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A free-air ionization chamber with a large aperture diaphragm

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ABSTRACT

Calculations of the electric field distributions in free-air ionization chambers reveal that the distortion of the charge collection volume is small even for wide X-ray beam passage if the diaphragm and the X-ray shielding box are kept at a potential equal to half that applied to the high-voltage electrode. Applying this potential to the diaphragm and the shielding box permits a larger aperture diaphragm to be used. This will allow a wider X-ray beam to enter the chamber, thus generating a larger signal. In addition, the distance between the diaphragm and the charge collection volume can be shortened to reduce the amount of X-ray attenuation. It is also possible to calibrate a dosimeter against a free-air ionization chamber that has a diaphragm whose aperture size is equal to the size of the dosimeter in an X-ray field that is collimated to the same size. This is important since free-air ionization chambers are not sensitive to X-rays that are incident at large angles, such as those scattered by the collimator, filters and air.

1. Introduction

Free-air ionization chambers are used at primary standards laboratories for absolute measurements of air kerma and X-ray exposure. Fig. 1 shows a horizontal sectional view of a parallel-plate free-air ionization chamber. Air kerma and exposure at the diaphragm aperture on the reference plane are obtained from the ratio of the signal charge from the collector electrode to the mass of air in the ionization volume. The ionization volume is equal to the product of the area of the diaphragm aperture and the length of the collector electrode in the direction parallel to the X-ray beam. It is necessary to correct for attenuation of the X-ray beam by air along the path from the reference plane to the charge collection volume and for various other factors [1–6].

Of these other factors, scattered X-rays have one of the largest effects when calibrating dosimeters using the substitution method. Free-air ionization chambers typically have a thick diaphragm with a small aperture and thus have low sensitivities to X-rays that are incident at large angles, such as those scattered by the collimator, filters, air, etc. [4,7]. In contrast, most dosimeters are sensitive to X-rays that are incident at large angles.

The effect of scattered X-rays can be eliminated if a diaphragm is used that has an aperture that is the same size as the dosimeter and the calibration is performed in an X-ray field collimated close to this size. However, the aperture size is usually limited by the space between the guard plates so that the X-ray beam does not strike the guard plates. This space is restricted to ensure that the electric field in the charge collection volume within the ionization chamber is not distorted by the effect of the potential of the X-ray shielding box, which is usually at ground potential.

The influence of the potential of the shielding box on the electric field in the charge collection volume occurs mainly through the entrance and exit windows of the X-ray beam. This is because the spaces between two adjacent guard plates can be narrowed by fixing as many plates as possible. The windows are fabricated by removing some sections of several guard-plate frames.

The influence of the potential through the windows on the electric field in the charge collection volume is expected to be small if the shielding box and the diaphragm are kept at a potential equal to half the voltage that is applied to the high-voltage electrode. Therefore, it may be possible to construct a free-air ionization chamber with wide windows.

In the present paper, electric potential distributions in free-air ionization chambers are calculated for various window sizes and for three different shielding box potentials: ground, high voltage and 50% of the high voltage. Electric field lines are calculated from the potential distributions and the effect of the potential of the shielding box on the charge collection volume is discussed.

2. Design of a free-air ionization chamber

The high-voltage electrode and the outer frame of the guard plates are assumed to be square and have the same dimensions.

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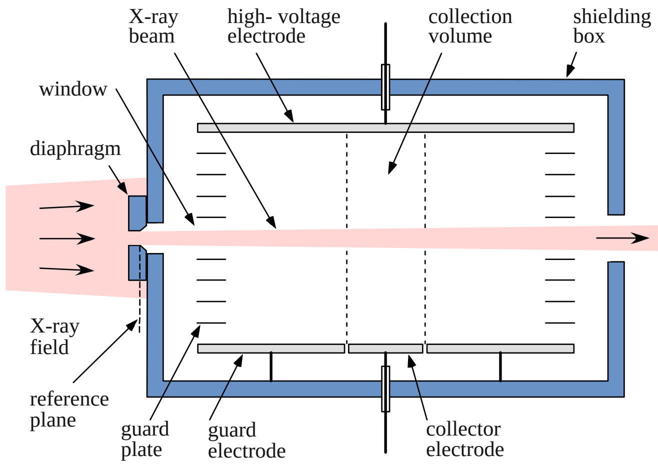

Fig. 1. Horizontal sectional view of a parallel-plate free-air ionization chamber.

The guard plates are 15 mm wide and 0.4 mm thick. Guard plates are located at intervals of 5 mm; the space between adjacent guard plates is 4.6 mm and that between a guard plate and a high-voltage electrode or a guard electrode is 4.8 mm.

In a free-air ionization chamber, all electrodes must be separated from the X-ray beam in the charge collection volume by a distance that exceeds the range of secondary electrons emitted by the X-rays. This condition is necessary to ensure that the number of secondary electrons that leave the volume is equal to the number of electrons that enter the volume. In other words, the electrons are in equilibrium in the collection volume in the direction parallel to the X-ray beam. The condition for the separation of the charge-collector electrode and the high-voltage electrode is required to ensure that secondary electrons that are emitted in the collection volume and those that enter the volume dissipate all their energy ionizing the air and do not strike the surfaces of the electrodes before losing their kinetic energy.

The range of secondary electrons in air is assumed to be 40 mm and the length of the charge-collecting electrode in the direction parallel to the X-ray beam is taken to be 20 mm. Consequently, the length between the inside edges of the guard plate frames parallel to the X-ray beam will be 100 mm (=40+40+20 mm).

The entrance and exit windows for the X-ray beam are assumed to be the same shape and have the same dimensions. Some sections near the center of several guard-plate frames are removed to form the entrance and exit windows. For example, when 10 mm sections at the front and back of the central guard plate frame are removed, windows are created that are 9.6×10 mm in size. When 15 mm sections are removed from the two central guard plates, the window dimensions will be 14.6×15 mm.

There are eight guard plates on each side of the central guard plates from which sections are removed to form windows. Consequently, the collector and high-voltage electrodes are separated by over 40 mm from the X-ray beam. The length between the inside edges of all guard plate frames in the direction perpendicular to the X-ray beam is designed to be 80 mm + the window width.

When calculating the electric potential distributions in free-air ionization chambers, all shielding box walls are assumed to be flat and there are no holes that the X-ray beam can pass through. The spaces between the walls and the guard plates are assumed to be 15 mm. The walls behind the high-voltage electrode and the collector electrode are ignored in calculations.

The potential applied to the high-voltage electrode is assumed to be 1 V. Calculations are performed for shielding box potentials of 0, 0.5 and 1 V, and for various window sizes. A commercially available program, ElecNet [8], is used for the calculation. It is based on finite element analysis methods.

3. Calculation results

Fig. 2 shows equipotential lines in a free-air ionization chamber obtained by calculation. The shielding box is at ground potential (Fig. 2 (a)) and at a potential equal to 50% of the voltage applied to the high-voltage electrode (Fig. 2 (b)). Both figures show a free-air ionization chamber with seven guard plates that have sections removed to form windows for the X-ray beam.

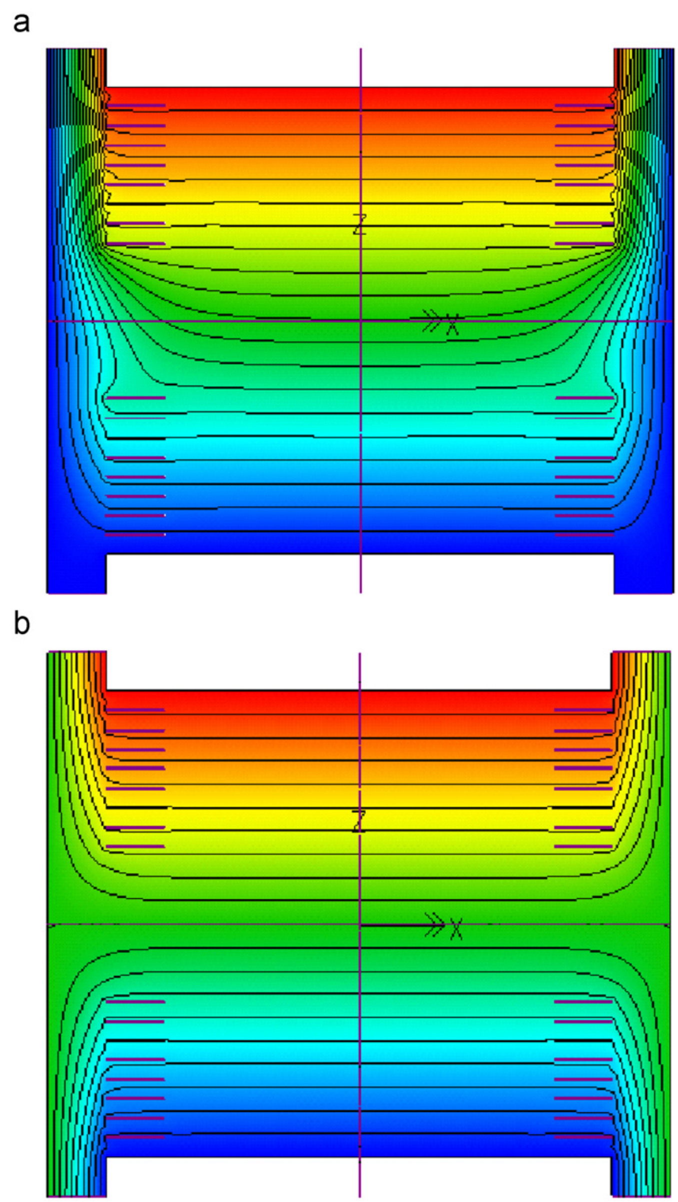

Fig. 2. Equipotential lines in a free-air ionization chamber that has $39.6 \text{ mm} \times 40$ mm windows for the passage of X-ray beams. The shielding box is at (a) ground potential and (b) half the voltage applied to the high-voltage electrode. The lower white rectangle in each figure corresponds to the collector and guard electrodes, while the upper white is the high-voltage electrode. The left and right edges correspond to the inner surfaces of the shielding box.