The effect of sample thickness on the critical current density of the superconducting strip

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ABSTRACT:
The critical current density (J_c) of a superconductor with a high transition temperature is a fundamental quantity that determines the scope of the application of new superconductors in practice. Reports show that the critical transport current density of thin films of yttrium-based superconductors grown by different methods can range from the value$10^6 A/cm^2$ in temperature$77k°$ to a value of the $10^7 A/cm^2$order of4 k°. These values of current density provide the use of superconductors on a small scale in the electronic industry In this work, the dependence of the critical transfer current density of type II flat superconductor with a rectangular cross-section that is mixed in three magnetic fields that are applied perpendicular to the surface of the superconducting strip is investigated. The results of these calculations clearly show that (a)- as the thickness of the superconducting sample increases, the critical current density decreases (b)- the comparison of the results of the calculations of the application of three different fields indicates that with the increase of the field, it decreases.

KEYWORD: Superconductor, Current Density, Magnetic Field, Kim Model.

1. INTRODUCTION

The critical current density (J_c) of a superconductor with a high transition temperature is a fundamental quantity that determines the scope of the application of new superconductors in practice. Reports show that the critical transport current density of thin films of yttrium-based superconductors grown by different methods can range from the value $10^6 A/cm^2$ in temperature $77k°$ to a value of the $10^7 A/cm^2$order of4 k°. These values of current density provide the use of superconductors on a small scale in the electronic industry. Of course, in small-scale applications of superconducting samples, the dependence on the local magnetic field should also be taken into account. On the other hand, among all forms of superconductors, the superconducting film has the most important and suitable structure for electronic designs and power transmission devices [1]. To reach the technical requirements to enable the aforementioned applications, it is necessary to increase the critical current (J_c) as much as possible [3,2].

An obvious approach to increase the critical current is to choose a superconductor with a greater thickness, but it has been seen that for some examples of superconductors,increasing the film $Y_1Ba_2Cu_3O_{7-x}$ thickness causes a severe reduction [8]. Some consider this effect caused by changing the thickness of the superconductor on the critical current density by geometrical effects and changes in the microstructures.

In this kind of superconducting film, the vortices of the nailing flux show strong, which indicates the high critical current density of these samples.[9]. Therefore, technological and fundamental needs are felt to understand the changes in the nailing phenomenon of the films made of superconductors based on yttrium due to the change of parameters such as thickness that are involved in the growth of the sample. The desired sample is a strip with a long length of type 2 superconductor with a rectangular cross-section of thickness 2b and width 2a (Figure 1). We choose the origin of the coordinates in the cross-section of the strip, which coincides with the z-axis, and for the ease of calculating the magnetic $\vec{B}$ ،induction, we choose the thickness greater than the depth of penetration in weak fields.

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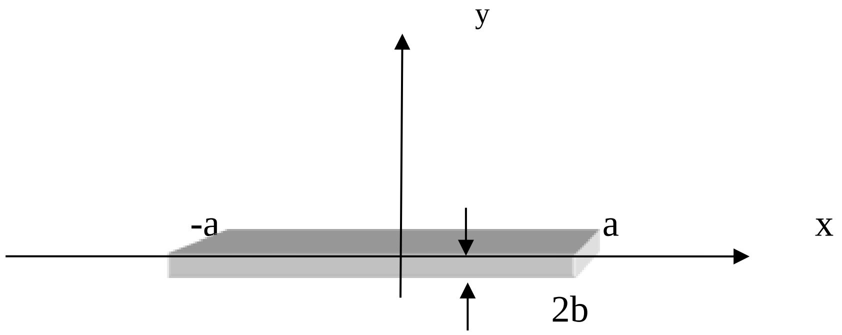

Fig. 1. The proposed sample.

In these conditions, when an external magnetic field perpendicular to the z-axis is applied to the sample, magnetic induction B has only x and y components that depend only on x and y. At the same time, we focus our studies on those coated superconductors (the second generation of high-temperature superconductors) in which b<<a.

In these conditions, if the current density attributed to the magnetic induction is represented by, $\vec{B} = \overline{\nabla} \times \overline{A}$ and $\vec{J}(x,y) = (1/\mu_\circ)\vec{\nabla} \times \vec{B}(x,y)$ the magnetic vector potential that is caused by $\vec{A}(x,y) = \hat{z} A_z(x,y)$ is obtained from the following relationship $\vec{J}(x,y)$ [2].

$$A_z(x,y,a,b) = -\frac{\mu_\circ}{4\pi}\int_{-a}^{a}\int_{-b}^{b} J_z(u,v)\ln\left[(x-u)^2 + (y-v)^2\right]dudv \quad (1)$$

This vector equation gives $\vec{A}$ the self-field from there $\vec{B}$.

In the case of interest, b<<a is chosen to simplify the calculations related to $\vec{A}$ and $\vec{B}$, when the thickness of b is chosen very small, there will be singularities at the edges of the strip. In this case, $\vec{J}_z(x,y) = \vec{K}_z(x)\delta(y)$ where the $\vec{K}_z(x)$ current density is the surface. Therefore, the z component of the magnetic vector potential becomes as follows:

$$A_z(x,y,a) = -\left(\frac{\mu_\circ}{4\pi}\right)\int_{-a}^{a} K_z(u)\ln\left[(x-u)^2 + y^2\right]du \quad (2)$$

If it is assumed $\vec{K}_z$ to be uniform along the width of the superconducting strip, the above integral can be solved analytically and from there the components $B_x(x,y,a)$ $B_y(x,y,a)$ and magnetism $\vec{B}$ can be obtained analytically [2]. We are interested in calculating the critical current or critical current density as a function of the thickness b of the superconducting sample located in the external magnetic field. Calculations show that if we put the current density J_z equal to the critical current density of the well $J_p(B)$ in equation (1) and for this, we use the Kim model in which ($\vec{J}_{pK}(B) = \vec{J}_{pK}(\circ)/(1+|B|/B_\circ$), we should self-consistently obtain the magnetic induction distribution which is equal to These calculations $\vec{B} = \vec{B}_a + \vec{\nabla} \times \vec{A}$ show that the cross-sectional area of the sample $J_p(B)$ is not constant and as a result, the critical current density $J_c(B_a) = J_c/(4ab)$ is not equal to $J_p(B)$. By choosing a very thin sample b<<a , the idea of a one-dimensional network can be used in solving equation (2). [5,4,2].

To perform these calculations, we divide the cross-sectional area of the sample into N flow elements with dimensions $\Delta x = \frac{2a}{N}$ and $\Delta y = 2b$ whose center is (x_n, o) , in which $n = 1,2,...,N$. It is clear that the bigger N is, the more accurate the calculations are. It has been selected in recent N=101 calculations. For easy of calculations, we use approximation $\vec{B} = \mu_\circ \vec{H}$ to have $\vec{J} \approx \vec{j} = \frac{1}{\mu_\circ}(\vec{\nabla} \times \vec{B})$ .According to the table (1), these calculations have been repeated for three samples of superconductors with relative thicknesses b/a equal to

$\frac{0/2}{240}$ to $\frac{1}{240}$ to $\frac{3}{240}$، and applied external magnetic fields $\frac{B_a}{B_\circ}$ of magnitude 0, 0.6, and 1. Figure (2) shows how the critical current density depends on the thickness of the sample in Kim's model.It can be seen that by increasing the thickness of the sample located in a certain external magnetic field, the current density decreases. The decrease in current density with the thickness of the sample has been calculated in another way, and for samples with $b/\lambda < ١٠$، where is the depth of penetration λ , this decrease is reported as the inverse of the second root of the thickness [6]. Other reports show that the critical current density decreases exponentially with increasing thickness [7]. The results of numerical calculations are shown in Fig. 2.

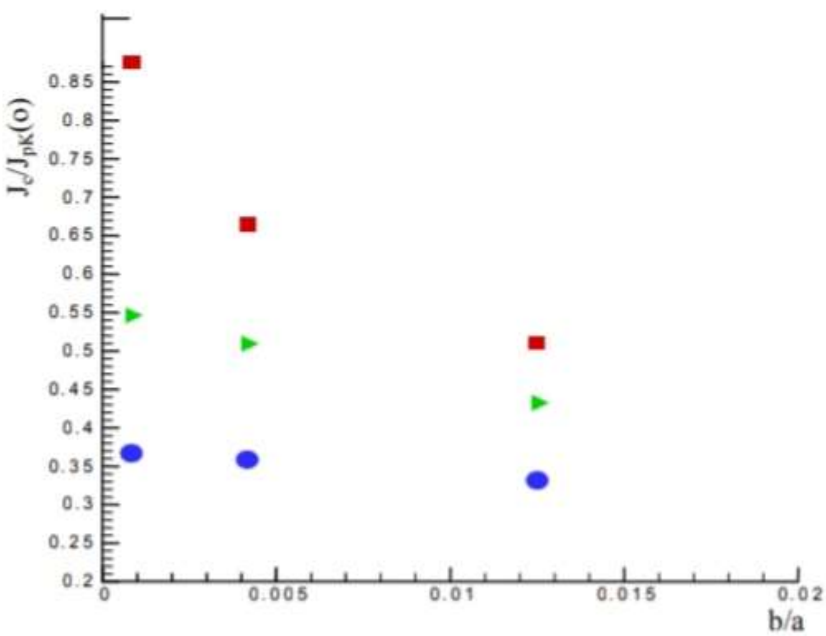

Fig.2. Dependence of the normalized current density on the normalized thickness of three samples of superconductors with a rectangular cross-section in different magnetic fields square: $\frac{B_a}{B_0} = 0.0$ triangle: $\frac{B_a}{B_0} = 0.6$ elliptic: $\frac{B_a}{B_0} = 1.0$.

Table 1. $\alpha = \frac{b\mu_\circ J_{pK}(\circ)}{\pi B_\circ}$, $\frac{B_a}{B_0} = 0.0$

b/a	$0.2/240$	$1.0/240$	$3.0/240$
$J_c/J_{pK}(0)$	0.875911	0.66583	0.511650
α	0.0983	0.3430	0.6770

Table 2. $\frac{B_a}{B_0} = 0.6$, $\alpha = \frac{b\mu_\circ J_{pK}(\circ)}{\pi B_\circ}$

b/a	$0.2/240$	$1.0/240$	$3.0/240$
$J_c/J_{pK}(0)$	0.546270	0.509475	0.432623
α	0.0983	0.3430	0.6770

Table 3. $\alpha = \frac{b\mu_\circ J_{pK}(\circ)}{\pi B_\circ}$, $\frac{B_a}{B_0} = 1.0$

b/a	$0.2/240$	$1.0/240$	$3.0/240$
$J_c/J_{pK}(0)$	0.367112	0.358802	0.331777
α	0.0983	0.3430	0.6770

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