Determination of true null electrode spacing of an extrapolation chamber for x-ray dosimetry

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Determination of true null electrode spacing of an extrapolation chamber for x-ray dosimetry

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Abstract. An accurate determination of the true null distance between electrodes, that defines the sensitive volume of an extrapolation chamber, is critical for the establishment of a primary measurement method for absorbed dose in tissue. In this work, a critical analysis of two methodologies for determining the true null electrode spacing of a 23392 Böhm model PTW extrapolation chamber was done.

1. Introduction

An extrapolation chamber to be used as a primary standard dosimeter for measuring the absorbed dose to tissue requires to be characterized by determining the true null spacing between its electrodes and effective volume. Besides, additional parameters should be determined like: the saturation current, the efficiency of ion collection, the polarity effect, repeatability and reproducibility of the chamber response, etc. A prior knowledge of the absolute distance between the chamber electrodes is required for majority of tests [1].

Electrode plate spacing exists because manufacturers keep a safe distance between them considering that it cannot be too short that the electric field would exceed the dielectric rigidity of the medium; besides, there are doubts regarding the parallelism between the plates and the material roughness. The nominal distance between the electrodes is showed with high resolution and low uncertainty in a micrometer cursor of the chamber; however, the absolute distance between them depends on the knowledge of the true null spacing value, which is not provided by the manufacturer [2].

The true electrode spacing of an extrapolation chamber is often determined by analyzing the experimental relationship between the ionization current and the electrode relative distances. The curve that defines this relationship is a line that intersects the horizontal axis at the correspondent true null spacing. It is quite reasonable to assume that, for constant intensity electric field and homogeneous radiation beam, the ionization current measured by the extrapolation chamber will be proportional to the sensitive volume and, therefore, for the absolute distance between the electrodes, since the overlapping area of the electrodes is constant.

The adjustment of the electric field intensity value, which is a proportionality condition, depends on the prior knowledge of the absolute distance between the electrodes. The relative distance given by the micrometer cursor has been used as a reference for adjusting the intensity of the electric field, which may introduce significant errors for smaller electrode spacing values. Assuming the constancy of electric field strength and uniformity of the radiation beam are necessary and sufficient conditions of proportionality, the use of relative distance, instead of the absolute distance for adjusting the electric field intensity, will produce inevitable loss of proportionality.

Considering that an inherent capacitance is associated with any parallel-plate ionization chamber, there should be a well-defined relationship among the capacitance, the effective colleting area and the electrode spacing of an extrapolation chamber. The knowledge of the capacitance allows the effective electrode spacing of the extrapolation chamber, to be calculated within reasonable uncertainties.

The aim of this work was to analyze the results of measurements of the true null electrode spacing in a 23392 Böhm type PTW extrapolation chamber by two different procedures: one based on ionization current and the other on the capacitance measurement.

2. Materials and Methodology

In order to promote international standardization and metrological coherency, the International Organization for Standardization, ISO, established four series of x- reference radiations for calibrating and typing-test of dosimeters [3]. ISO narrow spectrum series (N) with maximum energy from 10 up to 30 keV were used in this work. Table 1 shows the x-ray beam parameters that define the reference radiations that were reproduced in a Seifert-Pantak x-ray machine. [4]The procedure for determining the true null spacing of the 23292 Böhm type PTW extrapolation chamber based on ionization measurements was done with the extrapolation chamber positioned in the x-ray beams (Figure 1). The ionization current was measured during 60 s accumulated electrical charge for the electrode distance from 1.00 up to 5.00 mm. Each measured ionization current was corrected to the ambient reference conditions of 20ºC and 101.3 kPa; to correct the polarity effect, measurements were done for both voltage polarities applied to the chamber and the mean value was adopted; leakage current was also measured in order to assure that it was negligible in comparison to the measured ionization current. .

Table 1. Characterization parameters of low energy ISO narrow spectrum x-ray beams used in this work.

Reference radiation code	Spectral resolution (%)	Mean energy (keV)	Tube voltage (kV)	Additional filtration (mmAl)	1st half-value layer (mmAl)	2st half-value layer (mmAl)
N 10	28	8	10	0.1	0.047	0.052
N 15	33	12	15	0.5	0.14	0.16
N 20	34	16	20	1.0	0.32	0.37
N 25	33	20	25	2.0	0.66	0.73
N 30	32	24	30	4.0	1.15	1.30

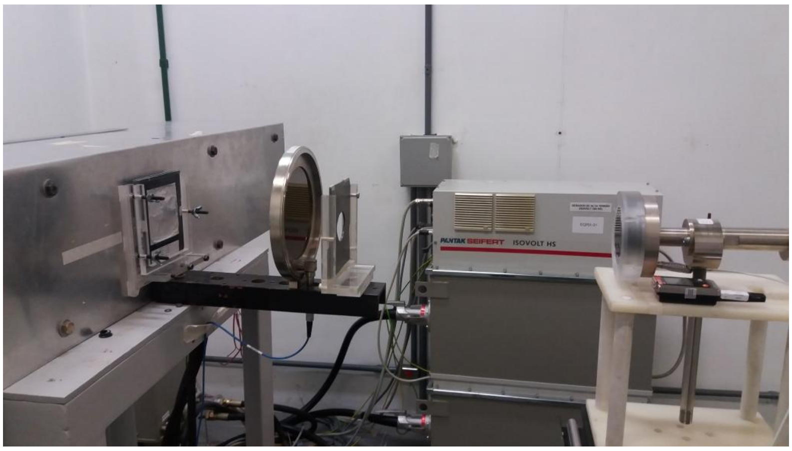

Figure 1. Experimental set-up for determining the true null spacing of the 23392 model PTW extrapolation chamber for low energy ISO N series x-reference radiations.

Capacitance is the ability of a body to store electrical charge; the parallel-plate capacitor is the most common device of energy storage. The capacitance of a parallel plate capacitor, which is defined as the ratio of the charge stored and the voltage applied to the plates, is directly proportional to the area of the conductive plates and inversely to the distance between them, as given by Equation 1.

$$C = \varepsilon_0 \varepsilon_r \frac{A}{d} \tag{1}$$

Where, C is the capacitance, in Farads; A is the area of overlap of the two plates, in square meters; ε_r is the relative static permittivity or dielectric constant of the material between the plate; ε_0 is the vacuum permittivity ($\varepsilon_0 \approx 8.854\times10^{-12}$ F m^{-1}) and d is the separation between the plates, in meters.

An extrapolation chamber can be seen as a parallel plate capacitor, which the distance between its plates can be continuously and accurately changed. The capacitance measurement of the 23392 PTW extrapolation chamber was done in absence of the radiation field using an L-C Bridge that operates by measuring the change in frequency when an unknown capacitance is added to an oscillator tank circuit; they were obtained by keeping the relative distance cursor set to zero.

3. Results and discussions

The results of the variation of the ionization current for nominal electrode distances from 1.0 mm up to 5.0 mm for N10, N15, N20, N25 and N30 ISO series are shown in Figure 2, 3 and 4. The linear fitting was done to obtain the equation and determine the true null spacing for each x-reference radiation [5]. The expanded uncertainties were assessed for the coverage factor equal to 2, according to international standards; the main sources of uncertainties were the repeatability of the measurements, the resolution and calibration of auxiliary equipments (thermometer and barometer) and the extrapolation chamber positioning [6].

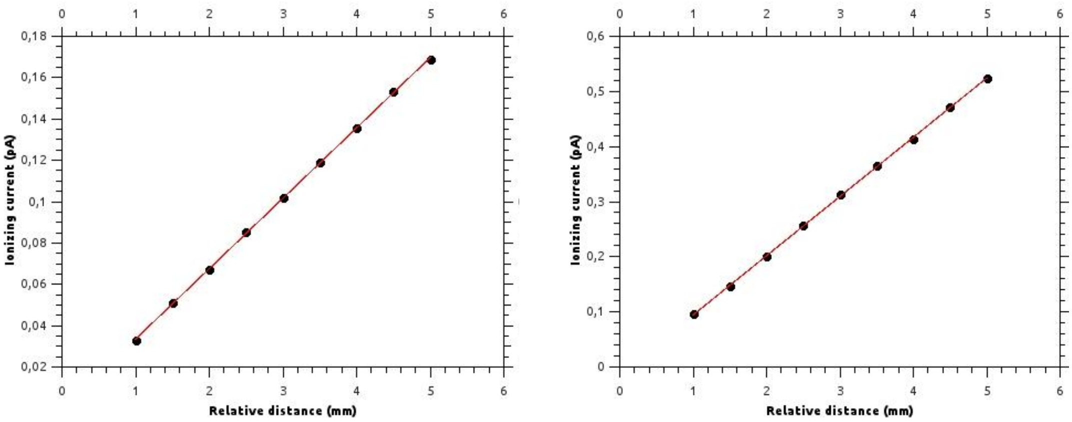

Figure 2. Extrapolation line to determine the true null spacing of the 23392 PTW extrapolation chamber for N 10 (*left*) and N15 (*right*) ISO x-reference radiation

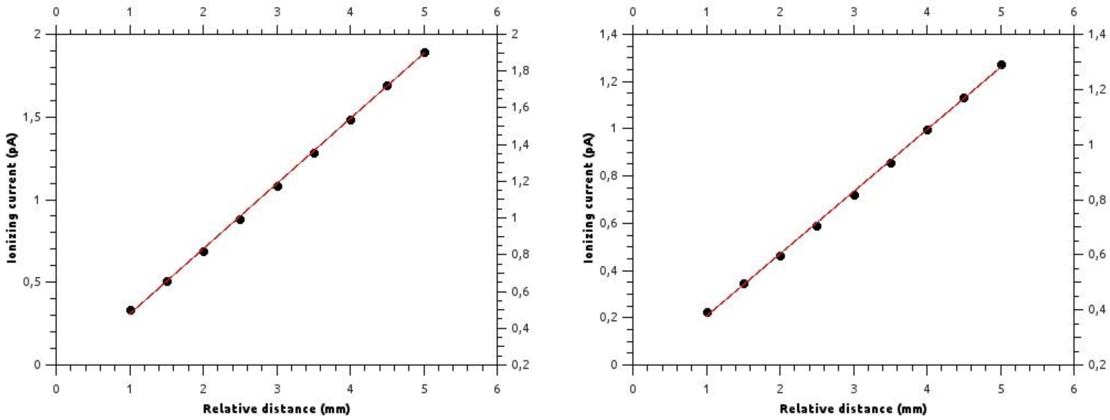

Figure 3. Extrapolation line to determine the true null spacing of the 23392 PTW extrapolation chamber for N 20 (*left*) and N25 (*right*) ISO x-reference radiation.

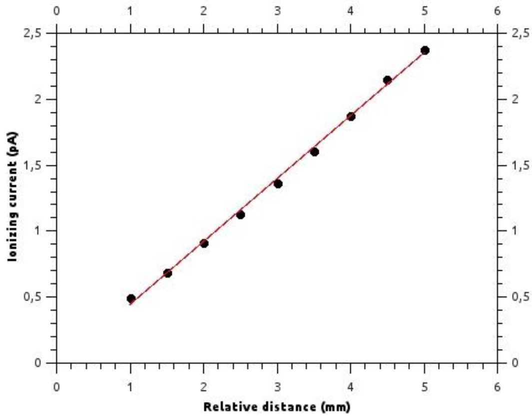

Figure 4. Extrapolation line to determine the true null spacing of the 23392 PTW extrapolation chamber for N 30 ISO x-reference

Table 2. True null spacing of a 23392 PTW extrapolation chamber for ISO x-reference radiations.

Reference radiation code	Linear fit equation	True null spacing (mm)	Expanded uncertainty* (%)
N 10	I = 0.034d - 0.0005	0.015	1.6
N 15	I = 0.108d - 0.013	0.121	1.6
N 20	I = 0.394d - 0.086	0.218	1.6
N 25	I = 0.263d - 0.056	0.213	1.6
N 30	I = 0.394d - 0.086	0.065	1,6

* Coverage factor = 2.

The results of true null spacing of the 23392 PTW extrapolation chamber (Table 1) showed a high sensitivity to the radiation quality; this could be partly explained by the loss of proportionality caused by the nonlinear electric field intensity adjustment.

The result of the direct measurement by means of a LC bridge of the capacitance between the electrodes of the 23392 PTW extrapolation chamber with the micrometer set at zero position is shown in Table 3. The mean value of the capacitance and the standard deviation were obtained from a set of 10 measurements.

Table 3. Capacitance of a 23392 PTW extrapolation chamber measured by an LC bridge with the micrometer cursor set to zero.

Mean capacitance (pF)	Standard deviation (pF)
16.5	0.311

In the absence of the radiation field it is assumed that the effective area of the electrode plate is defined by its diameter of 3.00 mm provided by the manufacturer [2] and it is equal to 7.068 cm^2.

Based on Equation 1, the *d* value that represents the true null spacing was calculated as 0.380±0.021 mm. Again, uncertainty was assessed based on international standard [5] for the coverage factor equal to 2 and the main sources of uncertainties were the capacimeter resolution and calibration, the repeatability of the measurements and the micrometer resolution.

4. Conclusions

For primary standardization purpose, the accurate determination of true null spacing of an extrapolation chamber is very important because it directly impacts on the calculation of its sensitive volume. The radiation quality dependence of the results obtained by the traditional method can be considered a weakness since, by definition, the true null spacing is just the distance between the electrodes necessary to prevent damage to the measurement procedure and therefore it should not be dependent on the quality of ionizing radiation.

Although the use of an LC bridge for capacitance measurements is a simple and direct method, it is highly dependent on the accuracy of capacimeter that can contribute to high uncertainty.

5. Acknowledgments

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