Radiation Shielding Design To Attenuate Bremsstrahlung X-rays Induced by Field Emission Electrons at the Vertical SRF Cavity Test

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1. Introduction

The Proton Engineering Frontier Project (PEFP) has been developed prototype five-cell superconducting rf cavity, which can be used for 1-GeV superconducting linac. And then, vertical test for the fabricated rf cavity was performed to verify the suitability for use in accelerator. Figure 1 and 2 shows five-cell cavity and the vertical test set-up [1].

During rf cavity test, the main hazard are bremsstrahlung x-rays produced by field-emitted electrons. These x-rays are only present while rf power is applied into the cavity. In this paper, the preparation of radiation shielding for attenuating the dose of x-ray during the rf cavity test, will be presented in this paper.

Fig. 1. Prototype five-cell cavity

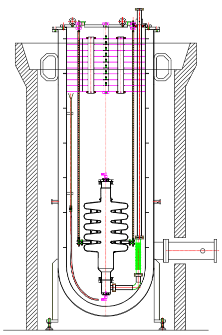

Fig 2. Set-up for Vertical test

2. Shielding Design

2.1 Shielding Criteria

During the vertical test for rf cavity, the residual electrons in the cavity are accelerated at high accelerating gradient with 4.2 MV/m. These high energy electrons are bombarded with Nb cavitiy wall and produce bremsstrahlung x-rays. The maximum kinetic energy of electrons can be achieved up to 1.9 MeV. To calculate the optimized radiation level after the shielding, one needs to determine the amount of radiation production by the cavity. But it is difficult to estimate radiation production because it is difficult to estimate the number of emitted electron and their trajectory in the cavity. Thus, we have estimate radiation production from past measurement have been made Cornell with TESLA. Their maximum instantaneous radiation values were 100 mSv/hr [2,3].

2.2 Anisotropy of bremstrahlung x-rays

As shows as Fig.2 five-cell cavity has been placed inside of the cryostat, which is made of stainless steel and installed at ground level vertically. Thus, principal concern radiation is the x-rays of lateral direction. In advance the determination of lateral shielding thickness, we have checked the anisotropy of bremstrahlung x-rays by MCNP calculation. The results indicate that x-ray has high intensity along to the electron direction and its lateral intensity is uniform.

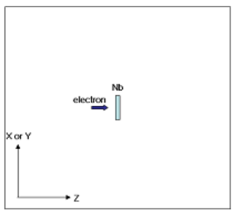

Fig. 3. Calculation model for anisotropy calculation

Table 1. Anisotropy of x-rays

direction	+x	-x	+y	-y	+z	-z
fluence [#/cm^2/e]	7.16E-5	7.34E-5	7.13E-5	7.19E-5	**1.68E-4**	9.16E-5

2.3 Shielding calculation

The radiation attenuation provided by matter depends both on the material and the energy of the x-rays. In this case, the energy spectrum of x-ray, which spilled out from the cavity, is continuous up to 1.9 MeV. But most of current of field-emission electrons are stopped at the first cell of cavity. Only 2% of field-emission electrons are accelerated up to 1.9 MeV. Thus, we calculated the attenuation of x-rays which is assumed the incident field emitted electron have mono-energetic 0.85 MeV. Figure 4 shows the calculation model by MCNPX code.

The radiation shielding consists of 9.5 cm-thick concrete, 2 cm-thick lead and 40 cm-thick concrete. Through the MCNP calculation, the number of photons was scored at the surface of each shielding. And then, the scored number of photons is converted to dose equivalent by using the fluence-to-dose conversion factor.

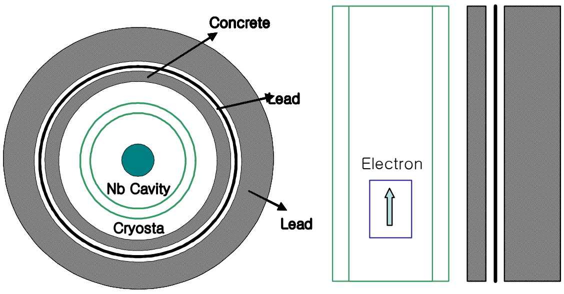

Fig. 4. Calculation model for x-rays attenuation

Table 2. the calculated dose at the shielding surface

Position	Cryostat	1st concrete	Lead	2nd concrete
Calculated Dose [(Sv/hr) / (#/sec)	1.47E-15	1.22E-16	9.74E-19	0
Attenuation ratio	1	1/12	1/1348.6	n/a

The calculation results are shown as Table 2, The bremsstrahlung x-ray was not achieved behind of shielding due to the very small scoring of photon. Also, the calculated results indicate that the shielding performance of 2 cm-thick lead is superior to that of the 9.5 cm-thick concrete. This result is caused by the difference between attenuation coefficients of both materials. Figure 5 shows the attenuation coefficient of both materials as a function of photon energy. As you can see as figure 5, the attenuation of lead (ux) is higher than the concrete at the low energy region.

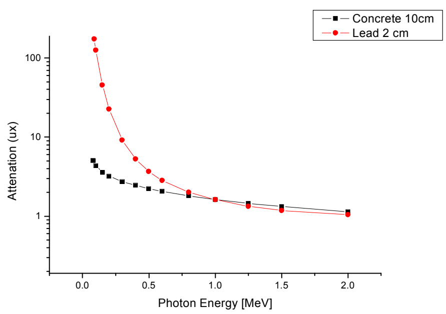

Fig. 5. Attenuation ratio of lead and concrete

In the actual SRF cavity test, we have measured the accumulated dose by electronic pocket dosimeter (PDM-192, ALOKA) at behind of each shield while 4.2 MV/m of maximum accelerating gradient was applied for 1.5 hours. The results show the good agreement with calculated attenuation ratio at the first concrete and lead. Through the measured radiation dose, we have estimated field-emission current in the cavity as 8.7 µA.

Table 3. Comparision between measured and calculated radiation dose

Position	1st concrete	Lead	2nd concrete
Measured dose [uSv]	9948	80	14
Attenuation	1	1/124.3	1/710.5
Calculated Dose [(Sv/hr) / (#/sec)	1.22E-16	9.74E-19	0
Attenuation	1	1/125	n/a

3. Conclusions

The shielding design is performed to attenuate the bremsstrahlung x-rays induced by field-emission electron during the vertical test of superconducting rf cavity. Through the designed shielding which consists of 9.5 cm-thick concrete, 2 cm-thick lead and 40 cm-thick concrete, the attenuation of x-rays, spilled out from the cavity, was verified by the radiation dose measurement.

Acknowledgement

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