FIRST EXPERIENCE OF THE HTS-II DIPOLE TYPE MAGNETS DEVELOPMENT AT NIIEFA

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Abstract

The possibility to design, manufacture and test the dipole type magnets from the second generation high-temperature superconductors (HTS-II like YBCO and ReBCO) was demonstrated at the Efremov Institute. The paper describes available computation techniques, design approaches and manufacturing equipment, which could be used to meet the modern requirements for the magnets of accelerators, research equipment, magnet levitation systems etc. The manufacturing equipment comprises the winding lines and insulating devices to provide different configurations and insulating schemes of coils. Additionally, an equipment to produce the Roebel-cable for high current applications was procured and put in operation. As an example, the results of development of the HTC-II dipole type magnets for the different kind dummies of maglev systems are presented. The ReBCO tapes produced by JSC "SuperOx" (Moscow) were used. Up to 0.5 T magnets cooled by liquid nitrogen were designed as a part of levitation system consisting of permanent, HTS-II and normal conductive magnets. Comprehensive tests verified the computation results and demonstrated the readiness to develop HTS-II dipole magnets under the customer requirements.

INTRODUCTION

Over the last fifty years the Efremov Institute holding leading position in design and production of large-scale superconducting magnets was successfully developing low temperature superconductor technology (LTS). However, progress in high temperature superconductivity (HTS) urged the Efremov magnet department to apply considerable efforts to that new area. Starting with measurements of YBCO monocrystals [1], and testing HTS-I current leads it gradually turned to HTS-II tapes, cables and windings. When looking at the critical characteristic of the ReBCO tape (Fig. 1), three specific regions of HTS application could be distinguished:

- Low temperature and high or extra high field – magnets for NMR spectrometry.
- When operating temperature ranges from 20 to 40 K, the HTS can replace LTS in their traditional 5 to 15 T applications – dipoles, magnetic lens etc.
- Low field and LN temperature (the most attractive region from cryogenic point of view) – current leads, power cables, small coils (<0.5 T), bias coils for electromagnets etc.

Some aspects of the work, which seem prospective for accelerator magnets, research equipment, levitation systems and other applications, are reported below.

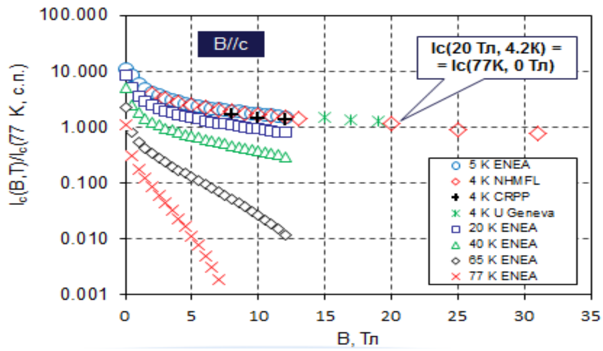

Figure 1: Critical characteristic of ReBCO tape.

WINDING AND INSULATING EQUPMENT

The HTS-II conductors suitable for coil winding are thin multilayer tapes. Typical dimensions of the tape are - width from 4 to 40 mm and thickness for 40 to 600 µm. A special insulating and winding equipment is needed to handle such a delicate conductor. The necessary equipment has been designed, manufactured, procured and put in operation in the Efremof Institute. The equipment allows winding of round, racetrack and saddle-shape coils up to 1.5 diameters. It can work with tapes, flat cables (Roeble or Rutherford type) and round wires with thickness ranges from 10 µm to 1.5 mm. The winding machine can get wire supply form nine delivery spools, so it can perform winding following "n-in-hand" technique. The optimal n in this scheme is two or three "elements", where an "element" is a composition of two or three tapes, for example, HTS tape, hastelloy tape and insulation tape. The machine can produce a pulling force up to 12 kg per spool. When performing racetrack or saddle winding the pulling force should vary with angle of the spin-table rotation. A special system controls the machine operation and the pulling force variation can be pre-programmed. Main parameters of the winding process are set form the touch panel and displayed at the monitor of the control console. The winding machine is shown in Fig. 2. At the rotating table in Fig. 3 is a coil in process of winding and assembly. The coil is 400 mm round section of the SMES model. It is designed to operate at

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20- 40 K and carry current over 600 A. The coil can work in liquids or be cooled by thermoconduction.

Figure 2: Winding machine at work.

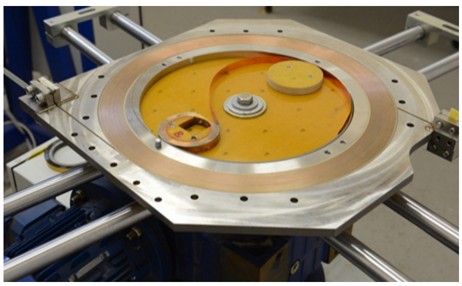

Figure 3: Pancake winding for HTS-II SMES.

FLAT TRANSPOSED CABLE WITH HTS-II STRANDS

While small coils and lab magnets can be wound with tapes carrying hundreds of amperes the large-scaled magnets require conductors with higher currents. Among the current carrying elements made of HTS-II tapes a flat transposed cable of Roeble-type seems the most compact and applicable for the purpose. Equipment to manufacture a flat transposed cable has been deigned, produced, procured and put in operation. It includes a punching machine (press) for cutting a meander shaped elements ("strands") and a planetary winding system to put the elements into a cable. The punching machine can produce strands up to 400 m long from 12 mm wide tape. The machine cuts strands from a bare (without stabilizing Cu) tape. Then bare strand goes to Cu electroplating. Usually thickness of the plated layer is about 20 µm. The Cu-plated strands should pass the Jc control and go to cable winding. A planetary winding system can produce up to 400 m cable with number of strands up to 26. Punching and planetary winding machines at work are shown in Fig. 4.

A short sample of Roeble cable (Fig. 5) has been produced and tested in LN. The cable was 3m long and consisted of 10 strands. Special design of the sample joint ensured uniform current distribution among the strands. The sample has shown the value of the critical current Ic (77 K, s.f) close to 1100 A.

Since current at the HTS–II tape flows through a thin 1 - 1.5 µm ReBCO layer a number of effects can be observed in cables and windings. A mathematical model has been developed to simulate characteristics of the complex tape-like current carrying elements [2]. The model allows performing analysis of the fine structure of magnetic field with a very good accuracy.

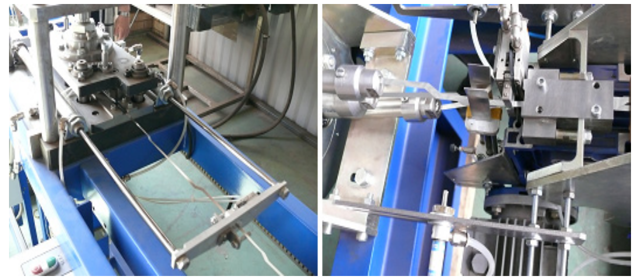

Figure 4: Punching (press) machine (left) and planetary winding system (right).

Figure 5: Insulated Roeble-type cable.

LN COOLED HTS-II COILS FOR MAGNET LEVITATION

A computation technique developed in the Efremov Institute for electromagnetic simulations of various devices related to accelerators, particle physics and fusion has been adapted for modeling and optimization of the maglev transport systems. Different principle types of maglev system have been analyzed [3-6]. The 3-D model gives detailed description of eddy currents, electromagnetic load, includes edge effects, takes into account all important elements and structures and can simulate various scenarios and regimes of vehicle motion. For verification of the modelling results and experimental check of electrodynamic suspension (EDS) performance a maglev dummy has been built. The dummy allows simulating distribution of electromagnetic force similar to that at the maximum vehicle velocity. The maglev dummy includes a guideway – stationary structure constructed from blocks of permanent magnets and a "vehicle" – suspended platform with a pair of permanent magnets or HTS blocks. The HTS block is shown in Fig. 6. It consists of the HTS-II racetrack coil placed into a compact cryostat. The coil – two-sectioned winding with dimension of 480×170×9 mm, made of 4mm insulated ReBCO tape was cooled with LN (77K). The coil winding was performed with insulation and winding equipment described above. The HTS blocks assembled at the platform have been successfully tested [7]. It should be mentioned that presence of permanent magnets, ferromagnetic materials and coils makes system non-linear and pooling force acting on the block in a complicated way depends on levitation gap and coil

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current. A specially designed feed-back system was responsible for gap and current control and coil positioning. During the tests, HTS blocks were exposed to magnetic field equivalent to that of a real EDS system and have shown stable performance at nominal and maximum current up to 55 A. The module during the test is shown in Fig. 7.

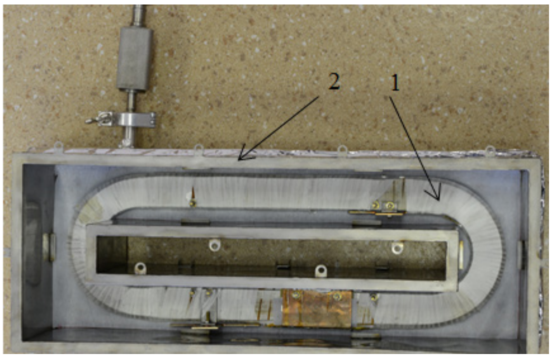

Figure 6: HTS-II block: racetrack coil (1) fixed into a compact cryostat (2) – double-wall stainless steel box providing vacuum insulation for the block.

Figure 7: The HTS-II module during tests: maximum levitation gap ~ 40 mm; total current – 14 kAt; total weight of the platform (two HTS blocks with cryostat filled with LN) – 48 kg.

The HTS-II coils are employed as support- magnets in the model of electromagnetic suspension (EMS) system, which is a part of combined magnetic suspension concept [3-6]. A schematic view of the test facility is given in Fig. 8.

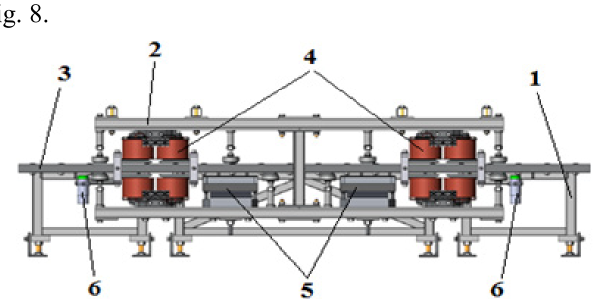

Figure 8: Facility to test elements of EMS system as a part of combined magnetic suspension concept: 1 – carrying frame; 2 – levitating platform; 3 – ferromagnetic guides; 4 – electromagnets; 5 – support- magnets; 6 – gap sensors.

A HTS-II coil replaces a block of permanent magnets. The coil current should remain constant or change slowly when operating. The coil for that model is a three-sectioned winding made of 12 mm tape, placed into a compact cryostat and assembled at the ferromagnetic core. Coil winding and magnet assembly is show in Fig. 9 Two coils have been successfully tested in LN: the coil current reached 120 A and pulling force was over 50 kg.

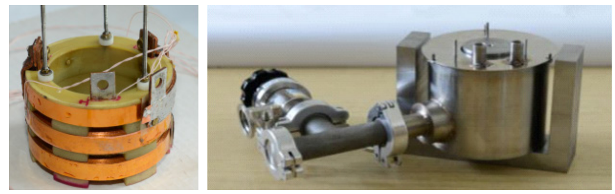

Figure 9: HTS-II support- magnet: HTS coil and assembly (coil, cryostat on the ferromagnetic core).

CONCLUSION

All necessary components to design and build HTS-II dipole magnets are concentrated in the Efremov Institute: the team of professionals able to perform a comprehensive analysis and numerical simulations of electromagnetic, mechanical and thermo-hydraulic processes and carry out design and technological support of the projects, modern engineering equipment, technology and mechanical production. The experimental equipment and test facilities allow conducting a wide range of research works from wire characterization to life test of the machine.

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