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Simulation of the saturation curve of the ionization chamber in overlapping pulsed radiation

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1. Introduction

Procedures for determination of collection efficiency in ionization chambers have been studied by numerous investigators. If the theoretical approach for air-filled ionization chambers exposed to continuous radiation is considered, the result in the near-saturation region is a linear relationship between $1/I(V)$ vs $1/V^2$, where $I(V)$ is the current measured with the ionization chamber at a given polarization voltage V. For pulsed radiation beams, Boag developed a model and the resulted in a linear relationship between $1/I(V)$ and $1/V$ when the collection efficiency, f, is larger than 0.9. The assumption of the linear relationship of $1/I(V)$ with $1/V$ or $1/V^2$ in the near-saturation region makes the determination of the saturation current simple, since the linear relationship may be determined with only two measured data points.

The above discussion of the collection efficiency of the ionization chamber exposed to the pulsed radiation is valid only if each pulse is cleared before the next one occurs. The transit times of the ions in the chamber must be shorter than the time interval between the radiation pulses. Most of the previous works concerning the characteristics of the saturation curve of an ionization chamber in the pulsed beam were done for the case where the transit times of the ions were shorter than the interval between the radiation pulses. However, the experimental data for the intermediate case, where the ion transit time was comparable to the interval between the radiation pulses or the ion transit time was slightly longer than the interval between the radiation pulses, were rare.

The saturation curves of the ionization chambers in the pulsed radiation were measured with the pulse-beamed electron accelerator at the Korea Atomic Energy Research Institute (KAERI), where the ion transit times in the ionization chambers were longer than the time interval between the radiation pulses. We used two ionization chambers: one was a commercial thimble-type ionization chamber, which was made by Exradin (Model A 12), and the other was a home-made thimble type ionization chamber.

2. Experiment

A 2-MeV electron beam with a beam current of 30 or 60 μA hit a stainless steel stopper with the thickness of 4 mm, and the currents from the ionization chambers were measured as the polarization voltage on the ionization chamber was varied. While the saturation curve of an ionization chamber was measured, the other ionization chamber with a fixed polarization voltage was placed in the forward region also to monitor the fluctuation of the incident beam current. When the saturation curve of the home-made ionization chamber was measured, a parallel plate ionization chamber (Exradin Model A15) with an active volume of 2.46cc was used as the flux monitoring detector, and when the saturation curve of the small thimble-type ionization chamber was measured, the home-made ionization chamber was used as the monitoring detector.

3. Simulation

A model calculation was done to explain the data. For the simplicity the following assumptions were included in the model: the space charge effect, which can be ignored in near-saturation condition, and the diffusion term were neglected. Since the electrons, which are generated in the air-filled ionization chamber, are attached to molecules very easily, our model assumed the conduction by positive and negative ion alone and the free electron was not considered. The mobility of the positive ions was assumed to be equal to that of the negative ions. Since the radiation pulse duration was very short in our case, the disappearance of the ionic charges due to recombination during charge production was neglected.

In the simulation, two one-dimensional columns of bins, which contained the densities of negative and positive ions at each position, were assumed. The charge density at each bin was declining, and it was drifted to the neighboring bin with the speed proportional to the velocity of ions, which depends on the polarization voltage and the geometry of the ionization chamber. The drift directions of the two columns of the charge density were opposite. The charge density at each bin was increased abruptly in a number of times while the charge was drifted, and the number of the sudden increase was proportional to the repetition rate of the radiation pulse. The number of the radiation pulses entered the ionization chamber during the ion transit was estimated from the ion transit time in the ionization chamber and the time interval between the electron-beam pulse, and it was fixed at each simulation case. The charge densities reaching at the end of the column were summed to simulate the measured current with the ionization chamber. The exponential term was included in fitting of the data with the small thimble-type ionization chamber to explain the break down of the linearity in the near-saturation region.

The data, measured with the small thimble-type ionization chamber for 30 μA and 60 μA electron beam, were fitted simultaneously to the model calculation by minimizing the chi-square. Five parameters were varied, and MINUIT was employed in the fitting process. The fitting parameters were α, the recombination coefficient, n_1, the normalization constant of 1/I for 30 μA electron beam data, n_2, the normalization constant of 1/I for 60 μA electron beam data, λ_1, the parameter of the exponential term for 30 μA electron beam data, and λ_2, the parameter of the exponential term for 60 μA electron beam data.

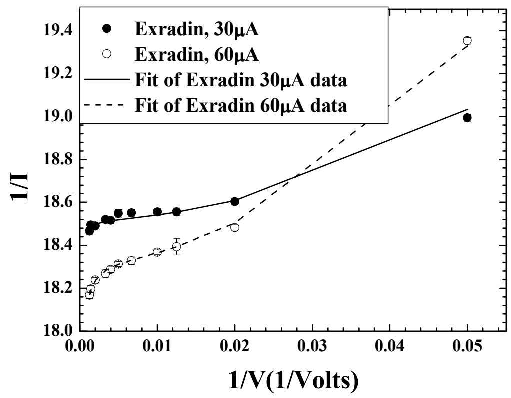

Figure 1. The measured saturation curve of the small thimble-type ionization chamber and the results of the fit.

3. Conclusion

The characteristics of the saturation curve in the pulsed radiation were studied in our work, where the ion transit times were longer than the interval between radiation pulses. A simulation code was developed and could explain the measured saturation curve successfully.

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