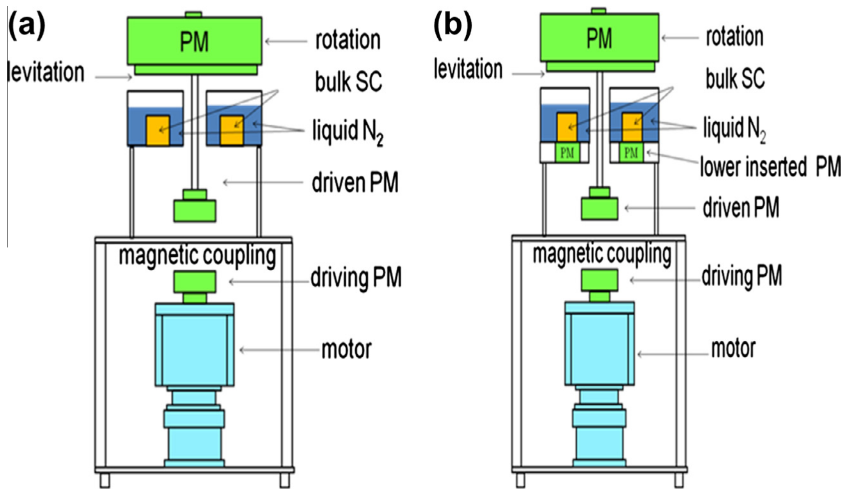

Fig. 1. Schematic illustration of non-contact superconducting rotational machines: (a) conventional type; and (b) that with inserting lower magnets.

to 1100 °C, held at this temperature for 1 h, cooled to 1010 °C, and then held at this temperature for seeding of $NdBa_2Cu_3O_y$ single crystal. The sample was then cooled at a rate of −0.4 °C/h to 970 °C. A highly textured structure with its *c*-axis oriented perpendicular to the disk surface could be fabricated with this process. To impart superconductivity, melt-grown Y–Ba–Cu–O disks were subject to annealing at 400 °C for 100 h in flowing oxygen.

Seven bulk superconductors are placed in a cryostat concentrically cooled by liquid nitrogen to face a levitated top magnet. This rotation magnet part is connected to a driven permanent magnet through a rod, which is magnetically coupled with a driving permanent magnet attached to a driving motor below. Both driving and driven magnets are Fe–Nd–B 60 mm in diameter and 15 mm in thickness consisting of N–S two poles in halves. When the driving permanent magnet was rotated with the motor, the driven permanent magnet also rotates since these two permanent magnet systems are magnetically coupled. The top permanent magnet then rotates without contact.

The gap between the driving and driven magnets will affect the rotation characteristics. In the present experiment, we altered the gap in the range of 40–100 mm. We evaluated the rotational characteristics by changing the gap with 10 mm interval. The transient behavior of the displacements along a horizontal direction together with a rotational velocity was monitored by using a laser displacement sensor.

We measured the stiffness and repulsive forces of such a system (see Fig. 1(a)) and that after inserting lower Fe–Nd–B permanent magnets (see Fig. 1(b)) for comparison. Here, the dimensions of inserted lower permanent magnets were 150 mm in diameter and 20 mm in thickness.

For stiffness force measurements, seven bulk Y–Ba–Cu–O superconductors were placed in a cryostat and cooled by pouring liquid nitrogen. After the cooling time of 20 min, a permanent magnet was levitated over the superconductors. The force was measured with a force gauge by moving the levitated magnet along the horizontal direction from the center toward the outer edge [10].

Repulsive force measurements were performed using a tensile testing machine (Autograph, Shimazu Co.) [11]. The superconductors were cooled by liquid nitrogen, and a permanent magnet was levitated in the same way as the stiffness force measurements. Repulsive force measurements were carried out by descending the levitated magnet toward the superconductors. The forces were measured with the strain gauges installed in the autograph.

In torque force measurements, the initial gap was 100 mm between a driving and a driven permanent magnet. We evaluated torque forces by changing the gap with 10 mm interval. The top permanent magnet was levitated on the superconductors cooled by liquid nitrogen and attached to a torque gage [12]. Then the magnet circuit was rotated at a certain gap. We measured the maximum torque force at which the magnet circuit was decoupled.

3. Results and discussion

3.1. Stiffness forces

Fig. 2 shows restoring forces or the stiffness of the non-contact rotation systems as a function of a displacement of the levitated disk magnet in a horizontal direction from the magnet center. The force was measured with a force gauge by moving the levitated magnet along the horizontal direction from the center toward the outer edge. One can see that the restoring force is increased with increasing the displacement travelled. It is also notable the recovering forces or the stiffness of the system with inserted lower magnets is larger than that without insertion magnets, probably due to the fact that the magnetic fields that interact with the superconductors were increased by arranging the lower magnets.

To confirm this fact, we measured the magnitude and distribution of the magnetic field in the region between a top permanent

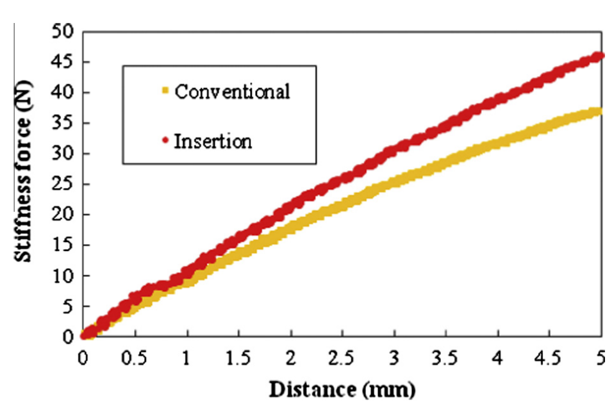

Fig. 2. Stiffness as a function of a displacement in the lateral direction between bulk Y–Ba–Cu–O superconductors and permanent magnets for the rotational systems with and without inserting lower magnets.