Available online at www.sciencedirect.com
ScienceDirect
Physics Procedia 65 (2015) 149 – 152
Physics Procedia

27th International Symposium on Superconductivity, ISS 2014

Current bypassing properties by thermal switch for PCS application on NMR/MRI HTS magnets

S.B. Kim[a,*], M. Takahashi[a], R. Saito[a], Y.J. Park[b], M.W. Lee[b], Y.K. Oh[b], H.S. Ann[b]

[a]*Graduate School of Natural Science and Technology, Okayama University, 3-1-1 Tsushima-naka , Kita-ku , Okayama 700-8530, JAPAN*
[b]*K·Joins, Inc. 913C H-1 KIST Venture Town Hwarangro 14 gil 5, Seongbuk-gu, Seoul 136-791, KOREA*

Abstract

We develop the compact NMR/MRI device using high temperature superconducting (HTS) wires with the persistent current mode operating. So, the joint techniques between 2G wires are very important issue and many studies have been carried out. Recently, the K·JOINS, Inc. has developed successfully the high performance superconducting joints between 2G wires by partial melting diffusion and oxygenation annealing process [1]. In this study, the current bypassing properties in a loop-shaped 2G wire are measured experimentally to develop the permanent current switch (PSC). The current bypassing properties of loop-shaped test coil wound with 2G wire (GdBCO) are evaluated by measured the self-magnetic field due to bypassed current by Hall sensors. The strain gauge was used as heater for persistent current switch, and thermal properties against various thermal inputs were investigated experimentally.

© 2015 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of the ISS 2014 Program Committee

Keywords: NMR relaxometry; HTS coil magnet; joints between 2G wires; persistent current switch (PCS); permanent current mode

1. Introduction

The low temperature superconducting (LTS) coils are used in present NMR / MRI devices and liquid helium is used for their cooling. However, it is possible to reduce the operating costs by manufacturing the superconducting magnet which is consisted of the high temperature superconducting (HTS) coil using liquid nitrogen cooling. We develop the compact NMR/MRI device using HTS wires with the persistent current mode operating. So, the joint techniques between HTS wires are very important issue and many studies have been carried out. Recently, the K·JOINS, Inc. has developed successfully the high performance superconducting joints between 2G wires by partial melting diffusion and oxygenation annealing process [1]. In general, the thermal heaters are usually used for persistent current switch (PCS), and the superconducting region turn into the normal state by a heater. In this study, the current bypassing properties in a loop-shaped 2G wire are measured experimentally to develop the PCS. The current bypassing properties of loop-shaped test coil wound with 2G wire (GdBCO) are evaluated by measured the self-magnetic field due to bypassed current by Hall sensors. The strain gauge was used as heater for persistent current switch, and thermal properties against various thermal inputs were investigated experimentally.

*Corresponding author. Tel.: +81-86-251-8116; fax: +81-86-251-8110.
E-mail address: kim@ec.okayama-u.ac.jp

1875-3892 © 2015 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of the ISS 2014 Program Committee
doi:10.1016/j.phpro.2015.05.088

2. Experimental details

Fig.1 shows the (a) schematic drawing of the proposed compact NMR magnet using the high performance superconducting joints and (b) photograph of the loop-shaped test coil with high performance superconducting joints between 2G (GdBCO) wires by partial melting diffusion and oxygenation annealing process. The proposed NMR superconducting magnet wound with 2G wires to be operating in the persistent current mode. The one layer test coil wound with GdBCO wire without stabilizer is prepared to study the PCS as shown in Fig. (b). A superconducting joint in Fig.1 (b) is prepared by K·JOINS, Inc.. It is necessary to install a PCS in NMR/MRI HTS magnets operating in persistent current mode. The current bypassing properties are determined by PCS. Fig.2 shows the schematic view of the test coils wound with GdBCO wire (a) with normal joint by soldering and (b) GdBCO loop-shaped test coil with superconducting joint. In test coil with normal joint by soldering, the thermal couples and voltage taps are attached to measure the current bypassing properties. The interval among T_1, T_2 and T_3 is 2 cm (Fig.2 (a)). The intervals between V_1 and V_2, V_2 and V_3, and V_3 and V_4 are 32 cm, 1.5 cm and 2 cm respectively (Fig.2 (a)). In both test coils, the two heaters (strain gauge) and the Hall sensors are attached to measure the current bypassing properties.

Table 1 shows specifications of GdBCO 2G wire and heater. Table 2 shows applied thermal heat by the heater. In test coils with normal joint and superconducting joint, the currents of 100 A and 10 A are transported respectively because the critical current at superconducting joint is 17 A. The current bypassing properties of loop-shaped test coils wound with 2G wire (GdBCO) are evaluated by measured the self-magnetic field due to bypassed current by Hall sensors.

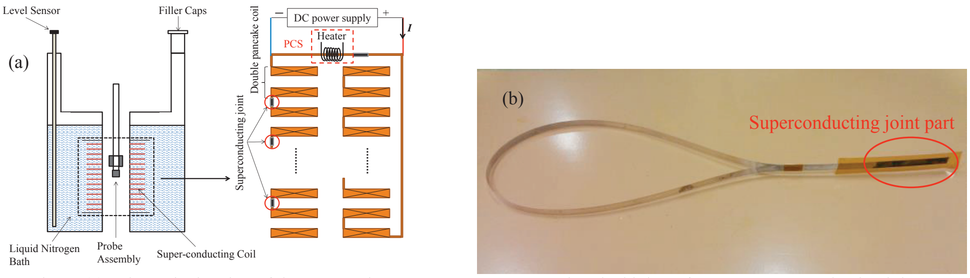

Fig. 1. (a) Schematic drawing of the proposed compact NMR magnet using the high performance superconducting joints; (b) photograph of the loop-shaped test coil with high performance superconducting joints between 2G (GdBCO) wires by partial melting diffusion and oxygenation annealing process.

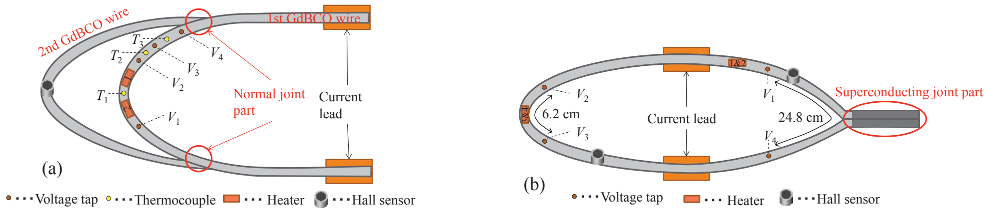

Fig. 2. The schematic view of the test coils wound with GdBCO wire (a) with normal joint by soldering and (b) GdBCO loop-shaped test coil with superconducting joint.

Table 1. Specifications of GdBCO 2G wire and heater

Components	Parameters	Specification
GdBCO conductor	Critical current at 77K	114 A
(Ag/GdBCO/Buffer/Substrate/Ag)	Length	100, 105 mm
	Width	4 mm
	Thickness	55 μm
	Thickness of upper Ag layer	2 μm
	Thickness of GdBCO layer	1 μm
	Thickness of buffer layer	~0.2 μm
	Thickness of substrate	50 μm
	Thickness of bottom Ag layer	1.8 μm
Heater	Thickness	50 μm
(Strain gauge)	Length	11 mm
	Width	5 mm
	Resistance	1000 Ω

Table 2. Applied thermal heat by the heater

The number of times of supply	The number of heaters	Times [s]	Loading interval [s]	Joule heating [J]
Once	1	0.5	-	1-5
		1*	-	1-5
		2	-	1-6
	2	0.5	-	1-5
		1*	-	1-6
		2	-	1-5
Twice	1	0.5	2,4	5
		1	2,4	5
		2	2,4	5
	2	0.5	2,4	5
		1	2,4	5
		2	2,4,6	5

* Applied various input heating for superconducting joint wire

3. Results and discussion (normal joint wire)

3.1. Single pulse heating

Fig.3 shows the generated voltage traces, and the 1/10 scaled heat input and measured self-magnetic field. Fig.4 shows measured temperature profiles at T_1-T_3. The self-magnetic field of the 2nd GdBCO wire was a maximum when 6 J was applied for 2 s with single heater and 5 J was applied for 2 s with two heaters. The heat which was applied by single heater is cooled by liquid nitrogen. In this case, part of the current flows to the stabilizer of the 1st GdBCO wire. But, the current is enough bypassed when 5 J was applied for 2 s with two heaters.

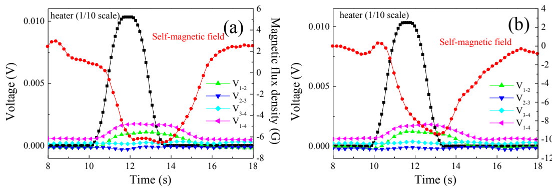

Fig. 3. Generated the voltages along the each point (V1-2-V3-4) and end-to-end (V1-4), and the 1/10 scaled heater input and self-magnetic field measured by Hall sensor attached on 2nd GdBCO wire (a) when 6 J was applied for 2 s with single heater; (b) when 5 J was applied for 2 s with two heaters.

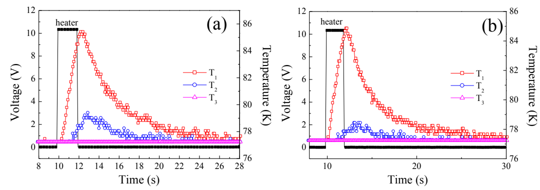

Fig. 4. Measured temperature profiles at T1-T3 (a) when 6 J was applied for 2 s with single heater; (b) when 5 J was applied for 2 s with two heaters.

3.2. Double pulse heating

Fig.5 shows the generated voltage traces, and the 1/10 scaled heat input and measured self-magnetic field. Fig.6 shows measured temperature profiles. Self-magnetic field of the 2nd GdBCO wire was a maximum when 5 J was applied twice by single heater for 1 s with 2 s intervals and twice by two heaters for 2 s with 4 s intervals. The second half of the self-magnetic field is getting stronger than the first half of it in Fig.5. The method of double pulse heating is the useful because the temperature is elevated in the second half in Fig.6.

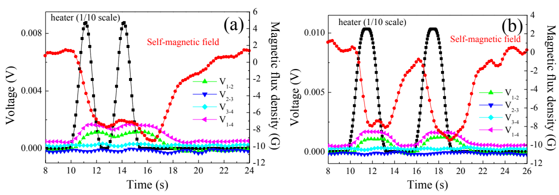

Fig. 5. Generated the voltages along the each point (V1-2-V3-4) and end-to-end (V1-4), and the 1/10 scaled heater input and self-magnetic field measured by Hall sensor attached on 2nd GdBCO wire when 5 J was applied (a) twice by single heater for 1 s with 2 s intervals; (b) twice by two heaters for 2 s with 4 s intervals.

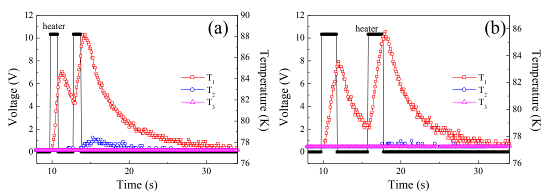

Fig. 6. Measured temperature profiles at T1-T3 when 5 J was applied (a) twice by single heater for 1 s with 2 s intervals; (b) twice by two heaters for 2 s with 4 s intervals.

3.3. The current bypassing value in each self-magnetic field

Fig.7 shows the measured self-magnetic field when the current of up to 100 A was transported with sweep rate of 3.257 A/s. The self-magnetic field is 10.5 G when a current of 100 A was transported in the 2nd GdBCO wire. So, self-magnetic field is 0.104 G per 1 A. Thus, the current bypassing value when 6 J was applied for 2 s with single heater was 62 A, when 5 J was applied for 2 s with two heaters was 90 A, when 5 J was applied twice by single heater for 1 s with 2 s intervals was 89 A and when 5 J was applied twice by two heaters for 2 s with 4 s intervals was 90 A. All of the current was not bypassed, because the GdBCO wire have stabilizer. We considered that the current was transpored a layer of stabilizer.

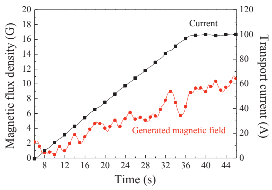

Fig. 7. Measured self-magnetic field when the current of up to 100 A was transported with sweep rate of 3.257 A/s.

4. Results and discussion (superconducting joint wire)

4.1. Single pulse heating

Fig.8 shows the measured self-magnetic field when the current of up to 10 A was transported with sweep rate of 3.257 A/s in joint part and no joint part. Fig.9 shows the 1/10 scaled heater input and self-magnetic field measured by Hall sensor attached on GdBCO wire when 2 J was applied. The self-magnetic field was increased linearly when the current of up to 10 A was transported. So, it is possible to convert the self-magnetic field into current value. In GdBCO loop-shaped test coil with superconducting joint, there are no difference of current bypassing properties between single and two heaters input when the input heating is 2J. In the case of GdBCO wire without stabilizer, the thermal diffusion along the longitudinal direction is very low, and inputted heat contributes to raising the local temperature in the wire.

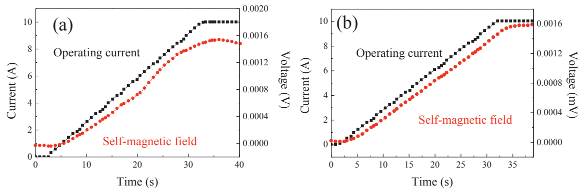

Fig. 8. Measured self-magnetic field when the current of up to 10 A was transported with sweeprate of 3.257 A/s (a) joint part; (b) no joint part.

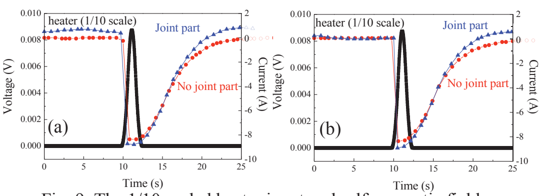

Fig. 9. The 1/10 scaled heater input and self-magnetic field measured by Hall sensor attached on GdBCO wire when 2 J was applied (a) by single heater for 1 s; (b) by two heaters for 1 s.

5. Conclusion

The self-magnetic field by transported current was measured as function of number of heat input and duration time of heating by heater. Then, the current bypassing properties in 2G wire loop circuits with/without superconducting joint were evaluated using converted bypassing current from measured self-magnetic field.

In test coil with normal joint by soldering, the whole transport current of 90 A was bypassed by 5J heat input. In GdBCO loop-shaped test coil with superconducting joint, there are no difference of current bypassing properties between single and two heaters input when the input heating is 2J. In the case of GdBCO wire without stabilizer, the thermal diffusion along the longitudinal direction is very low, and inputted heat contributes to raising the local temperature in the wire. Therefore, in the 2G wires without stabilizer, it becomes possible to bypassing the current using the single heater.

References

[1] Yeonjoo Park, Hyun-Jin Shin,Young-Gyun Kim, Young Kun Oh, and Haigun Lee, IEEE Trans, Appl. Supercond. 23 (2013) 6600804