Study of High Magnetic Field and AC Operation of a High Temperature Superconducting Magnet

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The technology of high-temperature superconductor (HTS) has been utilized such as current leads for low-temperature superconducting (LTS) magnets [1]. Only a few magnets, however, have been built using HTS coils in the accelerator field. A HTS magnet has some advantages in principle in comparison with a LTS magnet. Since the HTS system has higher operating temperature than LTS system, a simpler cryogenic system can be used for cooling. In addition, as the temperature range to keep superconductivity is wider than that of the LTS system, a larger thermal margin is expected. Therefore, an Alternating Current (AC) operation can be possible in spite of heating loads due to the AC loss in coils. HTS coils have some engineering difficulties, one of which is wire manufacturing of the HTS materials. Recently, it has become possible to obtain HTS wires larger than 100 m length [2].

We have designed and manufactured two solenoidal coils with a HTC wire [3]. Specifications of the design parameters of the present solenoid coils are summarized in Table 1. The HTS wire consists of filaments of $(Bi,Pb)_2Sr_2Ca_2Cu_3O{-}x$ (Bi2223), in a silver matrix. The tape is 4.2 mm wide and 0.21 mm thick. The critical temperature (Tc) of the material is about 110 K. Each coil consists of two double-pancakes and their inner and outer diameter is 156 and 225 mm, respectively. Each pancake has 146 turns of windings and is 9 mm in height. The critical current (Ic) strongly depends on the coil temperature and on the magnetic field at the coil position. The critical current for the solenoid coil is expected to be about 30 A (1 V/cm, self-field) at 77 K. The rated current was designed to be 90 A at the operating temperature of 30 K.

All design values in table 1 were found to be achieved after fabrication. The critical current was measured in the liquid nitrogen to be 36 and 39 A, respectively, which is even higher than expected. The values of Ic did not change after three heat cycles. The solenoid coils were mounted on the bobbin, electrically connected in series and assembled in a cryostat

Table 1: Design parameters of the HTS-magnet

HTS-coils	Superconductor	Bi2223/Ag tape Total length 360 m
	No. of turns	292 × 2 coils
	Windind construction	4 pancakes/coil
	Critical current expected at 77 K	30 A
	Rated current	90 A at 30 K
	Maximum magnetic field in the coil at the rated current	0.25 T in parallel to tape 0.36 T in normal to tape
Cryostat	Cooling method	Conduction cooling by a G-M refregirator
	Thermal insulation	Vacuum isolation, 80 K shield and super-insulation
	Cooling power of the G-M refregirator	9 W at 20 K, and 18 W at 80 K

[3]. Cooling tests were performed with measuring an ohmic resistance. After about 25 hours cooling time, a transition to superconductor was observed around 105 K which is consistent with the specification, 110 K. Coils and the thermal shields were cooled down to about 10 K and 83 K, respectively. The critical current is estimated to be higher than 200 A at 10 K.

After the successfull operartion as a solenoidal coils, the magnet was converted into a high-magnetic-field dipole magnet with only installing iron poles and a return yoke. The magnetic field measured and calculated by TOSCA code is shown in fig. 1 for the iron-core HTS dipole magnet as a function of a coil current. The magnetic field is saturated more than 50 A. With 197 A coil current, the magnetic field of 2.04 T was obtained. Measured magnetic fields were in good agreement with those calculated. It should be noted that an adequate HTS coil design for high magnetic field allows more intense field with the same ampere-turns.

Figure 2 shows the magnetic fields with coil current on an AC operation. Coils were excited by a homo-pole direct current (DC) power supply in 0.05 Hz. The coil current was controlled from 4 to 115 A with a triangle waveform. The magnetic field ranges from 0.14 to 1.73 T and reproducibility was quite well. No linear correlation of the observed magnetic fields to the coil current is due to saturation of the magnetic field shown in fig. 1. Since the magnetic field well followed up to the current, no significant effects from eddy currents were found. Coil temperature increased less than 2 K after 5 minutes operation.

More rapid cycling tests were also performed. Ramp rate of the magnetic field was observed about 0.5 T/sec at maximum in a 0.25 Hz operation. Present results clearly show that a large applicability of HTS wires to AC magnets, such as scanning magnets for the cancer therapy and high duty synchrotrons, etc. Beam scanning test with this HTS magnet will be carried out this April.

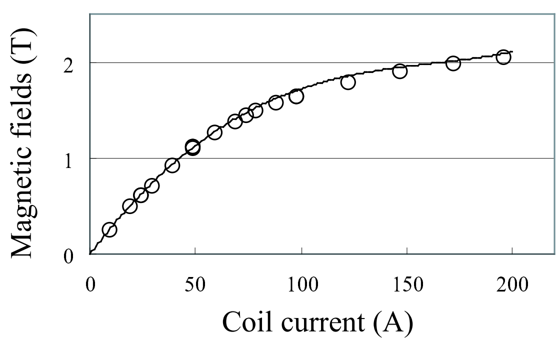

Figure 1. Magnetic fields Bz at the center of the air gap as a function of coil current(circle). Calculated magnetic fields are also shown(line).

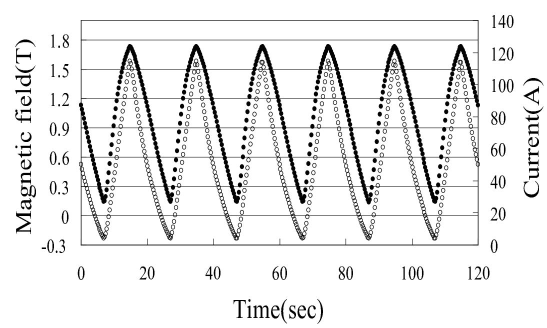

Figure 2. Observed magnetic fields on an AC operation(solid circle). The frequency is 0.05 Hz. Coil current measured at the current lead by a DCCT is also shown(open circle).

References

[1] e.g. L. Tkachenko et al., Proc. Of EPAC 2002, Paris (2002) 2454-2456.
[2] LJ. Masur et al., Proc. of MT-17, Geneva (2001) 1-5.
[3] K. Hatanaka *et al.*, RCNP Annual Report 2002, p141.