MEASUREMENT OF THE RADIATION INCIDENT ON ALS NdFeB PERMANENT MAGNET INSERTION DEVICE STRUCTURES AND A DETERMINATION OF THEIR LIFETIME*

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Abstract

Measurements of the radiation incident on ALS insertion device NdFeB permanent magnet structures were carried out using thermoluminescence dosimeters. A plastic scintillator gamma telescope was utilized to unravel the various contributions to the integrated dose. Magnet lifetimes were calculated for various operational conditions.

1 INTRODUCTION

The Advanced Light Source (ALS) [1] at the Lawrence Berkeley National Laboratory is a third generation electron accelerator that produces photons in the 10 eV-10 keV range. The descriptive “third generation” is given to light sources with low beam emittance incorporating insertion devices to produce extremely bright x-ray beams. The ALS is composed of a 50 MeV LINAC, a 1.5 GeV booster and a 1.9 GeV storage ring. The 200 m circumference storage ring has 12-fold symmetry and 10 available straight sections for insertion devices. Presently, the ALS storage ring has five insertion devices in operation (two more to be added in 1997-8) whose magnetic structures are fabricated from NdFeB permanent magnets. These devices have anywhere from 38 to 178 alternating North -South poles on either side of a vacuum chamber. Near the storage rings electron beam the radiation level is mainly due to γ brehmsstrahlung [2]. Since the x-ray brightness produced by the insertion devices will degrade with loss of magnetization, the stability of the permanent magnets to radiation exposure is of paramount importance. A number of studies have been carried out to measure the change in magnetic properties of NdFeB[2-10] and SmCo[2,4-6] due to radiation exposure. We have exposed over 400 thermoluminescence dosimeters (TLD) under various beam conditions to determine the magnitude of γ-radiation incident on the insertion device permanent magnets and have utilized a gamma telescope to help unravel the source of the integrated dose measured by the TLD.

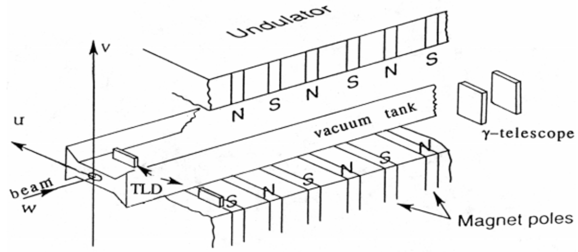

Figure 1: ALS insertion device showing coordinate system, vacuum tank, TLD and γ-telescope

2 MEASURING THE RADIATION DOSE

In this study we used TLD composed of $Li_2B_4O_7$. The TLD were calibrated using a ^{137}Cs irradiator over the range 0.04 Gy to 120. Gy[11]. The dose measured by a TLD reader[12] was consistent with the dose given the TLD by the ^{137}Cs source to within 7 %. TLD were placed on top of the storage ring insertion device vacuum chamber and on the bottom poles of the insertion device, see Figure 1. Two types of insertion device vacuum chambers with different vertical gaps are utilized in the ALS storage ring. The vertical distances from ideal beam center to the inside surface of the vacuum chambers are 5 mm and 9.5 mm for the small gap and large gap chambers, respectively. (Horizontal clearances are much larger.) For the small gap vacuum chambers, the TLD were located 7 mm above and 95 mm below beam center. The position above the vacuum chamber corresponds to the location of the insertion device permanent magnets during a typical running mode while at the highest magnetic field. The position of the TLD below the vacuum chamber corresponds to the location of the permanent magnets at maximum gap during the refilling phase of the storage ring.

3 RESULTS

Table I lists the integrated dose received by a series of TLD placed along the length of the insertion device vacuum chamber (small gap) above and below the electron trajectory. The coordinate system u,v,w is shown in Figure 1 where the origin is taken to be the entrance to the vacuum chamber. The irradiation occurred over 26.679 amp-hours with an electron energy of 1.5 GeV.

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Table I: TLD doses at 1.5 GeV

TLD #	u [mm]	v [mm]	w [mm]	Dose [Gy]
1	0	7	70	35
2	0	7	236	133
3	0	7	390	**134**
4	0	7	550	112
5	0	7	710	109
6	0	7	870	98
7	0	7	1030	104
8	0	7	1350	102
9	0	7	1590	111
10	0	7	1990	134
11	0	7	3110	123
12	0	7	3430	123
13	0	-95	236	31
14	0	-95	390	38
15	0	-95	550	38
16	0	-95	710	48
17	0	-95	1350	42
18	0	-95	1990	49
19	0	-95	3111	**55**
20	0	-95	3430	52
21	100	7	550	39
22	-20	120	390	2

At 1.5 GeV, the highest doses measured on the TLD for the insertion device gap closed position were typically 134 Gy for a period of one week (26.667 amp-hours). In the insertion device gap open position, the highest doses measured were about 55 Gy.

Shown in Table 2a,b are the doses received at an electron energy of 1.9 GeV for 24.7 amp-hours and for 4.7 amp-hr, respectively.

Table 2a: TLD doses at 1.9 GeV (24. 7 amp-hr)

TLD#	u [mm]	v [mm]	w [mm]	Dose [Gy]
23	0	7	70	17
24	0	7	390	**124**
25	0	7	870	109
26	0	7	1590	119
27	0	7	1990	102
28	0	7	3430	102
29	0	-95	390	38
30	0	-95	710	**45**
31	0	-95	1990	34
32	0	-95	3430	43
33	-20	120	390	0.2

Table 2b: TLD doses at 1.9 GeV (4.7amp-hr)

TLD#	u [mm]	v [mm]	w [mm]	Dose [Gy]
34	0	7	70	6.0
35	0	7	390	72
36	0	7	870	39
37	0	7	1590	24
38	0	7	1990	25
39	0	7	3430	68
40	0	-95	390	9.0
41	0	-95	710	10
42	0	-95	1990	10
43	0	-95	3430	17
44	-20	120	390	5

At 1.9 GeV, the highest doses measured on the TLD for the insertion device gap closed position were typically 124 Gy for a period of one week (24.7 amp-hours). In the insertion device gap open position, the highest doses measured were about 45 Gy.

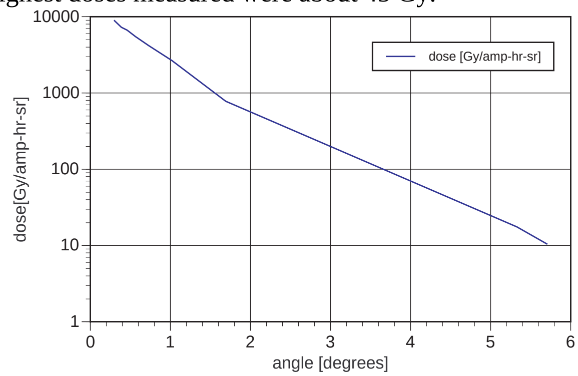

Figure 2: Dose at various positions inside the insertion device

From inspection of Table 2a and Table 2b it can be seen that the dose received by the TLD does not scale directly with amp-hours. This is because the dose received also depends on the number of storage ring fills occurring for each integrated irradiation as well as the electron beam emittance. During the electron ring 10-15 minute refilling process a much higher dose/min. is collected by the TLD than during the normal 240 min. running period. Figure 2 shows a typical relationship between the normalized dose recorded on a TLD versus angle to the TLD (measured relative to the insertion device vacuum chamber entrance). The dose has been normalized to amp-hours-steradians.

A series of experiments were also carried out with one insertion device that uses a large gap vacuum chamber. We found the radiation incident on the permanent magnets of the large gap chamber insertion device was approximately 100-120 times less than for the small gap chambers due to the larger minimum gap available to the magnets.

To determine the contribution to the integrated dose from the running period and the refilling period separately, we utilized a gamma telescope. This telescope was composed of two scintillator photomultiplier ‘paddles’ whose output signals, when in coincidence with each other during a 10 ns gate, produce a single signal count. The scintillator was 0.25 in. thick x 2 in. x 2 in. NE 102 plastic and the photomultiplier tube RCA 8575.

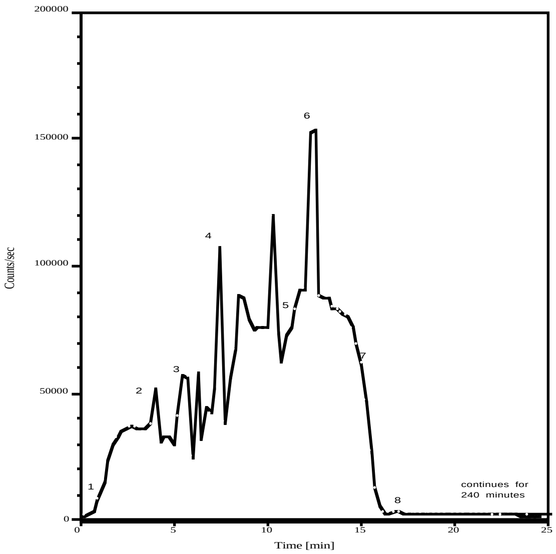

Figure 3

1.Insertion device gaps open
2.Ramp 1.5 to 1.9 GeV
3.Injection process begins
4.Beam stacking
5. Ramp from 1.9 to1.5 GeV
6.Running mode begins
7. Insertion device gaps closed
8. Beam lines opened

We were able to place the telescope about 10 cm from the electron beam in horizontal plane as shown in Figure 1.

We recorded the number of coincidence counts during the electron ring filling process and running period as shown in Figure 3. We found the average ratio (counts during refilling/counts during running) for the full running and refilling periods was 1.0 when running 1.5 GeV electrons but rose to 2.5 when running 1.9 GeV electrons. As shown in Figure 3, part of the contribution from the refilling process occurs when the energy of the stacked electrons were ramped from 1.5 GeV to 1.9 GeV.

Since the insertion device gaps at the ALS are always opened during the refilling process, and if we assume the insertion device gaps are fully closed during normal running, the actual dose seen by the permanent magnets when running in the 1.5 GeV mode is about

134 Gy/wk(1/2)+55 Gy/wk (1/2) $\approx$ 95 Gy/wk.

For 1.9 GeV electrons the average ratio resulted in a dose of

124 Gy/wk (1/3.5)+45 Gy/wk (2.5/3.5) $\approx$ 68 Gy/wk.

Previously, an estimate of the useful lifetime of the ALS insertion devices magnets was based on a loss of magnetic remanence of 0.5% (7). This loss was found to occur when the magnets were subjected to a dose equivalent of $8.5X10^4$ Gy. The number $8.5X10^4$ Gy is a worst case value with an error estimated at 25%. Making various operational assumptions a useful magnet lifetime was calculated to be about 85 years. Several assumptions made in determining that lifetime, though reasonable at the time, are now know to be incorrect. If we estimate the storage ring is in operation 37 weeks/year, the lifetime, T, of the insertion device magnets under current operating conditions is about:

at 1.5 GeV,

$T_{1.5} = 8.5X10^4$ Gy / [(37wk/yr)*(95 Gy/wk)] = 24.2 yr.

at 1.9 GeV,

$T_{1.9} = 8.5X10^4$ Gy / [(37wk/yr)*(68 Gy/wk)] = 33.8 yr.

If the gaps are closed during storage ring injection, the lifetime would be only about 17 years and 18.5 years for 1.5 GeV and 1.9 GeV operation, respectively. This result points clearly to the need for fully opening the ALS insertion device gaps during the short refilling period in order to minimize the radiation incident on the permanent magnets. In addition, when beam dumping is required, the insertion device gaps should also be opened to minimize the radiation damage to their magnets. Improving operation conditions, such as increasing the injection efficiency may further mitigate the radiation damage and increase the lifetime of the insertion devices.

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