STABILITY OF SUPERCONDUCTING WIRE IN MAGNETIC FIELD

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Abstract

A fundamental experiment was carried out to study the motion of superconducting wire under the influence of electromagnetic force. Experiments were conducted at 4.2 K by varying the experimental conditions such as applied tension to test superconducting wire, insulating material used at the interface of superconducting wire and base material. The experimental method and the test results are reported in this paper.

INTRODUCTION

The main factor of instabilities of the high field superconducting magnet coils is the abrupt and local wire motion and thus generating frictional heat during the current ramp. The wire motion occurs where electromagnetic force to conductor exceeds frictional force on surface of the conductor. Hence, frictional properties of the conductor and winding structure are important parameters for characterizing stability of the superconducting windings [1]. Kinsley and Iwasa [2] have made a detailed study to observe sliding behaviour at 4.2 K, 77K and 295 K for a number of polymers, laminated composites and coated pieces sliding against either copper or aluminium. Largest and potentially most harmful source of frictional heating is at the position where superconducting wire rests against structural insulating material. A fundamental experimental setup was prepared to observe the effect of insulating material used at the interface of superconducting wire and base material under the influence of varying electromagnetic force. A high magnetic field of 6 T was provided by a superconducting solenoid magnet and current up to 128 A was feed to the test superconducting wire. The voltage generated due to single wire motion under the electromagnetic force is reasonably enough to measure. Thus, enable us to measure directly the wire motion. The wire motion is detected by spike in voltage V of the test superconducting wire. The test set up consists of a high field superconducting magnet, power supplies, data recorder and sample holder for test superconducting wire with the later installed inside the superconducting magnet. A tension unit is attached to give tension to superconducting sample wire.

In this work, two different types of insulating material were used. They are Polyimide film (125µm thick) and high strength polyethylene fiber cloth sheet Dyneema ® SK-60 with 1320 dTex. The used cloth was a plain wave having 15 yarns/inch with 165 g/m^2. Dyneema ® is a registered trademark in Japan. Dyneema has unique property of low coefficient of friction [3] and negative thermal expansion on cooling from RT to 4.2 K [4]. The preliminary results indicate that use of Dyneema reduces the sudden and big wire motion. Hence, use of Dyneema may reduce the frictional heat generated due to wire motion and can make the magnet performance more reliable. Table 1 shows the measured coefficient of friction of Dyneema cloth and Polyimide film at room temperature.

Table 1: Frictional Coefficient Measurement Test Data at Room Temperature

Sample	**Frictional coefficient**	
	Static	**Moving**
Dyneema Cloth Sheet	0.1015	0.0055
Polyimide Film	0.1932	0.1401

EXPERIMENTAL SETUP

Figure 1 shows the basic schematic view of experimental setup. This system has a superconducting solenoid magnet, test superconducting wire holder, tensional unit to apply tension to the test sample wire and the power supplies. Figure 2 shows the detail of the wire holder. The tap voltage signal is connected at the end of semi-circular

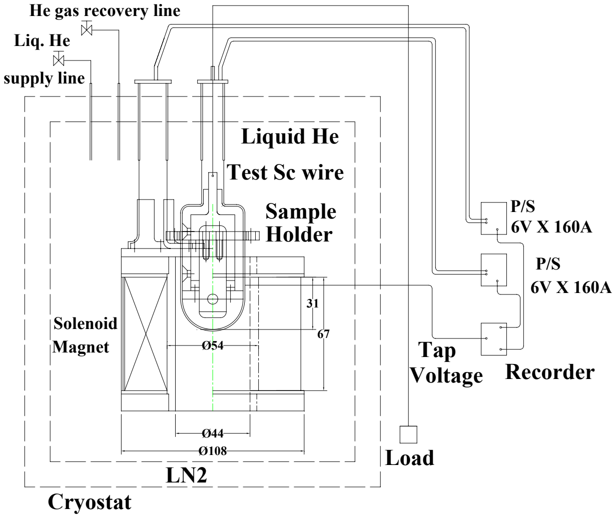

Figure 1: Schematic view of experimental setup.

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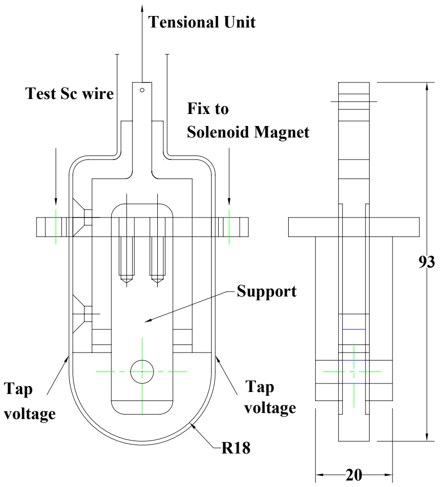

Figure 2: Cross-section of test superconducting wire sample holder.

hold. The sample holder consists of two parts. The round head part is fixed to magnet by support and the body part can move upward. The tap voltage signal is given to the data recorder/plotter along with the current waveform pattern of specimen and solenoid magnet. Tension is applied to the test sample via a pulley mechanism and can be varied.

FUNDAMENTAL EXPERIMENT

Experiment Procedure

Table 2 shows the specification of NbTi test superconducting wire which was used in the Outer Coil SSC Dipole Magnet. Current ramp up and ramp down rate in the test superconducting wire was 0.85 A/s with a flat top time of 60 sec. The current was ramped from 0 A to 128 A. In order to examine the dependence of test superconducting wire motion on ramp rate, ramp rate was varied from 0.4 A/s to 0.85 A/s. The applied tension to the test superconducting wire was varied from 7.1 N to 31.8 N while the magnetic field of 6 T is kept constant during all the experiments. Compressive force per 1 mm length of half circular holder for test superconducting wire varies from 0.039 kgf /mm to 0.18 kgf/mm. Experiments were carried out at 4.2 K using Polyimide film and Dyneema cloth as an insulating material between test superconducting wire and sample holder.

Table 2: Superconducting Wire Specifications

Parameter	**Value**
Wire diameter (mm)	0.7
Filament diameter (µm)	6
NbTi/Cu	1:1.8
Ic	383 A @ 4T 100 A @ 8.57 T
Pitch length (mm)	30

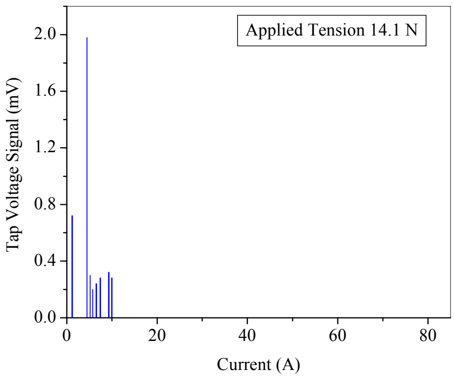

Figure 3: Measured voltage signal due to wire motion when polyimide film is used as an interface material.

The working principle is based on the Lorentz force experienced by the test superconducting wire. Current to the test superconducting wire is feed using an external power supply and solenoid magnet provides the magnetic field of 6 T. Wire motion is picked up by measuring the voltage across the test superconducting wire and by observing the voltage spike, wire motion was predicted.

Experimental Finding

The amplitude of voltage tap signal measured during ramping of test superconducting wire in the case when insulating material is Polyimide film is shown in Fig. 3. The applied tension to the test superconducting wire was 14.1 N. Large wire motions are observed when the applied tension to the test superconducting wire is 7.1 N. The amount of frictional heat generated during these wire motions is sufficient to drive the test superconducting wire from superconducting state to normal state. When the applied tension to the test superconducting wire is increased, the voltage generated due to wire motion decreases and relatively large electromagnetic force needed to start the wire motions. The voltage spike wave

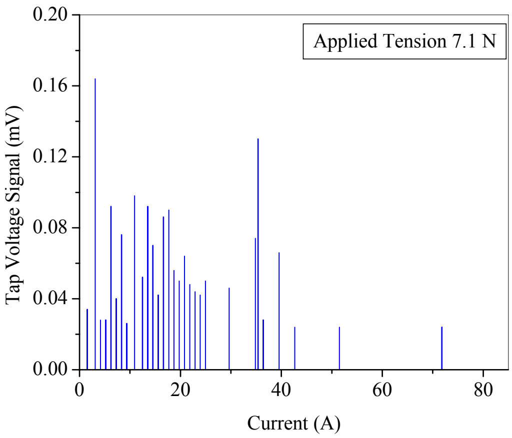

Figure 4: Measured voltage signal due to wire motion when Dyneema cloth is used as an interface material.

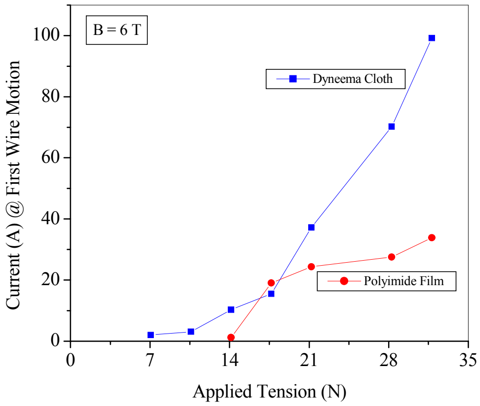

Figure 5: Dependence of current at which wire motion start with applied tension.

form pattern is asymmetric i.e. sticky wire motion. FWHM was obtained from voltage spike wave form pattern and found to be around 100 ms.

A large number of voltage spikes with low amplitude are observed during ramping of test superconducting wire when insulating material is Dyneema Cloth. Figure 4 shows the measured voltage pattern when the applied tension to the test superconducting wire is 7.1 N. The test superconducting wire does not turn to normal due to heat generated from frictional motion of wire even when the applied tension is 7.1 N. On increasing the tension in the test superconducting wire, amplitude of the tap voltage signal decreases and large electromagnetic force needed to start the wire motion. The amplitude of voltage signal is more than an order less as compared to Polyimide film. Figure 5 shows the dependence of current at which wire motion start as a function of applied tension. Figure 6 shows the training behaviour when Dyneema cloth is used. Similar pattern is obtained in case of Polyimide film. The voltage spike pattern is symmetric i.e. smooth wire pattern. FWHM was obtained from voltage spike wave form pattern and found to be around 60 ms.

Reversing the polarity of current in test superconducting wire erases the hystersis effect, also no significant effect on the electromagnetic force need to start the wire motion was observed. However, asymmetric voltage signal pattern is observed due to asymmetric position of test superconducting wire in the semi-circular sample holder. A typical pattern obtained for Dyneema cloth is shown in Fig. 7. No noticeable difference in the voltage pattern due to wire motion was observed when different current ramp rate was feed to test superconducting wire. The experimental results are repeatable under the same experimental conditions.

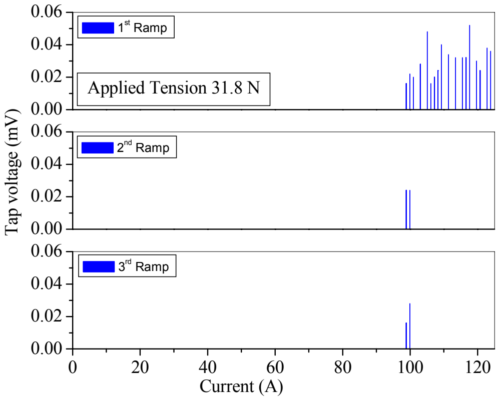

Figure 6: Training behaviour in case of Dyneema cloth.

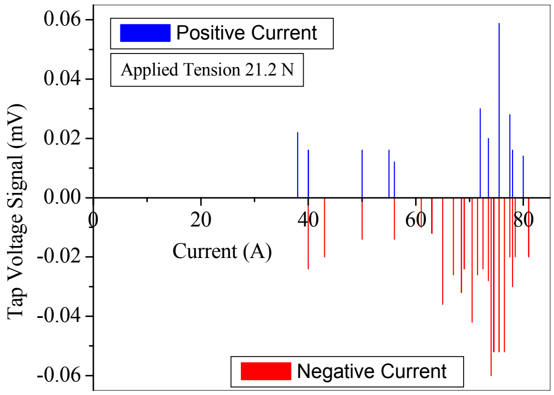

Figure 7: Typical voltage pattern due to wire motion after reversing the current polarity in case of Dyneema cloth.

In the next step of the study, we have a plan to resolve the time profile of voltage spike in order to understand the wire motion characteristics such as velocity, distance moved. We will also carry out the study using different insulating material such as Glass Fiber Reinforced Plastic (GFRP), Glass Fiber Cloth (GF), Dyneema Fiber Reinforced Plastic (DFRP), Zylon ® Fiber Reinforced Plastic (ZFRP), Zylon ® Fiber Cloth (ZF) and Teflon.

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