APPLICATION OF ACOUSTIC EMISSION FOR DIAGNOSIS OF QUENCH IN SUPER CONDUCTIVE MAGNET AT CRYOGENIC TEMPERATURE

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Abstract

It is well recently recognized that quench is one of the serious problems for the integrity of superconducting magnets, which is mainly attribute to the rapid temperature rising in the magnet due to some extrinsic factors such as conductor motion, crack initiation etc. In order to apply acoustic emission(AE) technique effectively to monitor and diagnose superconducting magnets, it is essential to identify the sources of acoustic emission. In this paper, an acoustic emission technique has been used to monitor and diagnose quenching phenomenon in racetrack shaped superconducting magnets at cryogenic environment of 4.2K. For these purposes special attention was paid to detect AE signals associated with the quench of superconducting magnets. The characteristics of AE parameters have been analyzed by correlating with quench number, winding tension of superconducting coil and charge rate by transport current.

1. INTRODUCTION

Superconducting magnet technology can be good method for the purpose of saving energy. In particular, superconducting technology is an innovative route to the realization of an electrical power system of high performance. A superconducting generator (Osamura, 1994) is one of the most important components of such an efficient power system.

In this study, the training and degradation behavior of racetrack shaped superconducting magnets have been examined aiming the high performance superconducting generator.

The correlation between training and degradation behavior, and the fabrication condition of the racetrack superconducting magnets was examined by referring to acoustic emission(AE) information (Ronnie et al., 1987). The AE signals in superconducting magnets are chiefly generated by mechanical disturbances such as conductor motion and epoxy cracking. Because each event generates an AE signal, monitoring of both the AE signal and the magnet voltage makes it possible to identify the source of the quench. However, in this study, AE techniques were used to clarify the quench cause and its source location. Moreover, the characteristics of the AE parameters have been analyzed by correlating them with the number of quenches, winding tension and current ramp rate by transport current of superconducting coil. However, it was shown experimentally that the AE technique was very useful for monitoring the operating conditions of superconducting magnets and can be used to detect quenching.

2. MATERIALS AND EXPERIMENTAL PROCEDURE

2.1 Materials

The test magnets examined in this study are constructed of Nb-Ti multifilament superconducting coil. The Nb-Ti-copper matrix coil has a 1 mm (0.04 in.)diameter and the number of filaments is 532 turns. The typical construction of Nb-Ti multifilament superconducting coil is shown in Figure 1. In Figure 1, the Cu-Ni barrier decouples the subunit of Nb-Ti filaments and copper matrix electro-magnetically. Tables 1 and 2 show the specification of the tested magnets, and the characteristics of the magnet's critical current and winding tension.

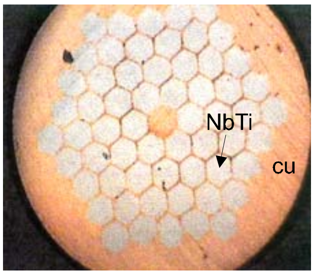


Figure 1. The cross section of the typical multi -filamentary composite superconducting coil

Table 1. The specification of the racetrack-shape superconducting coil.

Superconductor	Nb-Ti	Number of turns	532[turns]
Diameter	1mm (0.04in.)	Total length of wire	405m(16200 in.)
Number of filaments	60	Material of Bobbin	SUS316L

Table 2. The characteristics of the magnet critical current and winding tension.

Magnet No.	Wound Tension(N)	Critical Current(A)
A	43.3 (4.4kgf)	348A (7T)
B	55.6 (5.7kgf)	478A (6T)
C	61.9 (6.3kgf)	584A (5T)

2.2 Experimental Set-up

The racetrack-shaped superconducting magnets were wound using the Nb-Ti monolithic round multifilament superconductor on stainless steel(SUS316L). The quench test was carried out under impregnated condition without epoxy resin.

Figures 2 and 3 show the schematic diagram of the experimental set-up of the AE measurementThe three AE sensors were attached to the racetrack superconducting magnets as shown in Figure 3. In order to ensure close contact between the sensor and the magnet, the sensors were attached to the magnet with silicone vacuum grease and fastened tightly with cotton tape. The AE signals from the magnet were amplified by a preamplifier, which had a fixed gain of 40dB. After passing the band pass filter of 100～300kHz to remove background noise, the signals were further magnified by the main amplifier(40dB). The AE parameters, including event number, energy, and amplitude of the signals were measured in the AE system. A digital oscilloscope is used to analyze the AE signal waveform.

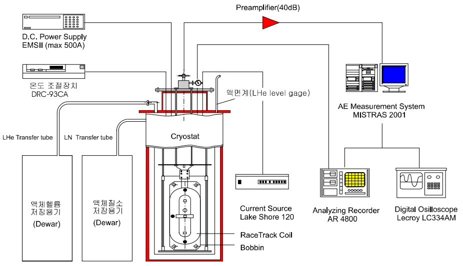


Figure 2. The schematic diagram of experimental set-up of the AE measurement

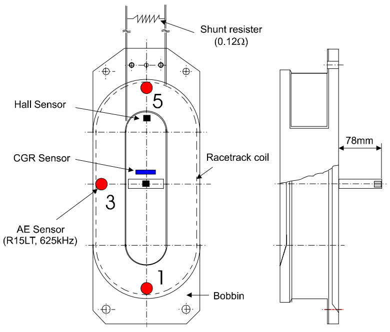


Figure 3. The AE sensors location attached on the racetrack shaped bobbin

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1 The AE characteristic

3.1.1The quench current and AE event counts

Figure 4 shows the relationship between the quench current and AE events of the test magnet coil B. As shown in Figure 4, the first quench was occurred at an excitation current (Iq) of 363A, and this value is about 61 percent of the short-sample critical current. However, the quench current was increased by increasing the number of quenches, and could be excited up to the critical current of 410A. It was confirmed that the quench current was greatly improved over the initial quench current by the training effect which is a gradual increase in the quenching current as the number of quenches is increased. Figure 5 shows the relationship between the AE event count and the quench current. Also, the AE event count is increased with the number of quenches and quench current. This is understood because AE signals are induced by the conductor motion caused by Lorenz force.

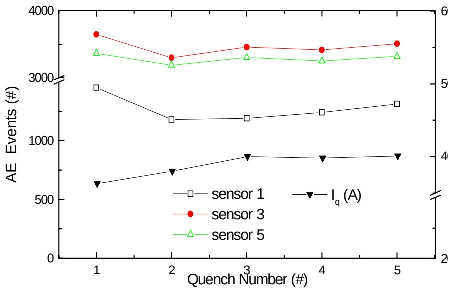


Figure 4. The relationship between the quench current and AE events of the test magnet coil B.

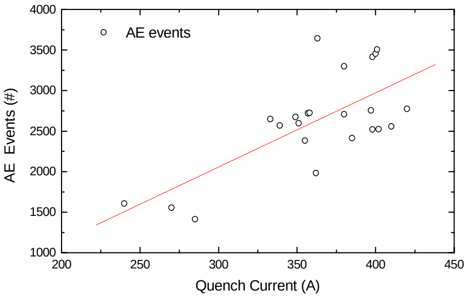
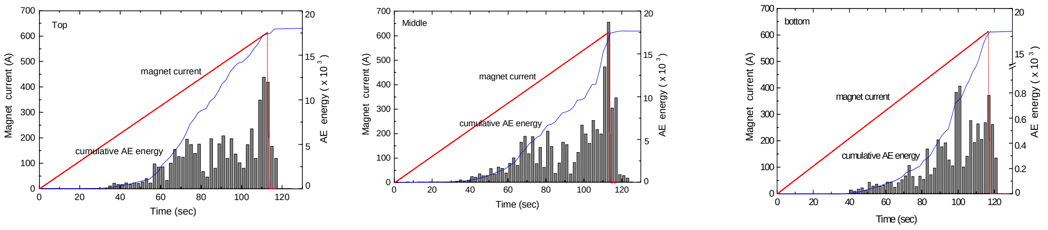


Figure 5. The relationship between the AE event counts and quench current.

3.1.2 The AE amplitude and AE energy

Most of the AE signals having low amplitude (60-65dB) were observed, and this suggests that the AE signals are the result of mechanical disturbances, such as micro-slip of the conductor motion. However, some AE signals having a high amplitude (>90dB) were detected, and it was confirmed that the AE signals were obtained during the quench.

Figure 6 shows an example(in the test magnet B) of the quench source location using the AE energy. In Figure 7, the diagrams contain the AE data from the top, middle and bottom sensors. The histogram is of the AE energy rate, and the continuous curve is the cumulative AE energy. However, the histogram is obtained by dividing the energy occurring over an interval of time by the number of events in the same interval. The sharp peak occurred in the middle sensor, therefore it seems that the quench occurred at the middle of the racetrack superconducting coil. This is confirmed in the oscillograms of the AE and magnet voltage signals obtained during the quench. Other quenches were similarly classified.



(a) top sensor (b) middle sensor (c) bottom sensor

Figure 6. The location of quench source using the AE energy (a) top sensor, (b) middle sensor, (c) bottom sensor

3.1.3 The Winding Tension

To prevent deformation by electromagnetic force, the test magnets having a wound tension of 43.3 N (4.4 kgf), 56.6 N (5.7 kgf)and 61.9 N (6.3 kgf)were prepared. The quench test was carried out under impregnated conditions without epoxy resin. Figure 7 shows the relationship between the cumulative AE energy and the winding tension of each of the test magnets. In Figure 7, the cumulative AE energy was increased by increasing the winding tension. Generally, the saturated value of the quench current(Iq) with high winding tension was higher than those with low tension. However, it was found that AE energy was conversely decreased in the case of test magnet C, in which the winding tension was too high. This is understood to be because the wound coil was degraded by further tensile strain.

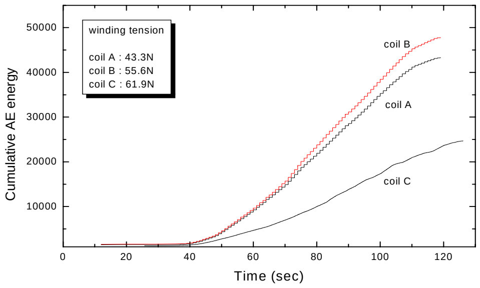


Figure 7. The relationship between cumulative AE energy and winding tension of the test magnets

4. CONCLUSIONS

In this paper, The acoustic emission(AE) technique has been applied to detect quench as a method of nondestructive evaluation of the racetrack shaped superconducting magnet. The results have shown experimentally that the AE technique is very effective at detecting the quench of superconducting magnets and can be used to prevent premature quench. The characteristics of AE parameters have been analyzed by correlating them with the number of quenches, winding tension and current ramp rate by transport current of superconducting coil. Three AE sensors were used to monitor the quench source location. It was confirmed that the magnet voltage and AE parameters such as cumulative AE energy were useful in distinguishing quench source. The results confirmed that AE signals were mainly caused by conductor motion(micro-slip), which was caused by premature quench. It was also found that optimized winding tension at superconducting coil was needed to prevent quench caused by conductor motion.

ACKNOWLEDGEMENT

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