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Design and Characteristics of Parallel Plate Type Ionization Chamber for the Measurement of High Energy Photon and Electron Beam

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The dosimetric system consisting of parallel plate type of air-filled ionization chamber and charge to voltage converter was designed to do constancy check of the high energy photon and electron beam of clinical linear accelerator. The ionization chamber had been fabricated using an acrylic plate for the air cavity and two printed circuit boards for electrical configuration. The air gap between two electrodes ranged from 3 mm, 6 mm and 10 mm. The sensitive volume of the chambers were 0.9 cc, 1.9 cc and 3.1 cc respectively. The major parameters of the chamber characteristics such as zero drift current, leakage current, saturation voltage, reproducibility, linearity, EPM(Effective Point of Measurement), dose rate effect and polarity effect were measured. The experimental results are as followings. Zero drift currents were 0.23 pA for the volume of 0.9 cc, 1.9 cc and 0.45 pA for 3.1 cc. Leakage currents were 0.38 pA for the volume of 0.9 cc, 1.9 cc and 0.56 pA for 3.1 cc. Saturation voltages were 300 V, 400 V and 500 V for three kinds of chambers with volume of 0.9 cc, 1.9 cc and 3.1 cc respectively. Standard deviation of reproducibility was less than 0.003, and the linearity was measured within 0.5% for all kinds of chambers. EPM(effective point of measurement) shifted towards the geometric center of the chamber as the plate separation increased. These data were comparable to those of commercially available dosimetric system for QA-purpose. This dosimetric system consisting of the ionization chamber, the PCB, and RF coaxial cables is satisfactory for the purpose of the constancy check of the high energy photon and electron beam from the medical linear accelerator.

KEY WORDS: Parallel plate ionization chamber, effective point of measurement, dosimetry

I. Introduction

For the treatment of deep seated tumors, high energy x-rays with penetrating characteristics are required. The medical linear accelerator (linac) is currently the most popular device for this application[1)]. The widespread use of high energy accelerators capable of producing high energy electron and photon beams has emphasized the problems encountered in the calibration of these beams for application in radiation therapy[2)]. However commercial dosimetry systems are not convenient for routine QA with many attaching devices such as computer, connector cables, and phantoms, though those are more suitable for precise dosimetry in calibration of the beam. Accordingly, we constructed a parallel plate type ionization chamber and investigated whether the chamber satisfied the routine criteria for calibration of therapy machine.

II. Materials

The parallel plate structure was chosen to easily implement the air-filled ionization chamber.

The basic principle of implementing the parallel plate chamber was well described in the literature[3,4)].

In this paper we applied this principle to the design of the QA dosimetric system for doing daily constancy check of the high-energy photon beams of the linear accelerator. The sensitive volume was implemented with the use of the various thickness (3 mm, 6 mm, and 10 mm) of acrylic and the printed circuit board (PCB) for electrical connection. The PCB for the electrical configuration was shown in the **Fig. 1** and **Fig. 2**. High voltage was supplied through many 9 V batteries, which are very cheap and also commercially available in local markets. The high voltage could be used for more than one year. Also the high voltage supplier assembly can be placed by the ionization chamber assembly, thus making it possible to replace expensive triaxial cables. The CVC(charge to voltage converter) can be implemented on the low-noise and low-drift operational amplifier (OPA128 Burr-Brown Co, USA). The schematic diagram of the charge to voltage converter is shown in the **Fig. 3**. The relay circuit is used to mechanically reset the charge storage capacitors in the CVC. The capacitors in the range of about 1000 pF to 27000 pF are used to choose

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the linear range of the CVC, which determines the linearity of the dosimetric system. The signal electrode is connected to the charge-to-voltage (CTV) converter to reproduce the DC voltage, and later to the analog-to-digital converter (ADC) for display purpose.

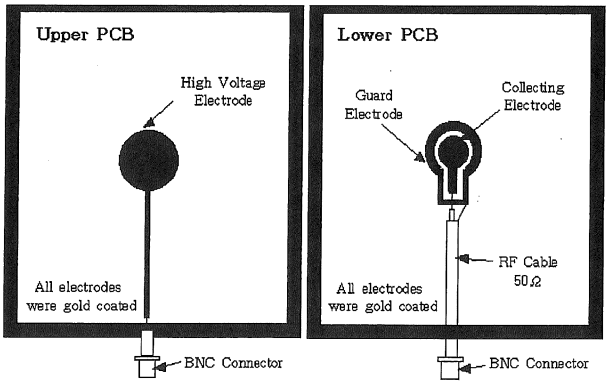

Fig. 1 Schematic diagrams of the printed circuit boards.

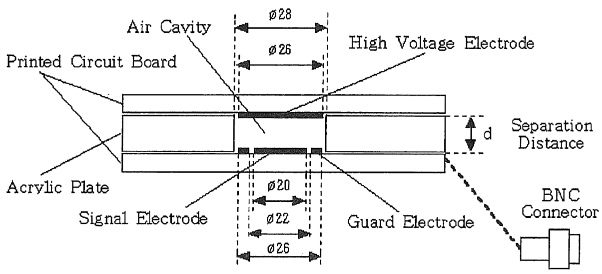

Fig. 2 Cut-away view of the parallel plate type ionization chamber. Separation distance d : 3 mm, 6 mm, 10 mm
Nominal volume of chamber: 0.9 cc, 1.9 cc, 3.1 cc

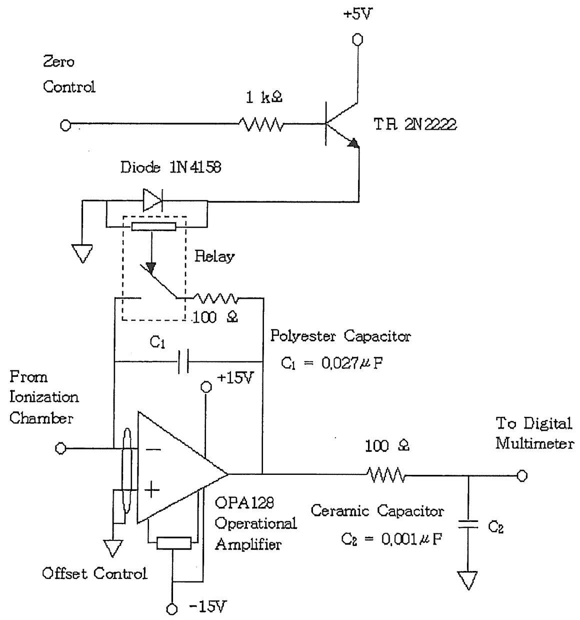

Fig. 3 Schematic diagram of charge to voltage converter.

The amplifier should be very carefully designed to minimize the possible noise pickup, for example, by isolating the input two ports from other signal or ground patterns in the PCB.

III. Methods and Results

The detailed electrical and radiological characteristics of the ionization chamber can be estimated by indirectly measuring zero drift current, leakage current, saturation voltage, short-term and/or long-term reproducibility (or stability), linearity, EPM(Effective Point of Measurement), dose rate dependencies and polarity effect and etc. All measurement data were taken by photon beams(6 MV, 10 MV) and electron beams(4 MeV, 6 MeV, 9 MeV, 12 MeV, 16 MeV) from the CL1800 linear accelerator (Varian, USA).

Zero drift current

The zero drift current was measured after reset electrometer in condition that there was no radiation at all. The variations of bias voltage were 0.005 V in 10 minute for the volume of 0.9 cc and 1.9 cc. And the variation of reading was 0.005 V in 5 minute for the volume of 3.1 cc. And the capacitance was 0.027 μf. Therefore, zero drift current was 0.23 pA for the volume of 0.9 cc, 1.9 cc and 0.45 pA for 3.1 cc.

Leakage current

The leakage current was checked by the variation of reading after irradiation. The irradiated dose was 100 cGy. The variations of reading were 0.005 V in 6 minute for the volume of 0.9 cc and 1.9 cc. And the variation of reading was 0.005 V in 4 minute for the volume of 3.1 cc. And the capacitance was 0.027 μf. Therefore, leakage current was 0.38 pA for the volume of 0.9 cc, 1.9 cc and 0.56 pA for 3.1 cc. The zero drift current and leakage current is determined by the electrical characteristics of the CVC and a charge storage capacitor.

Saturation voltage

We checked the saturation voltage[5-8] to find the applied voltage for the chamber at different plate separations.

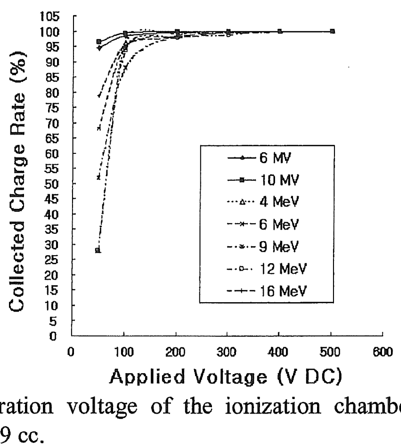

Fig. 4 Saturation voltage of the ionization chamber with a volume of 0.9 cc.

The saturation voltage was checked by large then 95% collection efficient of reading when the dose rate of radiation was 240 MU/min (1 MU ≐ 100 cGy) (**Fig 4**). Saturation voltages were 300 V, 400 V and 500 V for three kinds of chambers with volume of 0.9 cc, 1.9 cc and 3.1 cc respectively.

Reproducibility

The reproducibility was measured by short-term and/or long-term. The experiment results of reproducibility were less than 0.3% for one standard deviation(**Table 1**).

Table 1 Reproducibility of the ionization chamber with a volume of 0.9 cc.

No.	Photon Quality		Electron Energy				
	6 MV	10 MV	4 MeV	6 MeV	9 MeV	12 MeV	16 MeV
1	1.621	1.572	1.689	1.552	1.582	1.635	1.329
2	1.621	1.572	1.684	1.552	1.582	1.635	1.329
3	1.616	1.572	1.684	1.552	1.582	1.635	1.329
4	1.621	1.576	1.684	1.552	1.582	1.635	1.329
5	1.616	1.577	1.684	1.557	1.582	1.630	1.324
6	1.621	1.577	1.684	1.552	1.577	1.635	1.329
7	1.621	1.572	1.679	1.557	1.577	1.635	1.324
8	1.621	1.572	1.679	1.557	1.582	1.635	1.329
9	1.621	1.577	1.684	1.552	1.577	1.635	1.329
10	1.621	1.577	1.684	1.552	1.582	1.630	1.324
Average	1.620	1.575	1.684	1.554	1.581	1.634	1.328
Standard Deviation	0.002	0.003	0.003	0.002	0.002	0.002	0.002

Linearity

The linearity were measured from 5 MU to 160 MU(1 Monitor Unit = 1 Gy). The linearity of reading were less than 0.5% for 0.9 cc ionization chamber(**Fig 5**). And, the results were similar for 1.9 cc and 3.1 cc ionization chamber.

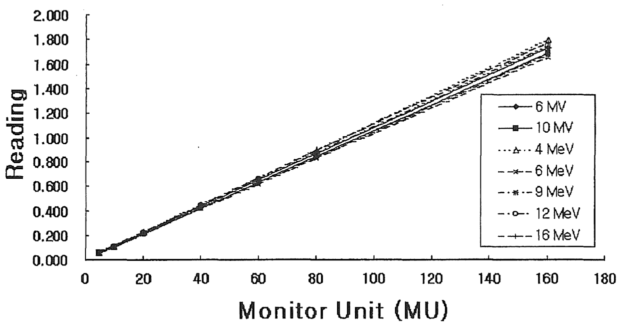

Fig. 5 Linearity of the ionization chamber with a volume of 0.9 cc.

Effective Point of Measurement

If the plate separation is not too large one generally assumes that the effective point of measurement is just behind the front plate of the chamber. For chambers with relatively large dimensions, such as the ones used for very accurate exposure measurements, this assumption breaks down and the effective point of measurement depend on plate separation and thickness of the front window[9-11].

The effective point of measurement of the constructed ionization chamber was determined experimentally. The measurement data were plotted against the depth defined by the geometrical center of the chamber(**Fig 6(a)**). And also the data were re-plotted for the depth to the upper electrode and for the location of the effective point of measurement (**Fig 6(b), (c)**). The effective point of measurement moved downstream from the inner front electrode towards the geometrical center of the chamber as the plate separation increased.

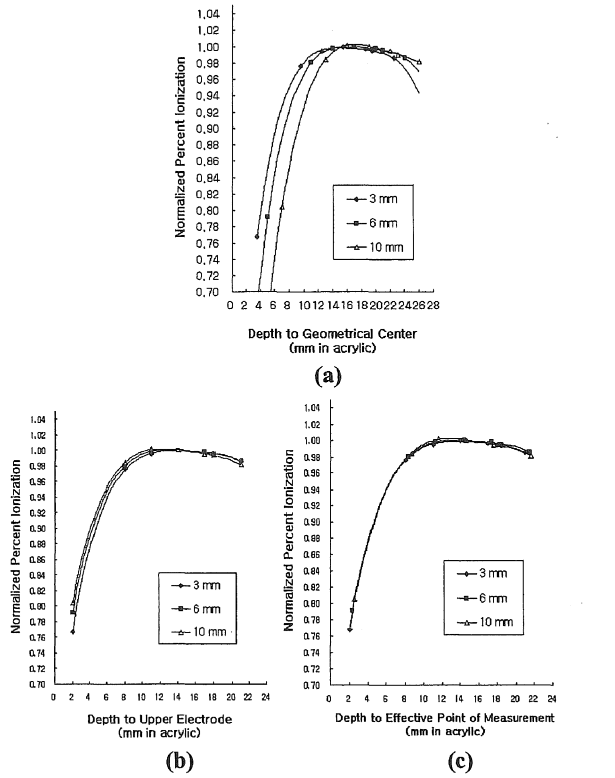

Fig. 6 Shift of the EPM in each chamber under the condition of 6 MV photon beam.
(a) EPM defined by the geometrical center in the chamber.
(b) EPM defined by the upper electrode in the chamber.
(c) Normalized percent ionization for the EPM.

Dose rate effect

The dose rate dependency[12-14] was measured from 80 MU/min to 400 MU/min.

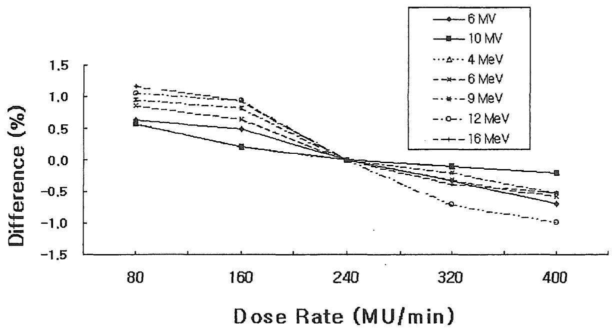

Fig. 7 Dose rate effect of the ionization chamber with a volume of 0.9 cc.

The reading of low dose rate was larger than that of high dose rate and the dose rate effect was less than 1.0%(**Fig 7**).

Polarity effect

The electrical field lines of plane parallel ionization chambers are parallel to the direction of the radiation. As such, secondary electrons that are predominantly forward directed gain energy if the entrance window is negatively and the collection electrode positively charged. This may lead to more ionization events than in the opposite polarity[13,15-17].

We checked the polarity effect of the constructed parallel plate ionization chamber. The data of polarity effect were taken from negative(upper electrode was negative) and positive(upper electrode was positive) measurement. The polarity effect was measured for 300 V and 400 V. The error of polarity effect were less than 0.5% in photon beams, but the error of polarity effect were maximum 3.5% for 0.9 cc ionization chamber in electron beams(**Fig 8**, **9**). And, the results were similar for 1.9 cc and 3.1 cc ionization chamber. The polarity effect must be checked before the measurement of electron beams.

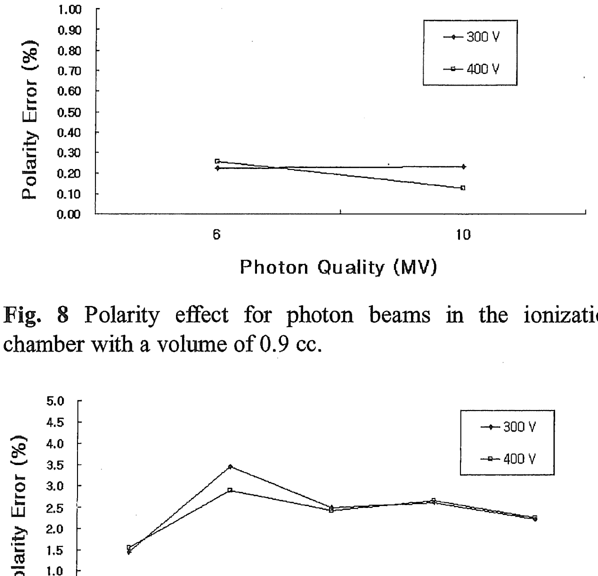

Fig. 8 Polarity effect for photon beams in the ionization chamber with a volume of 0.9 cc.

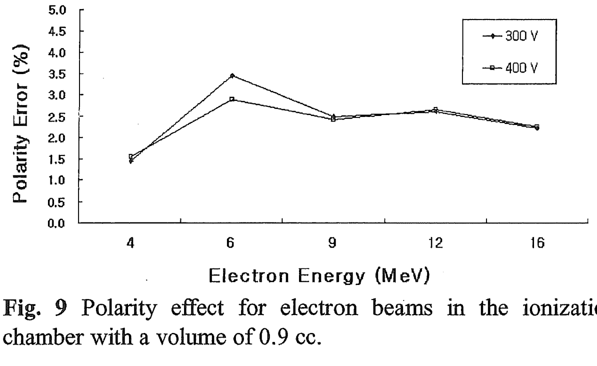

Fig. 9 Polarity effect for electron beams in the ionization chamber with a volume of 0.9 cc.

IV. Conclusion

This dosimetric system consisting of the ionization chamber, the PCB, and RF coaxial cables was satisfactory for the purpose of the constancy check of the high energy photon and electron beam from the medical linear accelerator.

This parallel plate chambers can be extended to do general dosimetric study: constancy check, flatness and symmetry test, energy measurement, and etc. Also the chambers can be used to measure the output and the energy of the various electron beams (generally 4 MeV to 20 MeV).

The reproducibility (0.3% for one standard deviation) of the dosimetric system seems to be quite effective to do daily QA.

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