Development of ionization chamber for in-line intensity monitoring of large profile parametric X-ray beam

T Tanaka¹, T Kuwada¹, Y Takahashi¹, K Hayakawa¹, Y Hayakawa¹, T Sakai¹, K Nogami¹, K Nakao¹, M Inagaki¹ and I Sato²

¹ Laboratory for Electron Beam Research and Application (LEBRA), Nihon University, Narashinodai 7-24-1, Funabashi, Chiba, 274-8501, Japan
² Advanced Research Institute for the Sciences and Humanities (ARISH), Nihon University, Gobancho 12-5, Chiyoda-ku, Tokyo, 102-8251, Japan

E-mail: tanaka@lebra.nihon-u.ac.jp

Abstract. An in-line ionization chamber has been developed for the real-time measurement of the absolute intensity of the pulsed parametric X-ray (PXR) beam during irradiation experiments. The quasi-monochromatic PXR generating system was developed at the Laboratory for Electron Beam Research and Application (LEBRA) in Nihon University. In contrast to typical narrow X-ray beams in synchrotron radiation facilities, the PXR beam profile is as large as approximately 100 mm in diameter with rather uniform flux distribution at the X-ray output port in the experimental hall. The energy of the PXR beam ranges from 5 to 34 keV, which is specified by the PXR target crystal plane and its geometrical condition. The ionization chamber is of a plane parallel type employing 6-µm thick double-sided aluminum vapor-deposited polyester films for the plane electrodes through which the X-ray beam passes. The plane bias electrode has been placed at an equal distance of 25 mm from the two plane earth electrodes that act as the beam windows with an aperture diameter of 120 mm. Due to the pulsed property of the PXR beam and the geometrical configuration of the ionization chamber, the charge-sensitive preamplifier output pulse height represents an integral of the fast electron current, corresponding to a half of the total ionization charge produced by the beam. The intensity of the PXR beam has been measured for various X-ray energies by using nitrogen and argon, respectively, as the filling gas.

1. Introduction

The pulsed X-ray beam from the parametric X-ray radiation (PXR) generation system developed at the Laboratory for Electron Beam Research and Application (LEBRA) in Nihon University [1] has been applied to the imaging of soft specimens such as biological tissues of small animals [2] or hard specimens such as human teeth [3], or measurement of X-ray absorption fine structure (XAFS) in various materials [4]. These applications have been aimed to investigate the applicability of the quasi-monochromatic and spatially coherent property of the PXR beam having a large profile at the X-ray output port. These experiments were carried out without monitoring the total dose or the intensity of

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³ Author to whom any correspondence should be addressed.
⁴ Present affiliation: Nihon University School of Dentistry at Matsudo, Sakaecho-nishi 2-870-1, Matsudo, Chiba, 271-8587, Japan
⁵ Present affiliation: High Energy Accelerator Research Organization (KEK), Oho 1-1, Tsukuba, Ibaraki, Japan
the X-ray beam, since the evaluation of irradiation dose was not necessarily required. In practical use of the PXR beam e.g. for experiments on biological irradiation effects, however, information on the intensity or the dose of the beam is crucial to quantitative treatment of the experimental data. Hence, an ionization chamber was developed and inserted into the X-ray beamline as an in-line monitor.

2. Design of the ionization chamber
As a reliable device to monitor the X-ray intensity, ionization chambers have been commonly used at the beamlines in many synchrotron radiation facilities. In contrast to narrow and continuous beams in these facilities, the PXR beam developed at LEBRA is a pulsed source having a beam profile as large as 100 mm in diameter at the X-ray output port which is approximately 7.2 m distant from the PXR generating target. Available energy of the quasi-monochromatic PXR beam ranges from 5 to 34 keV. Based on the horizontal dispersion property of X-ray emission in the PXR generation system of LEBRA, the horizontal energy spread is approximately 4 to 15 % of the central energy. The ionization chamber was designed to be located immediately downstream of the X-ray output port; specimens are irradiated with the X-rays that pass through the ionization chamber. Therefore, as a design constraint a low absorption loss in the ionization chamber should be achieved by reducing the thickness of the sensitive gas layer and the beam windows. The ionization chamber is intended for the measurement of the intensity of the large profile pulsed PXR beam with pulse duration of 5 to 10 µs, pulse repetition rate of 2 to 5 Hz, expected flux of $10^5 - 10^7$ photons/pulse, and X-ray energy range from 5 to 60 keV.

The ionization chamber is of a plane parallel type as shown in figure 1. The chamber wall is made of stainless steel. The thin beam windows are made of 6-µm thick double-sided aluminum vapor-deposited polyester films. The beam window aperture diameter of 120 mm has been chosen so as to accept the whole X-ray beam. Both the entrance and the exit windows act as the earth electrodes with a separation of 50 mm from each other. The thin plane bias electrode consists of the same material as the earth electrodes, which is placed at the middle point between the earth electrodes to form a symmetrical electric condition. Therefore, the bias electrode separates the chamber into two gas layers with an equal sensitivity. The outer aluminum rim of the bias electrode is supported from the chamber wall using insulator rods. The X-ray beam enters from the left side window in the side view of figure 1,

![Fabrication drawing of the ionization chamber.](image)
going through the chamber and out from the right side window.

In this configuration of the electrodes, the sensitivity of the ionization chamber is nearly a linear function of the thickness of the gas layers between the two windows, being independent of the X-ray incident position on the window plane. The gas layer thickness was determined by the calculation of the absorption dose for an expected incident flux of the X-ray beam when nitrogen was assumed as a filling gas material. Due to low absorption rate in the chamber, the ion-electron pairs are produced almost homogeneously along the X-ray beam axis or the direction of the electric field. During a normal operation, the incident X-ray beam has a pulse width of 5 µs and a repetition rate of 5 Hz. In this case the fast electron current can be distinguished from the slow ion current by using a charge-sensitive preamplifier.

For homogeneous ion-electron pair density distribution, average path length of the electrons along the homogeneous electric field in the chamber is a half of the distance between the two electrodes. This means the electric current attributed to the electrons is a half of the total ionization current. Thus the peak charge accumulated in the feedback capacitor of the charge-sensitive preamplifier is equivalent to a half of the total ionization charge [5]. At the lowest X-ray energy of 5 keV, approximately 18 % of the incident X-rays are absorbed in the chamber filled with nitrogen gas, which results in an obvious gradient of the ion-electron pair density along the direction of the electric field. However, the effect of the deviation from homogeneous density, estimated from the calculation of the field energy required to collect the electrons to the anode, causes change of only less than 1 % in the sensitivity.

3. Chamber gases and experimental method

The sensitivities of the ion chamber for nitrogen gas-filled case (N2 IC) and argon gas-filled case (Ar IC) have been calculated as shown in figure 2, where estimated charge-sensitive preamplifier output pulse height voltages for an X-ray injection flux of 1x10^6 photons/pulse at a feedback capacitance of 5 pF are given as a function of the X-ray energy. The output pulse heights have been estimated for use of 1-atm nitrogen and argon, respectively. The calculation has been performed on the basis of the absorbed energy obtained from the photoelectric absorption and Compton scattering attenuation coefficients [6], and average ion pair production energies of 34.6 and 26.2 eV/pair for nitrogen and argon gases, respectively [7]. The collection efficiency of the ionized electron charge was assumed to be 100 %. The energy spread of the X-ray beam was not taken into account here.

Rapid reduction of the sensitivities with the increase in the X-ray energy is shown in figure 2 for both gases except for the lowest energy region. The pulse height ratio shows the chamber sensitivity with argon gas is dozens of times higher than that with nitrogen gas. The sensitivity in Ar IC has a

![Figure 2. Calculation of the preamplifier output pulse height voltage as a function of the X-ray energy for the ionization chambers filled with nitrogen and argon gases, respectively.](image)

![Figure 3. Preliminary experimental result of the PXR beam intensity obtained by using the ionization chambers filled with nitrogen and argon gases, respectively.](image)
peak at around 7 keV, since most of the X-rays with energies lower than 7 keV are absorbed in the gas, where the pulse height is rather proportional to the incident X-ray energy. While, the absorption rate in N2 IC is still small at 5 keV. Therefore, use of nitrogen gas has an advantage in the energy region lower than 20 keV. For this reason, two ionization chambers with an identical design were fabricated to fill with nitrogen and argon gases, respectively.

Both the chambers have been installed at immediately downstream of the X-ray output port on the separate sliding stages, with N2 IC close to the port followed by Ar IC immediately downstream. The characteristics of the ionization chambers have been measured by the behavior of the preamplifier output pulse for the injection of the PXR beam. There have been no apparent changes in the output pulse height over the gas flow range from 30 to 150 cm$^3$/min. Then, at a normal use the gas flow has been controlled to keep 30 cm$^3$/min for both the ionization chambers. The bias voltage characteristics of both the ionization chambers have shown constant output pulse heights for the applied voltages from 200 to 400 V, which suggests that the recombination probability of the ion-electron pairs is negligibly small in that voltage region. The bias voltages for the chambers were set to 400 V during the PXR intensity measurement.

4. Measurement of the PXR beam intensity

On the basis of the sensitivities of both the ionization chambers as shown in figure 2, the PXR beam intensity has been estimated from preliminary measurement of the preamplifier output pulse height. In this experiment both the ionization chambers were inserted into the PXR beamline. The output pulse heights were measured simultaneously with an oscilloscope. For normal use in users’ irradiation experiments, an automatic dose counting system will be arranged.

The PXR beam intensities were measured with both the chambers at the X-ray energies of 5, 6, 8, 10, 12, 13.5, 14, 16 and 33 keV as shown in figure 3. For Ar IC data points at 10 and 12 keV are not shown due to pulse height saturation in the preamplifier caused by a large absorbed dose, which suggests the feedback capacitance of 5 pf is too small for Ar IC case. The estimated intensities show good agreement between the two chambers. Relatively large discrepancy at 33 keV is attributed to an error in the N2 IC output signal caused by a very low S/N ratio. For Ar IC the results have not been corrected for absorption of the X-rays in N2 IC and the air between the chambers or inhomogeneous ion production density, which are significant in the low energy region.

5. Conclusion

Ionization chambers for the measurement of the quasi-monochromatic pulsed PXR beam with a large profile were developed. The sensitivity of the ionization chambers was calculated from absorption energies for nitrogen and argon, respectively, as a filling gas. The deduced PXR beam intensities by simultaneous measurement of the output pulse heights of the nitrogen and argon ionization chambers have shown good agreement to each other. The ionization chambers are used for monitoring the X-ray intensity during irradiation experiments.

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