Experimental Investigation on Quench Characteristics of NbTi/Bi2223 Hybrid Superconductor

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Abstract—Quench characteristics of low temperature superconductor (LTS) and high temperature superconductor (HTS) hybrid superconductor made of NbTi/Cu wire and Bi2223/Ag tape are investigated experimentally. The results indicate: the minimum quench energy (MQE) of the hybrid conductor is much larger than NbTi/Cu; quench propagation velocity (QPV) and quench recovery time (QRT) are both less than NbTi/Cu. Those properties make the stability of the hybrid conductor better than NbTi/Cu, quench detection easier than Bi2223/Ag and operating current density greater than pure metal-stabilized superconductor. With advantages of high engineering current density and improvement of stability, the hybrid superconductor is expected to have some potential applications in large scale magnet and conductor-cooled magnets particularly.

Keywords- Low temperature superconductor (LTS); High temperature superconductor (HTS); Hybrid superconductor; Quench characteristics, Stability

I. INTRODUCTION

With the development of small-size cryogenic refrigerator technology and HTS technology[1-4], the superconducting magnet directly cooled by a cryogenic refrigerator has been realized[5,6]. The superconducting magnet cooled by refrigerator has many advantages compared with being cooled by liquid helium, such as easy operation and maintenance, long-time continuous running, portability, compactness etc. But superconducting magnets cooled by a cryogenic refrigerator have some worse cryogenic stability than those directly immersed in liquid helium [7-9]. In order to increase the engineering current density and the stability as well as meet the requirement of cryo-cooled technology, a new kind of LTS and HTS hybrid conductor was ever proposed and investigated[5]. In this kind of hybrid superconductor, HTS partly replaces the metal stabilizer of LTS or combines with LTS.

The stability of LTS/HTS hybrid superconductor was studied with numerical method by us before[10]. The simulation results show[10]: (1) the quench propagation velocity(QPV) is between LTS and HTS, which is very important for quench detection and protection of superconducting magnets; (2) minimum quench energy (MQE) of the hybrid conductor is much greater than LTS and smaller than HTS, improving the thermal stability of superconductor. In order to test the above simulation results and measure other properties, quench characteristics of LTS/HTS hybrid superconductor combined with NbTi/Cu wire and Bi2223/Ag tape are investigated experimentally in this paper.

II. EXPERIMENT

A. *Experimental sample*

Parameters of NbTi/Cu wire and Bi2223/Ag tape used in the experiment are listed in Table I.

TABLE I. PARAMETERS OF NBTI/CU AND BI2223/AG

Superconductor	Size(mm)	Metal/non Metal ratio	I_c (A) @4.2K	N-value
NbTi/Cu wire	ϕ0.702	5.87	~770	~33
Bi2223/Ag tape	4.020×0.202	0.91	~450	~28

As shown in Fig .1, NbTi/Bi2223 hybrid superconductor is fabricated by welding multi-core NbTi/Cu wire and Bi2223/Ag tape together in this paper.

Firstly, the insulating layer of commercial NbTi/Cu wire with sandpaper is removed, and the surfaces of NbTi/Cu wire and Bi2223/Ag tape are cleaned by dilute phosphoric acid solution. Then, hybrid composite conductor of NbTi/Cu wire and Bi2223/Ag tape are welded together with tin solder firmly to ensure good contact between them.

Figure 1. NbTi/Bi2223 hybrid superconductor welded by combination of NbTi/Cu wire and Bi2223/Ag tape

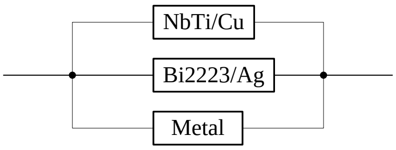

Figure 2. Parallel mode of NbTi/Bi2223 hybrid superconductor

According to the processing technology, NbTi/Bi2223 hybrid superconductor can be approximately considered as a parallel mode consisting of NbTi/Cu, Bi2223/Ag and metal, as shown in Fig .2.

B. Experimental set-up

The schematic of quench characteristic measurement is shown in Fig . 3. The heater is made of manganese-copper filaments (diameter 0.05 mm) wound around the experimental sample with non-inductance design, and located at the left.

Direct current (DC) source DC1 supplies operating current for hybrid superconductor and DC2 supplies pulse current for the heater. V1, V2 and V3 are three pairs of voltage taps along the sample, where V1 represents the voltage at the heater. L1 is the distance between the centers of V1 and V2. Similarly, L2 is the distance between the centers of V1 and V3.

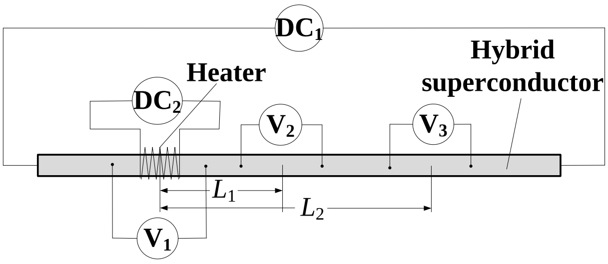

Figure 3. Schematic of the heater and voltage leads arrangement on hybrid superconductor

In the experiment, 4 K GM-type refrigerator is used as the cooling system. Fig .4 shows the schematic of the experimental set-up. The sample is bundled on the cold head of GM-type refrigerator by nylon threads tightly. Cryogenic insulating and heat-conducting glue is daubed between the sample and the cold head to ensure good insulation and heat conduction. The temperature is lowered below the critical temperature of NbTi by the refrigerator, so the experimental sample is in superconducting state. When a pulse current is applied, the heater generates a thermal disturbance on the hybrid superconductor. According to voltage waveforms measured at different locations of the superconducting sample, we can estimate whether the sample quenches or not. Thus, minimum quench energy (MQE)， quench propagation velocity (QPV) and quench recovery time (QRT) can also be measured.

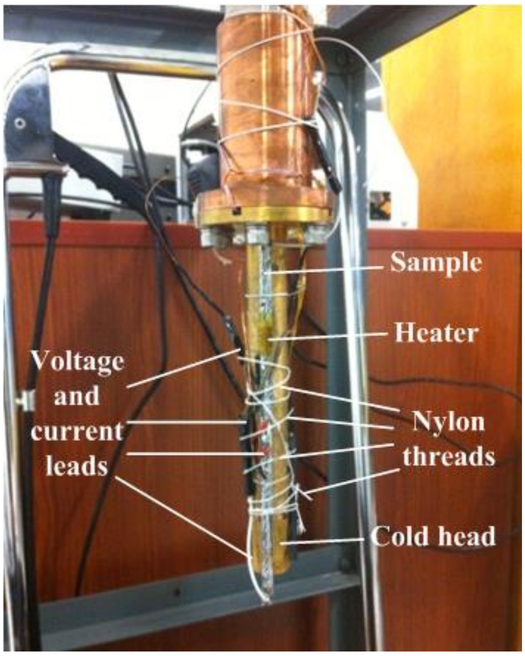

Figure 4. Schematic of experimental set-up

C. Experimental procedure

In this experiment, the temperature of the sample is 5.8 K and the operating current is DC 2.0 A. The resistance of the heater is 23.9 measured at 5.8 K, and the pulse current applied is 0.3 A. Pulse durations are separately 3 s, 5 s, 10 s, 15 s, 20 s, 25 s, 30 s, 35 s, 40 s, 45 s, 50 s, and corresponding thermal disturbance energies Q are 6.45 J, 10.67 J, 21.5 J, 32.26 J, 43.02 J, 53.78 J, 64.53 J, 75.28 J, 86.04 J, 96.80 J, 107.55 J respectively. L1 is 10.84 mm and L2 is 42.62 mm. Voltage waveforms at different positions with different thermal disturbance energies are measured. According to the voltage waveforms, quench characteristics of hybrid superconductor can be obtained.

In order to compare with hybrid superconductor, quench characteristics of NbTi/Cu are also measured as well as the above.

III. EXPERIMENTAL RESULTS AND DISSCUSSION

A. Voltage waveforms

Fig .5, Fig .6 and Fig .7 are voltage waveforms of the hybrid superconductor at different locations under different thermal disturbances. The three figures show that the farther away from the heat source, the smaller peak voltage and the rougher voltage curve. Voltage waveforms at V2 and V3 have two peaks, especially obvious at V2. In addition, peak values of the voltage of hybrid superconductor at every location are all much smaller than those of NbTi/Cu under the same thermal disturbance.

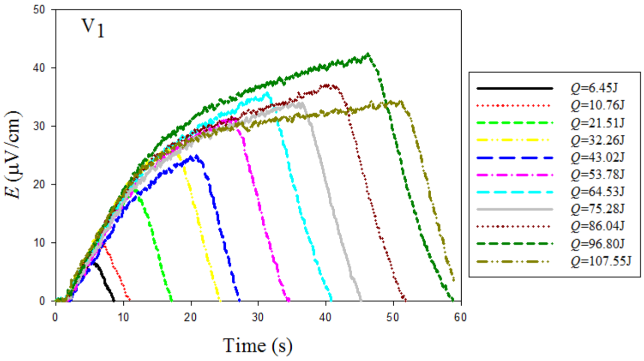

Figure 5. Voltage waveform of hybrid superconductor at V1

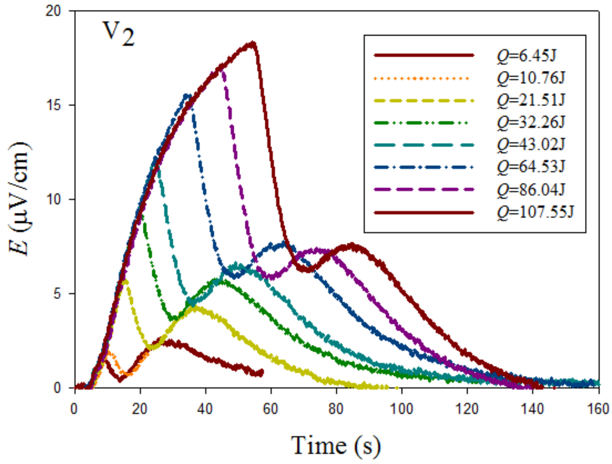

Figure 6. Voltage waveform of hybrid superconductor at V2

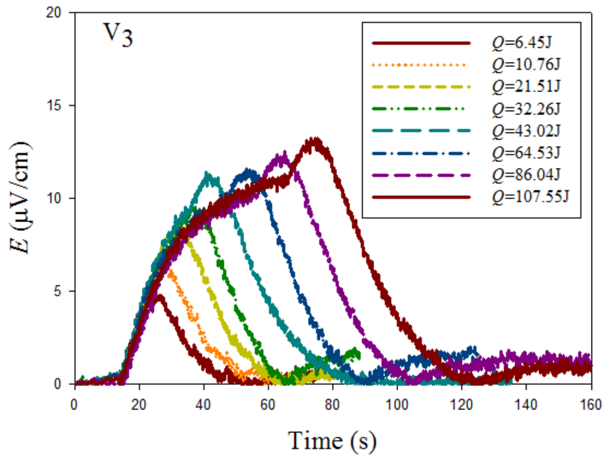

Figure 7. Voltage waveform of hybrid superconductor at V3

Fig .8 shows voltage waveforms of hybrid superconductor at different locations under the thermal disturbance Q=64.53 J. By defining the ratio of the distance between measured locations to the time difference of voltage waveforms as quench propagation velocity (QPV)[11-14], QPV of NbTi/Cu is 26.7 mm/s measured experimentally under thermal disturbance Q=64.53 J at 5.8 K. Likewise, QPV of NbTi/Bi2223 hybrid superconductor is 3.2 mm/s measured in the same condition much smaller than that of NbTi/Cu.

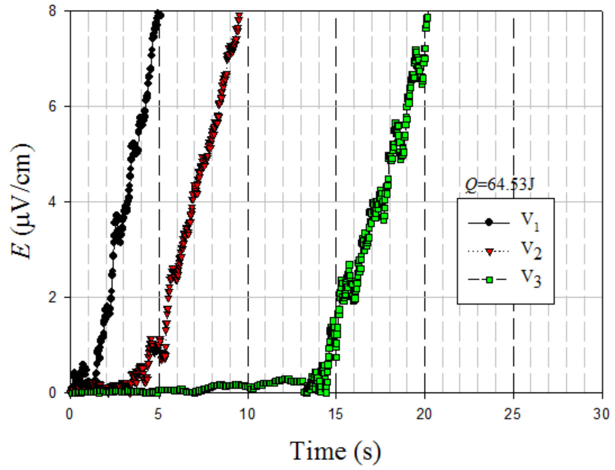

Figure 8. Voltage waveforms of hybrid superconductor at different locations under the same thermal disturbance

B. *Comparison of quench characteristics*

With defining the minimum thermal disturbance making the voltage rising to 1 V/cm MQE, MQE of NbTi/Bi2223 hybrid superconductor is 11.27 J measured at 5.8K. However, MQE of NbTi/Cu is 2.41 J measured in the same condition.

MQE and QPV of NbTi/Bi2223 hybrid superconductor and NbTi/Cu are listed in Table. Ⅱ.

TABLE II. COMPARISON OF MQE AND QPV

	MQE (J)	QPV (mm/s)
NbTi/Bi2223	11.27	3.2
NbTi/Cu	2.41	26.7

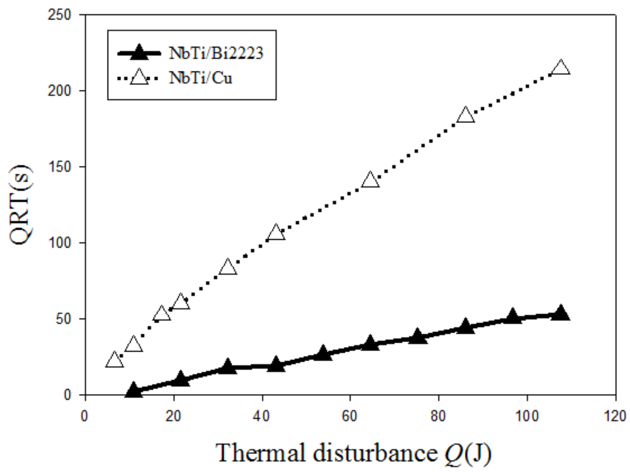

Figure 9. Quench recovery times (QRT) of NbTi/Bi2223 and NbTi/Cu under different thermal disturbances

According to Table Ⅱ, MQE of NbTi/Bi2223 hybrid superconductor is much larger than NbTi/Cu. The heat capacity of superconductor is increased and stability of superconductor is improved comparing with NbTi/Cu. General method to improve stability of superconductor is increasing matrix metal. However, operating current density of superconductor will reduce because of more metal added. Both stability and operating current density can be improved by using Bi2223/Ag as the stabilizer of NbTi/Cu. In other words, both stability and operating current density of NbTi/Bi2223 hybrid superconductor are superior to NbTi/Cu.

Table Ⅱ also shows that QPV of NbTi/Bi2223 hybrid superconductor is much smaller than NbTi/Cu, which is very important for quench protection of superconducting magnets. In addition, QPV of hybrid superconductor is larger than Bi2223/Ag[10], so quench detection of NbTi/Bi2223 hybrid superconductor is easer than Bi2223/Ag.

With defining the durations of voltage in superconductor dropping from higher than 1 V/cm to 1 V/cm as quench recovery time (QRT) under thermal disturbance, Fig .9 is the comparison of QRT in NbTi/Bi2223 with NbTi/Cu under different thermal disturbances. The figure shows that QRT of NbTi/Bi2223 hybrid superconductor is much smaller than NbTi/Cu. That is to say, NbTi/Bi2223 hybrid superconductor can recover from quench state to superconducting state faster than NbTi/Cu under the same thermal disturbance.

IV. CONCLUSIONS

Minimum quench energy (MQE), quench propagation velocity (QPV) and quench recovery time (QRT) of NbTi/Bi2223 hybrid superconductor are investigated experimentally in this paper. The results indicate: 1) both stability and operating current density of NbTi/Bi2223 hybrid are superior to NbTi/Cu; 2) quench detection of NbTi/Bi2223 is easier than Bi2223/Ag; 3) NbTi/Bi2223 hybrid superconductor recovers from quench state to superconducting state faster than NbTi/Cu. With those advantages, NbTi/Bi2223 hybrid superconductor is expected to have potential applications in high field magnet and conductor-cooled magnet particularly.

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