Characteristics Performance of Newly Developed Parallel Plate Chamber in Electron Beams

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Abstract

Background: To investigate the dosimetric performance of newly developed parallel plate chamber in electron beams. **Materials and Methods:** Rosalina Instruments India Private Limited (Mumbai, Maharashtra, India) has designed and fabricated PRATT2 parallel plate chamber. The various dosimetric characteristics, including pre- and post-irradiation leakage, stability, polarity effect, chamber response with bias voltage, dose linearity, dose rate effect, and chamber absorbed dose calibration, were performed for the developed chamber. The electron beam energies of 4, 6, 8, and 15MeV were used in this study. **Results:** The pre- and post-irradiation leakage of the developed chamber was within the acceptable limit. The chamber shows good stability over the electron beams used in this study. The maximum error in polarity effect was 0.7% for the developed chamber. The chamber shows the good linear response with dose, and its response is independent of the dose rate for all electron beams. The beam quality correction factor ($k_{Q, Q0}$) was determined for the all electron beam energies, which was used for determination absorbed dose in electron beams. **Discussion:** The developed parallel plate chamber (PRATT2) is suitable for dosimetry of electron beams in radiotherapy. The chamber is cost effective and shows precise and reproducible response. The study carried out confirms that the newly designed and fabricated ion chamber can be used in the measurement of absorbed dose for therapeutic electron beams.

Keywords: Absorbed dose, beam quality factor, chamber characteristics, electron beam, parallel plate chamber, PRATT2

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Introduction

The plane-parallel plate ionization chambers (PPC) are often used to measure dose in the buildup region of high-energy photon beams and in regions of several dose gradients. The recent protocol recommends the use of parallel-plate ionization chambers in clinical electron dosimetry.[1-3] The scattering perturbation effects are minimized when a parallel-plate ionization chamber is utilized for electron beam dosimetry below 10 MeV.[1] The design construction of PPC is described in the International Atomic Energy Agency Technical Report Series (IAEA-TRS) 381 protocol.[4] The air cavity is a disc-shaped circular cylinder, one flat face of which constitutes the entrance window. The inside surface of the entrance window is electrically conducting and forms the outer electrode. The inner electrode is conducting a circular disc inset in the body insulator which forms the other flat face of the cylinder opposite to entrance window. The sensitivity volume is a fraction of the total air volume. The inner and outer electrodes are mounted in a supporting block of materials to which the connecting cables are attached. The third electrode, known guard electrode, is present in the air volume as ring around the inner electrode. The polarizing potential is applied to the outer electrode, and the signal charge is collected from the inner electrode. The sensitivity volume of the chamber should be between 0.05 and 0.5 cm^3 and the entrance window thickness is ≤1 mm. The diameter of the inner electrode should be ≤20 mm and cavity height is ≤2 mm. The ratio of guard width to cavity height is ≥1.5.

The change in ambient temperature and air pressure should be taken into consideration for the ionization produced in the air cavity. The humid air may also affect the chamber response. As ionization chamber is an instrument of high precision, attention needs to be paid to test their dosimetric characteristics.[5] The use of PPC in teletherapy beam requires various correction

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factors. The response of the ionization chamber depends on radiation dose, dose rate, chamber material, volume, chamber polarity, applied voltage, and beam quality. The commercially available PPC chambers are very expensive, to compensate the cost-effectiveness, Rosalina Instruments India Private Limited (Mumbai, Maharashtra, India) has designed PRATT2 parallel plate chamber. The present study focuses on the design and dosimetric characteristics of newly developed parallel plate ionization chamber (PRATT2) by Rosalina Instruments India Private Limited (Mumbai, Maharashtra, India).

Materials and Methods

Chamber design and characteristics

The plane parallel plate ionization chamber was designed according to the specification provided by the IAEA-TRS 381 protocol.[4] Table 1 shows the detailed technical specification of the chamber. The schematic diagram of the chamber is shown in Figure 1. Figure 2 shows the newly developed chamber. The stability of the ionization chamber is vital as they are relatively fragile and may be with little or no visible sign of damage. Hence, the radiograph image of the developed chamber was obtained.

Treatment unit

The versa HD™ Linear Accelerator (LA) (Elekta AB, Stockholm, Sweden) was used for dosimetric measurement.

Table 1: Technical specification for parallel plate chamber (PRATT2)

Detector	Specification
Type	Parallel plate ionization chamber
Active volume (cm^3)	0.16
Material	Mylar foil (0.1 mm) and graphite (0.5 mm) window, body PMMA, electrode graphite
Electrode spacing (mm)	2.0
Collecting electrode diameter (mm)	10.0
Guard ring width (mm)	3.0
Guard ring diameter (mm)	18.0
Window thickness	104 mg/cm^2 (0.6 mm)
Water proof	Yes
Connector type	TNC triaxial
Polarizing voltage	±300 V (maximum±500 V)

PMMA: Poly methyl methacrylate, TNC: Threaded neill-concelam

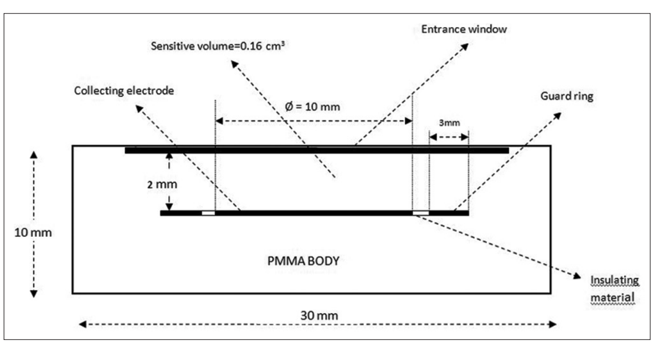

Figure 1: Schematic diagram of parallel plate ionization chamber

The LA is capable of delivering 6 MV, 10 MV, 15 MV, 6 FFF, 10 FFF photon and 4, 6, 8, 10, 12, 15 MeV electron energies. The accelerator contains the agility multi-leaf collimator as upper jaw replacement. It is an 80-pair of leaves; the width of each leaf is 5 mm and covers the maximum filed area of 40 cm × 40 cm at the isocenter.

Dosimetric study

The chamber characteristics and various dosimetric parameters were evaluated for the newly developed PPC. The PPC was used along with the calibratedDose1 electrometer (IBA, Germany) for all dosimetric measurements, and the calibration coefficient for the electrometer is 1.

Pre- and post-irradiation leakage check

The ionization chamber was connected to the electrometer with power-on condition and kept for an hour to attain the thermal stability of the chamber and electrical stability of the electrometer. The natural (preirradiation) leakage may occur due to dirty connectors, wet desiccators, no sufficient time given for the instrument to stabilize, and no preirradiation dose given to the chamber. The preirradiation leakage of the chamber was tested for 5 min, and measurements were repeated for 5 times. Radiation-induced (postirradiation) leakage associated with the chamber is identifiable only after the exposure of the chamberto radiation. If radiation-induced leakage is present, there will be a continued collection of charge even after the beam has been turned off. Radiation-induced leaks vary in their magnitude; nevertheless, it may be ignored if the leakage is small. The radiation-induced leakage of the chamber was tested for 5 min, and measurements were repeated for 5 times.

Stability check

The chamber stability was checked in 4, 6, 8, and 15 MeV electron beams. The measurement was performed at fixed geometry by repeated 100 MU exposure. The standard deviation and standard deviation of mean were calculated for each measurement.

Figure 2: Parallel plate ionization chamber (PRATT2)

Chamber response with bias voltage

The chamber response was studied by varying the bias voltages from 50 to 500 V with an increment of 50 V for the electron beam energies of 4, 6, 8, and 15 MeV. The chamber was placed at 1 cm depth for energies 4, 6, and 8 MeV, and for 15 MeV, it was placed at 2 cm depth in water equivalent polystyrene phantom with cone size of 10 cm × 10 cm.

Polarity effect

The polarity effect of the ionization chamber was checked for the use of opposing polarizing potential. The polarity effect can be accounted using the following relation.

$$k_{pol} = \frac{|M+| + |M-|}{2M} \quad (1)$$

where M_+ (+300 V) and M_- (−300 V) are the electrometer reading obtained at positive and negative potential, respectively, M is the electrometer reading obtained with the polarity used routinely (positive or negative). k_{pol} was measured for the electron beam energies of 4, 6, 8, and 15 MeV. The chamber was placed at reference depth in water equivalent polystyrene phantom with cone size of 10 cm × 10 cm.

Dose linearity and dose rate effect

The linear response of the developed chamber was investigated as a function of a monitor unit from 10 to 1000 MU for the electron beam energies of 4, 6, 8, and 15 MeV. The dose rate of 400 MU/min was used for the linearity measurement. For all the measurements, the chamber was placed at reference depth in water equivalent polystyrene (ρ = 1.045 g/cm^3) phantom with cone size of 10 cm × 10 cm. With the same measurement condition, the ionization chamber response for the various dose rates ranging from 100 to 1000 MU/min was determined for the electron beam energies 4, 6, 8, and 15MeV.

Determination of $k_{Q, Q0}$

The beam quality correction factor ($k_{Q, Qo}$) depends on the stopping power ratio of water to air ($S_{w, air}$) and overall perturbation factors (P_Q) for the beam qualities (Q, Q_0) can be expressed as:

$$k_{Q,Q0} = \frac{\left(s_{w,air}\right)_Q \left(w_{air}\right)_Q P_Q}{\left(s_{w,air}\right)_{Q0} \left(w_{air}\right)_{Q0} P_{Q0}} \quad (2)$$

The $k_{Q, Q0}$ were calculated for the electron energies and ^{60}Co beam, the ^{60}Co beam is considered as the reference of beam quality Q_0. Where w_{air} is the mean energy expended in air per ion pair formed. For therapeutic electron and photon beams, the $(w_{air})_Q = (w_{air})_{Q0}$.[1] Hence,

$$k_{Q, Q0} = \frac{\left(s_{w,air}\right)_Q P_Q}{\left(s_{w,air}\right)_{Q0} P_{Q0}} \quad (3)$$

where,

$$\left(s_{w,air}\right)_Q = 1.253 - 0.1487\ (R_{50})^{0.124} \quad (4)$$

R_{50} (gcm^{-2}) is the electron beam quality and $(S_{w, air})_{Q0}\ P_{Q0}$ is 1.161 for reference beam quality Q_0 (telecobalt). For each electron beam, the beam quality correction factor ($k_{Q, Qo}$) were calculated using the above relation.[1] Whereas the technical specification of developed chamber is similar to commercially available Nordic Association of Clinical Physics (NACP) parallel plate chamber, hence P_Q values of NACP chamber were used to calculate the beam quality correction factor for developed chamber.

Determination of absorbed dose to water

As per the reference condition recommended for telecobalt beam in TRS 398 protocol,[1] the chamber was placed at 5 cm depth in water phantom with 10 cm × 10 cm field size and 80 cm source to skin distance. The meter reading was recorded for the developed ionization chamber used in this study. The ionization chamber of volume 0.65cc (FC65G, IBA, Germany) is having the valid absorbed dose to water calibration coefficient for reference beam quality (Q_0) was used as a reference chamber. With the same measurement condition, the developed chamber was replaced by the reference chamber and the meter reading M_{ref} was recorded. The calibration coefficient for the developed ionization chamber was determined from the following relation:

$$^{developed}N_{D,w} = \frac{M_{ref}}{M_{developed}} \times {}^{ref}N_{D,w} \quad (5)$$

where $^{ref}N_{D, w}$ is the absorbed dose to water calibration coefficient for reference chamber, M_{ref} is the meter reading for reference chamber and $M_{developed}$ is the meter reading for developed chamber, both are corrected for influencing quantities. The absorbed dose to water was determined for the electron beam energies of 4,6,8, and 15MeV using the above absorbed dose to water calibration coefficient ($^{developed}N_{D, w}$) and calculated beam quality factor ($k_{Q, Q0}$).

Results and Discussion

Pre- and post-irradiation leakage check

The pre- and post-irradiation leakage current for the developed chamber were 1.968 pA and 0.108 pA, respectively. The measurement shows that the pre- and post-irradiation leakage current for the developed ionization chamber was within an acceptable limit.

Stability check

The stability of the chamber was verified in 4, 6, 8, and 15 MeV electron beams. The measured mean standard uncertainty was 0.004% and standard error of mean was 0.001%.

Chamber response with bias voltage

The chamber response was studied by varying the bias voltages from 50 to 500 V with an increment of 50V for all energies are shown in Figure 3. The dose rate of 400 MU/min was used for these measurements. The ionization response was found to increase for all energies from 1.0% to 12.0% as the applied voltage was increased from 50 V to 500 V. It was observed that as the applied voltage increases beyond 300 V, the maximum change in ionization response was 3.5% for 15 MeV electron energy.

Polarity effect

When the electrical field lines of the parallel plate ionization chambers are parallel to the direction of the ionizing radiation, the secondary electrons are predominant in forward direction, which gives more energy to the ionization chamber if the entrance window is negatively and collecting electrode is positively charged. This may lead to more ionization events in this polarity.[6-11] The polarity effect was calculated for the 4, 6, 8, and 15MeV electron beam energies. Figure 4 shows the polarity effect for electron beams. From our study, the maximum error of polarity effect was 0.7%. However, Kyo Chul Shin *et al*. observed that the maximum deviation of 3.5% polarity error in the electron beams.[6]

Gerbi and Khan measured the polarity effect for various parallel plate chambers in electron beams and they found 1%–2% effect at d_{max}, but increases with depth as high as 4.5% at greater depth.[12]

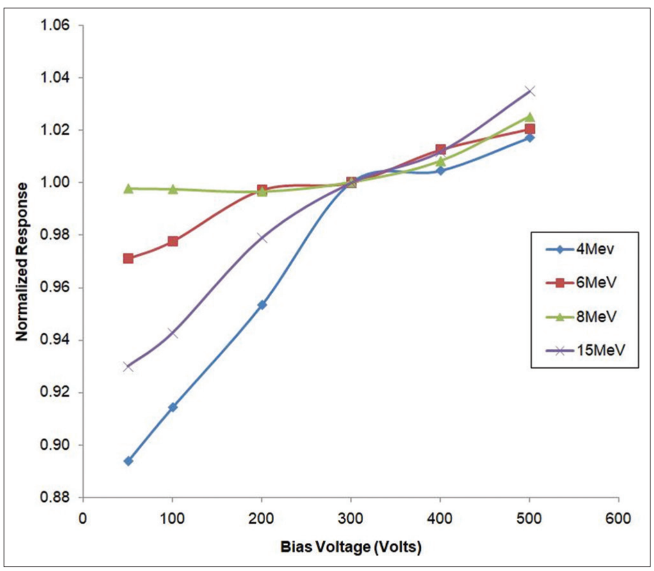

Figure 3: Chamber response for applied bias voltage

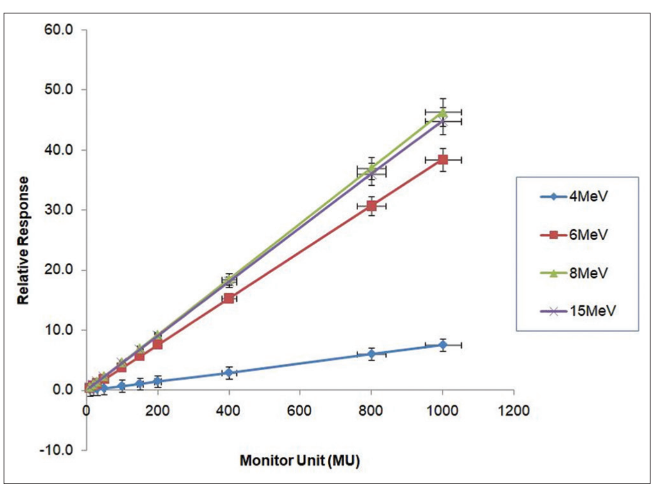

Figure 5: Dose linearity of the chamber

Dose linearity and dose rate effect

A good linear response was observed for the electron beam energies of 4, 6, 8, and 15MeV with monitor units ranging from 10 to 1000 MU. Figure 5 shows the linearity of the chamber for different monitor units. The linearity was <0.5% for increase in MU.

The ion chamber response for various dose rates ranging from 100 to 1000 MU/min for electron beam energies of 4, 6, 8, and 15 MeV was analyzed. The results are shown in Figure 6. The maximum deviation was found to be 2% with difference in dose rate for 4MeV electron beam. The results obtained show that the response of the chamber is independent of the dose rate for electron energies. However, the Kyo Chul Shin *et al.* observed the similar results for linearity and dose rate effect.

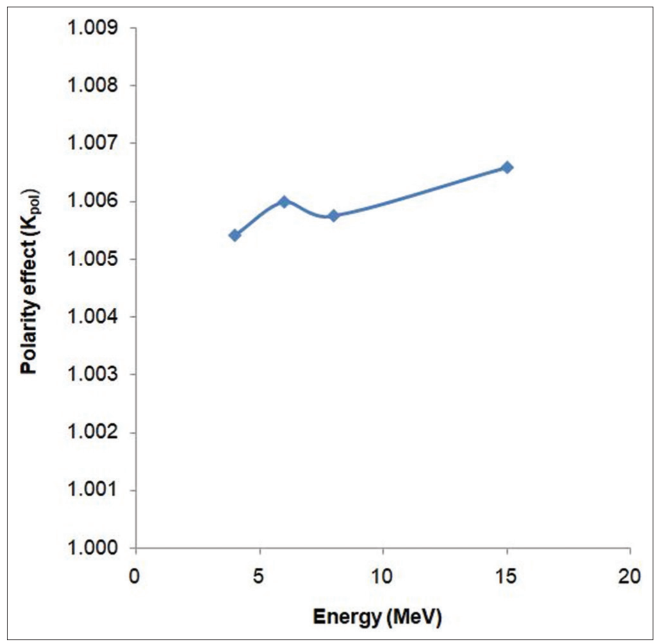

Figure 4: Polarity effect of the chamber

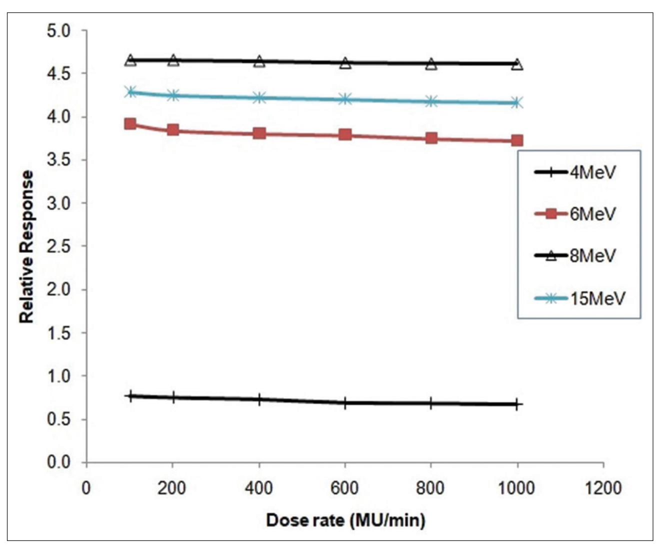

Figure 6: Dose rate effect of the chamber

Determination of $k_{Q, Q0}$

The beam quality correction factor was calculated for the electron energies using the equation.[3] The electron's mean energy and $S_{w, air}$ was obtained from the R_{50} values**.** The calculated beam quality correction factor ($k_{Q, Q0}$) for the developed chamber is shown in Table 2.

Determination of absorbed dose to water

The developed ionization chamber was cross-calibrated in a telecobalt beam as per TRS 398 protocol recommendation.[1,13] The determined calibration coefficient in terms of absorbed dose to water for the developed chamber was ($N_{D, W}$) 1.996×10^8 Gy/C. The telecobalt beam was used as the reference beam and the beam quality conversion factor ($k_{Q, Q0}$) is equal to 1. The 2 Gy dose was delivered to the reference and developed chambers in telecobalt beam. The measured dose with reference chamber was 2.02 Gy (1.0%) and developed chamber was 1.98 Gy (−0.7%).The absorbed dose was also determined for electron beam energies of 4, 6, 8, and 15MeV using above calibration coefficient and beam quality factor. The determined absorbed dose values are within 2% of the reference value.

Conclusion

The developed parallel plate chamber (PRATT2) is suitable for the dosimetry of electron beams in radiotherapy according to IAEA TRS 398 protocol. Added advantages are the cost-effective, good stability with less leakage. The measurements carried out with the newly developed ion chamber had shown a linear response with dose and independence of dose rate. The valuable work carried out with the newly fabricated plane parallel plate chamber (PRATT2) confirms that this can be used for absorbed dose measurement in therapeutic electron beams.

Table 2: Beam quality correction factor ($k_{Q,Qo}$) for electron energies

Electron mean energy at phantom surface (E_0) (MeV)	Beam quality R_{50} (g/cm^2)	$S_{w, air}$	$k_{Q,Q0}$
2	1.0	1.104	0.951
3	1.4	1.098	0.946
5	2.0	1.091	0.940
6	2.5	1.086	0.936
7	3.0	1.083	0.932
8	3.5	1.079	0.930
9	4.0	1.076	0.927
10	5.0	1.074	0.925
12	5.5	1.071	0.923
13	6.0	1.069	0.921
14	7.0	1.067	0.919
16	8.0	1.064	0.916
19	10.0	1.061	0.913
23	13.0	1.055	0.909
30	16.0	1.049	0.903
37	20.0	1.043	0.899

Acknowledgment

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Nil.

Conflicts of interest

There are no conflicts of interest.

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