The Behavior of Ionization Chambers and the Criterion of High Applied Voltage under the High Current Storage Ring Operation

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1. Introduction

Ionization chambers are widely in use as X-ray beam intensity monitors in synchrotron radiation experiments. It makes full use of the proportionality of an ionization current generated in an ionization chamber and the incident X-ray beam intensity. It is one of detectors that can surely be exposed to the highest X-ray beam intensity. At SPring-8 the storage ring current has been gradually increased during this year and now immediately after injection it can reaches 70 mA. It's expected that 100 mA operation will be performed not so far. In undulator beamlines we can obtain highly brilliant X-ray beams as one of the most important characteristics of third generation SR facilities and the ionizing current of 1 μA or more is generated frequently in ionization chambers. Moreover X-ray beam intensity is increasing further owing to the increase of the storage ring current and performance improvements of the beamline so that ionization chambers will generate even higher ionizing current.

In case of charged particle radiation, however, it has been known that the proportionality breaks in high ionization current region (higher than 1 μA)[1,2]. It can be said that SPring-8 beamlines exist to demonstrate that the proportionality between X-ray beam intensity and ionizing current breaks as well as the case of charged particle radiation. When data correction is made based on the storage ring current and the behavior of the beamline optics to the heat load by using the ionization chamber outputs, the proportionality failure becomes an extremely important issue.

2. Experimentals

In our previous works, an ionization chamber of some kinds of filling gases were characterized by varying the filling gas, the X-ray energy and the incident X-ray intensity at the BL47XU (R&D Beamline I) of SPring-8 [3,4]. One of the measured saturation characteristics is redisplayed in Fig. 1 under the condition of X-ray energy 14.3 keV, the filling gas of argon at atmospheric pressure and the storage ring current of about 20 mA with varying the thickness of aluminum absorber.

To observe saturation characteristics in a wider range of the beam intensity, the saturation voltage, Vsat, and the saturation current, Isat, using the filling gas of pure nitrogen were measured by varying beam flux with FE slits as shown in Fig. 2 at storage current of about 70 mA. Electric discharges become onset above the highest ionization currents indicated in Fig. 2, at which the measurements were terminated.

3. Discussion

As shown in Fig. 1, the ionizing current reaches its saturation value within the range of the applied voltage up to 2.4 kV with aluminum absorbers. Without aluminum absorbers it didn't saturate with the filling gas of argon, though with the filling gas of pure nitrogen it reaches its saturation value at about 500 V. The filling gas of He-N_2 mixture, therefore, was considered to be promising and its better characteristics has been verified in another experiment. Now there is technical difficulty to guarantee the uniformity of the gas mixture of which mixing ratio has large influence on gas quantum efficiency, W-value, through Penning effect. Thus it is recommended to use pure nitrogen gas with high applied voltage at this time.

As shown in Fig. 2, the Isat vs Vsat curves indicate large saturation voltages are needed in lower energy. It can be attributed to the fact that the density of electrons and ions are higher due to a higher absorption efficiency and a shorter photoelectron range in a lower X-ray energy.

Since the tendency of the curves holds in a wide range of X-ray energies, Fig. 2 can be used as a criterion to determine an optimal applied voltage when an ionization chamber is used in an actual beamline. Here it should be notified that the FE slits was changed to adjust the saturation current value. If the saturation characteristic largely depends on the beam size or the beam profile, the measured curves without changing the FE slits could have been different from the measured ones in Fig. 2 However, because this measurement was performed with a liquid-nitrogen cooled monochromator which has the best characteristics on the standard undulator beamlines of SPring-8 now and the FE slits were opened to obtain highest intensity, it is suggested that the Vsat in Fig. 2 were measured under most severe conditions and are larger than those measured in other beamlines. At least, a tentative applied voltage can be obtained from these curves in the storage ring current of 70 mA.

4. Summary and Future Plan

In order to analyze saturation characteristics more quantitatively one should experimentally compare Isat vs Vsat curve by changing the X-ray intensity with 4 dimensional slits in experimental hatches and by changing the intensity with the Δθ axis of the monochromator keeping the beam size constant. In parallel to such measurements, one could calculate the position distribution of the energy deposition by using the Monte Carlo simulation code based on EGS4. The position distribution of the energy deposition which was generated by an impulse-shaped X-ray beam of 14.3 keV is shown in Fig. 3. We are naming the position distribution of the energy deposition as "ionization profile" to clearly distinguish it from the "beam profile". The energy deposition indicates the maximum value at its incident 100 µm square pixel area though it corresponds to only 5.45 % of the whole energy and the major part of the energy is dissipated in much larger surrounding the incident point. Due to the influence of the horizontally linear polarization which is typical in SPring-8 beamlines, the profile manifests an asymmetric shape in horizontal and vertical directions. Strictly speaking, the actual ionization profile should be understood as the convolution of impulse-shaped incident ionization profile and the beam profile and is the function of beam size, X-ray energy and filling gas.

To verify this understanding, one should therefore compare the calculation of impulse-shaped incident ionization profile and experimental one. This theme seems to deserve a higher priority from the viewpoint of the position linearity of a position sensitive ionization chamber in high X-ray energy region [5].

References

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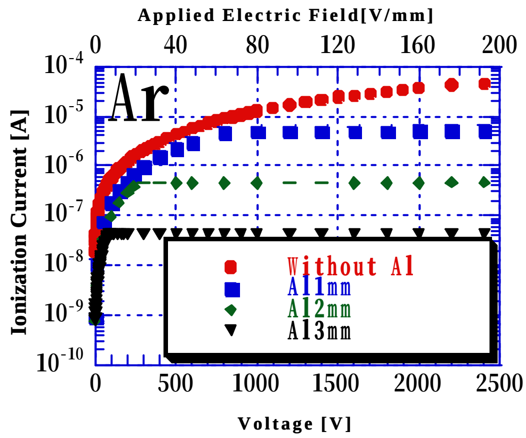

Fig. 1. Saturation characteristics of Argon, 1 atm, storage current of about 20 mA.

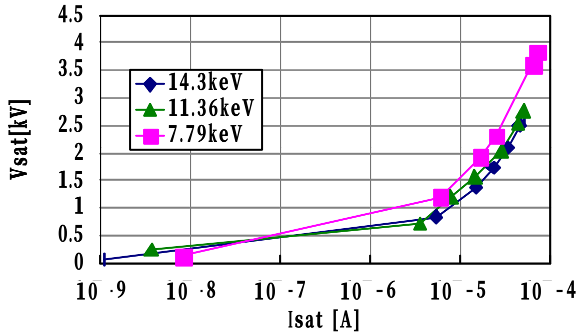

Fig. 2. Saturation current – saturation voltage characteristics in various energies.

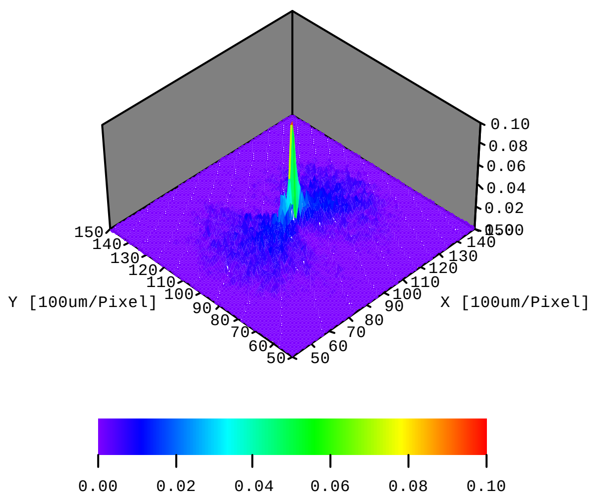

Fig. 3. Calculation result of impulse-shaped incident ionization profile of nitrogen, 1 atm., 14.3 keV, horizontal linear polarization, extended up to 0.10 MeV.