STABILITY STUDY OF HIGH-CURRENT SUPERCONDUCTING CABLES FOR ACCELERATOR MAGNETS

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Abstract

One of the main requirements to superconducting magnet is its stability, what can be estimated by means Minimum Quench Energy. MQE of Rutherford-type cables with different resistive coating of composite Cu-matrix NbTi multifilament strands has been measured. The equipment for MQE measurements of short cable samples versus magnetic fields is described. Current through the hairpin sample is created by superconducting transformer; the critical current of the primary winding is 100 A, which allows one to measure MQE of short samples at currents up to 15 kA. Current through the sample is measured with help of Rogowsky coil and integrator. In order to generate the heat disturbance in samples, the miniature heaters are used. The energy, released in heater, is changed step by step consecutively and the threshold energy, which causes quench (i.e. MQE), is found by this way. We measured dependencies of MQE upon the sample currents as well critical currents for the superconducting cables in magnetic fields up to 6.5 T. Experimental study of MQE was performed for 19-strands transposed cables, consisting of 0.85-mm diameter wires with natural oxide, Ni and Cr resistive coatings. A computer code for calculations of MQE in a cable has been created.

INTRODUCTION

One of the main requirements to superconducting (SC) fast-cycling dipoles is its stability. The stability of SC magnet can be estimated by means of a minimum quench energy (MQE). At present GSI, Darmstadt, Germany plans to build the new international Facility for Antiproton and Ion Research (FAIR) [1].

In the frame of collaboration between IHEP and GSI the series of designs of fast cycling SC dipoles for SIS300 accelerator have been developed. The results of a study of experimental and calculated differences between straight and bent dipole coils were shown [2]. The next step consists of manufacture and test of the 1-meter SC dipole model with the parameters of the last developed design.

The cable for these dipoles must have low losses and produce acceptable field distortions during the fast ramp. Data for optimization of the cable design for the SIS 300 are presented in paper [3]

Thermal stability for SC fast-cycling dipoles will play a vital role. We measured processes in Rutherford SC cables during the initiation of a quench by help of the tip heaters.

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Experimental study of MQE was performed on 19-strands keystoned transposed (transposition length Lp = 62 mm) cable, where NbTi 0.85-mm diameter wires have Ni or Cr resistive coating.

The cable, made from uncoated wires with natural oxide on surface, was measured too. Cu/NbTi ratio in the strand is 1.4; critical current density is 2.36 kA/mm^2 (5 T, 4.2 K). Cable samples were heated during ten minutes at 190 C under pressure of 60 MPa that corresponds to coil curing regime of a SC magnet. Experimental values of MQE were obtained in magnetic field up to 6.5 T for different currents through the cable sample. External magnetic field is generated by SC solenoid with maximal field of 6.75 T in 60 mm aperture.

Measuring part of cable sample with 40-mm length is pressed up to 60 MPa in a special fixture and immersed into liquid helium bath in the aperture of SC solenoid, by such way, that the wide side of the cable is perpendicular to magnetic field.

GENERAL DESCRIPTION

The design of device is given in Fig.1 and its basic parameters are presented in Table 1.

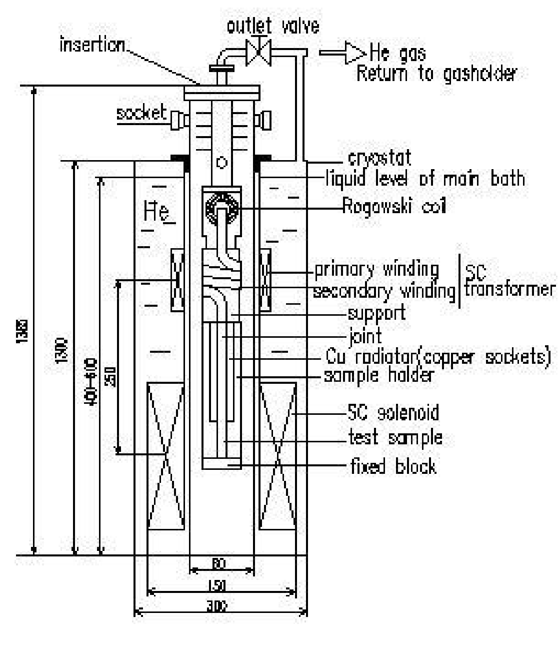

Fig.1: The general view of the device.

At achievement of current-carrying capacity of a superconducting cable of a level 10 кA, the customary method of input of a current from the external power source becomes impractical because of large losses of liquid helium in a cold zone. The inductive method of input of a current is applied for reduction losses of liquid helium and achievement of high values of a current in investigated SC-samples. Current through the sample is created by SC-transformer like [4], which provides current in secondary coil up to 15 kA at primary coil current change +/- 100A.

Table 1: The main parameters of the SC-transformer and SC-solenoid.

Parameter	SC-transformer		Solenoid
Number of turns	960 (I-winding)	3 (II- winding)	10362
Coil length, mm	48	40	200
Outer diam., mm	88	44	150
Inner. diam., mm	66	40	65
Self-inductance	45 mH	0.6×10^{-6} H	3.6 H
Max. current	100 A	15.3 kA	122 A

With the purpose of doubling maximum currents of a secondary SC-contour the original technique of two-polar operational mode of the power source is applied. In a primary winding of the SC-transformer the maximum current capacity (in our case, it is 95 A) is entered, then the heater, arranged on a top of a secondary winding of the transformer, is actuated. The heater (as which one was used a resistance strain gauge with resistance 100 Ohm) transfers a secondary SC-contour in a normal condition and promotes destruction of residual currents.

Descending a current of a primary winding to zero point and subsequent input of a current of an opposite direction follows further, that allows to reach in a secondary circuit a current, twice above, than at usage of the unipolar power source. The given technique of input of a current allows carry out measurement of critical currents of a miscellaneous direction in a superconducting sample by time code control of the form of a current of a primary winding of the transformer and actuation in the definite moment of the heater of a secondary winding of the superconducting transformer. Current through the sample is measured with help of Rogowsky coil and integrator.

Power supply is controlled from a functional generator Agilent 33200A, in memory which one the signals of the special form ensuring the necessary form of a current are recorded. High-sensitivity multimeter Agilent 34420A is optimised for low-level measurements combines low-noise and it is operated for measurements of voltage on a sample at measurement of a critical current of a SC-cable. Results of measurements the critical current of a SC-cable versus magnetic field and calculated values for 19-wire transport current sum are shown in Figure 2.

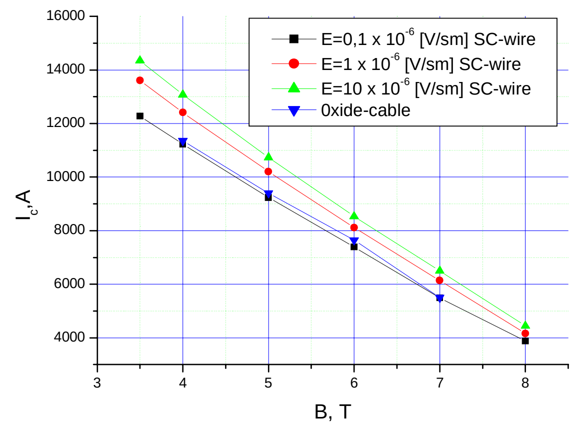

Figure 2: The dependences of measured quench current Ic(B) for cable with wires oxide coated on magnetic field. The dependences of product 19 x I_c(E) are shown for comparison, where value I_c(E) – critical current of single wire, measured by direct method of input of a current from the external power supply and registration voltage-current curves.

MQE MEASUREMENTS AND CALCULATIONS

In order to generate the heat disturbance in samples, the miniature heaters (like [5]) were used. Such heaters are formed on the surface of certain single wires by following way: approximately 0.6x0.6 mm^2 cut out is made in the cable insulation and than this hole is filled with carbon paste Epotechny E300. Thin copper foil strip is placed over heater and it serves as a current lead. The strand is used as a return current lead. The resistance of such heater is about half Ohm at 4.2 K.

When current achieves desired value, the short electric pulse from power supply feeds the heater. Pulse duration is 50 μsec, but amplitude is controlled. It is well known the MQE remains constant, if duration of energy pulse is (50 - 100) x10^{-6} sec [6]. Voltage drop across the heater and voltage, proportional to heater current, are measured by digital oscilloscope, then the heater energy is calculated. The energy, released in heater, is changed step by step consecutively and the threshold energy, which cause quench (i.e. MQE), is found by this way.

The dependencies of MQE functions of the currents are measured for the cables with Cr, Ni and natural oxide coating of the wire surface in different magnetic fields. This measurement was performed in the external magnetic field up to 6.5 T. The measured dependencies of MQE upon the current are presented in Figure 3 for the cables with Cr coating on the wire surface in different magnetic fields.

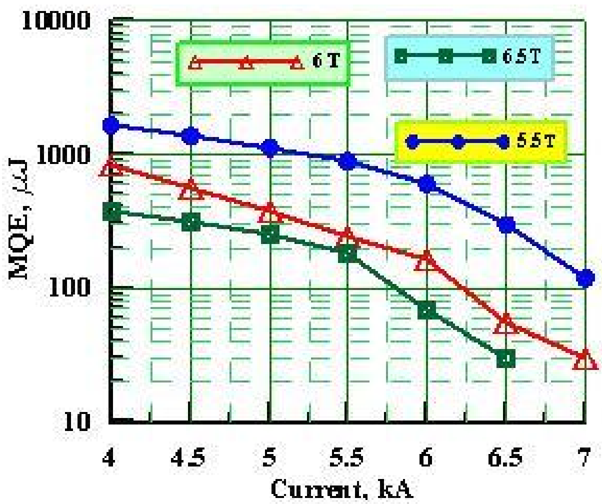

Figure 3: Measured MQE versus current for cables with Cr coating in different magnetic fields.

Calculations of MQE in Rutherford cables are complex and require detailed non-linear multiphysics models. A computer code for analysis of transient processes during the initiation of a quench in Rutherford cables has been developed. For the coupled numerical simulation of electromagnetic and thermal processes in Rutherford superconducting cables. The code is based on simultaneous numerical solution of the equations of thermal conductivity for strands of cable, the energy equation for helium in cable and network model. This code is described in [7].

Figure 4 shows the calculated and measured values of MQE versus function of the normalized current I/I_C, where $I_C(B)$ - is the critical current in magnetic field B=6 T. There is an agreement between calculations and experimental results with coefficients for heat transfer between strands x = 500 $W/m^2/K(1+b)$, b = 2 and for transient heat transfer with α_{trans} is 200 $W/m^2/K^4$ [7]. Cables with resistive coatings have sufficient stability.

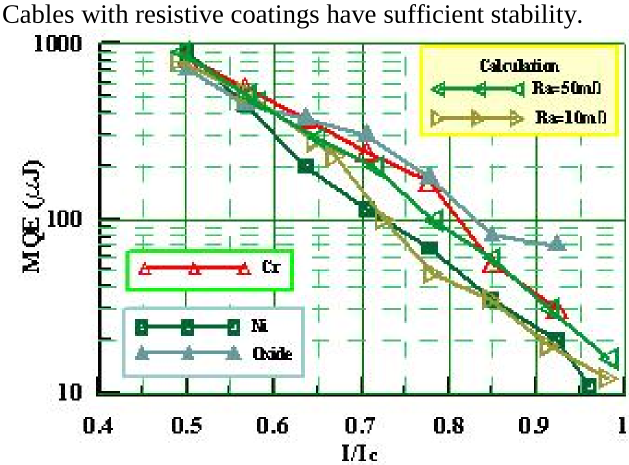

Figure 4: Calculated and measured values of minimal quench energy (μJ) versus ratio I/I_c.

The crossover resistance R_C of cables was also measured [8].

CONCLUSION

The apparatus for MQE measurements of high-current (up to 15 kA) SC cables were created to study short samples in magnetic fields up to 6.5 T. Transient non-linear numerical model was developed. This research showed that cables with studied coatings of strands have sufficient stability.

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