SYNCHROTRON RADIATION DAMAGE ON INSULATING MATERIALS OF TRISTAN MAGNETS

T.Ozaki, K.Takayama, Y.Ohsawa, Ta.Kubo, and K.Endo
National Laboratory for High Energy Physics
1-1 Oho, Tsukuba-shi, Ibaraki-ken 305, Japan

M.Hirano, T.Chugun, R.Kumazawa, and H.Mitsui
Toshiba Corp.
2-4 Suehiro, Turumi-ku, Yokohama-shi 230, Japan

The shielding design to protect the coils of the bending magnet against synchrotron radiation was performed. The absorbed doses to the magnet components, particularly on the insulating material such as epoxy resin of coil or rubber hoses for water cooling, were measured. The property against radiation exposure was studied.

Introduction

TRISTAN is an $e^+ e^-$ colliding beam accelerator with the collision energy in a range of $\sqrt{s} \sim 60$ GeV. The main ring was operated first in October 1986 at the beam energy of 25 GeV. Since then the beam energy has been increased step by step from 25 GeV to 30 GeV by adding RF accelerating cavities [1]. Thereafter the radiation damage on the accelerator components has become increasingly serious [2].

The average power density lost by the synchrotron radiation along the vacuum chamber is estimated to be 1.9 kW/m at 30 GeV and 10 mA in beam energy and current, respectively. The critical radiation energy at 30 GeV is 243 KeV. The synchrotron radiation in the TRISTAN ring is intensive and the radiation damage on accelerator components is an urgent problem.

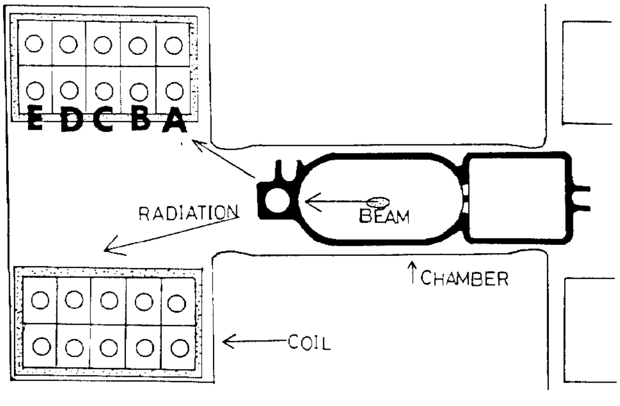

Fig. 1 Cross section of bending magnet. Definition of coil A,B,C,D,E.

Design of radiation shielding to magnet coils

An estimation on the absorbed dose rate to the coil windings of the bending magnet due to the synchrotron radiation is made according to the method of W.R.Nelson et al [3].

The dose distribution on the coils is influenced by the geometrical arrangement of iron yokes, vacuum chamber, lead shields and so on. Fig. 1 shows the cross section of the bending magnet of the TRISTAN main ring [4]. The magnet is C-type and its return yoke is outside the ring. The upper or lower coil has 10 turn windings of oxygen-free-copper hollow conductor. The winding is insulated with the semi-cure fiberglass tape pre-impregnated with the radiation resistant epoxy resin.

The radiation to the coil is generated as follows. Photons emitted along a tangent of the beam orbit hit the aluminum vacuum chamber and they are scattered in the process of the Compton scattering. The photons are scattered to all directions and hit the organic insulating layer of the winding of the coil.

The absorbed dose $D_i(\varepsilon)$ to the surface of each winding, indicated by the subscript i (i=A,B,C,D,E), can be calculated as a function of the incident photon energy ε,

$$D_i(\varepsilon)=\left\{\frac{\varepsilon}{1+\varepsilon/mc^2}\right\}\left\{\frac{\delta\theta}{360}\right\}\left\{\frac{1.6\text{x}10^{-11}}{2\pi RdZ}\left(\frac{\mu}{\rho}\right)\right\}$$
$$\text{X}\left\{e^{-\mu^* t\sec(\theta)}\right\}$$

where μ/ρ is mass absorption coefficient for carbon; carbon is assumed to represent the material of the insulator of the coil winding, and μ^* absorption coefficient for aluminum. The first three terms estimate the fraction of the incident energy ε that is compton-scattered by an aluminum atom into the azimuthal angle $\delta\theta$ defined by each winding, and the forth term accounts for the attenuation in the aluminum.

The photon density is given by

CH2669-0/89/0000-2015$01.00©1989 IEEE

$$\frac{d^2N}{d\varepsilon dt} = 5.43 \times 10^{16} \times \frac{IR}{E^2} dN(r)$$

where I is the beam current , R the radius of the electron orbit , E the electron energy , r equals $\varepsilon/\varepsilon_c$ where ε_c is the critical energy and $dN(r)$ equals $g(r)/r$ where $g(r)$ is the spectral distribution of the synchrotron radiation.

Dose rate to each winding (defined in Fig.1) can be determined from

$$\frac{dD}{dt} = \int_0^{\infty} D(\varepsilon)\frac{d^2N}{d\varepsilon dt}d\varepsilon .$$

As the coil A is essentially shielded by the magnet pole , the absorbed dose rate to the coil B is given in Fig.2(A) for various incident photon energy bins . The numerical integration gives the dose rate of 9030 rad/sec for circulating electron and positron beams of 30 GeV and 10 mA.

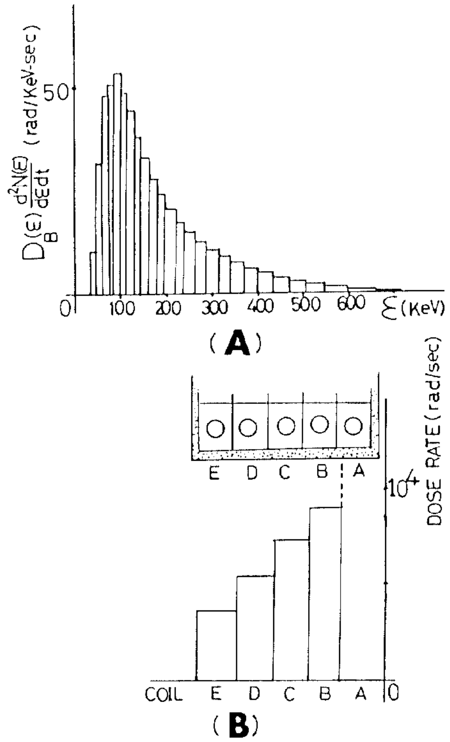

Fig. 2 (A) Plots of dose rate versus photon energy
(B) Absorbed dose rate to the coil windings.

Above calculations show that the coil windings are subject to high radiation doses leading to a coil failure. To protect the coil from the radiation, the vacuum chamber inside the bending magnet was covered with 1 cm thick lead shields on both sides , not on top and bottom . Outside the magnet pole gap , an additional 1 cm thick lead plate is placed between the poles to attenuate the radiation which attacks the coil surfaces at the yoke side.

<u>Radiation damage to rubber hoses of magnets</u>

At the spring of 1988, hardening of the cooling water hoses used for sextupole and wiggler magnets was found. (It is concluded from the radiation exposure tests on samples that these hoses suffered from radiation damage.) These hoses are made of Nitrile-Butadiene (NB) rubber. For other magnets , Ethylene-Propylene (EP) rubber hoses are used . However, in the same environment, EP hoses do not show any radiation damage till now.

Several NB rubber hose samples were put near the wiggler magnet, where the synchrotron radiation is most serious in the tunnel , and irradiated for a month. The absorbed dose was estimated by scaling the dose measured with TLD (thermo-luminescence dosimeter) which was irradiated under the circulating electron beam for a minute . Fig.3 (A) shows results of the hardness test. Figs.3(B) and (C) give results of the measurements of elongation at the breaking point and tensile strength , respectively . It is found that the samples show no radiation damage less than 10^6 rad, but above 10^6 rad the hardness increase with the absorbed dose. The decrease of the insulating resistance due to the radiation was not found .

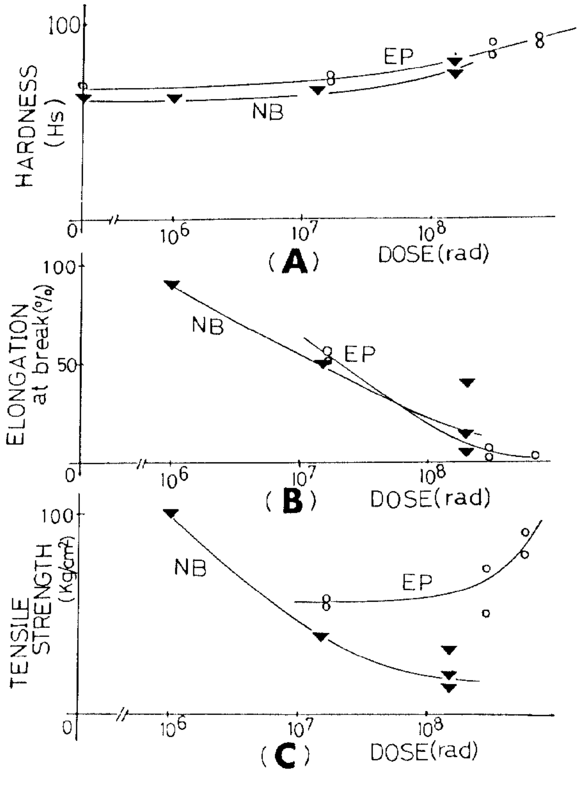

Fig. 3 Rubber property against absorbed dose .
(A) Hardness, (B) Elongation at break ,
(C) Tensile strength.

The same tests were performed on rubber hoses or sheets made of EP rubber ; the results are also shown in the same figure by open circles. The latter has superior properties compared to the former [5] [6].

It is concluded that all rubber hoses of the TRISTAN magnet in the arc section have been irradiated more than 10^6 rad so far. So, all NB rubber hoses were exchanged to the EP rubber hoses .

Radiation test on insulating material of coil

The insulation between turns of a coil is provided by the epoxy impregnated glass-tape wound on the conductor. Insulating material is also considered to have been irradiated more than 10^6 rad. Tests were also performed on three types of insulations. The type (A) is VPI(vacuum-pressure-impregnation) insulation prepared by glass cloth reinforced mica paper tape impregnated with epoxy resin. This type of insulation is really adopted for magnets. The types (B) and (C) are prepreg (resin-rich) insulations prepared by polyimide prepreg glass cloth tapes by the press mold method and the asphalt compound mold method , respectively. These samples were irradiated for a month in the TRISTAN tunnel. The results of the flexural strength and elastic modulus are shown in Fig.4 as a function of the absorbed radiation dose. The type (A) shows remarkable degradation at 10^9 rad. The types (B) and (C) are more radiation resistant than the type (A). The above result gives a criterion of dose limit at which the electric insulation of the coil would fail.

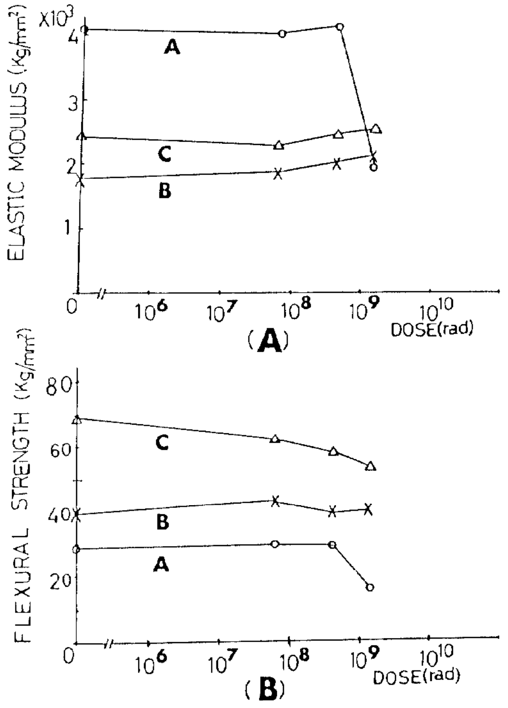

Fig. 4 Flexural property of insulation against dose (A) Elastic modulus, (B) Flexural strength

Shielding

The lead shieldings around the vacuum gate valves , feedthroughs for beam monitors and inside the correction magnets were not sufficient . Gaps in such places allow the radiation to leak out . The radiation leakage was examined using radiation sensitive color films (its commercial name is Radcolor). A board covered with radcolor films was installed across the beam axis between magnets. The board was irradiated for weeks. The spatial distribution of radiation can be visualized by the change of coloring. The pattern of radiation leakage is shown in Fig.5(A). During this exposure , the energy was 27 GeV per beam. The pattern reflects the spatial distribution of absorbed doses near the coil of the sextupole magnet .

After filling gaps with lead wool and plates all around the main ring in the long shutdown, the radiation leakage was again measured by the same method described above. In this case, the beam energy is 30 GeV and the result is shown in Fig.5 (B). Although the synchrotron radiation was increased nearly tenfold compared to the previous run, the dose was comparable. This indicates the effectiveness of the reinforced shielding .

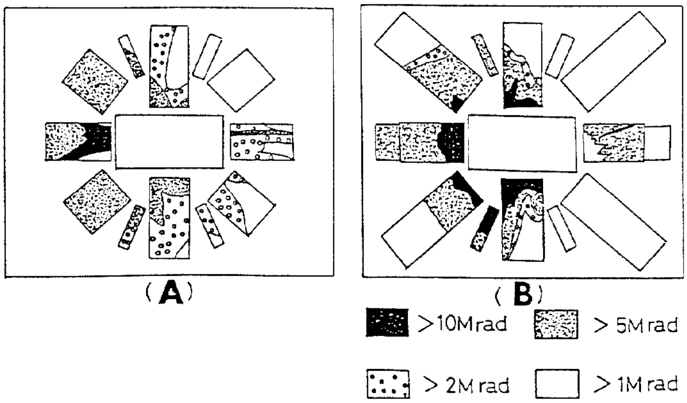

Fig. 5 Spatial distribution of absorbed dose. Radiation exposure: (A) 56 Hr at 5 mA, 27 GeV, (B) 238 hr at 6 mA, 30 GeV.

References

[1] Y.Kimura and H.Baba : Proceedings of the 6th Symposium on Accelerator Science and Technology, Tokyo, 1987, pp15-17.

[2] T.Momose et al : European Particle Accelerator Conference , Rome, 1988.

[3] W.R.Nelson , G.J.Warren and R.L.Ford : PEP-109 (1975)

[4] K.Endo et al : Hitachi Review, <u>34</u> ,101(1985).

[5] P.Beynel ,P.Maier and H.Schönbacher : CERN 82-10.

[6] H.Schönbacher and A.Stolarz-Iżycha : CERN 79-04.