LOCAL TEMPERATURE RISE AFTER QUENCH DUE TO EPOXY CRACKING IN IMPREGNATED SUPERCONDUCTING WINDINGS

Shigehiro Nishijima, Kazuya Takahata, and Toichi Okada

ISIR Osaka University, Ibaraki, Osaka, Japan

ABSTRACT

Relationships between epoxy cracking and the temperature rise in a coil after a quench have been investigated in epoxy-impregnated single-layer superconducting coils. The acoustic emission (AE) method was used to locate the cracking areas. The temperature rise of the wire was observed with voltage taps in the wire. The AE sources were localized in a certain area and a temperature rise was observed in that area. The temperature rise became greater as the quench number increased because the temperature rise itself caused further debonding and additional cracking. Areas where the epoxy was deliberately debonded during impregnation also exhibited temperature rises.

INTRODUCTION

The epoxy impregnation technique has been widely used in superconducting magnets with high current density. The premature quenching caused by the wire motion can be prevented by this technique. The training behavior, however, persists in the impregnated magnets.\textsuperscript{1,2} Premature quenches are brought about by releasing the previously stored energy in the form of epoxy cracking. The stored energy arises from the difference of thermal contraction between the wire and the epoxy. Consequently, even impregnated magnets must be designed taking into account the quench in order not to cause burn-out of the wire due to an excessive temperature rise.

Until now, the protection of magnets has been investigated using analysis of the normal zone propagation velocity and the current decay time.\textsuperscript{3} It is, however, also necessary to consider that inhomogeneous heat diffusion will be enhanced when epoxy cracking occurs in the magnet. If the magnet has been trained through several premature quenches, one must pay attention to the epoxy cracking.

In this paper, the behavior of epoxy cracking is examined using AE measurements, and the effects of epoxy cracking on the temperature rise of the wire after quench are investigated using an epoxy-potted short superconducting wire and single-layer coil.
EXPERIMENTAL

In this work, experiments were done using two types of samples. In the first experiment, an epoxy-potted short sample (named "Sample A") was fabricated. The experimental setup is illustrated schematically in Fig. 1 (a). The superconducting wire used in this work is multifilamentary Nb-Ti-Zr-Ta composite with a copper matrix of 0.35 mm diameter. The normal zone was induced locally by a manganine heater wound around the wire under a transport current of 100 A. Five potential taps were attached to the wire to monitor the normal zone behavior and the temperature rise of the wire. Two PZT type piezoelectric sensors which have resonant frequency of 140 kHz were attached to the epoxy block with vacuum grease. The coincidence method was used in order to reduce the noise. The AE may be generated by the wire and flux motions in addition to epoxy cracking. In this experiment, no external magnetic field was applied to the coil in order to detect only the AE induced by the epoxy cracking.

In other experiments, two epoxy-potted single-layered coils (called "Sample B" and "Sample C") were fabricated. The experimental setup is shown in Fig. 1 (b). The wire was wound on a bakelite bobbin of 30 mm diameter. The number of turns was 10. The coil was impregnated with epoxy resin. The thickness of the outside epoxy layer was approximately 3 mm. 70 quenches were induced in the same manner as in the first experiment. The transport current was also set at 100 A and cut off when the voltage difference between the two ends of the coil reached 10 V at each quench. Three potential taps were attached to the wire to examine the temperature of the wire as shown in Fig. 1 (b), and the voltage differences between taps 1 and 2 or 2 and 3 were measured. The heater was located between taps 1 and 2. The measured voltage differences were converted into the average temperature between the taps considering the temperature dependence of the electrical conductivity of copper. Four AE sensors were attached to the bobbin to locate the AE sources.

RESULTS AND DISCUSSION

Short wire

Figure 2 shows the change of voltage differences between the taps and the AE signals at the quench of Sample A. The voltage differences increased with increasing temperature of the wire. The AE signals were not detected just after the normal zone generation, but appeared after the temperature of the wire increased enough. The temperature was estimated to be more than 100 K at the time when the AE appeared. This AE feature indicates that AE signals are generated by epoxy cracking. The thermal stress is produced by the difference of thermal contraction between the wire and epoxy during the initial cooling-down process. The temperature rise of the wire may enhance the difference of thermal stress and trigger the epoxy cracking. The data obtained, information, and calculation method established in the preliminary experiment were applied to the coil simulation experiments described below.

Potted coil (B)

Figure 3 shows the change of voltage difference between taps 1 and 2 and the AE signals at the first quench of Sample B. The voltage difference increased with increasing temperature of the wire. It fell to zero when the transport current was cut, presented as "breaker on" in the figure. The interval between the normal zone generation and the