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J_c VS B CURVES AND THE JOSEPHSON JUNCTION ASSEMBLY MODEL FOR Y–Ba–Cu–O SUPERCONDUCTORS

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Considering the superconducting ceramic as a set of superconductive grains interconnected by Josephson junctions, the authors present a new way of averaging the "critical fields" in order to fit the experimental $J_c(B)$ vs B curve. The average is evaluated from a physical point of view and a typical fit is presented.

1. INTRODUCTION

THERE have been some attempts [1–4] to explain the sudden decrease of the critical current density of Y–Ba–Cu–O superconductors at low magnetic fields (0–1 mT) first reported by Ekin *et al.* [5] and Capone and Flandermeyer [6].

In this paper, a line of reasoning parallel to that used in Peterson and Ekin work [4] will be proposed which provides a better physical interpretation of some features of the mathematical fit. One experimental $J_c(B)$ vs B curve for Y–Ba–Cu–O ceramic will be fitted through the present formula.

2. THEORY

Peterson and Ekin [4] regarded the Y–Ba–Cu–O ceramic as a collection of superconducting grains interconnected by weak links behaving like Josephson junctions, which show a statistical distribution over junction lengths and over orientations of the junction planes relative to the external magnetic field.

Even though the average over those variables provides good fits to experimental curves, it depends on certain parameters whose physical interpretation are not clarified in an explicit form.

Let us consider not an average over junction lengths and orientations but over the intrinsic properties which characterize each link: the critical current density at zero field $j_c(0)$, and the field associated to the flux quantum, B_0. Then, the critical current density of the material depends on the external field B in the following way:

$$J_c(B) = \sum_i \sum_j n_{ij} j_{ci}(0) \sin(\pi B/B_{0j})/(\pi B/B_{0j}), \qquad (1)$$

where n_{ij} is the statistical weight or frequency of occurrence of the junction type $(j_{ci}(0), B_{0j})$.

If $p(j_c(0), B_0)$ is the probability density equivalent to n_{ij} for continuous variables, and if we suppose it is separable in the form $p(j_c(0), B_0) = \eta(j_c(0))\,\Omega(B_0)$, both factors normalised to unit, we obtain the following expression for $J_c(B)$ in continuous variables:

$$J_c(B) = J_c(0) \int_0^\infty \Omega(B_0) \sin(\pi B/B_0)/(\pi B/B_0)\, dB_0, \qquad (2)$$

where

$$J_c(0) = \int_0^\infty \eta(j_c(0))\, j_c(0)\, dj_c(0).$$

$\eta(j_c(0))$ is the distribution function of junction critical currents (which will not be worked upon here).

$\Omega(B_0)$ is the distribution function of junction fields B_0, where

$$B_0 = \Phi_0/((2\lambda + t)L). \qquad (3)$$

In equation (3), Φ_0 is the flux quantum, L the junction length, t the junction thickness and λ the London penetration depth [4]. It is worth noting that B_0 not only depends on the geometrical characteristics L and t of the junction, but on the London penetration depth too. Then, in averaging B_0, we are taking into account more than pure geometrical influences on $J_c(B)$.

3. RESULTS AND DISCUSSION

Figure 1(a) shows the computing of the $J_c(B)/J_c(0)$ curve following formula (2) along with the experimental points obtained for an Y–Ba–Cu–O ceramic processed in our laboratory by a procedure described elsewhere [7]. Figure 1(b) shows the fit made for the same sample, following the Peterson and Ekin procedure, in which a skewed triangular distribu-

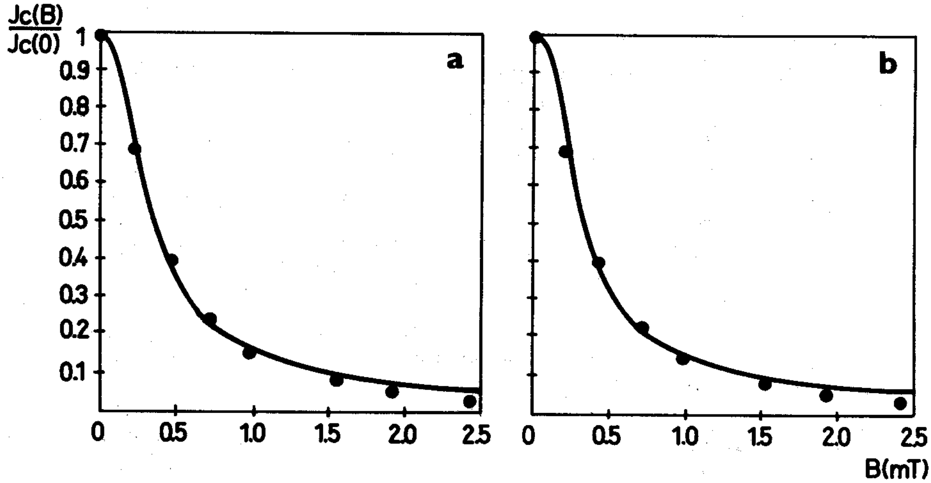

Fig. 1. Normalised transport critical current vs applied field values for a typical Y–Ba–Cu–O ceramic. The continuous curve in (a) is the fit made following formula (2) presented in this paper. The analogous one in (b) is the fit following formula presented in [4].

tion of the junction lengths has been used with L(smallest) = 1 μm, L(peak) = 7 μm and L(largest) = 22 μm in good agreement with our sample microstructure.

It can be seen that there are not significant differences between the qualities of the two fits.

Our fit was done by selecting an appropriate distribution $\Omega(B_0)$ and not by using B_0 as a moving parameter after averaging over orientations and junction lengths, as Peterson and Ekin [4]. The selected $\Omega(B_0)$ was a skewed triangular distribution with B_0(minimum) = 0.1 mT, B_0(peak) = 0.3 mT and B_0(maximum) = 1.7 mT.

We have obtained several fits to different experimental $J_c(B)$ vs B curves using formula (2) with a similar success to that obtained in the fit shown.

Two regularities of most of our fits have been observed. First, the values for B_0(peak) are in the range 0–0.3 mT, which coincides quite well with the one corresponding to the first field penetration into the granular material reported by others [8–11]. Second, the values of B_0(peak) are in the neighbourhood of the point in which the $J_c(B)$ vs B curves have their maximum rate of decrease.

Hence, it is reasonable to believe that the value of B_0(peak) selected to fit the experimental $J_c(B)$ vs B curve gives an estimate of the most probable value of the "upper critical field" [12] characterising the Josephson junctions, which seem to determine the first field penetration into the granular material.

4. CONCLUSIONS

Starting from a Josephson junction assembly model of the Y–Ba–Cu–O ceramic, we have presented an averaing formula for fitting the $J_c(B)$ vs B curves. Although our average is mathematically simpler, the fit is as good as any other reported, with the possible additional advantage that it could yield an estimate of the "critical field" of the sample intergrain material.

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