SUPERCONDUCTING TRANSFORMERS FOR STUDY OF HIGH-CURRENT SUPERCONDUCTING CABLES

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Abstract

A facility for measurement of the critical current and minimal quench energy of Rutherford-type superconducting cables for accelerator magnets is created. The current in the sample is energized by a superconducting transformer circuit, using an inductive method, where the sample conductor is a part of the secondary circuit. Two superconducting transformers have been built; one of them is a solenoid type coil. The transformer consists of two concentric solenoids; the secondary coil is placed inside the primary coil. External magnetic field up to 6.5 T is provided by a superconducting solenoid with the aperture diameter of 60 mm. The second superconducting transformer with race-track coils has been designed and taken into operation. Short-circuited sample, fixed on a special holder, is placed in the aperture of a superconducting dipole magnet such way that the plane of sample loop is perpendicular to direction of external magnetic field, which can reach up to 6 T. The critical current of the secondary superconducting coil is 18 kA. The equipment for measurements of characteristics of a superconducting cable versus magnetic field is described.

INTRODUCTION

One of the main tasks in a development of superconducting magnets is measurements of current carrying characteristics of a superconducting (SC) cables and wires. Some equipment for measurement of the critical currents and minimal quench energy (MQE) has been development and produced in IHEP.

A direct powering of the sample by a power supply causes high losses in current leads at a level of 10 кA, what leads to large losses of liquid helium in a cold zone. The inductive method of a current input is applied for reduction losses of liquid helium and achievement of high values of currents in samples.

The description of the SC transformer design, with a help of which a study of SC cables with different coating of SC wires has been carried out, is presented in [1]. The hairpin sample and the secondary winding of transformer are fixed on the cryostat insert, can be placed into the cryostat with liquid helium, where the superconducting solenoid and primary transformer winding are fixed stationary, thus allowing one to make a fast replacement of the sample. This equipment allows one to measure characteristics of usual Rutherford type cables. The current carrying element with the stainless steel core between two layers of Rutherford type cable (cored cable) [2] will be used for the SC coils of quadrupole magnets of the SIS 300 ring [3]. New equipment, developed and produced in IHEP, gives a possibility to study samples of different types of SC cables in an extended region of uniform magnetic fields.

Two designs of SC transformer are tested; one of them consists of solenoid coils. One of them is used a SC dipole for a creation of an external field, another one is based on a solenoid magnet.

TRANSFORMER WITH RACE-TRACK COILS

The design of equipment is shown in Fig.1 and its basic parameters are presented in Table 1. An external magnetic field with an enough large region of homogeneity is necessary for study of SC cable characteristics. From the technological reasons this magnetic field is created by SC dipole, placed into the boiling cryostat.

The part of the sample, which is being studied, is the secondary coil of the SC transformer. The measuring section of the sample is fixed in the holder at the length of 830 mm under the pressure 80 MPa. The secondary SC contour has one joint, located above the coils. The detachable insertion is put and fixed in the aperture of the dipole with a diameter of 80 mm.

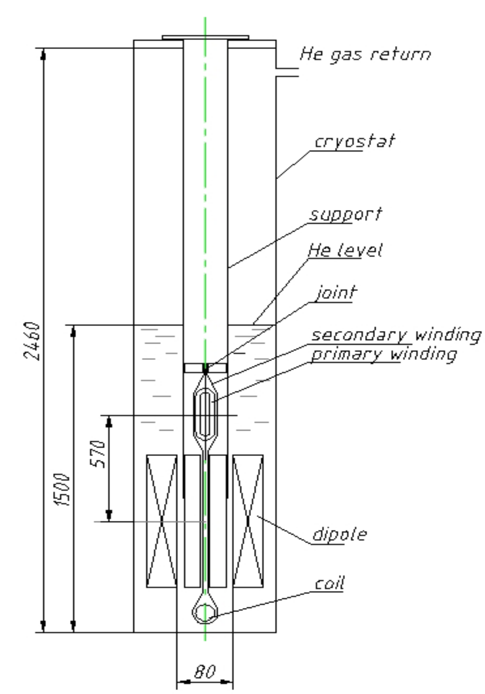

Fig.1. The general view of the equipment with SC dipole.

External magnetic field up to 6 T was created by the 1-m model of SC dipole, produced within the framework of the UNK program. The longitudinal length of the coil is 740 mm. The design of the coil block is presented in [4]. The iron yoke with a length of 500 mm was produced in order to increase the maximum magnetic field. Complete cryogenic tests have been carried out, including magnet training, the measurement of ramp rate dependence and AC losses. The longitudinal distribution of a field inhomogeneity in the dipole at radius of 30 mm is presented in Fig. 2 for the magnet with (+) and without (-) iron yoke. The point of origin coincidences with the dipole centre. It is seen the region of longitudinal 4% uniform field is 520 mm.

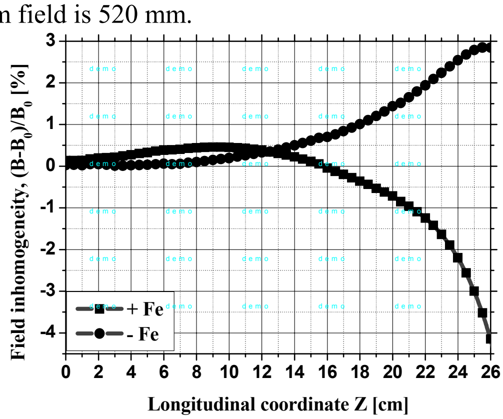

Fig. 2. The longitudinal distribution of a field inhomogeneity in the dipole at radius of 30 mm.

The magnet training was enough short and it consisted of 10 inputs of current at a rate of 100 A/s to quench. The first quench took place with the current of 6 kA (the transfer function is 0.98 T/kA), the maximum central field at quench current of 6.739 kA was 6.604 T.

Fig.3. The photo of the equipment.

The induction method of a current powering with a help of the SC transformer is used for an achievement of high values of current in the studied SC sample.

The design of the SC transformer is based on the equipment with the coil of the type race-track[5]. The primary coil of transformer contains 260 turns of the multiple strand superconductor with a diameter of 0.85 mm and has a straight part length of 230 mm. The studied cable with an overall length of 2.7 m uses as a secondary coil. It gives a possibility to use only one joint in the secondary circuit, which is placed above the transformer. The induction coil is used for the current measurements. This coil contains about 4 thousand turns of the copper wire with a diameter of 50 μm, wounded around the coil former, made from the fiberglass. The measuring circuit was calibrated by help of the direct powering SC sample with stabilized currents up to 800 A. During the calibration the voltage from the output of the analog integrator, connected to the output of induction coil, was measured in the dependence on the current in the sample.

Further the tests of SC transformer were carried out in the small cryostat with the short (less than 1 m) model of the SC cable, which was as a secondary winding. The maximum current of the primary coil was 220 A, it is possible to obtain the current above 18 kA in the secondary SC coil. The coefficient of the mutual inductance of the transformer coils was 33 μH, its own primary inductance was equal to 8 mH. Only one joint in the secondary circuit was produced by soft solder at the length of 75 mm and provides the decay time-constant of the current of secondary circuits above 100 s.

Then SC transformer was fixed on the changeable stock together with the sample. The stock was placed in the aperture of SC dipole and was fixed in the holder in order to exclude displacements. The details of the preparation of SC samples and the basic results of measurements are given in [6].

TRANSFORMER WITH SOLENOID WINDINGS

An external magnetic field in this transformer is created by SC solenoid. The primary solenoid coil and the external solenoid are fixed in the small cryostat, as it is shown in Fig. 4. The secondary coil together with the sample is fixed on the changeable stock, which is put into the cryostat. The measuring 40-mm length section of the sample in the shape of a hairpin is located in the centre of the external solenoid, which creates magnetic field up to 6.9 T.

The total length of the sample is 450 mm. It is possible to reach above 15 kA in the secondary circuit using bipolar power supply in the primary circuit. The operating current in both the external solenoid and the primary coil is not exceeding 100 A, which gives enough low expense of liquid helium.

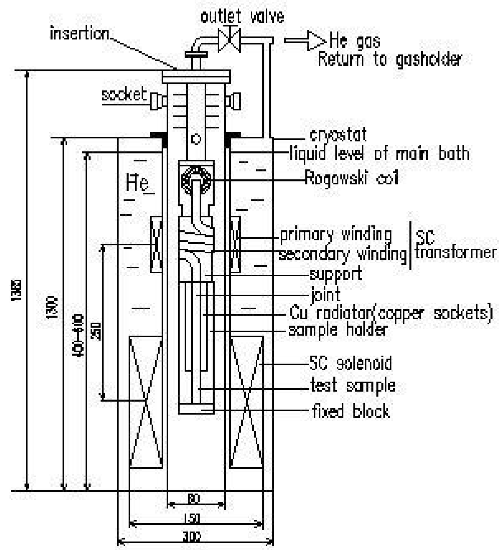

Fig.4. Scheme of equipment with SC solenoid.

The general view of the equipment is shown in Fig. 5. The suspension of SC solenoid and primary winding of the SC transformer are prepared before their arrangement in the cryostat with the neck of a 300-mm diameter.

Fig.5. The general view of equipment with solenoid coils

This equipment was used for measurements of cable samples with different coating of wires [7]. The overall dimensions of this equipment allow one to measure short samples of cables with total length lesser then 500 mm and measuring section does not exceed 40 mm.

The equipment with SC dipole gives a possibility increasing of the measuring section up to 500 mm, which heightens instrument sensitivity. The developed facility can be used for study characteristics of high current cables up to 20 kA. For comparison the main parameters of two designs of SC transformers are presented in Table 1.

Table 1: Main of parameters of the SC transformers.

Type of coils	Race-track	solenoid
Arrangement of the SC coils	The primary coil is inside the secondary coil	The primary coil is outside the secondary coil
Number of turns in primary coil	260	960
Diameter of NbTi wire, mm	0.85	0.5
Self-inductance, mH	8	45
Maximal current of the primary coil, A	220	100
The conversion ratio	84	75
Maximal current of the secondary coil, kA	18.6	15.3

CONCLUSION

The facility is developed and created in IHEP for study samples of high current SC cables on the base of the two types of SC transformer and diverse magnets for generation of an external magnetic field. This equipment is used for measurements of the critical currents and minimal quench energy for different types of cables.

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