DEPENDENCE OF SUPERCONDUCTING WIRE MOTION ON THE BASE INSULATING MATERIAL IN MAGNETIC FIELD

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Abstract

Experiments were conducted at 4.2 K to study the dependence of superconducting wire motion on the base insulating material under the influence of electromagnetic force. Dependence of superconducting wire motion on tension to the superconducting wire is also studied. The experimental method and the test results are reported in this paper.

INTRODUCTION

The frictional heat generated due to the sudden wire motion during current ramp is one of the major factors of instabilities in high field magnets [1]. The wire motion occurs when the electromagnetic force to the conductor exceeds the frictional force on the surface of the conductor. Hence, frictional properties of the conductor and winding structure are important parameters for characterizing stability of the superconducting windings [2].

We have already measured the superconducting wire motion under the influence of electromagnetic force when the base insulating materials are Polyimide film, Dyneema cloth [3]. Higher electromagnetic force was needed to start the wire motion in case of Dyneema cloth as compared to Polyimide film, which was presumably due to embedded of the superconducting wire in Dyneema cloth [4].

In this work, we perform experiments using sheet material fabricated with Dyneema fiber. Aim is to overcome the embedding of the superconducting wire in the Dyneema cloth. We carried out experiments using Dyneema cloth, Dyneema non-woven cloth, Dyneema random sheet and Polyimide film as an insulating material. The experimental conditions are same as those in the previous works [3, 4].

EXPERIMENTAL SET UP

Schematic view of the sample holder is shown in fig. 1. The sample holder consists of two parts; a semi-circular head part of radius 18 mm and a body part fabricated using G-10. The superconducting wire is wound on the head part and soldered to the copper terminals. The head part is installed and fixed to the solenoid using support bars. The body part can move upward to change the tension of superconducting wire. In order to apply the tension to the superconducting wire, a stainless wire is attached to the body part of the sample holder from the top flange and tension is applied by lever mechanism. Insulating material is inserted between the head part and superconducting wire. Figure 2 shows the schematic view of experimental setup.

Thrust force F_t exerted by the superconducting wire to the semi-circular head depends on the tension T of the superconducting wire. The relation between thrust force per unit length and tension to the test superconducting wire is given as

$$F_t = T/r$$

where, r = radius of semi-circular head part.

Current to the superconducting wire is feed using an external power supply and solenoid provides the magnetic field. Voltage tap signal is measured using pen recorder or 16-bit data recorder with a sampling rate of 1MS/s. Sudden wire motion was predicted by observing the voltage spike.

INSULATING MATERIALS

Before winding the superconducting wire on the former (bobbin), insulating material is used at the interface of

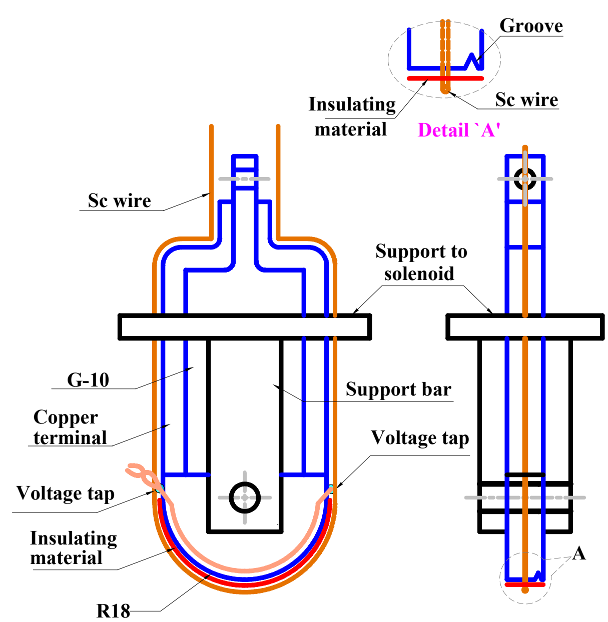

Figure 1: Cross-section of sample holder.

former and insulated superconducting wire. In present work, Polyimide film and Dyneema based insulating materials are taken for the study. Dyneema ® is a high strength polyethylene fiber manufactured by Toyobo Co.

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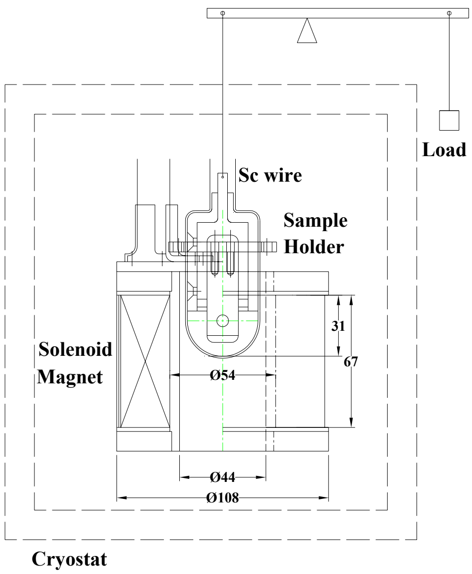

Figure 2. Schematic view of experimental setup.

Ltd., Japan. Dyneema has unique property of low coefficient of friction [5] and negative thermal expansion [6].

We use 125 µm thick Polyimide film (Upilex) manufactured by UBE Industrial Co. Ltd., Japan. The Dyneema based insulating materials are; Dyneema cloth SK-60, Dyneema non woven cloth and Dyneema random sheet. Dyneema cloth SK-60 was a plain wave having 15 yarns/inch with 165 g/m^2. In case of Dyneema non woven cloth, the length of Dyneema fiber is 50 mm with 220 g/m^2. Physical appearance of Dyneema non woven cloth is like a bulky paper. Dyneema random sheet was prepared by blending Dyneema short fiber (~38 mm long) PE(DF), polypropylene (PP) and polyethylene (PE). The volume fraction (%) was PE(DF)/PE/PP:50/25/25. Physical appearance of Dyneema random sheet is like a paper.

EXPERIMENTAL PROCEDURE AND FINDINGS

The superconducting wire was made of NbTi filaments in copper matrix with formvar insulation. The copper-to-superconductor area ratio is 1.8 and the filament diameter is 6 µm. Short sample critical current of the wire is 640 A in the 0 field and 260 A in 6T.

The current in the superconducting wire was ramped from 0 A to 84 A. The current ramp up and ramp down rate was 0.84 A/s with a flat top time of 60 s. In order to examine the effect of the current ramp rate on the superconducting wire motion, ramp rate was changed from 0.84 A/s to 1.69 A/s.

The superconducting wire tension was varied from 7.1 N to 31.8 N to study the effect of tension on the superconducting wire motion. The magnetic field of 6 T is kept constant during all the experiments.

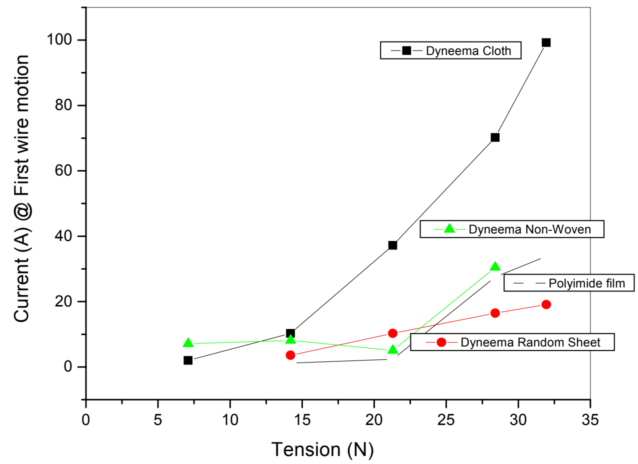

Figure 3: Dependence of current at which wire motion starts as a function of tension.

The pen recorder is not suitable for measurements of short duration pulses. So, we use 16-bit data recorder to measure the voltage tap signal. The voltage tap signal amplitude measured by the data recorder was more than one order of magnitude greater than with the pen recorder. The difference in voltage tap signal amplitude was validated by feeding a short duration pulse generated using pulse generator to the data recorder and the pen recorder.

Figure 3 shows the dependence of current at which the wire motion starts as a function of tension. At larger tension, amount of electromagnetic force needed to start the wire motion increases. One of the speculations for larger electromagnetic force in case of Dyneema cloth is the coarser texture of the cloth.

Figure 4 shows the effect of reversing the polarity of current in the superconducting wire. No significant effect on the electromagnetic force need to start the wire motion was observed. However, asymmetric voltage signal pattern is observed presumably due to asymmetric position of the superconducting wire in the head part.

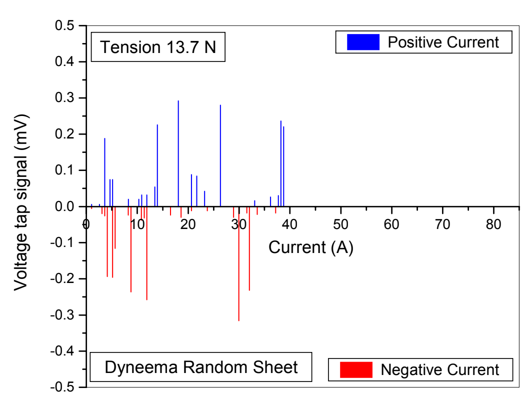

Figure 4: Voltage tap signal after reversing the current polarity in case of Dyneema random sheet measured using pen recorder.

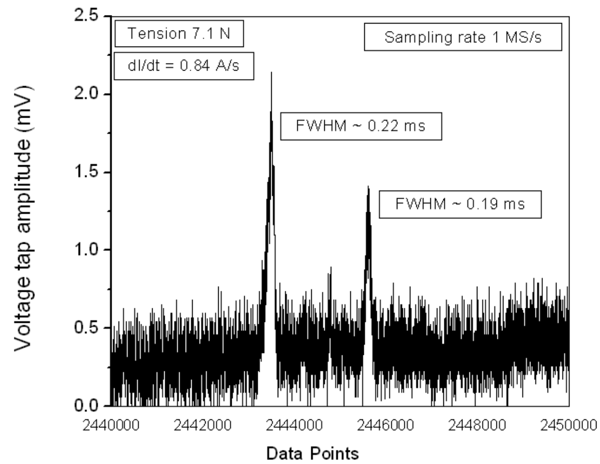

Figure 5: Typical pattern of voltage spike in case of Dyneema cloth.

Figure 5 shows the typical pattern of the voltage spike signals in case of Dyneema cloth when the tension to the superconducting wire is 7.1 N. From the peak profile, the full width at half maximum (FWHM) was found to be 0.22 ms. The current ramp rate was 0.84 A/s.

Figure 6 shows the typical pattern of voltage spike signal in case of Dyneema random sheet when the tension is 22.2 N. The FWHM was found to be 0.07 ms. The current ramp rate was 1.69 A/s. Similar data was obtained in case of Dyneema non woven and Polyimide film.

Figure 7 shows the comparison of maximum voltage tap signal amplitude as a function of tension. The voltage tap signal was measured using pen recorder. Low amplitude in case of Dyneema based materials are attributed to low coefficient of friction. In case of Dyneema based materials, amplitude of voltage spikes are more than 2 order less as compared to Polyimide film. Hence, use of Dyneema base materials as an insulating material between superconducting wire and base material may reduce the frictional heat generated due to wire motion and could make magnet performance more reliable.

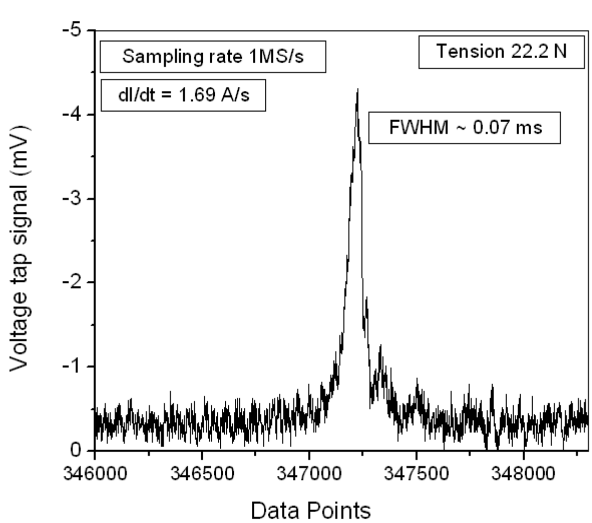

Figure 6: Typical pattern of voltage spike in case of Dyneema random sheet.

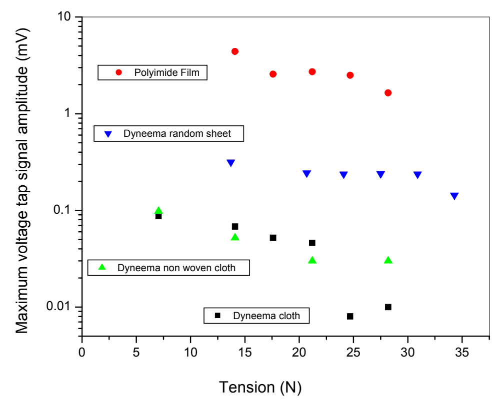

Figure 7: Comparison of maximum voltage tap signal amplitude as a function of tension measured using pen recorder.

No substantial dependence of tension to the superconducting wire on FWHM was observed in all the samples. FWHM is of the same order for Dyneema based materials and Polyimide film. No noticeable difference in the voltage pattern due to wire motion was observed when different current ramp rate was feed to the superconducting wire. The experimental results are repeatable under the same experimental conditions.

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