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THE INFLUENCE OF THE UNCLOSED SUPERCONDUCTING MAGNETIC SHIELD ON THE DYNAMICS OF THE CHARGED PARTICLES BEAM

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Abstract

The development of high-temperature superconducting (HTS) materials, especially HTS tapes of the second generation (2G HTS tapes) give us new opportunities to use superconductivity in high-energy physics devices and, in particular, in charged particle accelerators. The influence of the unclosed magnetic shield made of 2G HTS tape on the dynamics of a charged particles beam is studied in this paper. Within the framework of the simplest model of the interaction of the magnetic field of a charged particles beam with a superconducting shield, estimates of this influence are made. The superconducting shield shifts of a charged particles beam to its axis. In particular, the beam of ions $^{197}Au^{79+}$ energy of 4 GeV per nucleon and a current of 5 A passing at a distance of 5 - 10 mm from the axis of the superconducting screen with a radius of 50 mm and a length of 5 meter is shifted to the axis of the screen at a speed of about 130 m/sec. That is, the beam itself can be centered for a lot less than 1 second. The possibilities of using an unclosed superconducting shield to compress a charged particles beam are discussed, as well as the possibilities of controlling the shield.

INTRODUCTION

Magnetic fields are used in various areas of science and technology, in medicine, in industry, in devices of high energy physics, etc. Important for specific applications are the magnitude and quality (stability, uniformity,...) of magnetic fields. To improve the quality of magnetic fields, it is possible to use soft magnetic materials with high magnetic permeability (permalloy, μ - tapes of different composition, etc.) or superconductors. The difference between these materials is easy to demonstrate by the example of the behavior of hollow cylinders in a magnetic field, as shown in Fig. 1. Weakening of the magnetic field inside the cylinder made of soft magnetic material is due to the high magnetic permeability μ of the cylinder wall. That is, the shunting of the magnetic flux by a material with high magnetic permeability is used. The weakening of the field inside the cylinder can be radical with a noticeable (large) wall thickness and high permeability μ, which in some materials can reach 10^4. But to achieve zero magnetic fields inside the cylinder is in principle impossible. If the cylinder is not monolithic, and is a roll of μ - tape, its behavior in a magnetic field is no different from the monolithic, when the loss of energy at an alternating current in the system do not matter. It should also be noted that the need for high magnetic permeability leads to the limitation of the range of performance of such materials by magnetic fields of the order of tens of Gauss. In particular μ-tape can be used for shielding the magnetic field of the Earth.

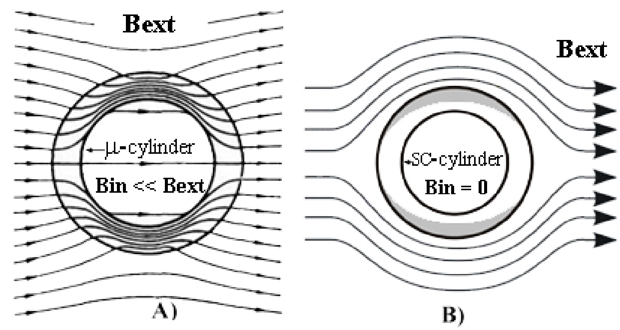

Figure 1: μ–cylinder -A) and the superconducting cylinder -B) in a perpendicular external field. Grey's are the flow region of the shielding currents in SP cylinder.

In the case of a superconducting material, the change in the external field induces shielding currents near its surface. As a result, the magnetic field does not penetrate inside the monolithic superconductor until the shielding currents reach a critical value. If the superconducting cylinder is a roll of thin superconducting tape (the simplest unclosed shield), the external magnetic field parallel to the axis of the cylinder is practically not shielded (the magnetic fields of the shielding current are small, since they are proportional to the thickness of the superconducting tape, and not to the size of the cylinder). At the same time, in an external magnetic field perpendicular to its axis, it behaves like a cylinder with a solid monolithic wall. That is, a roll of superconducting tape passes parallel to its axis, but shields the perpendicular components of the external magnetic field. This circumstance was used in the 70-ies of the last century. Bychkova M. I. and others [1,2] successfully demonstrated the possibility to use an unclosed magnetic shield in the form of a roll of superconducting tape made of alloy NT50 to increase the uniformity of the magnetic field of the superconducting solenoid.

Figure 2 shows design of a modern high-temperature superconducting wire in the form of a ribbon from the manufacturer's website.

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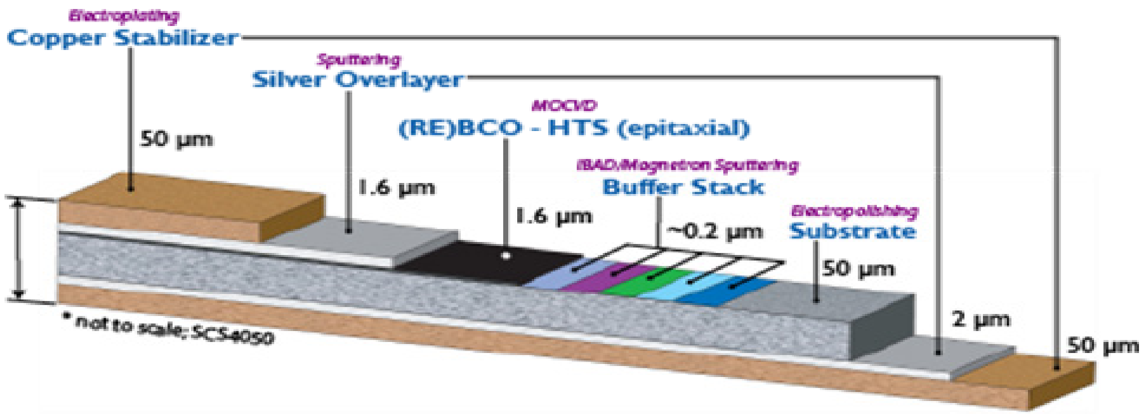

Figure 2: The design of 2G HTS wire.

A significant feature of 2G HTS tapes, currently produced by all well-known manufacturers, is their width from 4 to 12 mm (much less than the width of niobium-titanium tapes) and the thickness of 50 – 100 microns. But this fact is not a decisive obstacle for the use of 2G HTS tapes in unclosed shields. Indeed, it is always possible to make a superconducting leaf of the required dimensions, stacking pieces of 2G HTS tape (end-to-end layers or overlap) with a shift along the leaf as shown in Fig. 3.

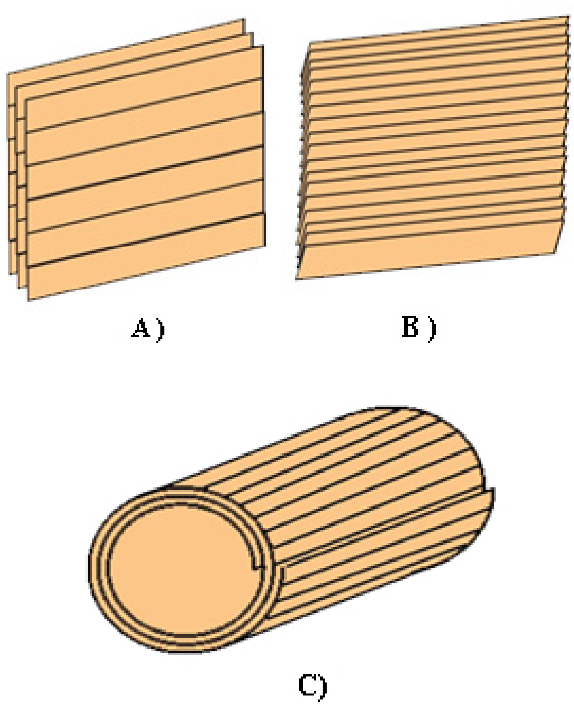

Figure 3: Superconducting leaf from pieces of 2G HTS tape stacked back to back layers A) or overlap B) and a roll of such leaf C).

It is obvious that due to the large ratio of the tape width to the thickness (>100), the magnetic bond of the superimposed pieces of tape for the perpendicular component of the magnetic field is close to one. That is composed in this way the leaf will behave in the first approximation as a continuous tape.

The development of modern superconductors, especially second-generation superconductors (2G HTSC wires) [3, 4] opens up new opportunities for the use of superconductivity in various devices, including for current leads, solenoids, superconducting fault current limiters (SFCL), etc. [5-7]. We study the possibility of using an unclosed superconducting shield of 2G HTSC tape in the electronic cooling system of the collider “NICA” [8,9], to align the magnetic field in the solenoids and to switch the flow between the coils, to rotate the axis of the magnetic system field, to correct the position of the magnetic field lines and to create a magnetic vacuum [10].

The purpose of this work is to study the effect of the magnetic shield of the 2G HTSC tape on the dynamics of the charged particles beam moving along (parallel) its axis.

ESTIMATIONS AND DISCUSSION

Imagine a shield in the form of a long cylinder like the roll of superconducting tape or the roll of superconducting leaf from pieces of 2G HTS tapes, stacked right next to each other with layers or overlapped, laid on the generatrix of the cylinder parallel to its axis as shown in Fig. 4.

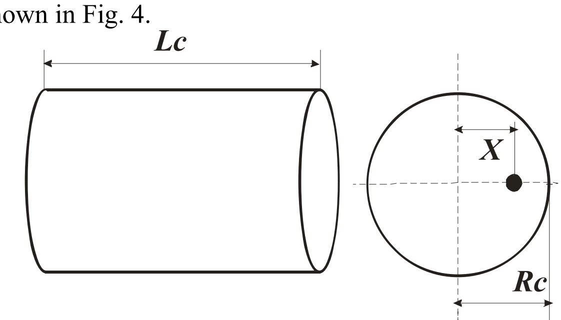

Figure 4: A superconducting shield with a length of Lc and a radius of Rc and a beam of charged particles moving along its axis at a distance of X.

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Let the shield with a radius of Rc =50 mm and length Lc = 5 m is part of the storage ring length Lo = 500 meters, for example, may be provided in the system of electron cooling of collider "NIKA" and a beam of ions $^{197}Au^{79+}$ with particle energy Eo and a current I is moving parallel to the axis of the shield at a distance X (x<Rc). Replacing the interaction of the magnetic field of the beam with the surface of the cylinder by interaction with two superconducting planes (magnetic mirrors), with the coordinates of the +Rc and –Rc, that is, at a distance +(Rc-x) and –(Rc+x) from the beam, it is possible to obtain for the force Fi(x), acting from the side of the shield for each meter of the beam and tending to move it to the axis of the shield (in SI units):

$$Fi(x) = -4 * 10^{-7} * I^2 * \frac{x}{(R_c^2 - x^2)} \quad (1)$$

And as a result of this force, the transverse velocity of the beam particles with energy Eo =4 GeV per nucleon with current I = 5 A, flying at a distance of 5 mm from the shield axis, reaches 130 m/sec during the movement in the shield, and the displacement for one passage along the ring – 1.1 µm. That is, the beam itself can be centered for a lot less than 1 second. Taking into account the beam duty cycle, for example, by averaging the effective current in the superconducting mirror increases the beam centering time to the order of a second. So, estimates show that a superconducting shield can be an effective tool for compressing a charged particle beam, as well as for controlling the beam, for example by moving and/or rotating the shield.

It should be noted that the estimates are made for the charged beam of heavy $^{197}Au^{79+}$ nuclei. And the effect of a superconducting shield on a mixed beam with the presence of light charged particles, such as electrons, in the linear region in the electronic cooling system of the collider "NICA" can be several orders of magnitude stronger.

REFERENCES

[1] Bychkova M. I., et al. Shielding properties of alloys of niobium-titanium,//Collection "Problems of superconducting materials", M.: Nauka, 1970, p. 166-172.(In Russian)

[2] Bychkov, Y. F., et al. Study of factors affecting the efficiency of the superconducting shields are used to increase the uniformity of the magnetic field // metallurgy and metallography of pure metals. M.: Atomizdat,1980. Vol. 14. p. 53-63(In Russian)

[3] www.superox.ru

[4] www.superpower-inc.com

[5] Diev D.N. et al. HTS current leads for the NICA accelerator complex. Cryogenics 94 (2018) 45-55.

[6] Siyuan Liang, et al. Tests and Analysis of a Small-Acale Hybrid-Type DC SFCL Prototype. IEEE Trans Appl Supercon. Vol.28, No.4, June 2018, 5602106-

[7] Ranjan Vera Modeling and Dynamics of HTS Motors for Aircraft Electric Propulsion. Aerospace 2018, 5, 21; doi:10.3390/aerocpace5010021

[8] Kulikov E., et al. "Improving homogeneity of the magnetic field by a high-temperature superconducting shield," J. Phys.: Conf. Ser. **507**, 032028 (2014).

[9] Smirnov A. et al .Experimental Study of High-Temperature Superconductor Shield for Electron Cooling System. Physics of Particles and Nuclei Letters, 2016, Vol. 13, No. 7, pp. 983–987. © Pleiades Publishing, Ltd., 2016.

[10] Dorofeev G.L. et al, Applications of unclosed superconducting shields in accelerator physics. 12th International Scientific Workshop in Memory of Professor V.P. Sarantsev "Problems of Colliders and Charged Particle Accelerators"3-8 September 2017, Alushta, Crimea, Russia