Research and Development of Future Radiation Resistant Accelerator Magnets based on High Temperature Superconductors

Masami Iio, Makoto Yoshida, Tatsushi Nakamoto, Kento Suzuki, Michinaka Sugano, and Toru Ogitsu

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Abstract - Research and development of a mineral insulated superconducting magnet based on REBCO coated conductor has been performing at the High Energy Accelerator Research Organization (KEK) to establish technology for a future radiation resistant high field magnet. A goal of the research is an experimental proof of a small-scale demonstration magnet composed of mineral insulated REBCO coils. Application research on ceramic coating technology to REBCO coated conductor is in progress. A short sample study confirms the adaptability of ceramic coating for electrical insulation of REBCO tape. In addition, an electrical insulation film is formed on the surface of a long tape of about 14 m in length by applying the ceramic coating. A small prototype double pancake coil was wound with the ceramic coated REBCO tape using a wet-winding technique with a ceramic adhesive.

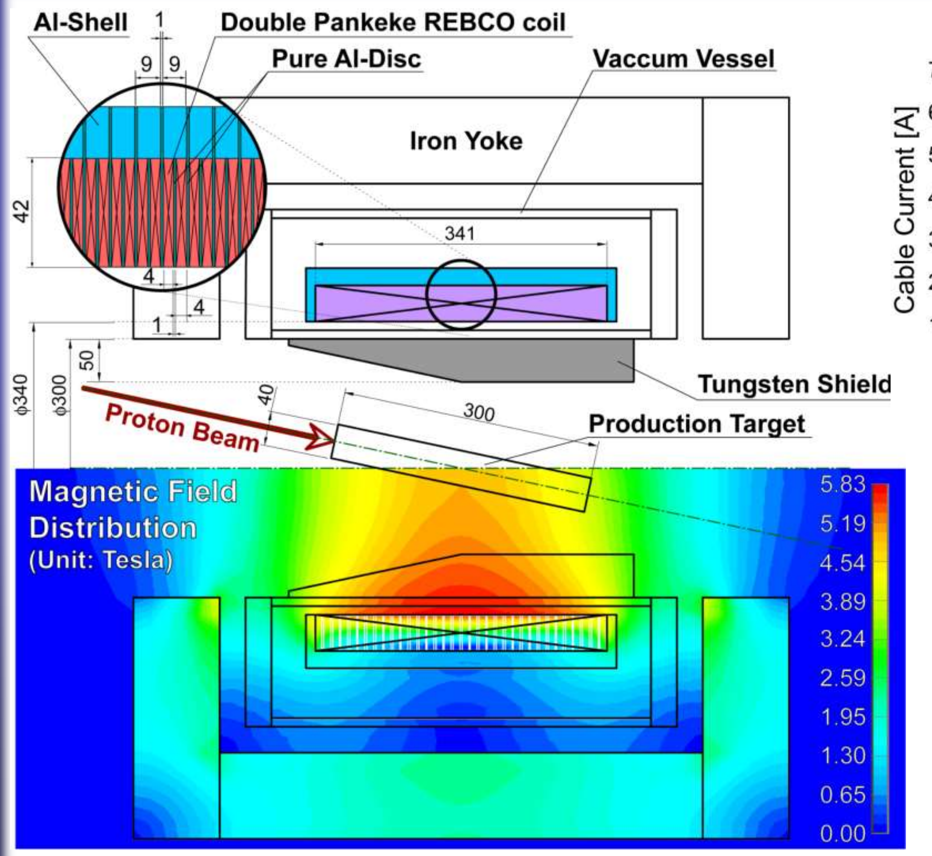
I. Introduction

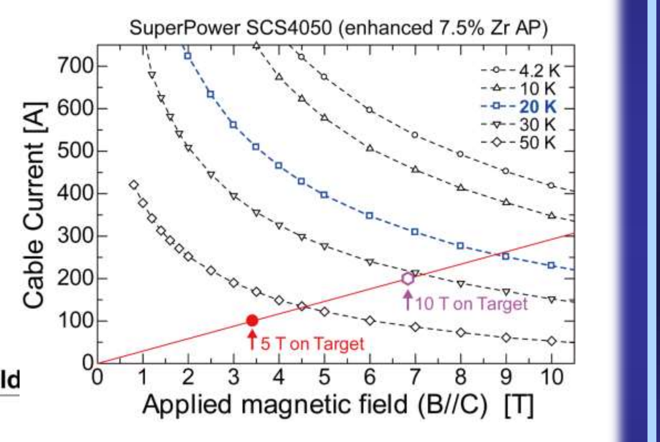
FCC (Future Circular Collider) proposed by CERN requires high field magnets with magnetic fields of approximately 20 T to control the extremely high energy beam. However, NbTi is not able to maintain superconducting state in its magnetic field higher than the critical magnetic field. REBCO (Rare-earth barium cop-per oxide) and BISCO (Bismuth Strontium Calcium Copper Oxide) have a high critical current (I_C) tolerance in high magnetic field, are the most promising candidate. Furthermore, radiation issues are quite important for future superconducting magnets for high luminosity accelerator and high intensity secondary beam line. Although it depends on the structure of the radiation shield, the total dose of the equipment near the collision point of FCC expected to reach several 100 MGy. On the other hand, a construction plan of 2nd MLF facility is proposed as one of the future plans of J-PARC. At the facility, superconducting solenoids are placed just behind the target to maximize the production of secondary particles. The absorbed dose of the superconducting magnet reaches 130 MGy in 10 years and the nuclear heating is roughly estimated to be 650 W.

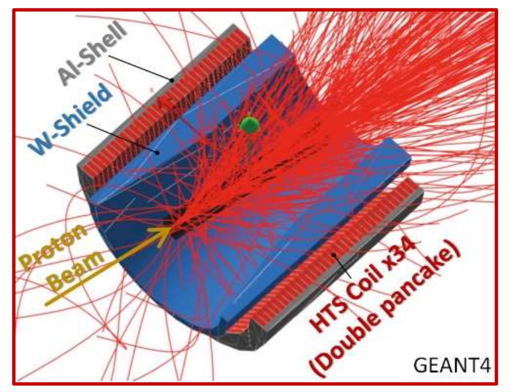
A research and development of radiation resistant magnets based on REBCO with less silver activation than BISCO has been performed at KEK for a feasibility demonstration for mineral insulated superconducting coils. The insulating film formation on the tape surface by ceramic coating and coil fabrications using wet winding technique with ceramic adhesive will be presented in this poster.

II. Demonstration Coil Design

A design study of a compact pion capture solenoid based on REBCO coated conductor was performed to confirm the possibility of application for particle physics experiment under high radiation environment. The specification of the compact solenoid is adjusted to the same performance as a pion capture solenoid using aluminum stabilized NbTi cable for J-PARC COMET experiment currently under construction.

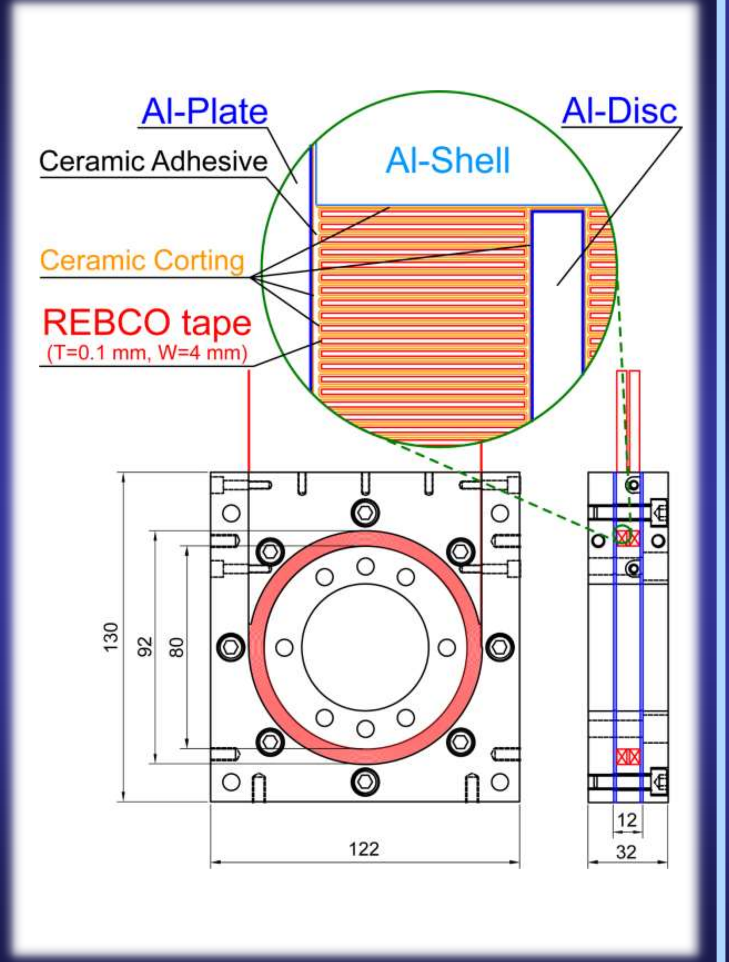






1. Size Reduction :
   1/100 (W= 45 t → 0.43 t)
2. High Temperature Margin:
   T_{max}= 21.6 K
   < T_C=59 K@5 T on Target
   Heat deposit by radiation:
   0.48 W/kg > COMET case
3. High Magnetic Field?:
   5 T (39%), 10 T (78%)

We decided to develop a small-scale mineral insulated coil based on REBCO tapes for feasibility demonstration. The demonstration coil is designed as a circular double pancake with an ID=80 mm and about 30 turns per layer.



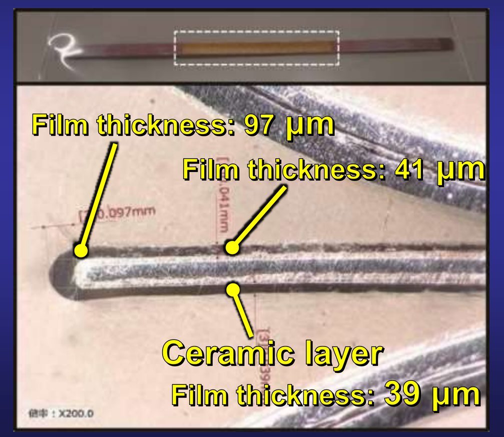
III. Ceramic Coating on Surface of Coil Components

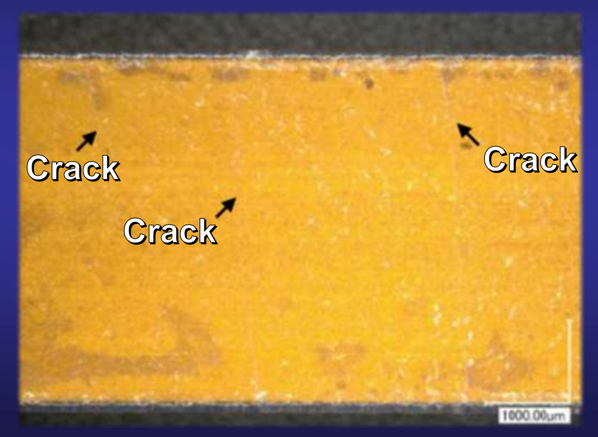
Superconducting properties of REBCO tapes degrades due to evaporation of oxygen in high temperature environment. We have confirmed 10% degradation from heat treatment at 180 ℃ for 5 hours by measuring I_C in liquid nitrogen without an external magnetic field. Therefore, we tried to form a ceramic film on the tape surface by applying a commercial paint using the sol-gel process.

Items	1st Trial	2nd Trial
Base material	**Al** (Al-123 Mg4.5Mn0.7), **Cu** (C-OF R1337), **SS** (L-No6X5CrNi18-9), **REBCO** (SCS4050-AP)	
Coating material	G-92-5 (NIKKEN .Ltd) Al_2O_3 : SiO_2 =1:3	Al_2O_3 : SiO_2 =1:1
Target thickness	50 μm	30 μm, 20 μm, 10 μm
Final heat treatment	180℃, 20 min	100℃, 20 min

A. Surface Coating for REBCO Tapes

Cross-section observation & Surface observation





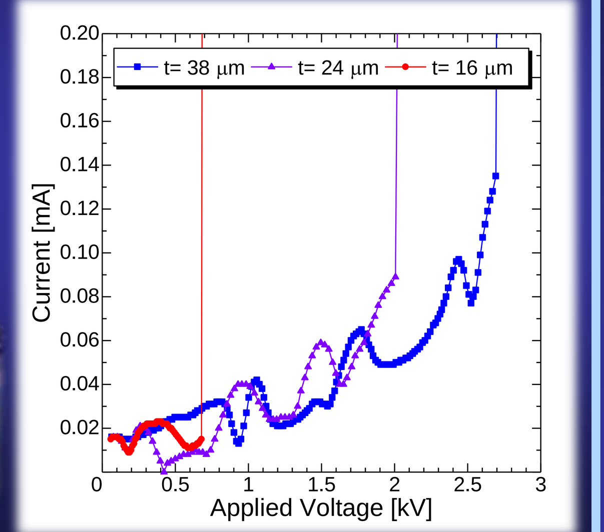
Several cracks are observed at the 1st trial with the target film thickness of 50 μm. There is no crack in the 2nd trial with the target film thickness of 30 - 10 μm and the heat treatment temperature of 100 ℃.

Withstand voltage test

Withstand voltage test by point probe is performed for evaluation of insulation. The load is applied with an AC voltage with a frequency of 50 Hz.

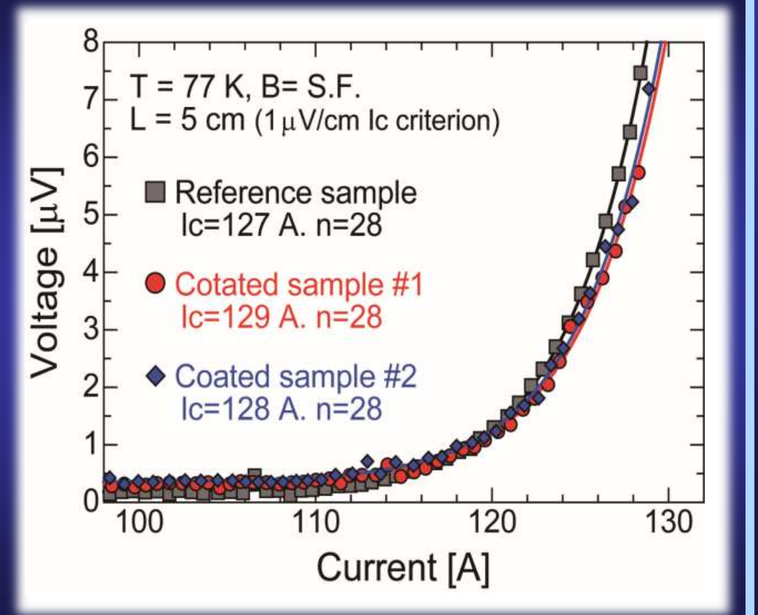
Withstand voltage

- t=16 μm : 0.679 kV
- t=24 μm : 2.006 kV
- t=38 μm : 2.693 kV



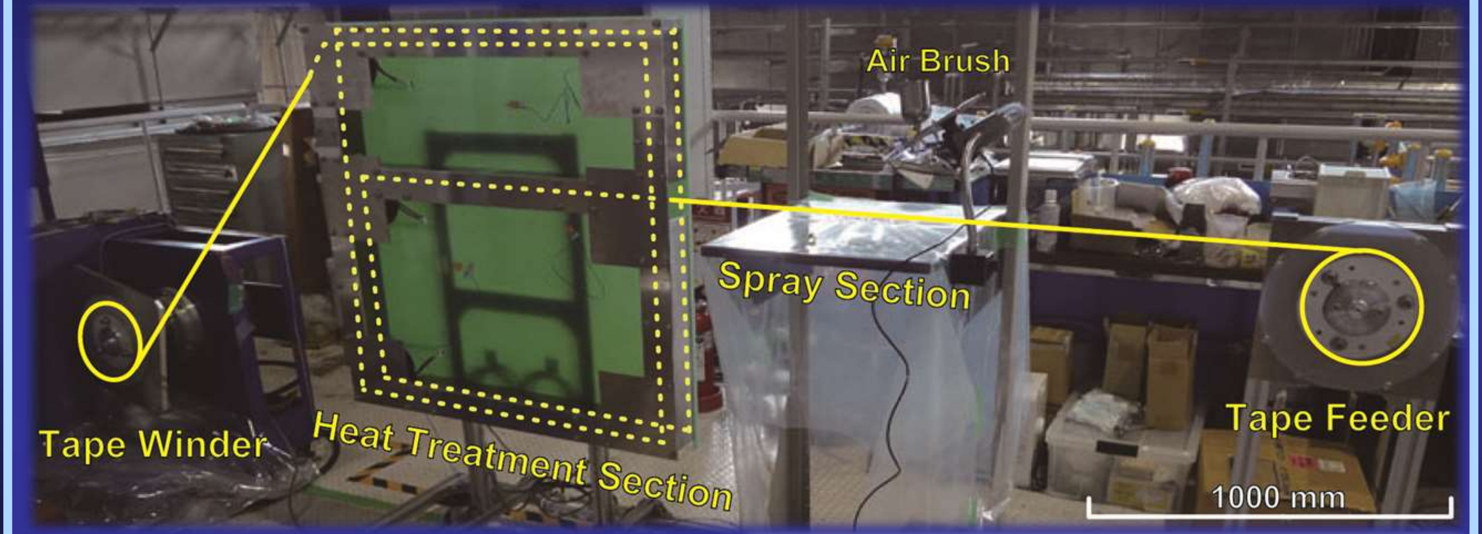
Critical current measurement

I_c of REBCO (SCS4050-AP) tapes coated with ceramics by final heat treatment at 180 ℃ for 20 min is measured in LN_2 without an external magnetic field. There is no degradation of superconducting characteristics. Although the ceramic coated tapes are given a cyclic thermal load between room temperature and 77 K more than 10 times, there is no change in appearance and critical current.

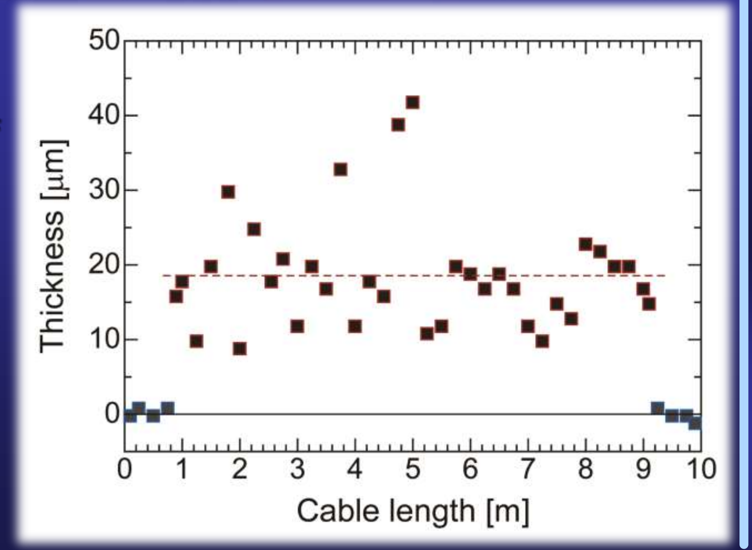


B. Trial of Continuous Coating on Long Tape

The sprayed tape is continuously sent to the heat treatment section where the temperature is controlled by some heaters. The heat treatment conditions optimized for short samples are adjusted by the passage time of a 7.6 m path with 10 pulleys.

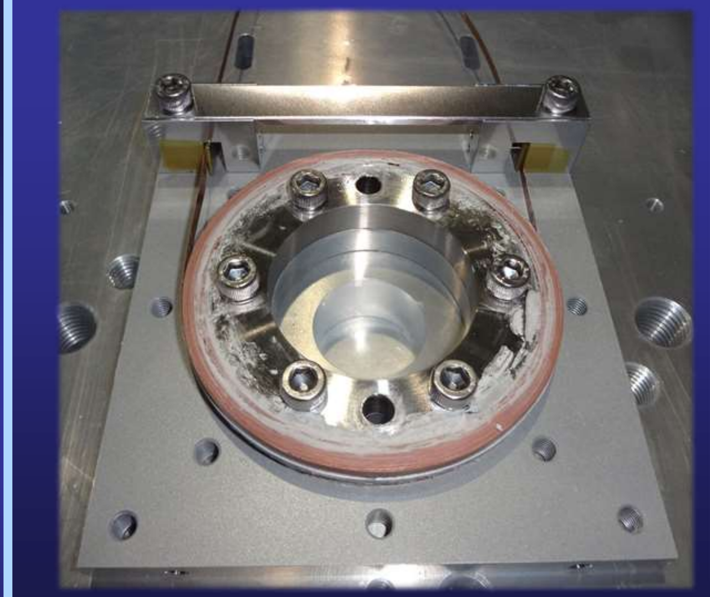


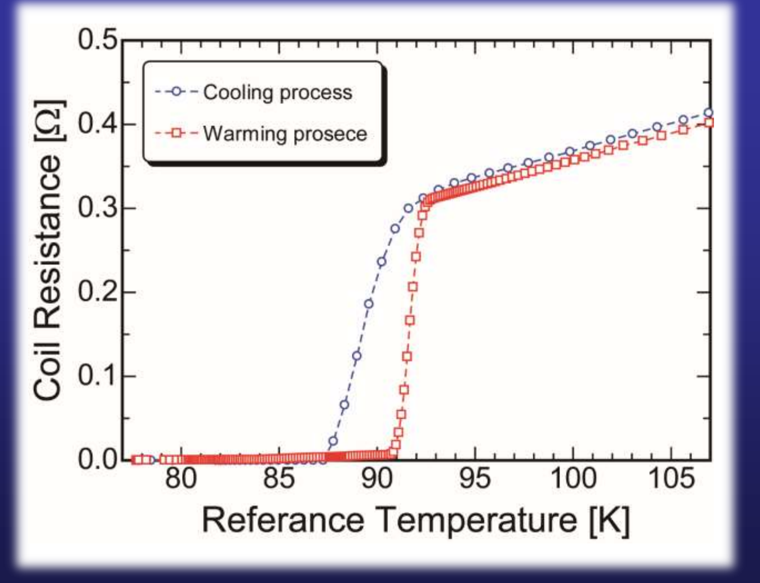
The ceramic insulating film with an average thickness of 19 μm is formed over an 8 m section of long REBCO tape. However, there is a large variation in film thickness due to manual application and tape winding. The quality control by automation is essential for tapes longer than several tens of meters to wind practical coils.



IV. Winding of Demonstration Coil

A 14 m long REBCO tape with ceramic coated on both surfaces using the reel-to-reel system is used for the winding. Aron Ceramic type C made by Toagosei Co., Ltd. is adopted as the ceramic adhesive for the wet winding. Complete curing of the adhesive requires a heat treatment at 90 ℃ for 1 hour and then at 150 ℃ for an hour after drying at room temperature for 16 hours. The coil is fabricated to wind the tape around a stainless steel center bobbin ceramic coated on the tape contact surface with a target film thickness of 50 μm. We succeeded in fabricated a seamless double pancake circular coil for the first layer of 26 turns and the second layer of 24 turns in the first winding trial. The electrical resistance disappearance of the coil cooled with LN2 is clearly observed due to superconducting transition in the temperature region below 100 K.





V. Summary and Future Prospects

- Research and development of mineral insulated coils based on REBCO has been performing for future radiation resistant high field magnet applications.
- Trials of ceramic coating using the sol-gel process succeeded in forming an insulating film reaching a withstand voltage of 2 kV with a thickness of 30 μm on the surface of REBCO tape. No degradation of the critical current characteristics of the coated tape is observed.
- 14 m long REBCO tape is continuously coated with ceramic by a reel-to-reel heat treatment system. The Quality control by automation is essential for tapes longer than several tens of meters.
- A first small-scale demonstration coil is wound using wet winding technique with ceramic adhesives. The double-pancake circular coil with 26 turns first layer and 24 turns second layer shows a superconducting transition in a cooling test with liquid nitrogen.
- Fabrication of small circular coils will continue to optimize coil structure and verify the possibility of conduction cooling.
- A racetrack coil with about an inner diameter of 220 mm and a length of 560 mm will be developed after the feasibility study of mineral insulated coil. The racetrack coils will be tested in a high magnetic field in a test stand with common coil configuration using A15 coils.

Acknowledgments

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