Magnetic Properties of YBCO Superconducting Bulk

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Magnetic properties of a field cooled YBaCuO superconductor beneath the toroidal permanent magnet was examined by means of improved magneto-balancing method at 77 K. Magnetic flux measurements of a toroidal magnet revealed a concave shaped field distribution with a single minimum and a null field along the axis of the torus at the point where the field reversed. The observed values of both the suspension position and the force exerted upon the superconductor specimen were in good agreement with those calculated from the magnetization curve of the specimen and the intensity of the magnetic field of the used permanent magnet.

Keywords : YBaCuO, Magnetic effect, Toroidal

1. INTRODUCTION

It is well known that a superconductor can be levitated on a magnet by the Meissner effect. If the superconductor is provided with effective flux pinning center, it can be suspended under a magnet. The levitation is accounted for by the diamagnetic repulsive force with a gradient proportional due to the Meissner effect in the high temperature superconductor (HTS). Peters et al[1], showed that a $YBa_2Cu_3O_7$ having a strong pinning force floated below a cylindrical permanent magnet balancing with the gravity. Superconductor suspension over a permanent magnet and vice verse has attracted many engineering attention because it offers a non-contact lubrication free and virtually friction free bearing systems. The stable suspension of HTS under a permanent magnet (PM) is attributed to the flux pinning and the field cooling of the doped sample is preferred for the enhanced flux pinning[1-3]. In order to find out the origin of the Suspension force, we carefully examined the magnetic field distribution of the magnet and found that a pair of magnet cages trapping a superconductor were created below the toroidal magnet.

2. EXPERIMENTAL PROCEDURE

Sample was made by the conventional solid state method using Y_2O_3, $BaCO_3$, and CuO powders of 99.9 % purity. The powder mixture was calcined in an alumina crucible at 950 °C for 24 h in air. After grinding the calcined cake, the precursor powder was mixed with Ag_2O powder of 99.9 % purity. The powder mixtures were pressed into pellets under 300 kg/cm^2, followed by sintering at 950 °C for 24 h. The disk sample with a diameter of 8 mm and thickness of 1mm weighed 0.3 g. The magnetic suspension of a high Tc superconductor beneath a toroidal permanent magnet was examined by means of a magneto-balancing at 77 K. The toroidal magnet used in this study was a samarium cobalt rare earth, NEOMAX, produced by Sumitomo Special Metals Co. LTD, and had following specifications : 46 mm OD, 12 mm ID, 10 mm in thickness, and B=1500 G.

3. RESULTS AND DISCUSSION

The magnetic field along the axis of the torus was calculated using the Poisson/Superfish code for the toroidal magnet of 46 mm OD, 12 mm ID, and 10 mm thickness in the cylindrical coordinates (r, θ, z). Dirichlet and Neumann boundary conditions were used to calculate the magnetic field, respectively for the boundaries parallel and perpendicular to the symmetric axis. The calculation boundaries were set to be sufficiently large compared with the magnet size, and the magnetization of a toroidal magnet was assumed to be a constant along the axis direction. Magnetic field calculation was carried out with +1 and -1 stat-ampere of the surface current at r=6 mm and 23 mm surface, respectively, and the field strength at the magnet surface was set to be 1500 G. The calculated magnetic field along the axis at the radial center in Fig. 1 showed a single asymmetric concave shaped distribution on each

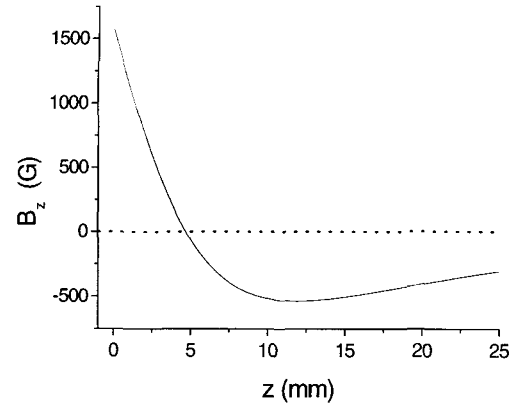

Fig. 1. The calculated magnetic field along the symmetric axis for the toroidal magnet.

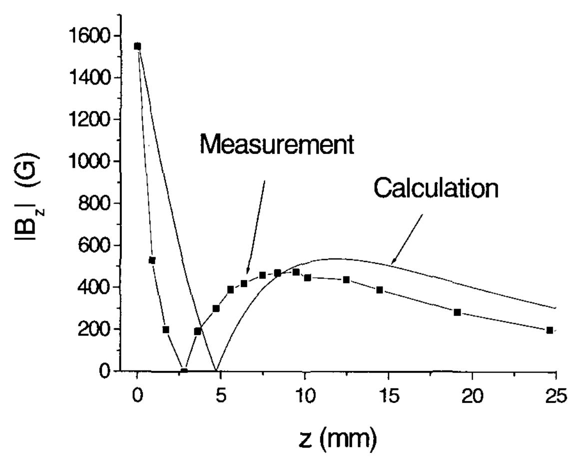

Fig. 2. Magnetic field strength along the symmetric axis by measurement and Poisson code calculation.

side of the magnet (Z > 0 and Z < 0) with a null field at 4.8 mm, where the field vector reversed.

The variation of the field strength along the symmetric axis at r=0 of calculated and the measured were compared in Fig. 2, where one can see that general pattern agrees reasonably, except the position of null field. This may be attributed to the assumption of a constant magnetization in the axial direction we made in the calculation.

If the magnetic moment, m, of the HTS is assumed to be proportional to –Bz, the interacting magnetic force exerted on the HTS in the magnetic field B is given as F = m (dB/dZ). Along the symmetric axis at r=0, $F \propto Bz$ (dB/dZ).

The interaction force between a 2 % Ag_2O doped HTS sample and a toroidal magnet of the calculated and the one measured by using an electronic balance were compared in Fig. 3 along the symmetrical axis as a function of axial distance.

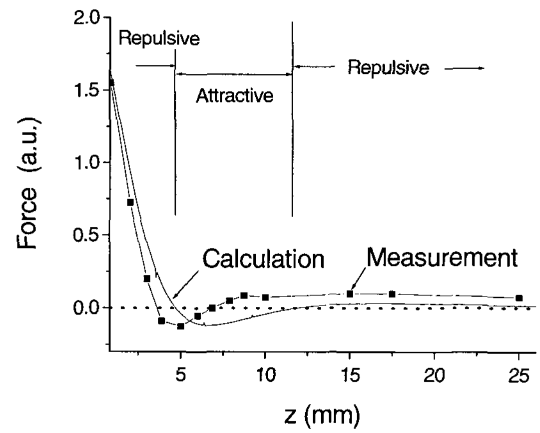

Fig. 3. Magnetic force exerted on the HTS sample in the magnetic field of a toroidal magnet.

The presence of a HTS sample perpendicular to the non-linear magnetic field of a toroidal magnet distorts the original field lines distribution, as a result, the interaction force between the magnet and the sample exhibits a concave shape on each side of the magnet (Z > 0 and Z < 0), i. e. the regions of repulsive (Z < 4.8 mm), attractive (4.8 mm < Z < 11.8 mm), null force (Z=4.8 mm and 11.8 mm) and repulsive force (Z > 11.8 mm).

The results in Fig. 3 indicates that the force exerted on the HTS sample changes the direction with respect to the null force points along the Z-axis. The repulsive force in the repulsive force region along +Z direction balances the weight acting in the -Z direction, resulting in the stable levitation above a toroidal magnet. Similarly, by the symmetry with respect to the Z=0 plane, the suspension of the HTS sample occurs in the attractive region by balancing the weight. The asymmetric concave shaped interacting magnetic force forms a vertical conical shaped magnetic wall around a levitated/ suspended HTS sample, as demonstrated with a bowl shaped Type 1 superconductor lead providing a gravitational minimum leading lateral stability. Thus, the lateral stability of the levitated/suspended HTS sample above/beneath a toroidal magnet is achieved by the characteristic asymmetric nature of the magnetic force respect to the axis of magnet.

4. CONCLUSION

The sample levitated at 3 mm above and suspended at 2 mm beneath the toroidal magnet, indicating the greater attractive force exerted on the sample. However, the difference between the measured and calculated distance of levitation/suspension may be caused by the assumptions of constant magnetization of the permanent magnet along the symmetric axis.

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