Improving homogeneity of the magnetic field by a high-temperature superconducting shield

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Abstract. The shielding opportunity of the magnetic field perpendicular component by the high-temperature superconducting tape (HTS) is shown experimentally for the first time. The tapes are laid closely to each other with a shift of pieces from layer to layer equal to a half of the tape width at the experimental set-up. This multilayer cylindrical structure inserted into the solenoid is similar to the unclosed shield from a uniform piece of the superconducting foil with the corresponding current-carrying capacity. It has been found that the maximum shielding field is proportional to the number of layers and a half of the full magnetization field of one tape for the regular multilayer structure of the HTS segments. The obtained results are necessary to construct systems with the high magnetic field homogeneity, in particular, for the electron cooling system of charged particle beams at the new accelerator complex which is being developed at JINR in Dubna, Russia.

1. Introduction

Forming of the highly homogeneous magnetic field is the main requirement to construct an electron cooling system for charged-particle beams, as a part of NICA accelerator complex [1, 2]. For this purpose, the magnetic field homogeneity must be at least 10^{-5} with the length of the cooling system solenoid of about 6 m and the magnetic field of up to 0.2 T. However, it is very expensive due to the complexity of the precision winding. Moreover, multiple sections will inevitably lead to the non-uniform field at solenoid junctions. Generation of the highly homogeneous magnetic field using the unclosed superconducting shields is the most promising direction to solve this problem. It is known that low-temperature superconductors can be used for these purposes [3, 4]. On the other hand unique properties of the HTS make this idea even more attractive. The purpose of this paper is to demonstrate an opportunity of using the existing HTS tape to increase the magnetic field homogeneity in the laboratory magnetic system.

2. Planar multilayer structure in the magnetic field perpendicular to the sample

The 2-G HTS Y123 ceramic tape produced by Super Power Company was used as a basic structure element. The tape was 12 mm wide and 50 μm thick. At the first stage the impulse method was used to

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estimate a simple planar structure shielding ability. Samples of multilayer structures were measured: one was built of stacked HTS 24 mm tape pieces; the other one having the same type tape parts was combined as a „tile”. The magnetic field impulse, with the amplitude up to 0.2 T and width of 5 ms, was delivered upon the sample. The electromotive force (EMF) in the measuring coil, placed in the middle of the sample, and current in the energizing coil were recorded. The magnetic field in the middle of the sample was obtained through the integration of the EMF. The full magnetization field of this multilayer structure was defined using the fact that this field depends on the applied field (namely on the current in the energizing coil).

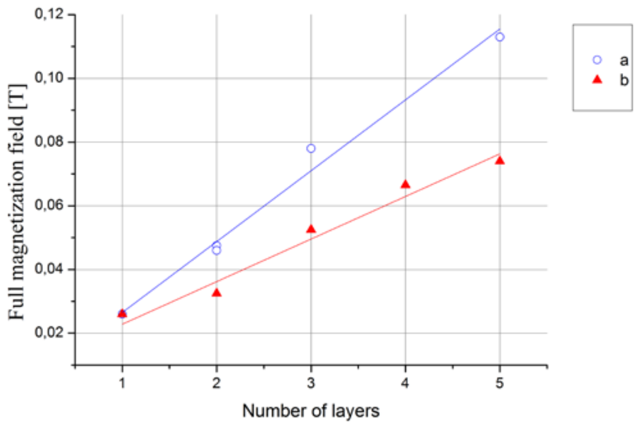

Figure 1. Full magnetization field vs. number of layers. a- structure as a stack of the tapes, b– structure as a “tile” of the tapes.

Figure 1 shows that the full magnetization field of one tape is about 25 mT (curve a). Each next "tile" layer increases the shielding field by an average of 12.5 mT (curve b). So, the shielding ability is proportional to the number of layers and a half of the full magnetization field of one tape for the regular multilayer structure of the HTS segments.

3. Multilayer structure in the form of the lengthwise shield

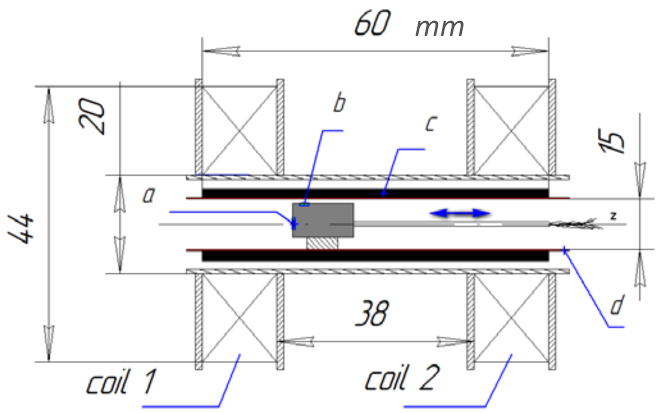

Figure 2. Experimental set-up. a- Hall sensor to measure the longitudinal field component; b– Hall sensor to measure the radial field component; c – HTS lengthwise shield; d - non-magnetic steel tube.

The lengthwise shield is made of the same tape as the samples in the previous experiments. The tapes are laid closely to each other on the tube along its generatrix. The following layers were put with a shift of pieces from layer to layer equal to a half of the tape width to form the “tile”.

The magnetic field was measured by Hall sensors (PXA_602817A type) with sensitivities 45 mV/T - for longitudinal component and 245 mV/T - for radial component correspondingly. Liquid nitrogen was used to cool the experimental set-up. Longitudinal (B_z) and radial (B_r) components of the magnetic field near the inner surface of the shield depending on the position

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along Z axis are given in the figures below.

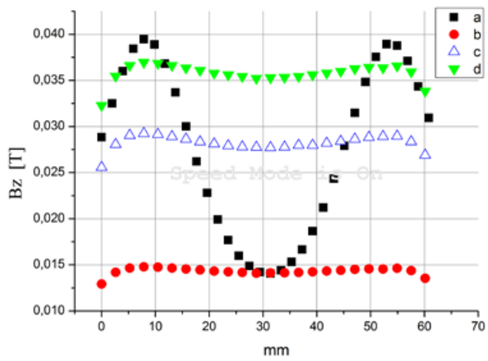

Figure 3. B_Z of the 4-layer shield vs. *Z*-coordinate for different currents in the coils: a- without shield, 1A; with shield: b- 0.5A; c- 1 A; d- 1.5A.

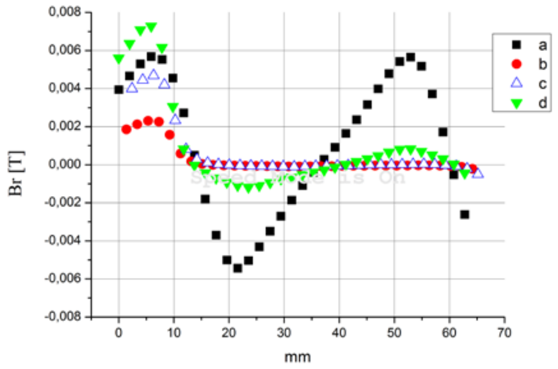

Figure 4. B_r of the 4-layer shield vs. *Z*-coordinate for different currents in the coils: a- without shield, 1A; with shield: b- 0.5A; c- 1 A; d-1.5A.

The radial component demonstrates the quality of the shielding (See figure 4). Shielding at any current in the coils is observed in figure 3. However, figure 4 shows that the shield performance deteriorates at the current of 1.5 A! The congruence of figure 4 and figure 5 allows to say that the 4-layer shield performs more efficiently than the 2- layer shield.
The comparison of the qualitative results with those of the papers [3-5] have shown that the introduced "tile" lengthwise shield inserted into the solenoid is similar to the unclosed shield from a uniform piece of the superconducting foil with the corresponding current-carrying capacity.

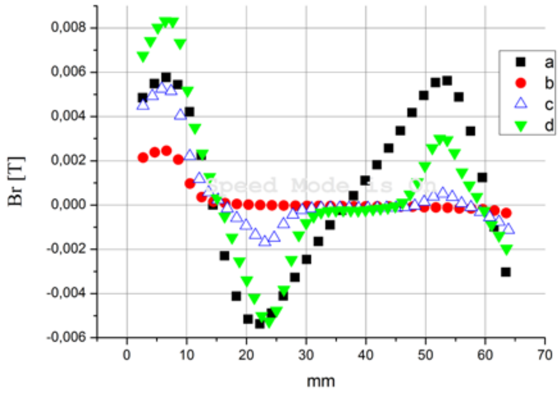

Figure 5. B_r of the 2-layer shield vs. *Z*- coordinate for different currents in the coils: a- without shield, 1A; with shield: b- 0.5A; c- 1 A; d-1.5A.

The accuracy of the magnetic field measurements was about $\Delta B/B \sim 10^{-2}$, which was basically determined by the stability of the DC power supply.

4. **Conclusions**

1. The "tile" structure performs as a uniform piece of the superconducting foil and can be used to construct the unclosed shield.
2. The shielding ability of this lengthwise construction is proportional to the number of layers and a half of the full magnetization field of one tape for the regular multilayer structure of the HTS segments.
3. The developed method makes it possible to construct the unclosed superconducting shields using the latest 2-G HTS tape to increase the magnetic field homogeneity of the large magnetic systems, such as the electron cooling system for the NICA complex.

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