Measurements of X-rays from the RF systems of the Electron-Linear Accelerator for KEKB

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1. Introduction

The RF systems of an electron linear accelerator are important sources of X-rays.
A unit of the RF system consists of a klystron, an RF compressor, three RF dividers and a set of waveguides in KEKB linac. X-ray exposure from a klystron collector is well known. Recently, RF compressors have been used in a high peak-power RF system and X-rays from the compressors became an important problem[1].

In the KEK 8-GeV electron-linear accelerator for KEKB (two rings, electron-positron colliders), the klystron uses a 50MW peak-power tube (PV3050 MELCO, E3730 Toshiba, 40MW in present operation)[2]. After (Downstream) the SLAC-type RF compressor, called SLED(SLAC energy doubler)[3], intensity is about five times the peak power of the microwaves from the klystron. The energy of the microwaves radiation is divided into four with three RF dividers, and goes to four accelerator tubes through a waveguide. Figure 1 shows a diagram of the RF unit. There are 58 units in the 8-GeV electron-linear accelerator.

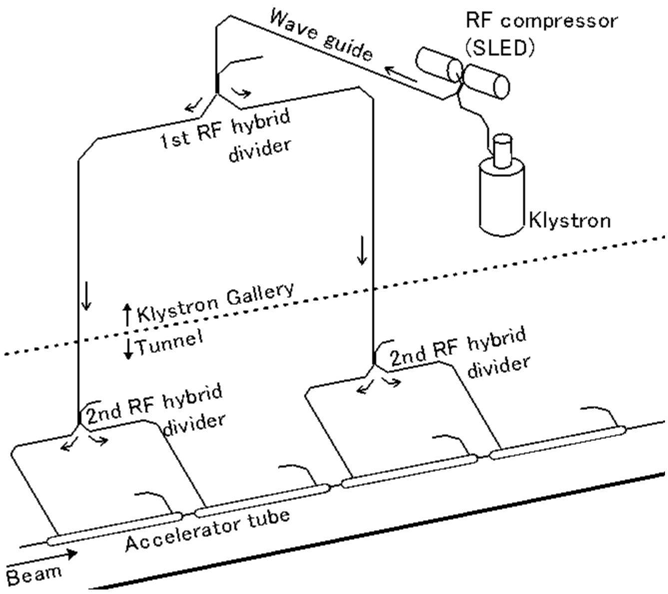

Fig. 1 Diagram of the RF unit

The X-rays doses from these components were measured with a TLD (thermoluminescent dosimeter). The spatial distribution of the X-ray intensity around these components (SLED, RF divider) was measured by using an IP (imaging plate).

2. Measurements of the dose rates around the klystron and the RF compressor

The X-rays from all units were measured with a TLD (martial $Li_2B_4O_7$ (Cu), UD-806PQ, Matsushita). Two TLDs were set in each RF unit for a month. One of the TLDs, set at 60cm distant from the klystron, measured the radiation from the klystron, and the other TLD, set at 10cm distant under the SLED divider, measured the radiation from the SLED. The measurements were done every month.

The variance of the dose at the klystrons was about 0-5 mSv/month. However the variance of the dose at the SLED was about 0-100 mSv/month. This was larger than what we had expected. Although we compared the dose at the klystrons with that at the SLEDs, there was no correlation between them. The number of the SLEDs, which dose less than 1mSv/month, was about one-third of all SLEDs.

Figures 2 and 3 show the dose variations by time at the some typical klystrons and those at the some typical SLEDs. The absolute dose related to the operation time of the accelerator in a month. Every klystron and SLED dose changed similarly except Jun. 1999. The number of high dose SLEDs didn't change. Each SLED kept its feature of dose emission. This condition was not temporary.

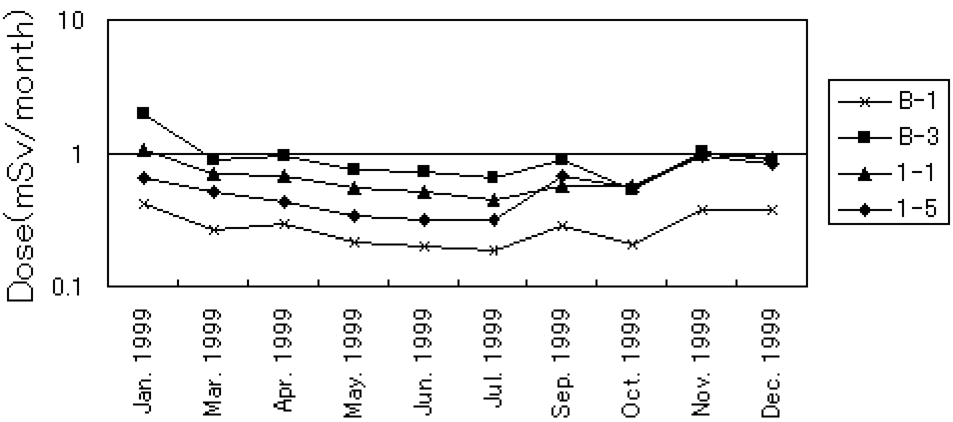

Fig. 2 Time variations of dose at 60cm from the some typical klystrons.

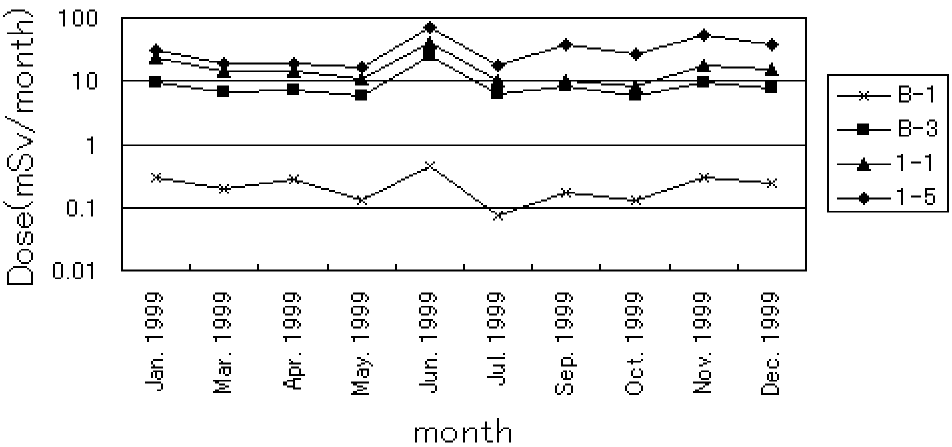

Fig. 3 Time variations of dose at 10cm under the some typical SLEDs.

3. Measurements of the spatial distribution of X-rays from the RF system

The X-ray spatial distribution around the RF unit was measured with an IP (BAS-3, Fuji photo film). The size of the IP is 20x40cm. IP was calibrated using 59.5-keV photons from an 11.1 GBq ^{241}Am gamma-ray source (Amersham, AMC 17 type).

Figure 4 shows an outline of a klystron. The height of the klystron is 2.2m. Six IPs were arranged vertically at 25cm distant from a typical klystron, determined by a TLD measurement. Although there were no X-rays below 1.6m of the klystron, the average dose at the top region of the klystron was 0.3μSv/h; the partial-peak dose in this region was 10-times of the average one. There are some connectors, cables and a wave guide at the top of the klystron. These components are not shielded well. The peak dose was seen at the small area around the cooling water pipe, and X-rays were not generated toward the aisle. The dose at the opposite side of this klystron, which had the RF window, was also measured. The average dose at the top of this side of the klystron was 2-times higher than the opposite one. The partial-peaks of dose were also seen in this region, which was placed at a height greater than 1.6m.

Fig. 4 Outline of a klystron

The average dose at the surface of waveguide from the klystron to the SLED was 0.2-0.3μSv/h. The dose at the waveguide near to the SLED was slightly higher than at other parts of the waveguide.

Figure 5 shows an outline of a SLED. The SLED consits of two cylindrical cavities and a RF divider

Fig. 5 Outline of a SLED

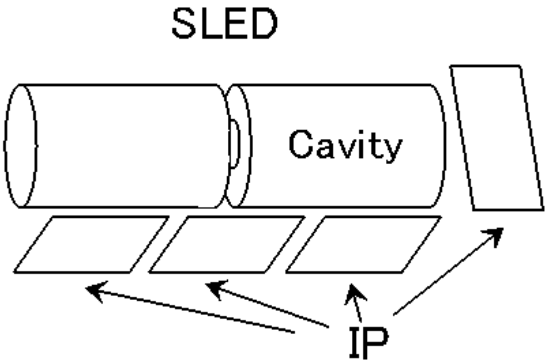

Fig. 6 Diagram of IP set at SLED

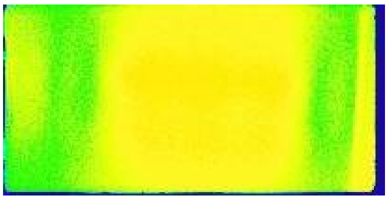

Fig. 7 IP image of X-ray distribution under higher dose cavity.

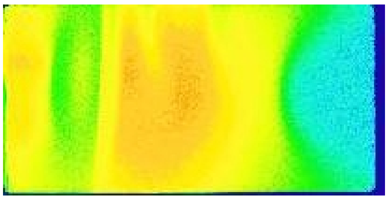

Fig. 8 IP image of X-ray distribution under the RF divider between the cavities.

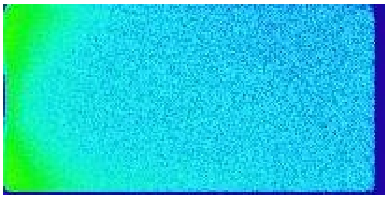

Fig. 9 IP image of X-ray distribution under lower dose cavity.

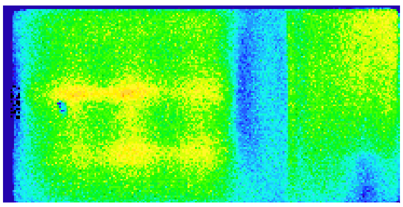

Fig. 10 IP image of X-ray distribution under the cavity of another SLED.

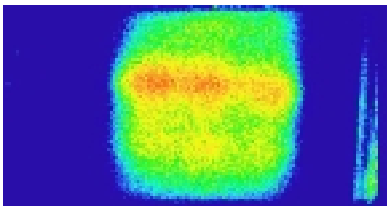

Fig. 11 Another IP image (fig.7) by adjusting the dynamic range.

between the cavities. The microwaves radiation from the klystron is divided into two at the RF divider, and is then passed to two cylindrical cavities. The microwaves join after being compressed by the cavities, and then pass to the accelerator tubes through a waveguide.

IPs were set as in Fig. 6. Three IPs were set at 2cm distant from the cylindrical side of the cavities. An IP was set at 9-10cm distant from the cylindrical base of the cavity. Figures 7,8,9 show typical IP images under the two cavities and the divider between the cavities. Red colour means high dose and blue colour means low dose in these figure. Although average dose under one of the cavities was 1.4μSv/h, the dose under the other cavity was almost background level (0.05μSv/h). Figure 10 shows an IP image under the cavity of another SLED. We can see some yellow lines in this figure. The dose in this yellow line was 8.6μSv/h and it was 1.7 times higher than that in green area. (Because the irradiation time of this IP was one-tenth of that of the previous IP (fig.7), the same color in these figures indicates different dose rate.) There were some SLED cavities that have the lines like fig. 10, we analyzed the IP image (fig.7) again. By adjusting the dynamic range of the IP image, we

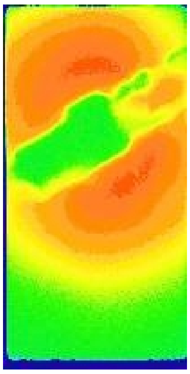

Fig. 12 IP image of X-ray distribution over the cylindrical base of the cavity of higher dose cavity.

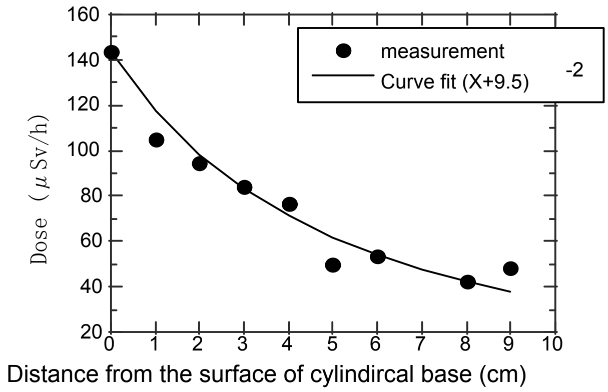

Fig. 13 Dose attenuation at SLED by distances from the surface of cylindrical base.

obtained fig.11. The dose in the orange line was 1.8μSv/h and the dose in the green area was 1.4μSv/h in this figure. These IP images in figures 10 and 11 show these lines are one of the important sources of the X-ray emission.

Figure 12 shows an IP image over the cylindrical base of the higher dose cavity. The shadow in Figure 10 is the connector on the cavity. The dose in this region, which was shielded with the connector, was 0.5μSv/h. The dose in the region without the connectors was 12-16μSv/h. Because the cylindrical base is thinner, this dose was about 10-times higher than that under same cavity.

The position of the X-ray source in the SLED was estimated by comparing the dose at different distances from the cylindrical base of the cavity. Figure 13 shows the relation between the distances from the cylindrical base and the dose at its distance. The rule that the dose was inverse proportion to square of its distance from the source determined the positon of the source. It was 9.5cm inside from the cylindircal base.

The microwave radiation from the SLED is divided with the 1st divider, called a 3dB-hybrid divider. Figure 14 shows an outline of the hybrid divider. There is a tuning button in the middle of the divider.

An IP was set on the surface of the hybrid divider. Figure 15 shows an IP image on a typical lower dose hybrid divider. The average dose on the hybrid divider was almost background level. We can see a green spot in this figure. The spot dose was 0.4μSv/h. The position of the spot was between the wave guide and the hybrid divider. This is a welded point between them.

Figure 16 shows an IP image on a typical higher dose hybrid divider. The dose peak was about 60μSv/h and the position was a welded point too.

Figure 17 shows an IP image on a medium dose hybrid divider. We can see the shape of the hybrid and the tuning button.

The energy of the X-ray source from the SLED was estimated by using Pb plates at a typical RF unit. Three Pb plates 1mm in thickness were piled between the IPs. This set was put on the cylindrical base of the SLED. Figure 18 shows the dose attenuation through the Pb plates. A one-tenth value layer was about 2mm in thickness. The energy of the X-ray source was 200-250kV. The energy of X-ray source from the hybrid was also estimated by the same method. It was 250-300kV.

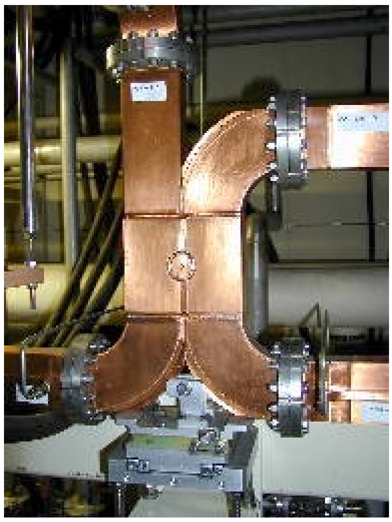

Fig. 14 Outline of 3dB-hybrid RF divider.

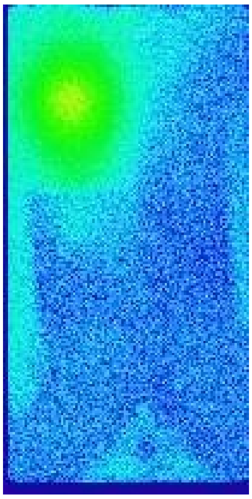

Fig. 15 IP image on a lower dose hybrid divider.

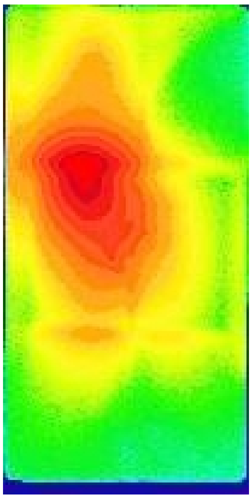

Fig. 16 IP image on a higher dose hybrid divider.

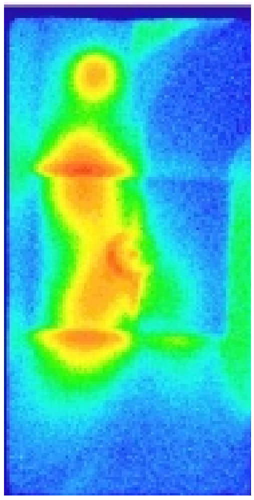

Fig. 17 IP image on a medium dose hybrid divider.

4. Summary

The X-ray doses around the high-power RF system were measured during a period of one year. The X-ray dose rates were high around some of the SLEDs, klystrons and 3dB hybrid dividers. The doses are always high at some components and always low at others. This shows that the X-ray doses were not due to any temporary condition of the high-voltage power supply and electric discharge.

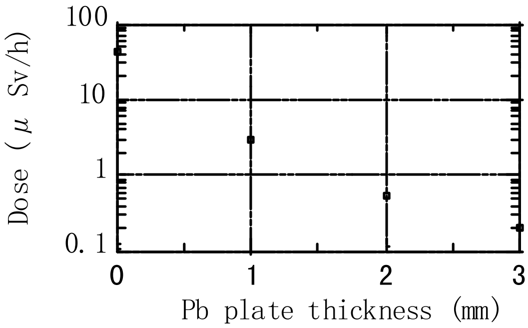

Fig. 18 Dose attenuation at SLED with Pb plates.

Some kinds of RF cavities such as an accelerating cavity containing microwave fields on the surface produce X-ray emission. This radiation depends on the surface conditions, and becomes lower after aging the cavity. However, the SLEDs and the 3dB-hybrid dividers produce the X-rays for one year. The SLED in the linear accelerator for KEKB was well modified [1] to reduce the electric fields on the surface near to the coupling hole between the SLED cavity and the waveguide. The X-ray dose from one-third of the all SLEDs is small. One SLED requires two cylindrical cavities and the cavities are connected to the same klystron. The X-rays are often seen from one cavity and not from another. The dose from the cylindrical base of the cavity is 10-times higher than that of the cylindrical side, because the cylindrical base is thinner. There are some higher dose lines on the cylindrical side of high dose SLED and some slightly higher dose lines on that of low dose SLED. We measured the X-ray distribution from only about 10 SLEDs, these lines in fig.10 are often seen and they are one of the important sources of the X-ray emission in the SLED for KEKB.

Although a 50-MW klystron is well shielded, the doses are high around some components. Some leakage X-rays are seen around the cooling water pipes.

The waveguide was not shielded at all, and the dose rates were low. However the dose rates were high on some 3dB-hybrid dividers where RF from the SLED is divided. X-rays were generated where the divider was welded to the waveguide. The dose rates are also high at the tuning button of some 3dB-hybrid divider and not at all at others.

The performance of the RF system is always monitored during the linear accelerator operation. However, it is not easy to find the components that produce X-rays, because a small mismatching does not directly affect the RF performance. By measuring the dose rates, we can find such a component.

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