

# The study of relaxation characteristics of stack of HTS tapes for use in levitation systems and trapped flux magnets

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**Abstract.** We present experimental data and analysis of application of coated conductors (CC) for levitation and trapped field magnets. The magnetization loops and magnetization relaxation curves were obtained in fields up to 14 T and temperatures from 4.2 K to 77.4 K. The levitation force and its relaxation were measured for the stack of superconducting tapes at  $T=77$  K. The measurements of levitation force for different stack sizes demonstrate the linear growth of the force amplitude and the improvement of the relaxation characteristics as a number of tapes in a stack increases.

## 1. Introduction

The recent development in the high temperature superconductor (HTS) tapes production expands their application area to magnetic systems. In this paper we represent the study of properties of CCs allowing to use them in trapped flux magnets and magnetic levitation systems [1-3]. It is known that the Bi-based tapes show a large critical current degradation under applied magnetic field as compared to the YBCO-based coated conductors. In turn, the modern CC samples maintain the critical transport current at several amperes at 77 K in the fields up to 8 T. This is the main reason to choose coated conductors for magnetic applications.

The bulk YBCO superconductors were widely used for levitation systems over the last decades. However they have some obvious weaknesses such as heterogeneity of superconducting properties through the sample volume, frailness, the problem of manufacturing of the extended samples, etc. In addition, there is a question about the performance of the superconducting material: large part of a bulk superconductor (up to 30-40 % [4]) is normally shielded from an external magnetic field and does not contribute to the levitation force. On the other hand the industrial high quality coated conductors have a good uniformity and texturing properties across the length. It also exhibits the extremely high critical current densities. The geometric parameters of such tapes provide flexibility in the formation of stacks of tapes of different sizes and structures.

## 2. Experimental details

Firstly, we studied the behavior of individual coated conductors samples in a wide range of magnetic fields and temperatures. The experiments were carried out on the SuperPower tapes by using the vibrating magnetometer [5]. The external magnetic field was perpendicular to the 4x4 mm sample large surface. Under these conditions, the magnetization loops  $M(H)$  were measured in the fields up to 14 T and in a temperature range from 4.2 K to 77.4 K. Also the relaxation curves were obtained after finishing each loop measurement in the zero magnetic field.



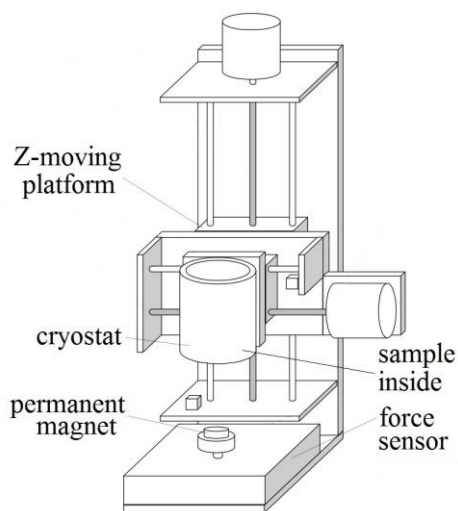
The setup for measuring of levitation force (Figure 1) provides an ability to determine the levitation force over the gap between the superconducting sample and permanent magnet [6]. The coated conductors of 12 mm wide and 15 mm long were used for measurements. Stack size was varied from 3 to 10 tapes and the minimum levitation gap was 2 mm. The dependencies of the levitation force on the time were measured in a similar way as the magnetic moment relaxation.

### 3. Results

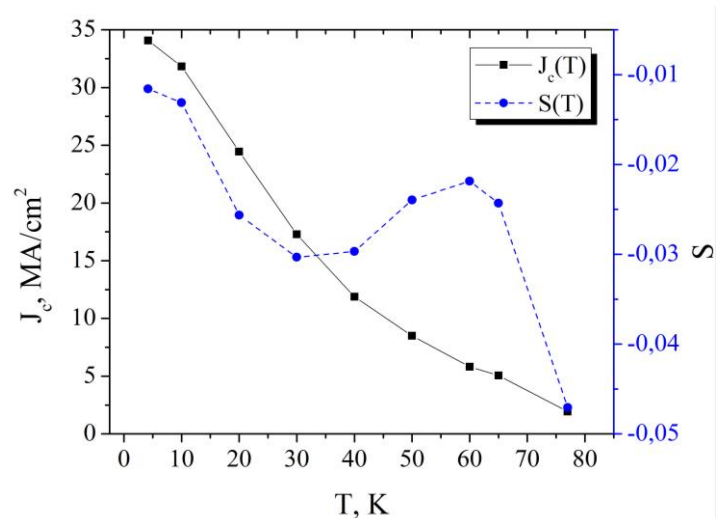
The dependencies of magnetization on applied magnetic field (magnetization loops) obtained at different temperatures were used to calculate the critical current over the temperature relationship (Figure 2). A strong relationship between magnitude of the critical current density and levitation force points out to a proportional increase in levitation force with decreasing temperature. Also the obtained relaxation curves allow to calculate the magnetization change time constants for a wide range of temperatures. An analysis of dynamic magnetization properties demonstrated that the range of possible optimal temperatures for a steady magnet system is 4.2 – 20 K.

The dependence of the levitation force  $F_z$  on the levitation gap  $z$  for CC stacks was measured at 77 K in two modes: zero field cooling (ZFC), Figure 3a, and cooling in the field of permanent magnet (FC), Figure 3.b. The obtained results and its comparison with ones for bulk samples show that the main difference between a stack of tapes and the bulk superconductors is a strong hysteretic behavior (the appearance of the attractive force) of the stack, in ZFC as well as in FC mode, which is confirmed in [2]. This may be due to easier magnetic field penetration to the HTS film.

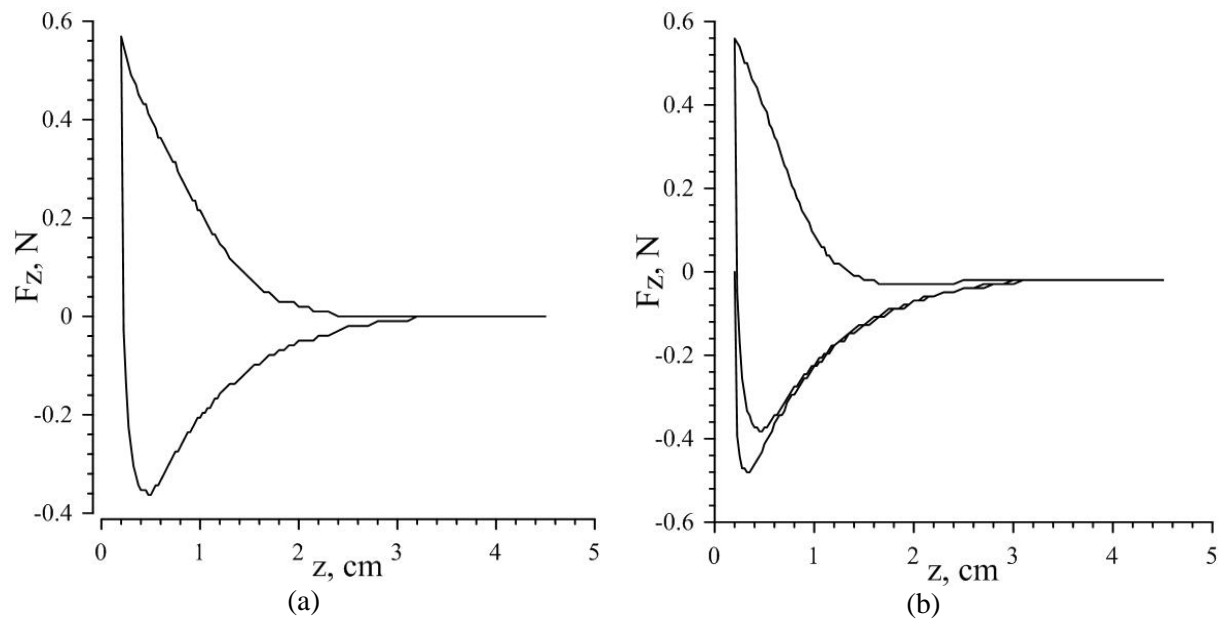
As was mentioned above, the number of tapes in the stack was varied from 3 to 10. The maximum repulsive force (for levitation gap of 2 mm), and maximum attractive force were chosen for the comparison of values for various number of tapes (Figure 4). Resulting curves show a linear rise with increasing of tapes numbers in a stack. It is expected that a further increase in the number of layers in the HTS composite will cause the rise of the force with subsequent saturation, similar to bulk superconductors [7].



**Figure 1.** Scheme of the levitation force measuring setup.

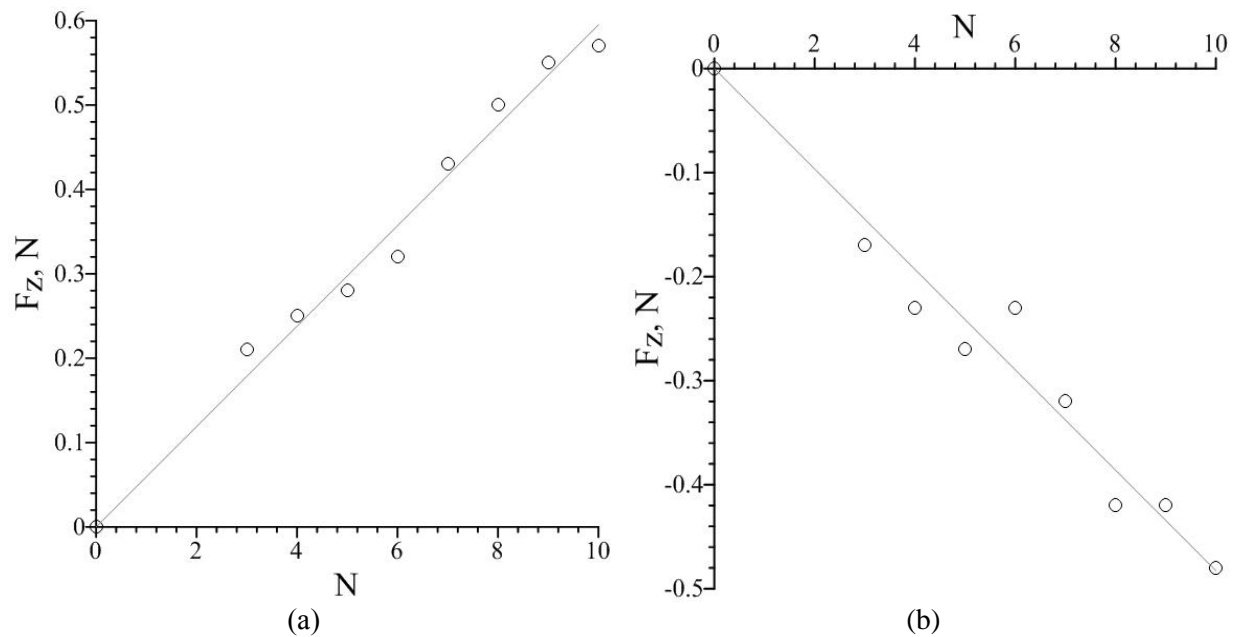


**Figure 2.** Temperature dependences of critical current density  $J_c$  and relaxation constant  $S$  in zero magnetic field.

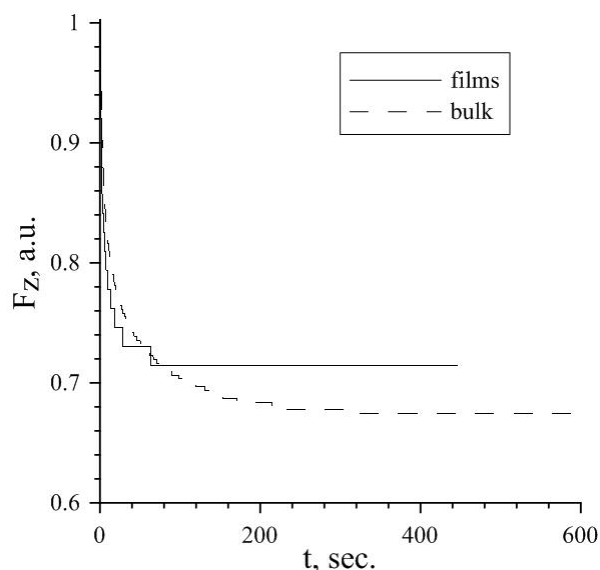


**Figure 3.** Levitation force for 10 CC tapes stack at  $T = 77.4$  K in two modes: (a) ZFC, (b) FC.

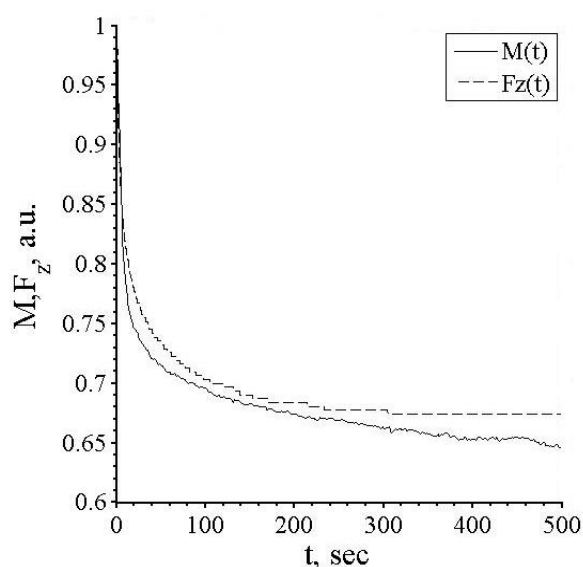
Figures 5 and 6 present the comparisons of the repulsive force relaxation curves for the stack of tapes and a bulk superconductor. In contrast to the bulk superconductor, the decrease in the force at the initial stage is more abrupt for the stack. However, after approximately of 50 seconds the decrease gets slower, and the value reaches a plateau earlier than one for the bulk sample. Also a residual repulsive force for a tapes stack maintains higher. Comparison of relaxation of the normalised magnetization (single tape) and the levitation force (for a stack of 10 layers) leads to the conclusion that the stack is more stable in time interaction.



**Figure 4.** Peak force between HTS stack of  $N$  tapes and a permanent magnet at  $T = 77.4$  K in two modes: (a) repulsive force, (b) attractive force.



**Figure 5.** Comparison of relaxation curves for 10 tape stack and a bulk sample at  $T=77.4$  K.



**Figure 6.** Compared relaxation curves for levitation force (10 tape stack) and magnetization of a single tape at  $T=77.4$  K.

#### 4. Conclusions

The main aspects of possible realization of an effective levitation systems or trapped field magnets by using CC tapes were discussed: working temperature, relaxation and stack size. The amplitude of the tape critical current and magnetization decreases dramatically as a temperature rises, what can be used by applying modern cryocooling systems and shifting the working temperature down to 20 K. On the other hand, the relaxation constants of individual tape shows a local minimum of the relaxation speed at the temperature of 60 K, even lower speed is reached only at 15 K.

Tapes stack looks more stable than a bulk sample and addition of more tapes in a stack increases the magnitude of the levitation force and the time stability. Making of a multilayer tape would be very useful for applications in levitation systems.

#### Acknowledgments

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