Spatial distribution of the magnetic induction near a permanent magnet in connection with the attraction of a high-temperature superconductor toward the poles of a magnet

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The capture of a high-temperature superconductor by a magnetic field which has been observed is caused entirely by the particular magnetic-field configuration and an ordinary Meissner effect.

An ability of certain samples of high-temperature superconductors in the yttrium[1] and thallium[2] systems to be attracted to magnets was reported in the first half of 1988. Hermann and Sheng[2] published photographs of high-temperature superconductor samples which were being held in the magnetic field at a certain distance from the plane of the pole of a ring magnet, whether the magnet was in a horizontal or vertical position, at liquid-nitrogen temperature. We have observed a similar attraction of high-temperature superconducting samples, in their superconducting state, to the pole of a magnet having the shape of a tetrahedral prism. In this case the sample is attracted to the magnet pole without any gap. Hermann and Sheng[2] assert that the effect they observe cannot be explained on the sole basis of the Meissner effect. They offer explanations based on a "programmable" capture of magnetic flux in the superconductor. An alternative suggestion is the coexistence of superconducting and ferromagnetic phases in the volume of the sample or the coexistence of ferromagnetism and diamagnetism in a single-phase, high-temperature superconductor.

Our own analysis shows that all observed cases of an "anti-Meissner" behavior of superconductors can be explained in terms of the particular way in which the magnetic induction is distributed near the poles of a permanent magnet.

In practical applications, permanent magnets are ordinarily used with magnetic circuits of a magnetically soft material which produces the required magnetic field configuration in the gap. In a permanent magnet without a magnetic circuit, the demagnetizing factor is much more apparent, and the distribution of the magnetic induction in the magnet is nonuniform.

Figure 1 shows the distribution of the normal component of the magnetic induction, measured with a Hall magnetometer, at various distances from the plane of the pole of a prismatic magnet with dimensions of 120×80×15 mm, magnetized along its short axis. The magnetic induction right at the surface of the pole, which has the same value as the induction in the interior of the magnet, has a maximally nonuniform distribution with a minimum at the center of symmetry. With increasing distance from the surface of the pole, the distribution of the magnetic induction changes. Curve 1 in Fig. 1 shows the change in the induction along the normal to the surface of the pole. It follows that near the pole there is a region in which the induction decreases toward the surface of the magnet. The size of this region is comparable to the dimensions of the superconducting samples. When a sample which exhibits an ordinary Meissner effects enters this region, it will be attracted toward the magnet pole, rather than repelled from it.

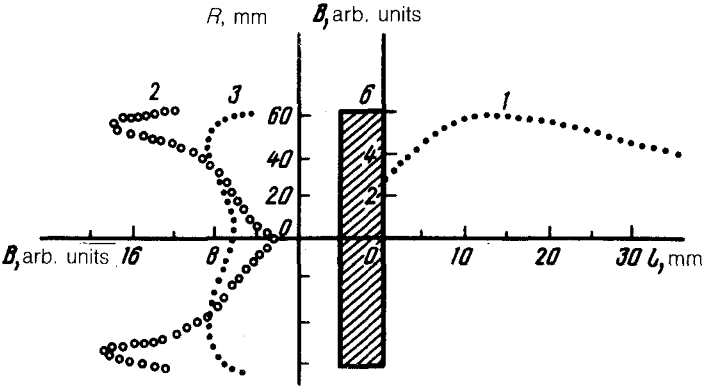

FIG. 1. Distribution of the normal component of the magnetic induction near the poles of a prismatic magnet. 1—At the center, along the normal to the surface; 2—at the surface, along the long axis passing through the center of symmetry; 3—the same, 10 mm from the surface of the magnet.

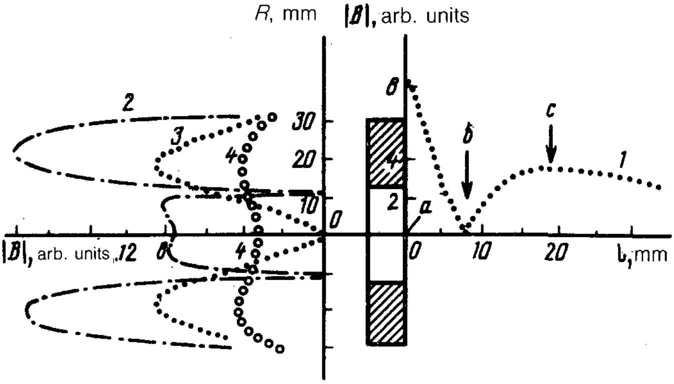

FIG. 2. Distribution of the normal component of the magnetic induction of a ring magnet. 1—At the symmetry axis above the surface of the poles; 2, 3, 4—in the radial direction, at points *a*, *b*, and *c*, respectively, on the symmetry axis.

In the case of a ring magnet the presence of a region with a minimum of the magnetic induction near the plane of the poles is a consequence of the magnet's configuration itself. Figure 2 shows the distribution of the magnetic induction along the axis of a ring magnet and in the radial direction at various distances from the surface of the poles. At the axis of the magnet, at a point *b* lying a certain distance from the plane of the pole, the magnetic induction is zero; it increases in absolute value in both directions away from this point. The specific distance from the plane of the magnet to point *b* is determined by the geometric characteristics of the magnet. In this particular case, in which the diameter of the magnet is 60 mm, its thickness is 18 mm, and the diameter of the hole is 24 mm, we find the region with a zero induction to be 7 mm from the surface of the pole.

In all cases, the capture of magnetic field by a high-temperature superconductor thus occurs during the formation of regions with a minimum of the magnetic induction near the poles of permanent magnets. These regions are bounded by spatial regions with a higher induction or, in the case of a plane magnet, by the surface of the pole and a region with a higher magnetic induction.

The capture of magnetic field by a superconductor is a general effect, not a consequence of any specific properties of high-temperature superconductors. It is caused solely by the presence of an ordinary Meissner effect in a magnetic field of the corresponding configuration, and it can be observed for type I superconductors at liquid-helium temperatures.

[1] M. K. We, J. R. Ashburn, C. A. Higgins, *et al.*, Abstract, International Conference on the First Two Years of High Temperature Superconductivity, April 11–13, 1988.
[2] A. M. Hermann and Z. Z. Sheng, in: Abstracts of JCMC, Shenyang, China, DD2, June 7–10, 1988.

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