Characterization and Quality Control Tests of a Transmission Ionization Chamber Using an X-ray Equipment

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Abstract. A transmission ionization chamber, PTW model 34014, was tested under the conditions proposed by the publication IEC 61674. These tests were realized to characterize the transmission chamber using X-radiation. The tests were: saturation curve, recombination losses, air kerma rate dependence and energy dependence of response; the quality control tests verified were: leakage current, repeatability and long term stability. The maximum variations for the quality control tests were 0.2% for the response repeatability and 1.1% for the long term stability. The leakage current was negligible. Concerning the characterization tests of the transmission chamber, its performance was adequate. The collection efficiency was about 99%, the response dependence on air kerma rate was linear and the energy dependence of response was lower than ±5% for unattenuated and attenuated beams. In conclusion, the transmission ionization chamber response is within the recommended limits, showing therefore a satisfactory performance.

KEYWORDS: quality control, transmission chamber, X-rays.

1. Introduction

The International Electrotechnical Commission published, in 1997, a document with some recommendations on the performance of diagnostic dosimeters, the IEC 61674 [1]. The objectives of this document are: “to establish requirements for a satisfactory level of performance for diagnostic dosimeters” and “to standardize the methods for the determination of compliance with this level of performance”. The concerning on the performance of such equipment is due to the fact that the largest percentage of dose received by the public, proceeding from man-made ionizing radiation, comes from diagnostics, i.e., the diagnostic radiology procedures contribute with the largest dose to which the population is exposed.

At the Calibration Laboratory at Instituto de Pesquisas Energéticas e Nucleares (IPEN), some ionization chambers were developed for different X-radiation energy beams. These ionization chambers were submitted to quality control and characterization tests to assure their good performance [2, 3]. The international recommendations followed are not the same for all ionization chambers; they depend on their energy range response.

In this work a commercial transmission ionization chamber was tested using the IEC 61674 [1] recommendations to study its performance in standard X-ray beams.

2. Materials

A transmission ionization chamber, Physikalisch Technische Werkstätten, PTW, model 34014, with 86.0 cm^3 of sensitive volume was utilized. This ionization chamber was connected to a PTW electrometer, models UNIDOS E.

The tests were performed using an X-ray generator with standardized beam qualities, Pantak/Seifert, model ISOVOLT 160HS, with inherent filtration of 0.8 mmBe, variable current between 0.5 and 45.0 mA, and voltage range from 5 to 160 kV. The radiation quality RQR 4, diagnostic radiology level, that corresponds to 60 kV, 10 mA and total filtration of 2.5 mmAl (according to the IEC Report

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1267 [4]) was utilized in all tests except in the case of the energy dependence test, in which ten other radiation qualities were also utilized. The characteristics of these radiation qualities are presented in Table 1. The transmission chamber was positioned at 30 cm from the focal point.

To determine the air kerma rates of the radiation beams and to perform the energy dependence test of the transmission ionization beam, a plane-parallel ionization chamber, secondary standard system, PTW, model 77334, traceable to the German primary laboratory Physikalisch-Technisch Bundesanstalt, PTB, Germany, was utilized.

Table 1: Radiation beam characteristics according to IEC recommendations (IEC 1267 [4]), diagnostic radiology level, defined at a focus-detector distance of 100 cm at the Calibration Laboratory of IPEN

Radiation Quality	Voltage (kV)	Additional Filtration (mmAl)	Half-value Layer (mmAl)	Effective Energy (keV)	Air Kerma Rate at 30 cm (mGy/min)
Unattenuated Beams					
RQR 3	50	2.5	1.79	27.15	278.1
RQR 4	60	2.5	2.09	28.80	407.9
RQR 5	70	2.5	2.35	30.15	544.2
RQR 6	80	2.5	2.65	31.65	694.8
RQR 7	90	2.5	2.95	33.05	857.0
RQR 8	100	2.5	3.24	34.40	1026.6
Attenuated Beams					
RQA 3	50	12.5	3.91	37.30	37.2
RQA 4	60	18.5	5.34	43.25	41.9
RQA 5	70	23.5	6.86	49.40	45.5
RQA 6	80	28.5	8.13	54.75	55.0
RQA 7	90	32.5	9.22	59.70	69.1

3. Results

3.1 Saturation current, charge collection efficiency and polarity effect

The saturation current test allows the determination of the operational voltage of the ionization chamber. Therefore, measurements of the chamber response were taken varying the X-ray tube voltage in intervals of ±50V. The transmission ionization chamber was positioned at 30 cm from the focal spot and the air kerma rate, at this position, was 407.9 mGy/ min.

The transmission ionization chamber achieved the saturation of the current at ±50 V, as shown in Figure 1. The maximum deviation of the measurements was 0.4%. The operational voltage commonly utilized is -400 V, condition maintained in this work.

The polarity effect was determined by the ratio of the collected charge using the positive and the negative polarities. In Table 2 it can be observed that the results for both voltages (positive and negative) are very similar.

The charge collection efficiency can be determined by Equation 1:

$$k = \frac{(V_1/V_2)^2 - 1}{(V_1/V_2)^2 - (M_1/M_2)} \qquad (1)$$

where V_1 and V_2 are two values for the applied voltage, provided that the value of V_2 is half of the value of V_1, and M_1 and M_2 are the charges collected using the voltages V_1 and V_2, respectively. In this case, the chosen voltages V_1 and V_2 were 400V and 200V. According to the Equation 1, the k value is 1.0023 for the positive polarity and 1.0004 for the negative polarity.

The recommended result for an ionization chamber is a charge collection efficiency greater than 95%. The transmission ionization chamber presented a very satisfactory performance, since the charge collection efficiency obtained was over 99%.

Figure 1: Saturation curve of the transmission ionization chamber

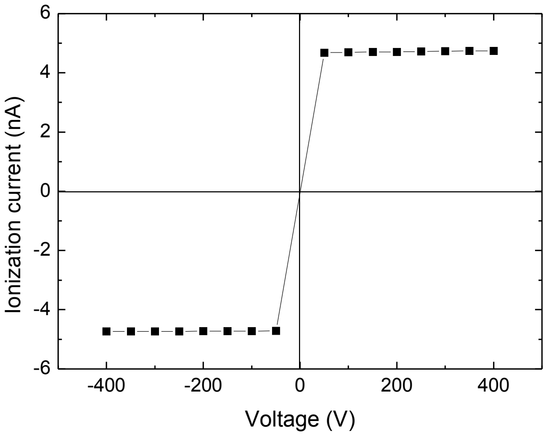


Table 2: Polarity effect of the transmission ionization chamber

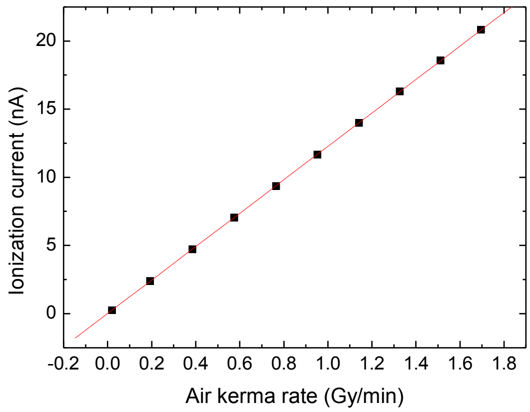
Voltage (V)	Collected charge (nC)	Ratio
+50 / -50	70.22 / 70.72	0.99
+100 / -100	70.42 / 70.81	0.99
+150 / -150	70.53 / 70.84	0.99
+200 / -200	70.65 / 70.87	0.99
+250 / -250	70.83 / 70.91	0.99
+300 / -300	70.92 / 70.93	0.99
+350 / -350	70.99 / 70.96	1.00
+400 / -400	71.14 / 70.96	1.00

3.2 Response linearity

The response linearity test was performed using the X-ray equipment, and the radiation quality RQR 4. The tube current was varied from 0.5 mA to 45.0 mA. The results obtained are showed in Figure 2.

A linear adjustment to the curve was made. This adjustment permitted the determination of the angular coefficient of the curve with an uncertainty of 0.15%. The uncertainty associated to this coefficient is related to the linearity of the curve. The maximum deviation of the measurements was 0.5%.

Figure 2: Response linearity test of the transmission ionization chamber



3.3 Energy dependence

The energy dependence of the transmission ionization chamber was determined from the calibration factors obtained for different radiation qualities. The secondary standard ionization chamber, PTW, model 77334, was used as a reference instrument. The calibration factors were obtained from the Equation 2:

$$N = \frac{M^{*}.k_T^{*}.k_p^{*}.k_c^{*}}{M.k_T.k_p} \tag{2}$$

where M is the measurement of the instrument, k_T and k_p are the correction factors for the normal temperature and pressure conditions, respectively, and k_c is the calibration factor of the secondary standard ionization chamber. The symbol (*) refers to the secondary standard ionization chamber equation terms.

The correction factors were obtained from the normalization of the calibration factors to the qualities RQR 5 and RQA 5. The energy dependence of the transmission ionization chamber was lower than 5% for both unattenuated and attenuated beams (Table 2 and Figure 3), as recommended [1].

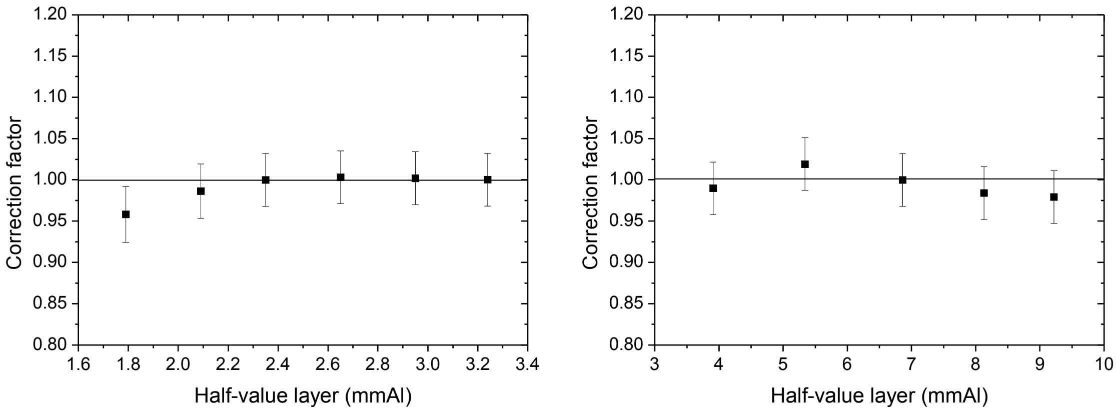
Table 2: Calibration factors of the transmission ionization chamber

Radiation Quality	Calibration Factor ($\times10^5$ Gy/C)	Correction Factor	Radiation Quality	Calibration Factor ($\times10^5$ Gy/C)	Correction Factor
Unattenuated Beams			Attenuated Beams		
RQR 3	4.23(7)	0.96(3)	RQA 3	3.54(6)	0.99(3)
RQR 4	4.11(7)	0.99(3)	RQA 4	3.46(6)	1.02(3)
RQR 5	4.06(6)	1.00(3)	RQA 5	3.52(6)	1.00(3)
RQR 6	4.04(6)	1.00(3)	RQA 6	3.58(6)	0.98(3)
RQR 7	4.05(6)	1.00(3)	RQA 7	3.60(6)	0.98(3)
RQR 8	4.06(6)	1.00(3)	-	-	-

3.4 Leakage current

For the leakage current test, the transmission ionization chamber was irradiated during 15 seconds, in the radiation quality beam RQR 4. The charge collected by the chamber was measured 20 minutes after the irradiation ending. The leakage current presented by the transmission ionization chamber was only 0.02% of the total collected charge, thus within the recommended value of 5% [1].

Figure 3: Energy dependence of the transmission ionization chamber: (a) unattenuated beams and (b) attenuated beams

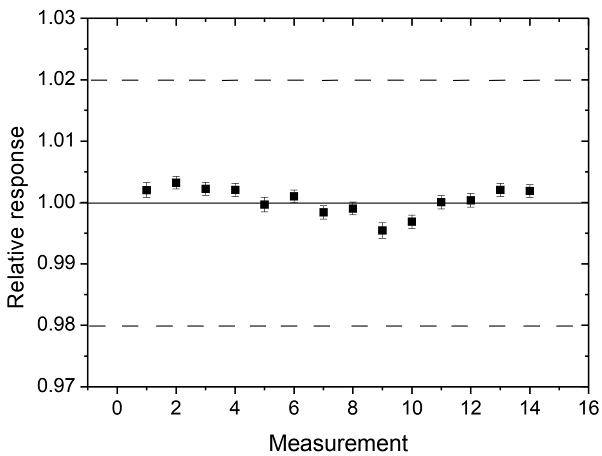


(a) (b)

3.5 Short and long term stability

The short term stability test (or repeatability test) was performed taking 10 consecutive measurements of collected charge in an integration time of 15s, radiation quality RQR 4. The long term stability test (or reproducibility test) is obtained from the repeatability test data along the time. The maximum standard deviation was 0.19% for the repeatability test and 1.11% for the reproducibility test. These values are within the limits recommended by the IEC publication [1] of 3% and 2%, respectively. The results of the reproducibility test are shown in Figure 4.

Figure 4: Reproducibility of the transmission ionization chamber. The dashed lines show the limits recommended by the IEC publication [1]



4. Conclusions

All tests evaluated with the transmission ionization chamber in this work allowed the verification of its characteristics in X-ray diagnostic radiology beams. The transmission chamber characteristics, studied in this work – response linearity, charge collection efficiency, polarity effect, energy dependence, leakage current and stability - showed the good performance of the chamber to these irradiation conditions, attending to the international recommendations. The quality control tests were performed during seven months, and the behaviour of the transmission chamber was constant during this period; the maximum deviation of the chamber response for the reproducibility test was lower than 2%.

The transmission chamber response was considered adequate for these tests, allowing its use in the routine of the Calibration Laboratory at Instituto de Pesquisas Energéticas e Nucleares. More tests have to be performed to characterize the chamber in terms of other influence factors, and the quality control tests must be done constantly to guarantee the ionization chamber response stability.

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