GENERATION OF PERIODIC MAGNETIC FIELD USING BULK HIGH-TC SUPERCONDUCTOR*

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Abstract

We have constructed a prototype of bulk high-Tc superconductor(HTSC) staggered array undulator using 11 pairs of DyBaCuO bulk superconductors and a normal conducting solenoid. Periodic transverse magnetic field on the central axis of the solenoid was successfully produced. The transverse magnetic field was 0.0036 T in peak to peak when the solenoid field of 0.027 T was used to magnetize bulk magnets. Numerical analysis using simple assumption of Bean model was also performed. It was numerically found that simple treatment of superconducting loop current can reproduce the field distribution in the undulator.

INTRODUCTION

A short period undulator with strong magnetic field will play an important role in synchrotron light sources or free electron lasers. Resonant wavelength emitted from the undulator λ_R is written by following well-known equations

$$\lambda_R \cong \frac{\lambda_u}{2\gamma^2}\left(1+\frac{K^2}{2}\right) \tag{1}$$

$$K = \frac{e \cdot B_0 \cdot \lambda_u}{2\pi \cdot m_0 c} \approx 93.36 B_0 \cdot \lambda_u \,. \tag{2}$$

Here, λ_u is the undulator period, γ is Lorentz factor, K is the undulator parameter, e is the charge of the electron, B_0 is the maximum transverse magnetic field strength of the undulator, m_0 is the electron mass, and c is the speed of light. In order to obtain shorter wavelength radiation without changing undulator parameter K and electron beam energy, undulator period should be shortened and transverse magnetic field should be increased.

In order to realize strong periodic magnetic field in short period, superconducting undulator[1] and in vacuum permanent-magnet cryogenic undulator[2] have been developed and new idea such as pure type superconducting magnet undulator[3] and hybrid staggered undulator[4] have been proposed. Each undulator aims to realize short period undulator with higher magnetic field than the performance obtained by permanent magnet undulator. Recently, we also proposed a new structure of bulk HTSC stacked array[5, 6]. These proposals which use bulk HTSC magnets are aiming to apply the high performance of bulk HTSC magnet whose maximum trapped field reaches to 17 T[7].

The bulk HTSC staggered array undulator[6] consists of bulk superconductor magnets with same magnetization direction which are magnetized by a single external solenoid. Schematic drawing of the bulk HTSC staggered array undulator is shown in Fig. 1. Merits of this configuration are

- Only single external solenoid magnet is required for magnetization of each bulk HTSC magnets.
- Transverse magnetic field can be controlled by changing solenoid field without any mechanical structure.

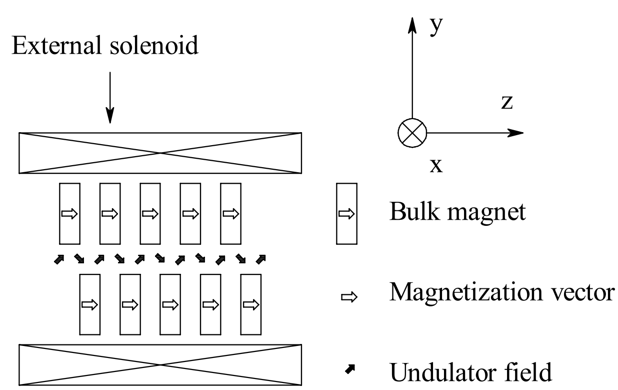

Figure 1: Conceptual drawing of the bulk HTSC undulator. Stacked bulk HTSCs are magnetized by a single external solenoid. The magnetized bulk SC magnets make transverse magnetic field (B_y) on center of the solenoid.

Proof of principle experiment has been carried out by using prototype device which consists of 3 periods of bulk HTSC stacked array[6]. Transverse magnetic field was successfully generated and controlled by changing solenoid field.

EXPERIMENT

In order to prospect properties of a bulk HTSC undulator, we made the 2nd prototype of the bulk HTSC undulator. Period number has been extended from 3 to 11 to reduce the edge effect and estimated the transverse

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magnetic field strength. Maximum Strength of a normal conducting solenoid magnet has been increased from 0.035 T to 0.3 T.

Experimental setup is shown in Fig. 2. Cupper pieces and DyBaCuO bulk superconductor are stacked in a solenoid as shown in Figs. 3 and 4. The DyBaCuO bulk magnets made by QMG method are used[8]. The critical temperature of DyBaCuO is around 91 K and the critical current J_c is about 100 A/mm$_2$ at 77 K, 0 T. Typical trapped field distribution at 77K is shown in Fig 5. Magnetic field was measured by using a Hall generator. Distance between the Hall generator and the bulk superconductor was 0.5 mm.[9] The average and standard deviation of peak field of 22 pieces were 0.11 T and 0.017T respectively. The stacked array is inserted in a liquid nitrogen cooled vacuum duct. A vacuum insulation panel is used for thermal shielding. Temperature on the bulk HTSC array is monitored by Pt100 temperature sensor attached to the cupper piece of stacked array. The vacuum duct is inserted in a normal conducting solenoid. Transverse and axial magnetic field is measured using the Tesla meter Model 460, manufactured by Lake Shore Cryotronics, inc. and axial and transverse Hall generators attached to the linear motion drive.

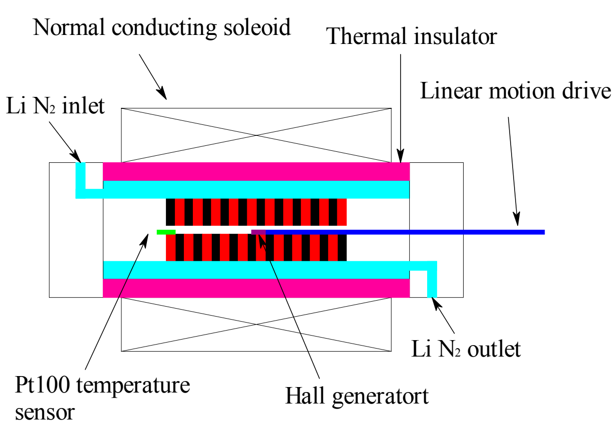

Figure 2: Schematic drawing of the experimental setup. A stacked array of bulk HTSC is inserted in a normal conducting solenoid. Transverse and axial magnetic field can be measured using Hall generators attached to the moving rod.

Figure 3: Photograph of the stacked array.

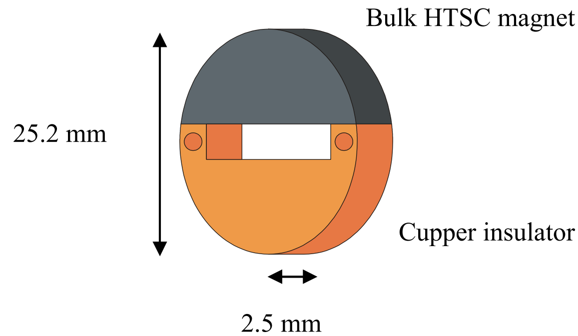

Figure 4: Schematic drawing of half period of the stacked array. Diameter of each pair of bulk HTSC and cupper support piece is 25.2 mm. Thickness of each pieces is 2.5 mm. Size of the void on the beam axis is 4 mm × 14 mm.

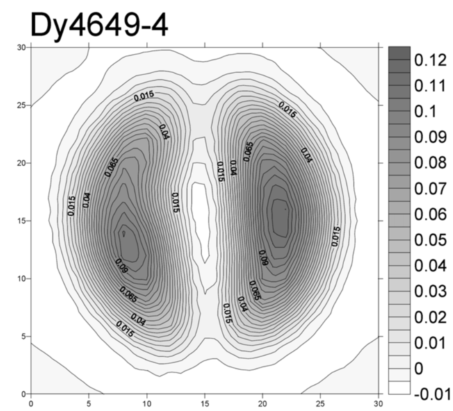

Figure 5: Trapped field distribution at 77K.

Field measurements of the prototype bulk HTSC undulator were carried out by field cooling method as described below. Solenoid field was applied before cooling down to 77K. In order to avoid saturation effect of each bulk HTSC magnet, solenoid field was set to 0.027 T. The superconductors were cooled down below critical temperature of the bulk DyBaCuO (91K) in the presence of magnetic field generated by the external solenoid. After switching off the external solenoid, transverse and axial magnetic field B_y and B_z were measured. Field distribution along z axis is shown in Fig. 6. The periodic magnetic field was successfully observed. The field strength at z = 0 was 0.0036 T in peak to peak.

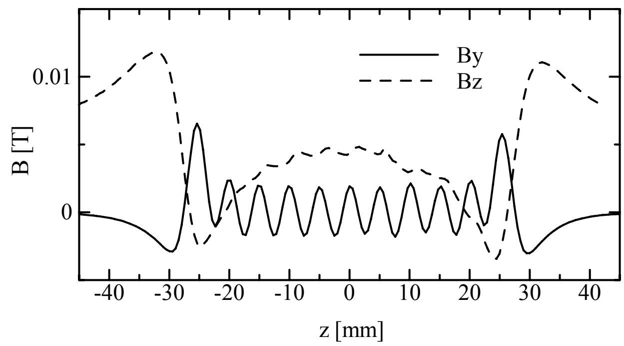

Figure 6: Transverse and axial field distribution along z axis. Bulk magnets were magnetized in solenoid field of 0.027 T. Field measurement have been carried out after the solenoid field was turned off.

DISCUSSION

The qualitative analysis using simple assumption of Bean model[10] and magnetostatic field calculation code "Radia"[11] was performed to understand the potential as a short period undulator. Under the approximation of Bean model, bulk superconductor can be replaced by superconducting current loop determined by the critical current density J_c, and when small external magnetic field compared to the saturation field in bulk superconductor, current loop appears only in rim of the bulk superconductor. Numerical results are shown in Fig. 7. Shapes of the field distribution are well reproduced with the simple treatment of Bean model. Consequently, performance of the bulk HTSC staggered array undulator can be estimated by increasing critical current J_c. Extreme large J_c in the melt processed REBaCuO system (RE: rare earth element selected from Nd, Sm, Eu, Gd) was reported by Murakami et al.[12]. We assumed critical current density J_c of 10^4 A/mm^2 when bulk superconductor are cooled down to 10K and extrapolate the performance from experimental results. Transverse field was expected to be 0.36 T in peak to peak for the solenoid field of 2.7 T.

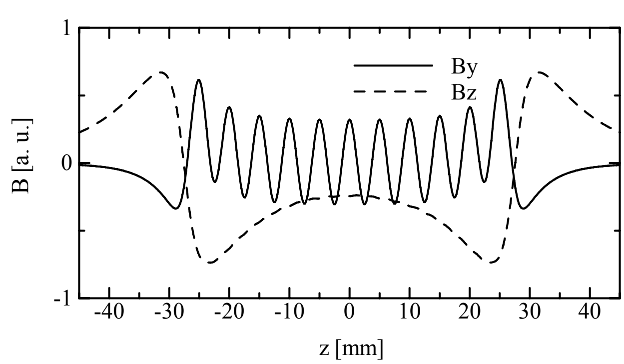

Figure 7: Transverse and axial field distribution obtained by the numerical calculation.

CONCLUSION

The periodic magnetic field was successfully generated with a new structure using bulk HTSC magnets and single external solenoid. Field strength at center of the undulator was 0.0036 T in peak to peak.

In order to investigate the potential of the bulk HTSC staggered array undulator, the numerical calculation using Bean model was also performed. Field distribution along z axis was successfully reproduced. It was expected that the transverse magnetic field of 0.36 T will be obtained by increasing critical current density up to 10^4 A/mm^2.

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