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Levitation characteristics of HTS tape stacks

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Abstract

Due to the considerable development of the technology of second generation high-temperature superconductors and a significant improvement in their mechanical and transport properties in the last few years it is possible to use HTS tapes in the magnetic levitation systems. The advantages of tapes on a metal substrate as compared with bulk YBCO material primarily in the strength, and the possibility of optimizing the convenience of manufacturing elements of levitation systems. In the present report presents the results of the magnetic levitation force measurements between the stack of HTS tapes containing n = 2 ÷ 200 of tapes 12mm x 12 mm and NdFeB permanent magnet in the FC and ZFC regimes. It was found a non- linear dependence of the levitation force from the height of the array of stack in both modes: linear growth at small thickness gives way to flattening and constant at large number of tapes in the stack. Established that the levitation force of stacks comparable to that of bulk samples. The numerical calculations using finite element method showed that without the screening of the applied field the levitation force of the bulk superconductor and the layered superconductor stack with a critical current of tapes increased by the filling factor is exactly the same, and taking into account the screening force slightly different.

Keywords: HTS, YBCO, coated conductors, tape stacks, magnetization, critical current density, levitation performance

1. INTRODUCTION

In the field of using superconductors for contactless suspensions and bearings one of the most important problem is the optimization of device parameter, in particular to obtain the highest levitation force with compact design and improve its reliability. The traditional material to design and manufacture of levitation machines are the bulk samples of HTS ceramics ReBCO. However, ceramic materials have some disadvantages. In particular, bulk samples are susceptible to damage due to action of the ponderomotive forces and thermocycling. Also ceramic samples do not have a high strength and can crack under loading. The advantages of the tapes on a metal substrate as compared with bulk material ReBCO mainly are in a much higher strength characteristics, possibilities of optimizing and simplicity of manufacturing elements of suspensions for example as stacks of HTS tapes. Also tape stacks are capable to trap a high magnetic field [1].

2. EXPERIMENTAL DETAILS AND NUMERICAL CALCULATION

The measurements were performed for stacks of the commercial HTS tapes produced by SuperOx, each piece have a size 12mm x 12 mm. Tapes contain $GdBa_2Cu_3O_{7-x}$ layer thickness of 1 μm, buffer layers, and silver. The fill factor of superconductor is 1/70. At the first step contactless measurements of the critical current density of the tape were performed and most homogeneous sections with critical current equal to 250A were selected. Nonuniformity of the critical current distribution is less than 2%.

Than we have carried out measurement of the levitation force on the gap between the magnet and the stack of superconducting tapes in zero field cooling (ZFC) and field cooling (FC) modes. To make inhomogeneous magnetic field we have used NdFeB permanent magnet (PM) of 25 mm diameter and 20 mm thick. The residual magnetic induction on the surface of magnet was equal to 0.65 T. The minimum gap between PM and stack was 4 mm. Tape stacks were cooled to a superconducting state by liquid nitrogen.

To perform the calculations the finite element method (FEM) was used (for details, see. [2]). The experimental and calculated configurations are shown in the Fig. 1.

Interaction force superconductor with the permanent magnet is calculated as the multiplication of currents in the superconductor **j** and magnetic induction **B**, the integration is performed throughout the volume of the superconductor **V**:

$$\mathbf{F} = \int_V \mathbf{j} \times \mathbf{B}\, dv$$

Calculations were carried out within the Bean's model [3] by assuming that the value of the critical current density of the superconductor is constant and equal to $\mathbf{j_c}$. The distribution of currents in the superconductor is calculated taking into account the magnetic history by front-tracking algorithm [2].

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3. RESULTS AND DISCUSSION

In this work we have investigated the dependence of the levitation force on the distance between the permanent magnet and a stacks of HTS tapes of different thickness in ZFC and FC modes.

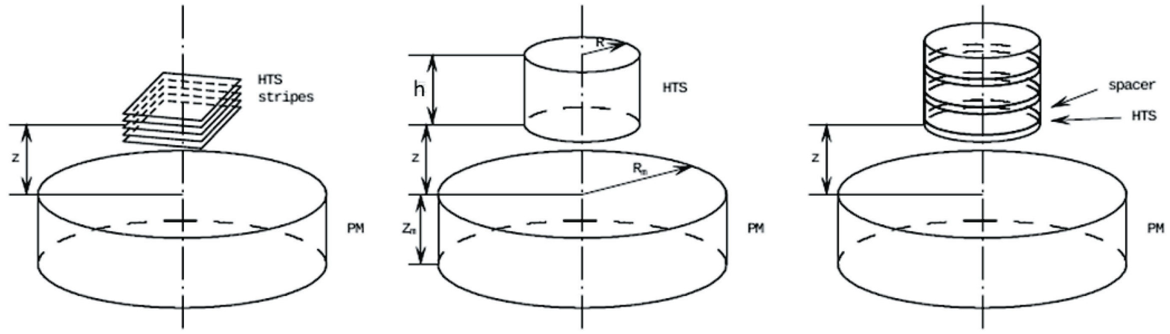

Fig. 1. Scheme. Left- experimental configuration; middle - the calculation geometry for the bulk sample, right - the calculation geometry for the stack.

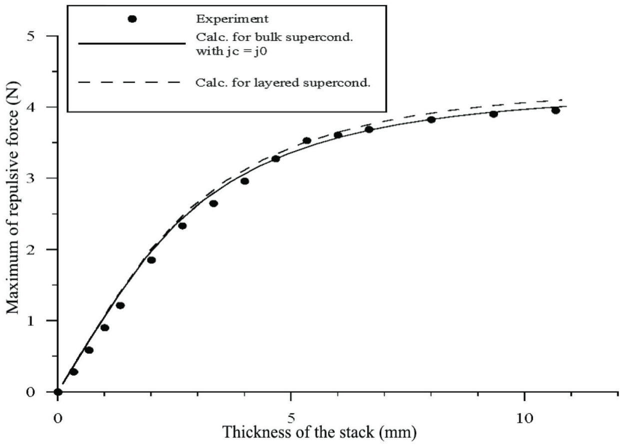

Fig. 2. The dependence of the maximum of repulsive force on the thickness of the stack of superconductors, ZFC mode.

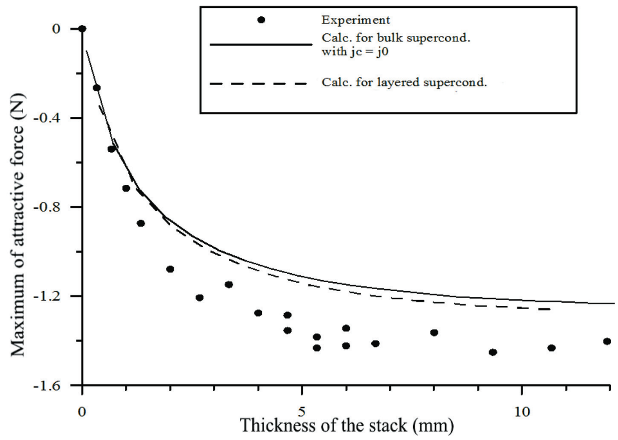

Fig. 3. The dependence of the maximum of attractive force on the thickness of the stack of superconductors, FC mode.

On the basis of the experimental curves were determined maximum repulsive force $F_{z\ rep}$ (ZFC mode) and the maximum attractive force $F_{z\ attr}$ (FC)and dependences of these forces on the thickness of the stack **h**.(Fig. 2 and Fig. 3).

In the ZFC mode (Fig. 2) when the thickness of the stack is less than 2 mm is observed linear growth of the maximum of repulsive force. For thicknesses greater than 6-8 mm $F_{z\ rep}(h)$ dependence flattens and tends to a constant. Such a result is expected and is typical for bulk samples [4, 5]. In FC mode (Fig. 3), dependence also tends to a constant. But the point corresponding to the end of the linear part of the curve is different (h = 1 mm).

Also we have calculated the levitation force for the stack and the bulk sample with a same geometry. It was obtained the values of the critical current density of the superconducting material for both cases. For example in the ZFC mode at the minimum gap and the thickness of the stack of tapes 8 mm (120 tapes), force is 3.83 N. The calculated critical current density of tape is 2.054 MA/cm^2 that is consistent with the critical current value measured by resistive method. Similarly the $\mathbf{j_c}$ value for bulk superconductor should be 29 kA/cm^2, which corresponds to the value of the critical current for good bulk ceramic samples ReBCO.

Calculation of levitation force for a bulk sample of the same geometry and critical current density (taking into account filling factor) shows that the force is equal to corresponding value for the stack.

In the case of ZFC mode, the theoretical dependence of the force of levitation on the thickness of the sample for a bulk superconductor and stacks are in good agreement with the experimental results (see Fig. 2). In FC mode is observed a slight discrepancy between the theoretical and experimental curves (see Fig. 3). However the mismatch of results does not exceed 10%. This error is related to the model assumptions underlying the calculation algorithm. In particular, it is not considered the screening effect of external magnetic field of bulk sample that may leads to a redistribution of the current in superconductor. Also, we have not included in our model mutual influence of the individual tapes in stacked one on another.

Thus levitation characteristics of the tape stack and the bulk superconductor almost identical for equal values of the critical current density. However, significant progress in the development of manufacturing technology of the second generation superconducting tapes already today allows to produce short samples of tape with a critical current density greater than of 5 MA/cm^2. In this case, we should expect to the achievement of levitation force on the stacks unavailable for bulk superconductors with the same geometrical parameters.

4. CONCLUSIONS

Magnetic levitation force of on a stack of ReBCO tapes with various thicknesses in the FC and ZFC modes was measured. It was observed that the levitation force of a stack is comparable to that of good bulk ceramic samples with a considering the fill factor for a stack of industrial HTS tapes. It was found that the functions of dependency of maximum of the repulsive force (ZFC mode) and attractive force (FC mode) on the thickness of the tapes stack have nonlinear character that allows us to make the optimal choice of geometrical parameters of the stack while keeping the necessary values of the levitation force. The numerical calculations using finite element method, showed that without the screening of the applied field the levitation force of the bulk superconductor and the layered superconductor stack with a critical current of tapes increased by the filling factor is exactly the same, and taking into account the screening the force slightly different.

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