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An Ionization Chamber for a Steel Sheet Thickness Measurement

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Abstract - An ionization chamber is still widely used in many fields by virtue of its' simple operational characteristics and the possibility of its' various shapes. A parallel type of an ionization chamber for a steel sheet thickness measurement was designed and fabricated. High pure xenon gas, which was pressurized up to 6 atm, was chosen as a filling gas to increase the current response and sensitivity for a radiation. A high pressure gas system was also constructed. The active volume and the incident window size of the fabricated ionization chamber were 30 cm^3 and 12 cm^2, respectively. Preliminary tests with a 25 *m*Ci ^{241}Am gamma-ray source and evaluation tests in a standard X-ray field were performed. The optimal operation voltage was set from the results of the collection efficiency calculation by using an experimental two-voltage method. Linearity for a variation of the steel sheet thickness, which is the most important factor for an application during a steel sheet thickness measurement, was 0.989 in this study.

Key words : ionization chamber, xenon, steel sheet thickness, saturation curve, aging test

INTRODUCTION

Although a variety of solid-state radiation detectors such as room temperature semiconductors and scintillators have been developed, an ionization chamber which is based on sensing a direct ionization created by the passage of a radiation still retains its position as the most widely used and most accurate method [1,2]. An ionization chamber can be made in various shapes, sizes and with various filling gases according to a demand. An ionization chamber is used in a steel sheet thickness measurement by virtue of its stability and radiation hardness for long period of time in comparison with other radiation detectors. Accurate measurement of a thickness is one of the most important factors in the quality control of a steel sheet manufacturing process.

Currently, an array of three ionization chambers is usually used in commercially available measurement systems to examine some points of a steel sheet thickness. But, this may allows missing measurement points and increasing error rate of a steel sheet thickness. More than three ionization chambers are needed to be applied with a proper measurement system to reduce inferiority rate of a steel sheet manufacture. So, the performance of respective ionization chambers, such as its linearity against both a variation of the thickness and a variation of the radiation intensity, are the most important and must be certified experimentally.

An ionization chamber was designed and fabricated to improve the existing measurement system. The main design considerations were the gas tightness and the incident window dimensions. The incident window must be as thin as possible so as not to attenuate the radiation intensity. But this conflicts with the filling gas pressure. Xenon gas was chosen for a filling gas due to its high atomic number (Z=54), non-trapping electron, and the fact it withstands a high radiation. To increase the sensitivity of the ionization chamber's response, xenon gas was pressurized up to 6 atm.

Preliminary tests such as a leakage current and a saturation curve were performed with a 25 *m*Ci ^{241}Am gamma-ray source in a laboratory. Aging test was also implemented to evaluate a leakage of the gas. Response for a variation of the steel sheet thickness and the intensity of a radiation were measured in a standard X-ray field to verify its' field application. The collection efficiency was calculated by using an experimental two voltage method.

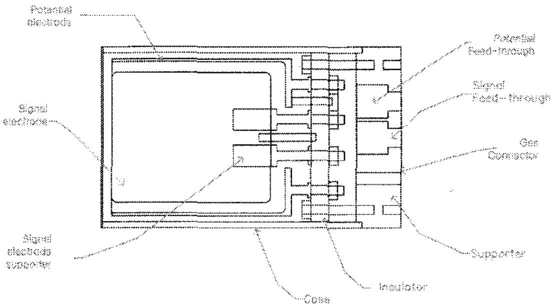

Fig. 1. Schematic of the designed ionization chamber. Two feed-throughs and a gas-quick connector were installed on the supporter. Two electrodes were supported by a ceramic. The thickness of the incident window and the active volume of the ionization chamber were 0.5 mm and 30 cm^3, respectively.

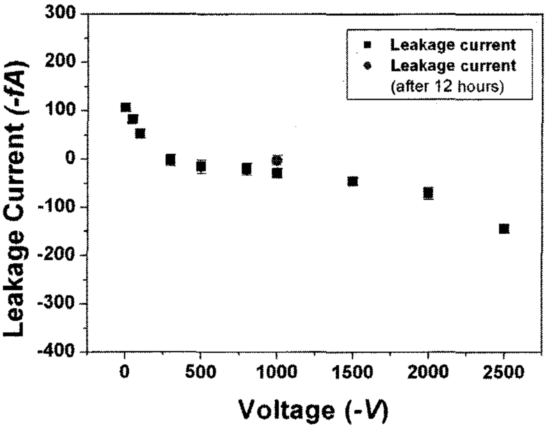

Fig. 2. Leakage currents of the ionization chamber with increasing bias voltage. The leakage current was stable when the voltage is fixed at one point for several hours (round mark). The error bars are smaller than the sizes of the symbols.

EXPERIMENTS

A schematic of the designed ionization chamber is shown in Fig. 1. The ionization chamber was made of a stainless steel for the electrodes and ceramics for the insulators. Two feed-throughs and a gas connector were installed on the supporter by a welding. The thickness and the area of an incident window were 0.5 mm and 12 cm^2, respectively. The active volume of the fabricated ionization chamber was 30 cm^3. Before a fabrication and welding, all the parts were cleaned with a surface active reagent, alcohol, and DI water. The cleaned parts were all baked in a furnace for a day.

To fill 99.9995% xenon gas, a high pressure gas system was constructed. All the parts of the high pressure gas system were baked and vacuumed. A gas regulator gauge, which has 0.01% pressure error range, was incorporated to fill the gas accurately. Before filling the gas, the fabricated ionization chamber was vacuumed by using a vacuum pump and baked at 90 ℃.

BNC and the SHV connectors were used to obtain the signal and to bias the high voltage. The ionizing current from the ionization chamber was measured with a high-precision Keithley 6517A electrometer which is known to measure a 1 *f*A level, and the potential electrode was biased with an ORTEC 673 high-voltage supply. Data were logged by using the LabVIEW program via the GPIB card and cable. Preliminary tests such as the leakage current test, the saturation curves, and the aging test were implemented. The leakage currents were measured with an increasing bias voltage up to -2500 V. This is shown in Fig. 2. The saturation curves of the ionization chamber were measured with a 25 *m*Ci ^{241}Am gamma-ray source when the filling gas pressures were 3 atm and 6 atm (Fig. 3). The distance between the radiation source and the

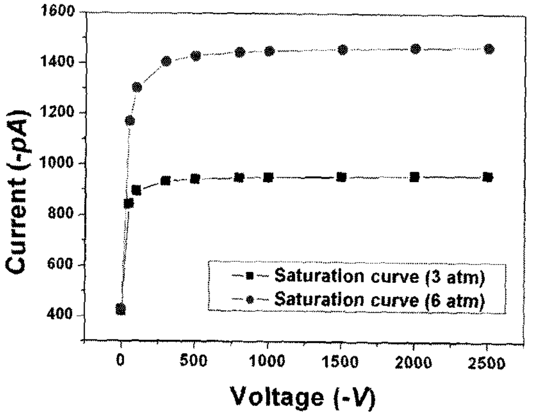

Fig. 3. Saturation curves for 25 *m*Ci ^{241}Am gamma-ray source when filling gas pressures were at 3 atm and 6 atm . Source to chamber distance was fixed at 1 mm. The error bars are smaller than the sizes of the symbols.

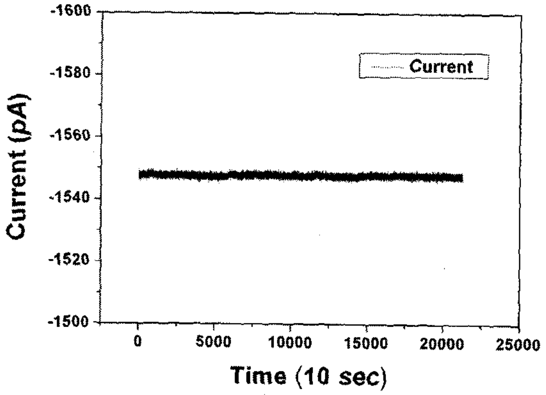

Fig. 4. Aging test during 3 days with 25 *m*Ci ^{241}Am gamma-ray source. The distance from the source to the chamber was fixed at 1 mm. The applied voltage was -1100 V. The filling gas pressure of the ionization chamber was 6 atm. From this figure, the leakage of the filling gas was not observed. The fluctuation of the signals was below 0.1%.

ionization chamber was 1 mm. To evaluate the gas leakage rate of the ionization chamber, an aging test was performed for 3 days. The applied voltage was set at -1100 V and the gamma-ray source to the chamber distance was also fixed at 1 mm. The fluctuation of the signals was below 0.1% and no gas leak was observed.

The fabricated ionization chamber was also tested in a standard X-ray field to verify its' application in the field. The saturation curve of the ionization chamber was measured again, because the ion saturation characteristics can be changed due to different radiation environments. The applied voltage and current of the X-ray tube were 120 kV and 0.5 *m*A, respectively. The

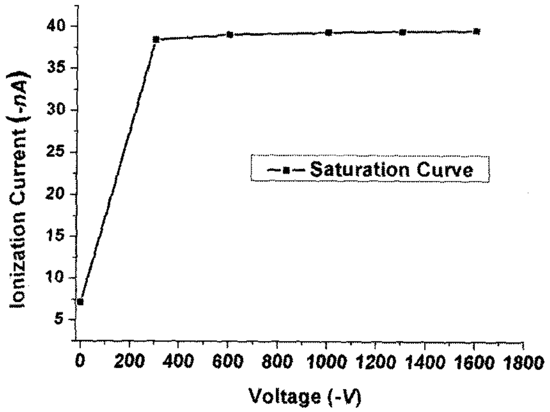

Fig. 5. Saturation curve in a standard X-ray field. The gas pressure of the ionization chamber was 6 atm. The applied voltage and current of the X-ray tube were 120 *k*V and 0.5 *m*A, respectively. The ionization chamber was located at 900 mm distance from the X-ray tube. The error bars are smaller than the sizes of the symbols.

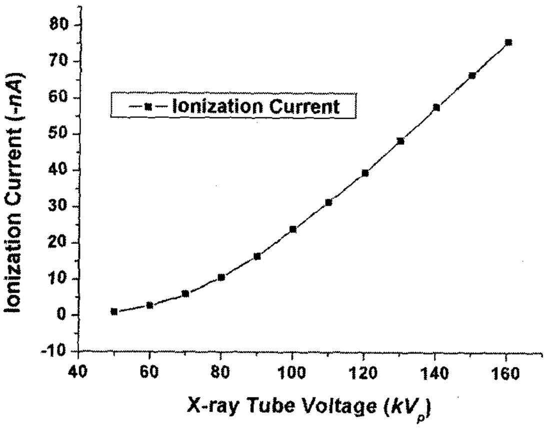

Fig. 6. Plot of the ionization current with increasing the X-ray tube voltage. The applied current of the X-ray tube was 0.5 *m*A. Gas pressure of an ionization chamber was 6 atm. The operation voltage of an ionization chamber was -1100 V. A linearity for the X-ray tube was 0.974. When the X-ray tube voltage is above 90 kV, a linearity of the ionization currents and the X-ray tube voltages was 0.998. The error bars are smaller than the sizes of the symbols.

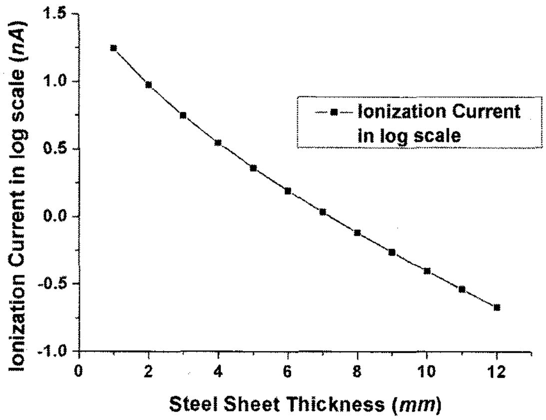

Fig. 7. Log scaled plot of the ionization current with increasing a steel sheet thickness. The applied voltage and the current of the X-ray tube were 120 kV and 0.5 *m*A, respectively. The gas pressure of the ionization chamber was 6 atm. The ionization chamber was located at 900 mm distance from the X-ray tube. The operation voltage of an ionization chamber was -1100 V. A linearity for the steel sheet thicknesses was 0.989.

ionization chamber was located at a 900 mm distance form the X-ray tube. This is shown in Fig. 5. The ionization currents with respect to the voltages of the X-ray tube were also measured when the operation voltage of the ionization chamber was -1100 V (Fig. 6). The ionization chamber responses with respect to the steel sheet thicknesses were tested in the range from 1 mm through to 12 mm. The log scaled plot is shown in Fig. 7.

RESULTS

The leakage currents, which are the currents flowing from the potential electrode to the collecting electrode in the absence of a radiation, were maintained in the range of 300 *f*A throughout all the applied voltages (Fig. 2). When the applied voltage was set at one point and the leakage current was measured after 12 hours, the leakage current can could maintained to within a few *f*A. Therefore the leakage current could be negligible because the ionization chamber will be used at one set voltage point during a field application. The high ionization currents due to a high radiation intensity also contribute to this assumption because several Ci ^{241}Am and a high rated X-ray are used in the field.

The plateau regions were observed both in the preliminary test and in the standard X-ray field test (Fig 3, 4). Ion recombination processes are the main factors affecting the collection efficiency in the ionization chamber. Ion recombination processes are distinguished as a columnar recombination and a volume recombination. For a continuous radiation, such as X- and gamma-ray beams at a high dose rate, a volume recombination dominates the total recombination losses [3-6]. To quantify the volume recombination losses of the ionization chamber, an experimental two-voltage method was used [7]. The collection efficiency is

$$f = \frac{1}{i_{sat}} = \left(\frac{(V_1/V_2)^2-(i_1/i_2)}{(V_1/V_2)^2-1}\right) \qquad (1)$$

i_1 is the measured ionization current at a normal operating bias voltage V_1 and i_2 is that at a much lower voltage V_2. A voltage ratio V_1/V_2 from three to five allows the two-voltage method to be used for dosimetric protocols [8,9]. The 99% collection efficiency is observed when the minimum voltage is -1100 V by using the saturation currents in the standard X-ray field. The ionization current with an increasing X-ray tube voltage was measured (Fig. 6). Linearity for the ionization current against the X-ray tube voltages was 0.974. But, when the X-ray tube voltage was above 90 kV, the linearity was 0.998.

The main role of the fabricated ionization chamber was a linear response for the steel sheet thicknesses on a log scale (Fig. 7). The linearity experiment must be performed using the X-ray, because the X-ray generator is used in field as a radiation source. The applied voltage and current of the X-ray tube were same as the saturation current measurement. The operation voltage of the ionization chamber was -1100 V. Linearity for the ionization current against the steel sheet thicknesses was 0.989. This indicates that the fabricated ionization chamber has linear response for the steel sheet thicknesses and it can be applied in the field.

CONCLUSION

We designed and fabricated an ionization chamber for a steel sheet thickness measurement. The fabricated ionization chamber was made with radiation hardness materials such as a stainless steel and ceramics. Before installing it in the field, we had to evaluate the fabricated ionization chamber in a standard radiation field. For the standard X-ray field experiments, the ionization chamber has to have linearity for a radiation intensity and a uniform saturation curve. The optimum applied voltage was set at a 99.9% collection efficiency. The experimental two voltage method, which can be applied when a volume recombination is dominant, was used to evaluate the operational characteristics of the ionization chamber. A linearity for the ionization current against the X-ray tube voltages and the steel sheet thicknesses was observed. Thus the fabricated ionization chamber is ready to be applied in the field.

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