IMPROVEMENT OF TERMINATION FIELD OF BULK HTSC STAGGERED ARRAY UNDULATOR

Naoki Kimura#, Toshiteru Kii, Ryota Kinjo, M.A. Bakr, Y.W. Choi, M. Omer, Kyohei Yoshida, Keiich Ishida, Takuya Komai, Marie Shibata, Kyohei Shimahashi, Hidekazu Imon, Taro Sonobe, Heishun Zen, Kai Masuda, Hideaki Ohgaki,
Institute of Advanced Energy, Kyoto University, Gokasho Uji, Kyoto, 611-0011

Abstract

We proposed bulk High-temperature Superconductor Staggered Array Undulator (bulk HTSC SAU) to achieve shorter period and higher undulator field. While studying this undulator, we found that there is a strong vertical (Y-axis) magnetic field on the edge of the undulator and it strongly kicks a trajectory of the electron beam. By using newly developed numerical simulation code based on Bean model, it was found that the strong vertical field could be suppressed by adding bulk HTSC pieces at end of the undulator. Effectiveness of the developed method was also confirmed by experiments

INTRODUCTION

We proposed a bulk High-temperature Superconductor Staggered Array Undulator (bulk HTSC SAU) to realize shorter period and higher undulator field [1]. The schematic view of the bulk HTSC SAU is shown in Fig.1. We put bulk HTSC magnets and a solenoid coil as is seen in the Fig.1 and magnetize bulk HTSC magnets by applying an external magnetic field by the solenoid. These magnetized bulk HTSC magnets make an undulator field. We can control magnetization of bulk HTSC magnets by changing the external magnetic field made by solenoid, so that we can control the amplitude of the undulator field without any mechanical system.

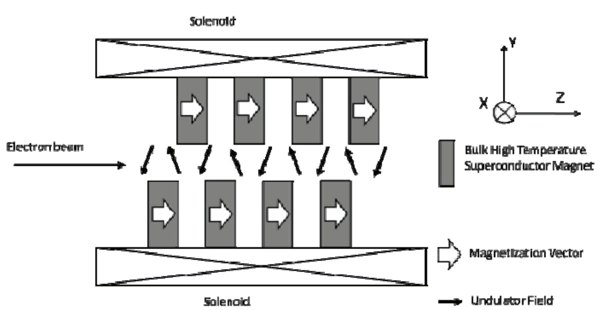

Figure 1 : Schematic view of the bulk HTSC SAU.

Results from numerical simulation and experiments by a prototype machine showed that there are strong magnetic field peaks in Y-axis direction on the both edge of bulk HTSC SAU [2]. We calculated the electron beam trajectory through bulk HTSC SAU and found that these strong peaks of magnetic field strongly kick the electron beam trajectory. Due to this, we studied on correcting the end field of bulk HTSC SAU.

END FIELD TERMINATION METHOD

Bulk HTSC SAU

When the magnetic field changes in the bulk HTSC magnet in superconductive state, loop current is generated so as not to change the magnetic field according to Faraday's electromagnetic induction law, so that the bulk HTSC magnet is magnetized. In bulk HTSC SAU, we change the magnetic field in Z-axis direction by using a solenoid coil so that each bulk HTSC magnet is magnetized in Z-axis direction. Bulk HTSC magnets are arranged alternately as Fig.1 and generate an undulator field. In the central area of bulk HTSC SAU, neighbour bulk HTSC magnets make a magnetic field which cancels the external magnetic field made by the solenoid coil. Thus, the effective magnetic field in bulk HTSC magnets in the central area is weakened, so that they are weakly magnetized. For that reason the undulator field in the central area of bulk HTSC SAU is weakened. On the other hand, on the edge of the undulator, the effect from neighbour bulk HTSC magnets is small and bulk HTSC magnets are strongly magnetized and undulator field is increased. The result of numerical calculation supports this estimation. Therefore we developed a method to reduce the magnetization of bulk HTSC magnets on the edge of the undulator.

End Field Termination Method

We proposed an end field termination (EFT) method by adding bulk HTSCs on the edge of the undulator. We expect that additional bulk HTSC magnets make magnetic field and weaken the magnetic field in the bulk HTSC magnets on the edge so that the magnetization of bulk HTSC magnets on the edge are reduced. Furthermore, by adding the bulk HTSC magnet on the edge, the shape of the edge of the undulator turns into symmetric in Y-axis direction and we expected that the outside magnetic field in Y-axis direction is also reduced.

We developed a simulation code based on the Bean model [3] for simulating the magnetic field of bulk HTSC SAU. The Bean model is a model for superconductivity in a critical state. The Bean model describes that when the external magnetic field changes, loop current is generated in the area in the same depth from the surface, which is described as d_Y in Fig.2 and the current density in the area (critical current density: J_C) is uniform. This loop current makes a magnetic field thereby the bulk HTSC magnet is

#n.kimura@iae.kyoto-u.ac.jp

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magnetized. Consequently, penetration ratio Λ_d in Fig.2 which is normalized d_Y determines the magnetization.

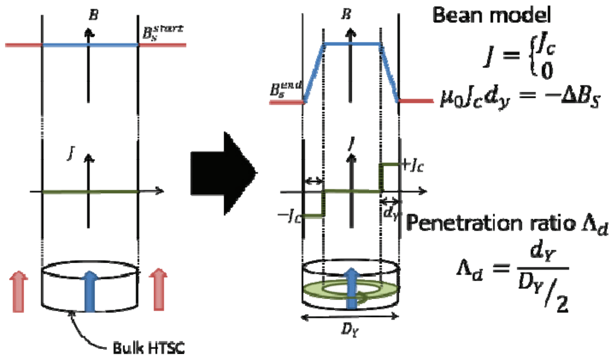

Figure 2 : Outline of the Bean model. In the frame of Bean model, an induced current flows in the area of the same depth (d_Y) from the surface of the bulk HTSC magnet, and is uniform in the area (J=J_C). The larger the penetration ratio (Λ_d) is, the stronger the bulk HTSC is magnetized.

The result from this simulation code showed that the undulator field on the edge of the undulator can be corrected by this method, so we measure the magnetic field of the prototype of bulk HTSC SAU with this EFT method.

RESULT

We measured the undulator field of the prototype of bulk HTSC SAU, and its radius is 25.2mm, period length is 5mm, gap is 4mm. A schematic view and a photo of the prototype is shown in Fig.3. We used 22 pieces of bulk HTSC in the undulator. The proposed configuration of the EFT method was applied on edge of the undulator. We tested two configurations as (B) and (C) in Fig.4. Configurations of the undulator and the penetration ratio of each bulk HTSC magnet is shown in Fig.4. The results from the measurement and simulation are shown in Fig.5 and 6.

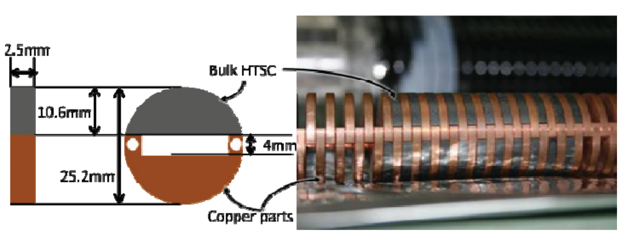

Figure 3 : Prototype machine of bulk HTSC SAU.

From Fig.4, we found that penetration ratios of bulk HTSC magnets on the edge are decreased with additional bulk HTSC magnets. The right end of the undulator, which is located at approximately Z=30mm in Fig.5 and 6 is the edge without the EFT method and the left end located approximately Z=-25mm in Fig.5 is with the EFT method (B) in Fig.4. We can find from Fig.5 that the large peak on the right edge is decreased in the left end.

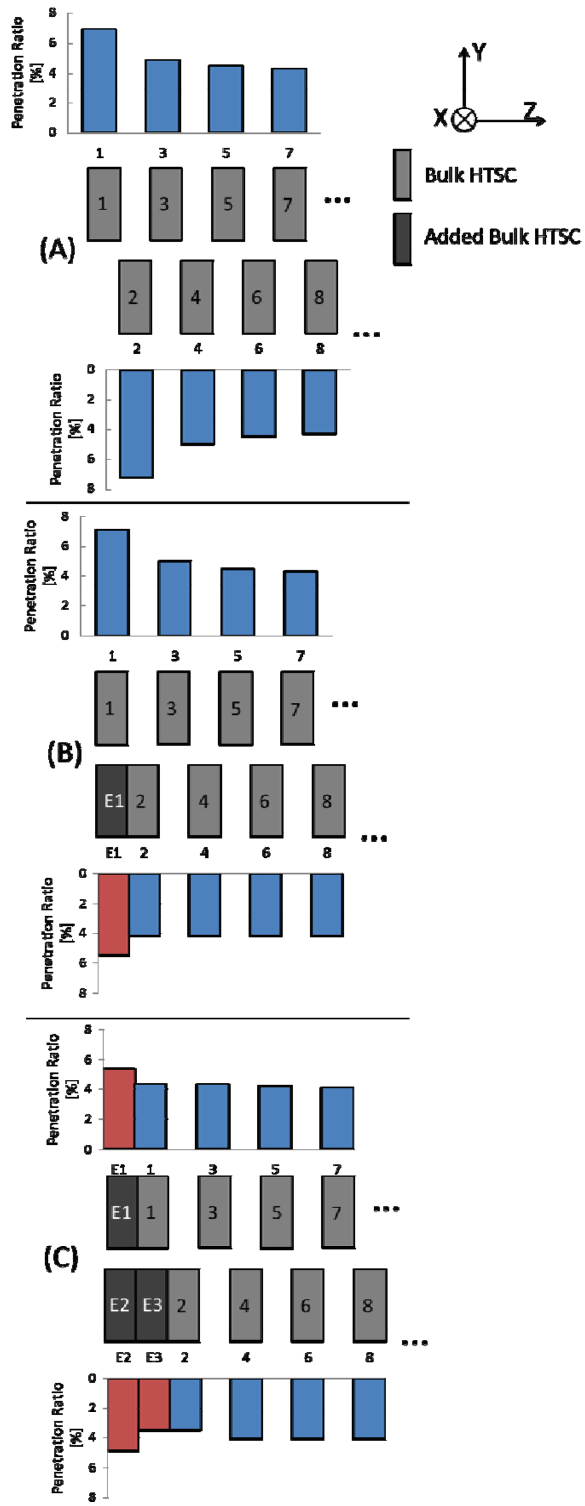

Figure 4 : Configurations of bulk HTSC SAU and penetration ratios of bulk HTSC magnets.

We added another two bulk HTSC magnets on the left end ((C) in Fig.4). As far as amplitude of the undulator field is concerned, there is no significant difference between configuration (B) and (C), whereas a small peak

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at Z=-28mm in Fig.5 almost disappeared and the magnetic field at outside of the undulator of the left is flatten in Fig.6. This is due to improvement of the symmetry property of the edge of the undulator by adding bulk HTSC magnets and offsetting outside magnetic field in Y-axis direction.

We calculated electron trajectories in the bulk HTSC SAU with and without the EFT method. We calculated the trajectory by double integral of the magnetic field in Y-axis direction through Z-axis. The result is shown in Fig.7. The electron beam with EFT method is less kicked than that without EFT method.

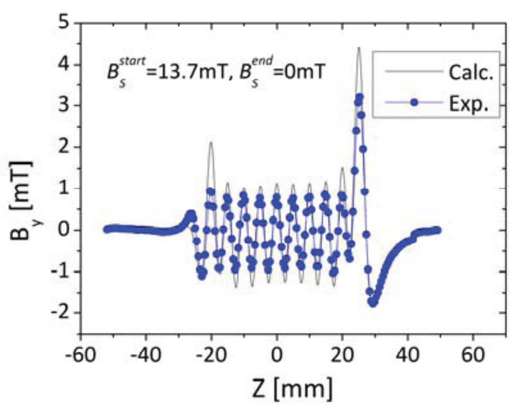

Figure 5 : Results of calculation and experiment with EFT configuration (B).

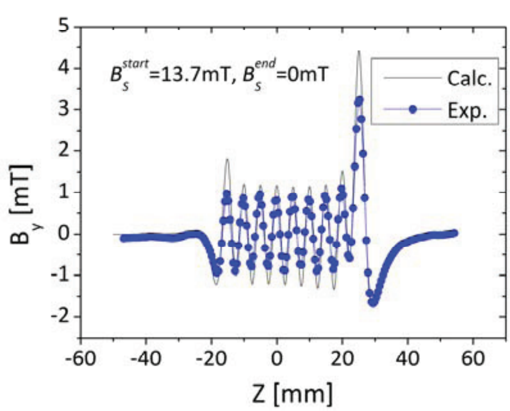

Figure 6 : Results of calculation and experiment with EFT configuration (C).

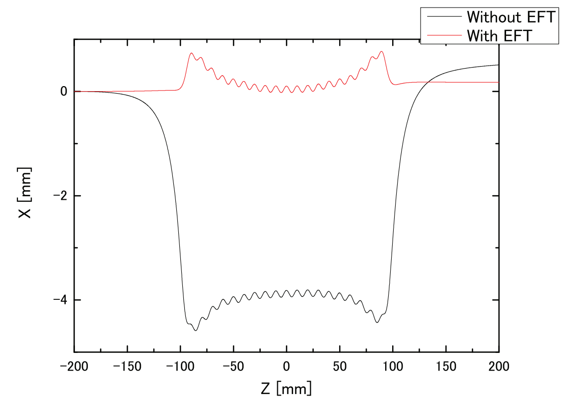

Figure 7 : Electron trajectory in the bulk HTSC SAU. The condition of calculation; Gap=4mm, number of periods=20, radius=30mm, Energy of electron beam=10MeV. EFT configuration is (C).

CONCUSION

To reduce the strong magnetic field on the edge of the bulk HTSC SAU, we proposed an EFT method by adding bulk HTSC magnets on the edge of the undulator. By this EFT method, the magnetization of bulk HTSC magnets on the edge of the undulator is released and the magnetic field is reduced. The effectiveness has been confirmed by experiment and calculation. We can lower strong peaks of magnetic field on the edge by this EFT method.

We plan to study to correct a magnetic field in Z-axis direction as well as Y-axis direction.

REFERENCES

[1] R. Kinjyo, et al., "BULK HIGH-TC SUPER CONDUCTOR STAGGERED ARRAY UNDULATOR" Proceedings of FEL08, Gyeongju, Korea, THAAU03, p. 473 (2008)

[2] R. Kinjo, et al., "End Field Termination for Bulk HTSC Staggered Array Undulator" Proceedings of IPAC'10, Kyoto, Japan, WEPD029, p. 3156 (2010)

[3] C. P. Bean, "Magnetization of high-field superconductors", Review of Modern Physics, p. 31 (1964)

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