The interaction between the permanent magnet and ceramic superconductor with organic filler

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Abstract. The aim of the study was to examine the phenomenon of magnetic levitation for YBaCuO superconducting samples in pure form and with epoxy resin content of 40%. Samples of superconductors were prepared by the standard reaction in the solid state. The forces of interaction between the superconductor and neodymium permanent magnet were measured. Samples with epoxy resin fillers had significantly smaller levitation force than the sample of the sintered superconductors. This is due to a much lower content of pure superconducting material in the sample volume (about 60% of the YBaCuO). However, the obvious advantage of such samples is the possibility of preparation superconductors with complicated shapes, eg. for use in a superconducting bearings or other devices.

1. Introduction
Magnetic levitation phenomenon is directly related to the Meissner effect, that is, repulsion the induction of the external magnetic field from the inside of superconducting material [1-2]. If the source of the magnetic field is a permanent magnet, it occurs repulsion effect between magnet and superconductor. From the application point of view, it is important to determine the magnetic levitation force that can be really achieved in practice.

The phenomenon of magnetic levitation, due to its properties can be used for

- high-speed bearings - with virtually no losses due to friction [3],
- shock absorbers for precision equipment - levitating magnet dampens vibrations [4],
- levitating railway construction [5-6].

Levitation force depends crucially on the quality and type of superconducting samples, their composition, mass and properties of permanent magnets. For practical applications of this phenomenon it becomes increasingly important to obtain the superconducting materials of any shape. This can be achieved by adding to the powdered superconductor adhesive material. Therefore, the aim of this study was to determine the levitation force values for samples of superconductors in pure form and with the addition of epoxy resin.

2. Sample preparation
The well-known YBa$_2$Cu$_3$O$_x$ high-temperature ceramic superconductor has been used in work. Its synthesis was performed by standard solid state reaction at 950°C in an air atmosphere from Y$_2$O$_3$, BaCO$_3$ and CuO reagents.
Material obtained after grinding has been compressed and subjected to further annealing according to the following scheme:

- temperature rise time: from 220 to 945°C, 4 h,
- the heating time at 945°C: 3 h,
- natural cooling to a temperature of 750°C,
- time annealing at 750°C: 1 hour,
- natural cooling process to room temperature.

The prepared material was thoroughly grinded and divided into two parts. The first portion was pressed, sintered at about 950°C and cooled in accordance with the previous procedure. The remaining powder was mixed with the epoxy resin (the content of YBaCuO - about 60% by volume).

3. The test results

Figure 1 shows a photograph of the magnets stably levitating over the YBaCuO sample in a superconducting state (77 K).

![Figure 1. Permanent magnets levitating above the superconductor sample.](image)

For measurements they were used type N42 neodymium magnets due to their very good parameters:

- remanence $B_r = 13$ kG,
- energy density $BH = 330$ kJ/m$^3$,
- good ratio of the weight of both the induction value $B_r$ as well as energy density $BH$.

The levitation forces were measured by self-made setup. The measurement principle was based on the measurement of the mass of weights balancing repulsive force between the permanent magnet attached to one arm of the balance-pan and a superconducting material located below the magnet in the open cryostat. Repulsive force was measured for different values of the distance between the magnet and superconductor regulated by a micrometer.

Levitation force values depending on the distance between the superconductor and the permanent magnet for the sample superconductor without the epoxy resin is shown in figure 2 and for the sample with the addition of epoxy resin - in figure 3. Figure 4 shows a comparison of the levitation for both types of samples and for different sizes of magnets.
As would be expected, the force of interaction between a superconductor and a magnet decreases rapidly with increasing distance between them. This force is greater for the larger size of the interacting materials (figure 4). A similar effect can be observed by comparing the levitation force for pure samples of superconductors and with the addition of epoxy resin (figure 2, 3 and 4). In this latter case, the repulsive forces are much smaller. This is due to lower effective volume of the superconducting material in the samples with addition of the resin.

Figure 2. Dependence of levitation force on the distance for sample without epoxy resin.

Figure 3. Dependence of levitation force on the distance from sample with epoxy resin.
4. Conclusions
On the basis of the measurements it can be stated that:
- The results obtained in the work allowed to determine the levitation force depending on the type and weight of the samples and used magnets.
- The largest levitation forces were measured for the pure samples (without addition of epoxy resin) having the largest diameter and for magnets of the maximum dimensions.
- Samples with the addition of epoxy resin showed a reduced levitation force compared to the pure samples of the same size by the use the same magnets.

5. References
[1] Kordyuk A A 1998 J. Appl. Phys. 83 601
[2] Okano M, Iwamoto T, Furuse M, Fuchino S and Ishii I 2006 J. Phys. Conf. Ser. 87 999
[3] Hull J R, Mulcahy T M, Uherka K L and Abboud R G 1995 IEEE Trans. Appl. Supercond. 5 626
[4] Teshima H, Tanaka M, Miyamoto K, Nohguchi K, and Hinata K 1997 Physica C Supercond. 274 17
[5] Fujimoto H 1998 J. Appl. Phys. 50 16
[6] Fujimoto H, Kamijo H, Higuchi T, Nakamura Y, Nagashima K, Murakami M and Sang-Im Yoo 1999 JOM 9 301

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