Rotation Test of an Integrated Magnetic Bearing Using Multiple HTS Cubic Bulks Units.

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Abstract
For magnetic bearings combining multiple cubic superconducting bulk units, placement is a crucial factor. In this paper, the magnetic bearing surface constructed by arrangement optimization was composed of eight superconducting cubic bulk units. The combined arrangement of cubic superconducting bulk units was determined by optimizing the spatial uniformity of the magnetic bearing, i.e., a trapped magnetic field distribution. We constructed a physical model in which a permanent magnet in the form of a floating rotor was magnetized from above and below by an integrated magnetic bearing surface. Using rotation test equipment and an encoder, we investigated the influence of an optimal arrangement index on rotation loss that occurs due to magnetic flux distribution nonuniformity. In addition, the rotation axis tilt angle due to nonuniform magnetic flux distribution was measured using a laser displacement meter.

1. Overview of Integrated Superconducting Bulk Magnetic Bearings

(a) Basic cubic bulk.
(b) Three-row, three-column square arrangement of cubic bulks.

The magnetic bearing used in this experiment is a floating rotor using a composite superconducting bulk bearing surface consisting of multiple cubic bulk units and a cylindrical permanent magnet. The magnetic bearing surface is composed of cubic bulks as shown in (a), and it is arranged as shown in (b). This bearing surface has a square arrangement consisting of nine blocks as shown in Figure 2. (a), and one of the centers is a spacer made of Glass Fiber Reinforced Polymer (GFRP) with a hole through which the rotor’s rotating shaft passes.

2. Optimal Placement of Bulks

(a) Arrangements.
(b) Calculation of the inclination of the rotating shaft of the floating rotor by the magnetic field of the cubic bulk.

Regarding the arrangement of the cubic bulk on the magnetic bearing surface, it is necessary to calculate the magnetic field for the optimal arrangement so that the magnetic flux distribution is uniform, considering that adjacent bulks affect one another’s magnetic flux. In this calculation, the magnetic field is calculated for each position of the arranged bulk, with the influence of magnetization by the permanent magnet and by the cubic bulk taken into account (Figure 2. (a), (b)). In these calculations, the optimal placement pattern was calculated when the values of 48x and 68 of the constraint condition were changed to approximately 1.5. Table I shows the optimal arrangement pattern based on the calculation results.

<table>
<thead>
<tr>
<th>Group</th>
<th>Position</th>
<th>Pz (degree)</th>
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<tbody>
<tr>
<td>Gc²</td>
<td>P1</td>
<td>0.128</td>
</tr>
<tr>
<td>Gc²</td>
<td>P2</td>
<td>0.169</td>
</tr>
<tr>
<td>Gc²</td>
<td>P3</td>
<td>0.150</td>
</tr>
<tr>
<td>Gc²</td>
<td>P4</td>
<td>0.119</td>
</tr>
<tr>
<td>Gc²</td>
<td>P5</td>
<td>0.105</td>
</tr>
<tr>
<td>Gc²</td>
<td>P6</td>
<td>0.136</td>
</tr>
<tr>
<td>Gc²</td>
<td>P7</td>
<td>0.122</td>
</tr>
<tr>
<td>Gc²</td>
<td>P8</td>
<td>0.121</td>
</tr>
<tr>
<td>Gc²</td>
<td>P9</td>
<td>0.103</td>
</tr>
</tbody>
</table>

Table I, Specification of HYS Cubic Bulks

3. Rotation Test

3.1. Overview of Test Equipment

Rotation test equipment incorporating HTS bulk integrated magnetic bearings.

3.2. Measurement Result of Rotation Test

First, the test equipment was driven, and the rotational speed range over which stable operation was possible was measured. A comparison was made between two combinations of “best” and “bad”.

(a) Photo of test equipment.
(b) Illustration of test equipment.

In the case of the “best” combination, the maximum speed at which stable operation was possible was 450 rpm. At higher speeds, vibration increased, and the system became unstable. The maximum stable speed for the “bad” combination was 398 rpm.

4. Discussion & Conclusions

We aimed to construct magnetic bearings using basic unit cubic bulks, with the goal of performing an optimization calculation of the configuration of bulks. The integrated bearing construction used in this optimization calculation was constructed in two contrasting patterns, “best” and “bad.” A comparative examination was conducted using a rotation test. Simultaneously, the gap distance between the bearing and the rotor was measured. In the test result, the positive effect of optimal arrangement on the duration of the free rotation state was confirmed. However, observed differences between the two contrasting bulk arrangements were not as large as expected. There are several possible reasons for this.

(a) The difference between “best” and “bad” configurations was not particularly large, possibly due to an unexpected lack of variation in the magnetic properties of individual cubic bulks.
(b) Also, because the number of cubic bulks was small, the upper and lower parts of the bearing could not be optimized simultaneously.
(c) The observed differences between the two contrasting bulk arrangements may also have been minimal simply because natural variation (i.e., noise) in the performance of the other parts were more dominant in the rotation test than that of the bearing parts under investigation.

Acknowledgment
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