Comparing two methods of electrometers coulomb calibration

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***Abstract* — This paper describes two methods of electric charge calibration, one based on capacitors and a voltage source, another in a commercial current source. They were compared, and good agreement was found. Strengths and weakness of the two methods are remarked.**

***Index Terms* — Calibration, current, dosimetry, measurement standards, measurement techniques.**

I. INTRODUCTION

Electrometers are widely used in many high sensitivity measurements due to their high input resistance and low input current. They usually measure voltage, resistance, current and charge, these last two functionalities are employed in radiotherapy dosimetry, for example. In which case, the instrument measures a transducer output, and both must be calibrated periodically [1].

In charge and current measurement modes the electrometer readout is proportional to the charge accumulated in a capacitor or to the voltage drop in a resistor, with this last technique charge is derived as the numerical integration of the measured current. The traditional method to calibrate the coulomb mode of a device under test (DUT), is to yield a known charge using a standard capacitor and a voltage source [1]–[2]. An alternative calibration method based on a commercial [3] or home–made [4] current source can also be applied.

The two verification methods are described in sections II and III, in section IV results are shown and compared.

II. VOLTAGE SOURCE AND STANDARD CAPACITOR METHOD

This is the most spread method today. A voltage source charges a calibrated capacitor in series connection to the DUT configured in coulomb mode. The reference charge value is $Q=C\cdot V$, where C is the capacitance of the standard and V is the applied voltage.

The capacitor was mounted in a small metal box in series to a 1 MΩ resistor. The unconnected terminal of each element was soldered to the inner conductor of a BNC connector, and their shields were connected to the chassis. Three capacitors of 1 nF, 10 nF and 100 nF nominal values were used to obtain several reference values. The box is connected to the voltage source using a BNC-Banana plug wire. The connection with the electrometer is achieved using high quality adapters. Several capacitor types have been tested, particularly good results have been obtained with commercial polystyrene–dielectric capacitors. They have the advantage of having a very small frequency dependence, and isolation resistance bigger than 10^{12} Ω between terminals. Their repeatability resulted within 0.1% between days, so the capacitors must be measured prior to use.

III. CURRENT SOURCE METHOD

Our current source method experimental set up is very simple, a Keithley 6220[1] programmable current source is connected to the electrometer configured to measure charge. A current pulse, defined as 0–I–0 A, is programmed on the source and measured by the electrometer. The reference charge value is obtained as $Q=I\cdot T$, where I is the peak current and T the pulse width. An offset current (I_o) could be on the experimental set up; hence the system must be zeroed. The offset is measured and subtracted from the desired pulse.

The current pulse characteristics of the digital current source have been studied measuring the voltage drop on the input impedance of a digital oscilloscope. For example, a 10 s–10 nA pulse has a 0.05% width error and 0.6 ms of settling time. Current values have been calibrated using a multimeter and a high resistance standard.

IV. RESULTS AND COMPARISON

The methods are compared from two different points of view, capabilities and uncertainties.

A. Capabilities

Since several standard capacitors have to be used and automation is not possible, the traditional method tends to be more time consuming. It is stable at low charges, but values higher than 400 nC can be very difficult to generate, because a high value capacitor or a high voltage is mandatory. On the other hand, automation is possible when using a current source and charges of 100 nC or larger can be easily generated. However, references lower than 10 nC are very unstable due to the source offset current.

The current temporal behavior of the two methods is a key index. While in the alternative method a pulse output is used,

[1] Identification of commercial equipment does not imply an endorsement by INTI or that it is the best available for the purpose

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in the capacitor–voltage method the current has an exponential dependence, with an overshoot limited by the series resistance. Some resistor based electrometers, those that measure the voltage drop in an internal resistor, have low current limits and an overload can be produced. This creates a trade–off negotiation between the time constant (τ) and the peak current. To neglect τ from the uncertainty budget the measurement has to be recorded after 7·τ, then an uncertainty lower than 0.1% is obtained. However, leakage through the capacitor and the electrometer input current generates a drift in the reading. Because of this, the measurement must be performed just after the voltage is applied. As an example, if a reading is taken after 3 s using a 1 nF capacitor, a maximum time constant of 0.43 s will be necessary. Thus, the series resistor has to be lower than 430 MΩ, which will produce a minimum peak current of 23 nA at 10 V (larger than many –low range– current limits of resistor based electrometers). When a current source is used, the DUT overload can be easily avoided configuring the peak current below the limit value, and setting the pulse width.

The relative measurement error is defined as the difference between the reading and the reference charge, relative to the reference. In Fig. 1(a) the relative measurement error for a resistor based electrometer is shown. Results obtained with the capacitor–voltage method have an unacceptable variation. The maximum applied voltage was limited by the instruments current limit, only low coulomb references could be applied without overloading the DUT. The measurement error changes at each level, maybe produced by the exponential dependence of the current. This instrument was also calibrated in current mode using a voltage source and a high value standard resistor. A measurement error of 0.10% was obtained with an expanded uncertainty better than 0.05%. The outstanding agreement between this result and the ones obtained using the current source method validates the latter. It is important to point out that this behavior is typical of resistor based electrometers, showing that the numerical integration plus time reference stability have negligible effect on the measurement error.

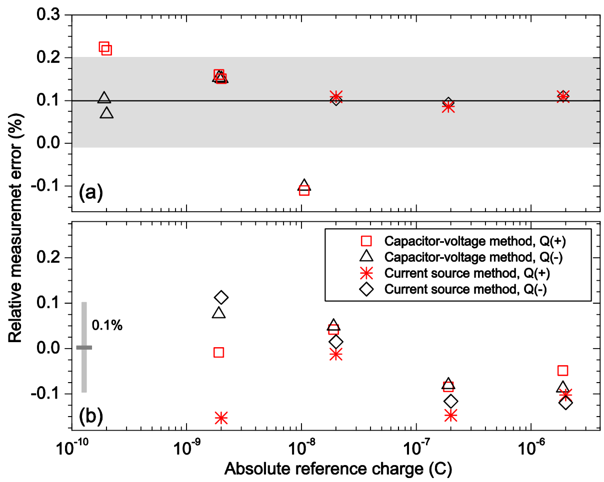

Fig. 1. (a) relative measurement error of a Standard Imaging Premier 3000 electrometer and (b) of a Keithley 6517B. The first one is a resistor based instrument, while the second is based on a capacitor. In (a) a single range is shown, the black line is the calibrated result with its expanded uncertainty in grey. In (b) the results correspond to four ranges calibration, the expanded uncertainty is indicated with the small grey line on the left

B. Uncertainties

The expanded uncertainty of the two methods is similar, typically 0.1%. It is mainly limited by the resolution and stability of the DUT, and the calibration and stability of the standard. Fig. 1(b) shows the calibration results for a Keithley 6517B with both methods. An excellent agreement was obtained, although in the 1 nC range the difference between methods is larger than the expanded uncertainty, this could be the effect of the source offset current.

VI. Conclusion

Electrometer testing with both capacitor–voltage and current source methods resulted in good agreement. The traditional procedure has the disadvantage that full scale calibration is not always possible due to the high ranges and current limits of some instruments. The alternative method achieves full scale in all ranges and automation is not an issue. Further studies could allow establishing the alternative method as a usual electrometer calibration procedure.

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References

[1] *Calibration of Reference Dosimeters for External Beam Radiotherapy,* International Atomic Energy Agency, Technical Reports Series no. 469, 2009. Available: http://www.pub.iaea.org/MTCD/publications/PDF/trs469_web.pdf.

[2] *Keithley 6517B, Electrometer Reference Manual*, Keithley Instruments Inc., document 6517B-901-01 Rev. B, Jun. 2009.

[3] M. Morgan, *et al.*, "IPEM guidelines on dosimeter systems for use as transfer instruments between the UK primary dosimetry standards laboratory (NPL) and radiotherapy centers", *Phys. Med. Biol.,* 45, 2000, pp. 2445–2457.

[4] B. Blad, P. Wendel and P. Nilsson, "A simple test device for electrometers", *Phys. Med. Biol.*, 43, 1998, pp. 2385–2391.