RADIATION DAMAGE OF MAGNET COILS DUE TO SYNCHROTRON RADIATION

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Abstract

We have measured the radiation damage done to magnet coils. Test pieces were irradiated with synchrotron radiation of 10^6 to 10^9 Gy. The insulator of the irradiated test pieces was carbonized and became more fragile with increasing radiation dose. However, the coil function did not deteriorate.

INTRODUCTION

SPring-8 is an 8-GeV synchrotron radiation source that has been in operation since 1997. The integrated beam current has reached 2200 Ah and problems related to radiation damage to the accelerator components have begun to occur [1].

Synchrotron radiation from bending magnets in a cell is absorbed by two crotch absorbers and four absorbers. The radiation scattered by these absorbers passes through vacuum chambers and damages the equipment around the absorbers. Last year, rubber hoses made of EPDM broke because of radiation damage and this caused water leakage. However, the highest radiation dose position is on the surface of the magnet coils around the absorbers. Though the magnet coil is considered resistant to the radiation, change in the coil characteristics owing to radiation damage would be a serious concern. Thus, we have studied the relation between radiation dose and coil damage.

We performed an acceleration test to investigate the coil damage. An acceleration test may lead to damage that differs from the damage that occurs during actual operation. Therefore, we also investigated the radiation damage done to magnet coils taken from the storage ring. In this paper, we describe the radiation damage done to magnet coils in the acceleration test and that done to a magnet coil from the storage ring tunnel.

ACCELERATION TEST

We made test pieces and carried out the acceleration test as described below. The test pieces were set on a beamline and exposed to the radiation from a bending magnet.

Test Pieces

As shown in Fig. 1, a magnet coil is made from a hollow conductor. Prepreg tape made of glass cloth with epoxy resin is wound around the coil for insulation. We made test pieces by disassembling a coil and cutting it into pieces 20 cm in length. These test pieces were directly exposed to radiation. To avoid a rise in the sample temperature, we cooled the test pieces with water. We made two kinds of test piece. One was a single hollow conductor for measuring the damage to the coil insulator. The other consisted of two neighboring hollow conductors for measuring the conductivity between two conductors.

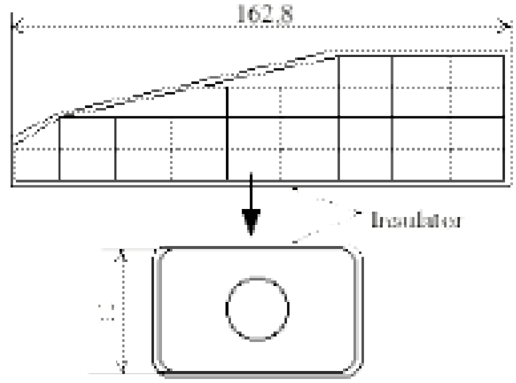


Figure 1: Cross section of a magnet coil.

Experiment

We used the BL33B2 beam line where radiation from a bending magnet was available. In the beamline, the radiation was collimated by a mask and a collimator and passed through two 0.15-mm-thick beryllium windows and 0.1-mm and 0.5-mm-thick aluminum windows. The test pieces were set 34.5 m from the bending magnet as shown in Fig. 2 and were cooled by pure water during exposure. Temperature was monitored with a thermocouple attached to the test piece. In the experiment on conductivity between two conductors, the resistance between the two conductors was measured with a resistance meter (ADVANTEST, R8340A).

The relation between the integrated beam current and the radiation dose obtained by GAFCHROMIC film [2] was measured beforehand. The radiation dose of the test pieces was then calculated from the integrated beam

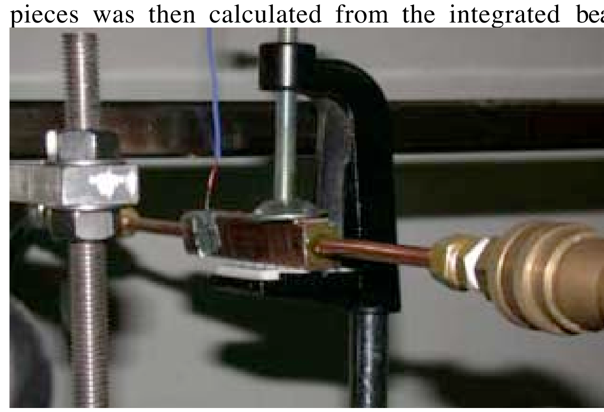


Figure 2: Test piece mounted on a beamline.

current. The maximum integrated radiation dose of the magnet coils placed in a storage ring tunnel is about $2.1 \cdot 10^7$ Gy. Therefore, we prepared four test pieces and exposed them to radiation for $1.8 \cdot 10^2$, $1.8 \cdot 10^3$, $1.8 \cdot 10^4$, and $1.8 \cdot 10^5$ s so that the radiation dose would be 10^6, 10^7, 10^8, and 10^9 Gy, respectively. In the experiment on the resistance between two conductors, the measurement was continued for about 1.7×10^5 s.

RESULTS AND DISCUSSION

External View

The test pieces after irradiation are shown in Fig. 3. The irradiated part of the test piece was slightly colored in the case of 10^6 Gy irradiation. When the irradiation increased to 10^7 Gy, the center of the irradiated part became white. It became black when the irradiation was greater than 10^8 Gy. The temperature rise in the test pieces during the irradiation was 2°C, so the effect of temperature was negligible. Photographs magnified by a microscope are shown in Fig. 4. We can see the glass cloth vaguely under the milky-white epoxy resin in the non-irradiated test piece. The glass cloth could be seen more clearly under the epoxy resin when the irradiation was 10^7 Gy. With more irradiation, the epoxy resin was carbonized and became black. The irradiated part expanded in volume.

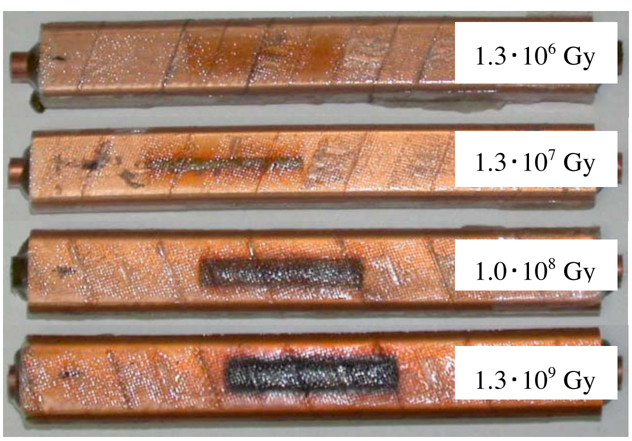
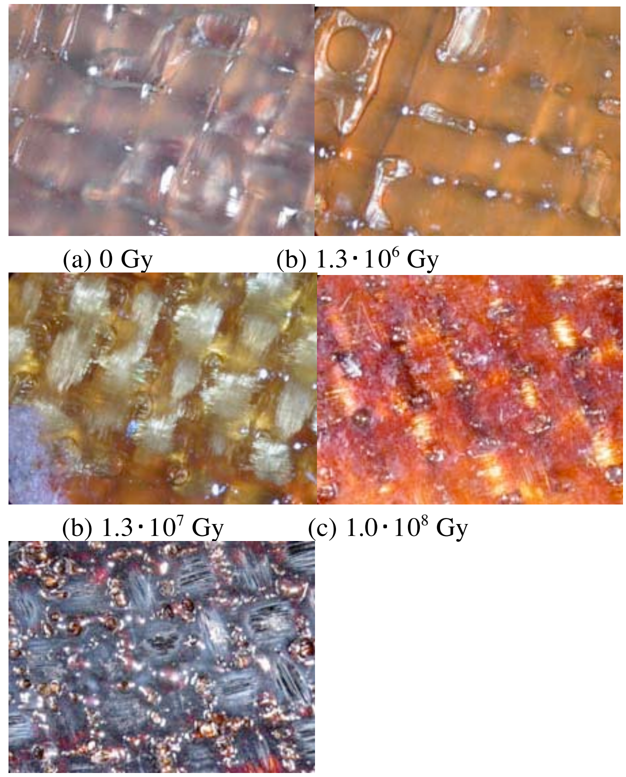


Figure 3: Test pieces after irradiation.

Insulation Resistance

We measured the insulation resistance of the non-irradiated and irradiated coils with the resistance meter. Though the measured resistance values were scattered, every coil had resistance greater than 10^9 Ω. This value is sufficient as the insulation resistance of a magnet coil.

The measured insulation resistance between two conductors during irradiation was above 10^7 Ω. The resistance between conductors was dominated by the cooling water rather than the insulator.



(a) 0 Gy (b) $1.3 \cdot 10^6$ Gy

(b) $1.3 \cdot 10^7$ Gy (c) $1.0 \cdot 10^8$ Gy

(d) $1.3 \cdot 10^9$ Gy

Figure 4: Test piece photographs magnified by a microscope.

Strength

We did a scratch test to study the change in the insulator strength due to radiation damage. As shown in Fig. 5, force was applied to a needle and a test piece was moved with constant speed under the needle while the needle force increased. The tip of the needle was rounded with a 200-μm radius and force from 0 to 100 N could be applied at 100 N/min. The stage on which the test piece was mounted moved at 10 mm/min.

Test results showed almost no difference between the non-irradiated and the 10^7 Gy irradiated test pieces. Above irradiation of 10^8 Gy, the scratch width became wider and the area of damage spread as the radiation dose increased. Photographs of the non-irradiated and irradiated test pieces are shown in Fig. 6. Although the glass cloth of the non-irradiated test piece was not damaged, that of the 10^9 Gy irradiated piece was seriously damaged. That is, the glass prepreg was weakened as the radiation dose increased.

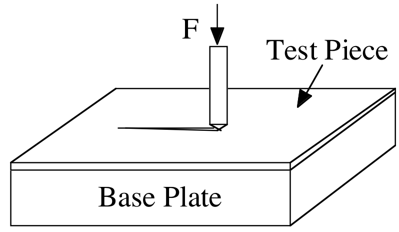


Figure 5: Outline of scratch test.

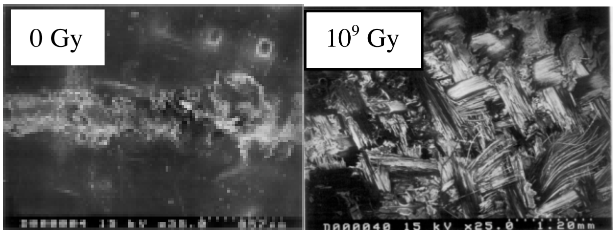


Figure 6: Scratch test results for non-irradiated and irradiated test pieces.

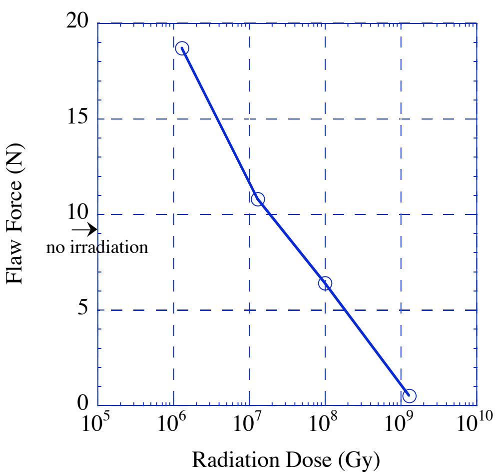


Figure 7: Relation between radiation dose and the flaw force.

When the force was applied, we saw that flaws appeared in the test pieces at certain levels of applied force. We refer to this force as the flaw force. The relation between the radiation dose and the flaw force is shown in Fig. 7. With 10^6 Gy irradiation, the glass prepreg hardened and the flaw force became higher than that for no irradiation. However, the flaw force decreased with increasing irradiation and reached 3 % of the flaw force for 10^6 Gy irradiation at 10^9 Gy. This shows the epoxy resin becomes increasingly fragile with greater radiation exposure.

DAMAGE TO A MAGNET COIL PLACED IN A TUNNEL

In August 2000, we rearranged the magnet lattice to make a long straight section and removed some magnets [3]. We investigated the damage caused by radiation to one of the removed magnet coils.

The measured magnet had been located near the absorber. The greatest part of the radiation dose was in the lower left side of the coil and the estimated accumulated radiation dose was 6×10^6 Gy. After removal of this coil, we investigated the coil damage.

An external view of the removed magnet coil is shown in Fig. 8. The side of the coil was milky-white in color, but the color of the part that had faced the absorber had changed to brown. We applied the scratch test to five test pieces taken from the coil. (The test pieces were numbered as shown in Fig. 8.) The five flaws arising from the scratch test were similar in appearance to each other and to that of the acceleration test piece exposed to 10^6 Gy irradiation. The measured flaw forces for pieces one to five were 8.5, 13.1, 5.1, 7.5, and 7.1 N, respectively. These values correspond to irradiation of 10^6 to 10^8 Gy (Fig. 7). The resistivity was more than 1 GΩ. From the above results, we can see that the coil was still able to perform properly. The degree of damage suggested by the external view and scratch test results corresponded to the damage caused by irradiation of 10^6 to 10^7 Gy in the acceleration test. This agrees roughly with the estimated radiation dose of this magnet and shows the validity of the acceleration test results.

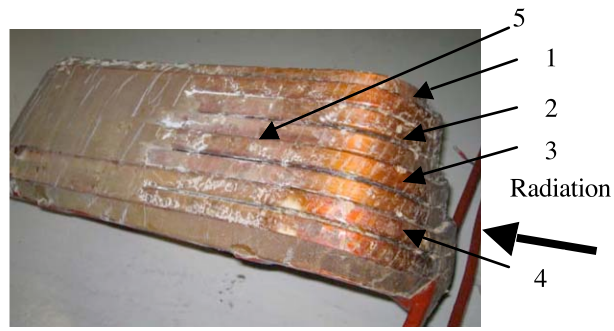


Figure 8: External view of the removed magnet coil.

SUMMARY

An acceleration test was done to investigate the relation between radiation dose and the radiation damage to a magnet coil. Test pieces were directly irradiated with synchrotron radiation of 10^6 to 10^9 Gy. As the radiation dose increased, carbonization of the epoxy resin of the coil insulator increased and the strength of the insulator decreased. However, the resistance between the conductor kept its high resistivity and we concluded that the coils continued to function well. We also investigated the radiation damage done to a magnet coil taken from a storage ring tunnel. We estimated that this coil had been irradiated with a dose of 10^6 Gy. The external view and the insulator strength were consistent with the acceleration test results for 10^6 Gy irradiation, which confirmed the effectiveness of the acceleration test.

REFERENCES

[1] K. Tsumaki, et al., Proc. of the 2003 Particle Accelerator Conference, Portland, U.S.A., May, p884.

[2] GAFCHROMIC film produced by ISP TECHNOLOGIES INC. is the name of a dosimetry medium.

[3] K. Tsumaki, et al., Proc. of the 7th Int. Workshop on Accelerator Alignment, November, 2002, SPring-8, p590.