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INFLUENCE OF TUBE VOLUME ON MEASUREMENT UNCERTAINTY OF GM COUNTERS

by

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GM counters are often used in radiation detection since they generate a strong signal which can be easily detected. The working principal of a GM counter is based on the interaction of ionizing radiation with the atoms and molecules of the gas present in the counter's tube. Free electrons created as a result of this interaction become initial electrons, *i. e.* start an avalanche process which is detected as a pulse of current. This current pulse is independent of the energy imparted on the gas, that being the main difference between a GM counter and the majority of other radiation detectors. In literature, the dependence on the incidence of radiation energy, tube's orientation and characteristics of the reading system are quoted as the main sources of measurement uncertainty of GM counters. The aim of this paper is to determine the dependence of measurement uncertainty of a GM counter on the volume of its counter's tube. The dependence of the pulse current on the size of the counter's tube has, therefore, been considered here, both in radial and parallel geometry. The initiation and expansion of the current pulse have been examined by means of elementary processes of electrical discharge such as the Markov processes, while the changes in the counter's tube volume were put to test by the space – time enlargement law. The random variable known as the "current pulse in the counter's tube" (*i. e.* electrical breakdown of the electrode configuration) has also been taken into account and an appropriate theoretical distribution statistically determined. Thus obtained theoretical results were then compared to corresponding experimental results established in controlled laboratory conditions.

Key words: GM counter, enlargement law, measurement uncertainty

INTRODUCTION

According to the known characteristics of a GM counter [1], by detecting ionizing radiation, potential sources of measurement uncertainty can be identified: the dependence on energy and incident angle of radiation, counter dead time, reading system (resolution of the instrument), instrument calibration errors, influence of background radiation, uncertainty arising from the measurement process (counting impulses), influence of the overvoltage phenomenon in electronic devices (their wire structures) generated by the induction of overvoltage upon the electromagnetic rays which are a consequence of electromagnetic radiation in the environment where the measurements are performed (this phenomenon being especially marked in urban environments). In essence, the functioning of a GM counter is based on the self-sustained avalanche gaseous effect, and in that sense, the energy of incident radiation determines the number of free, potentially initial electrons in the counter's tube, contributing significantly to the stochastic response of the counter and, in fact, to the statistical discharge time [2], thus directly determining the nature of type A uncertainty. The angle of incident radiation contributes to type A uncertainty in a similar way, because the number and position of free electrons depend on this angle, this being especially marked in a tube with a coaxial electric field [3]. The dead time of a counter is a source of type B or combined uncertainty which depends on the determining method. Determining the dead time by recording pulses at the counter's output can be conditionally arranged to type B uncertainty and determining dead time by the two sources method has to be considered as a combined uncertainty, because the stochastic nature of radioactive decay has to be taken in consideration. An applied reading system is a source of type B uncertainty and depends on the resolution of the counter's technological solution, as well as on the true value of the measured variable (the electrical discharge

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throughout the counter's tube which is of analog nature) and is symmetrically arranged throughout the digital reading and, in fact, uniformly distributed in intervals between $n-1/2$ and $n+1/2$ digits [4]. The uncertainty due to instrument calibration is of type B and almost always a component of uncertainty arising from systemic effects. Background cosmic radiation is a source of combined uncertainty and the determination of this kind of uncertainty is the most difficult one because of its fluctuation and energy structure. The contribution of background radiation to uncertainty can be decreased by applying anticoincidence protection and by background radiation correction, but it can never be completely eliminated [5]. The uncertainty of counting impulses from a radioactive source is of type A, because the deexcitation of a nucleus is completely random and nothing can determine the deexcitation moment. In other words, it is impossible to connect deexcitation with any measuring law: all processes initiated in this manner are of a stochastic nature and to be associated with the Gaussian distribution (because of the possible time balance of their occurrence) [6]. The minimization of electronic components and, to an even greater extent, the exposure to environmental electromagnetic radiation, lead to frequent occurrences of overvoltages within electronic devices of GM counters which can, independently of the counter's tube, trigger the reading system and in that way cause type A uncertainty. The influence of this source of uncertainty can be decreased by applying overvoltage protection of electronic devices (co-ordination of isolations at a low voltage level) and/or by performing measurements in an area protected from electromagnetic radiation (over 100 dB protection).

TUBE VOLUME REDUCTION

Since the probability of a self-sustained discharge occurrence is geometrical by nature, tube volume reduction causes the reduction of the Geiger discharge occurrence probability.

In order to describe this effect using a mathematical model, it is suitable to present tube volume reduction as a reduction of the capacitor's interelectrode gap in following two steps: 1 – n times reduction in the direction of the z-axes and 2 – m times reduction in the xy-plane (electrode surface).

The first step, *i. e.* the determination of the pulse number and its deviation from the function of interelectrode gap reduction is based on gas discharge development as a Markov process [7]. A free electron becomes an initial electron when it finds itself within the critical volume where it can take enough energy from the electrical field to start an avalanche process.

The interelectrode gap reduction, followed by a lowering of operational voltage and/or increase in pressure, causes critical volume reduction, according to the similarity law [7, 8], where the number of electrons activated by the primary ionization increases following an increase in gas density. The result of these two effects is a less stochastic primary ionization position within a smaller interelectrode gap. Taking into account mentioned effects, the change of a pulse number and its standard deviation, with a n times reduction of the interelectrode gap, can be expressed as [8, 9]

$$I_{n,1} \quad \frac{I_1}{n^2} \tag{1}$$

$$\sigma_{n,1} \quad \frac{\sigma_1}{n^{2r}} \tag{2}$$

where parameter r is higher than zero.

Second step, *i. e.* tube reduction in the xy-plane is based on presenting the starting system as a capacitor or, in fact, as a parallel connection of m identical capacitors, equivalent to the said capacitor. Non-breakdown probability, *i. e.* no Geiger discharge, in the starting system presupposes non-breakdown of all m subsystems, meaning that the value of the breakdown voltage U_m is higher than the value of operational voltage U. In the case of a discrete random variable with two possible events (breakdown and non-breakdown), the problem can be presented through constant voltage testing. The critical volume of both two-electrode systems is proportional to the voltage applied, with no respect to the electrode configuration [10-12]. Therefore, the random number of breakdown, *i. e.* the number of pulses and the standard deviation of the reduced size tube in the xy-plane can be expressed as [8, 9]

$$I_{1,\mathrm{m}} \quad I_{1,1} \quad L(\beta) \;\; 1 \quad \frac{1}{\mathrm{m}^{\beta}} \quad \frac{\sigma_{1,1}}{m^{1/\beta}} \tag{3}$$

$$\sigma_{1,\mathrm{m}} \quad m^{1/\beta}\sigma_{1,1} \tag{4}$$

Summing the effects of a tube volume reduction of n times in the z-axes direction and m times in the xy-plane gives

$$I_{\mathrm{n,m}} \quad I_{1,1} \;\; 1 \quad \frac{1}{n^2} \qquad L(\beta) \;\; 1 \quad \frac{1}{m^{\beta}} \quad \frac{\sigma_{1,1}}{m^{1/\beta}} \tag{5}$$

$$\sigma_{\mathrm{n,m}} \quad \sigma_{1,1} \quad \frac{1}{n^{2,2}} \quad m^{1/\beta} \tag{6}$$

THE EXPERIMENT

Two types of tubes were used in the experiment. Type 1 tube was used for analyzing the influence of the interelectrode gap on measurement uncertainty of type A. This tube was made out of glass and filled with He gas with a pressure of 50 mbar where the cylindrical shape of electrodes ensured a homogeneous electrical field (plain-parallel configuration). The interelectrode gap had values of 0,1 mm, 0,3 mm, 0,5 mm, 1 mm, 3 mm, 5 mm, and 10 mm where the ratio of the interelectrode gap and cylindrical electrode radius was constant. Type 2 tube was a commercial tube made in two variants (2a – coaxial geometry and 2b – plain-parallel geometry). This type was used for measuring the influence of size change in the xy-plane.

The experimental procedure for testing the influence of tube reduction in the z-axis direction on measurement uncertainty consisted of the following steps:
– measuring the pulse number for 5 minutes,
– measuring the dead time of the GM counter by a two sources method,
– repeating steps 1 and 2 fifty times,
– measuring the background radiation for an hour,
– one step of tube reduction in the z-axis direction, and
– repeating the procedure.

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– repeating steps 1 and 2 fifty times,
– measuring the background radiation for an hour,
– one step of tube reduction in the xy-plane, and
– repeating the procedure.

The obtained results were then processed by a statistical calculation consisting of the following steps:
– pulse number correction due to background radiation and dead time of counter,
– formation of the statistical sample composed of 50 values of the random variable "mean value of pulse number" and an appropriate statistical sample composed of 50 values of the random variable "counter's dead time" for all series of measurements (for all sizes of the tube used),
– the use of Chauvenet's criterion for rejecting spurious measurement results,
– U-test with a 5% significance level was employed to establish whether random variables belonged to the same random variable,
– χ^2 -test and graphical test were applied for testing the random variables on belonging to normal, Weibull, and double-exponential distribution, and
– the determination of measurement uncertainty of type A for statistical samples: comparison of quantitatively and qualitatively obtained values of measurement uncertainty of type A, determined experimentally with theoretically expected values according to the enlargement law [8, 9].

EXPERIMENTAL RESULTS

Figures 1 and 2 show results obtained for the mean value and standard deviation of the detected pulse number with respect to the counter's tube reduction, where an americium source is used. Figures 3 and 4 show results obtained for the mean value and standard deviation of the detected pulse number with respect to the counter's tube reduction, where a caesium source is used.

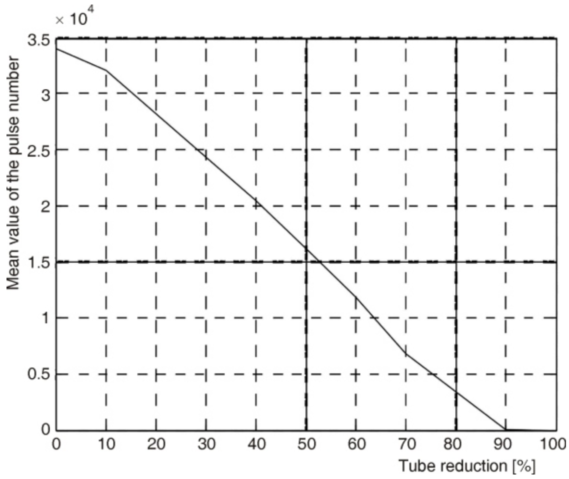

Figure 1. Detected mean value of the pulse number using an americium source (^{241}Am)

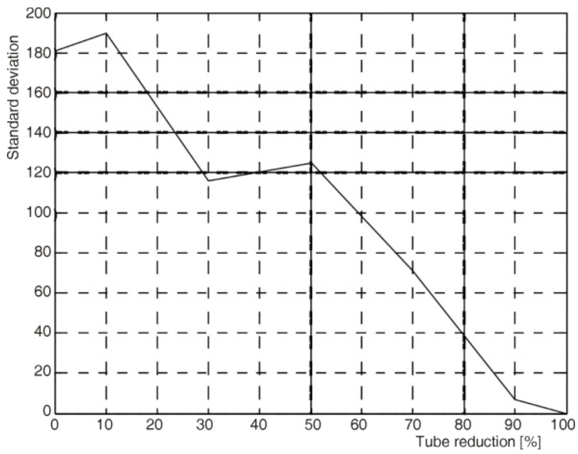

Figure 2. Standard deviation of the pulse number using an americium source (^{241}Am)

The agreement of experimental and theoretical results has been achieved for the mean value of the pulse number (figs. 1 and 3) where the applicability of the enlargement law (reduction, in our case) has been approved. The discrepancy between the theoretically expected effects of reduction (or enlargement) and the results obtained experimentally can be noticed in figs. 2 and 4, where the standard deviation of the pulse number is shown.

CONCLUSION

The agreement of experimental and theoretical results has been achieved for the mean value of the pulse number detected, where the discrepancy between the theoretically expected standard deviation and the experimentally obtained values has been found. This could be the consequence of the radiation energy emitted from the sources used and the angle of incidence energy, but this remains to be investigated.

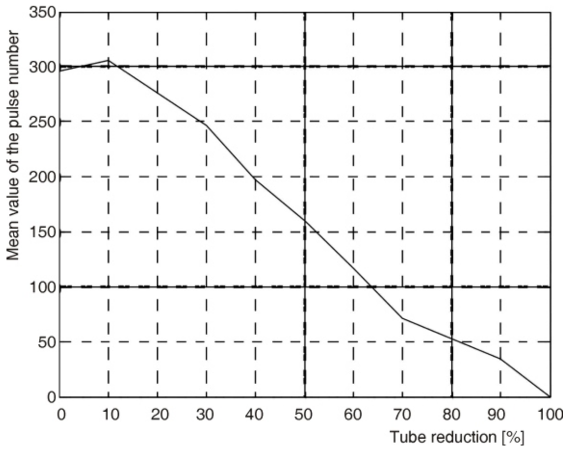

Figure 3. Detectede mean value of the pulse number using a caesium source (^{137}Ce)

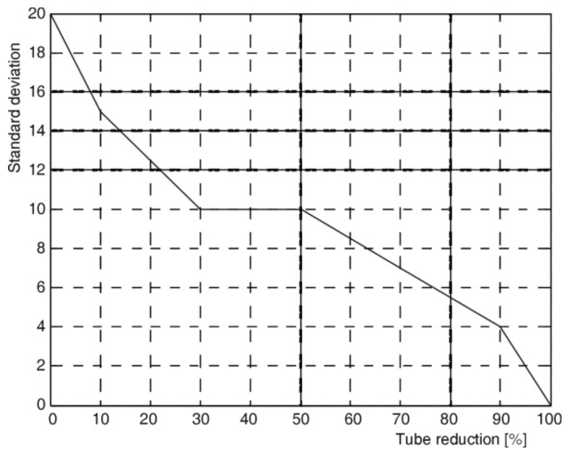

Figure 4. Standard deviation of the pulse number using a caesium source (^{137}Ce)

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УТИЦАЈ ДИМЕНЗИЈА БРОЈАЧКЕ ЦЕВИ ГМ БРОЈАЧА НА МЕРНУ НЕСИГУРНОСТ

ГМ бројач се често користи у детекцији зрачења пошто генерише јак сигнал који се може лако детектовати. Принцип рада ГМ бројача заснива се на јонизационој интеракцији зрачења са атомима и молекулима гаса у бројачкој цеви. Слободни електрони, настали као резултат ових интеракција, постају иницијални електрони који покрећу лавински процес детектован као струјни импулс. Овај струјни импулс не зависи од енергије предате гасу, што представља основну разлику између ГМ бројача и већине других детектора зрачења. Као главни извори мерне несигурности ГМ бројача, у литератури се наводе зависност од енергије инцидентног зрачења, оријентације бројачке цеви и система за очитавање. Циљ овог рада је да се одреди утицај димензија бројачке цеви на мерну несигурност ГМ бројача. Из тог разлога разматра се зависност формирања струјног импулса у односу на димензије бројачке цеви, како у радијалној тако и у паралелној геометрији. Иницијација и развој струјног импулса третирају се кроз елементарне процесе електричног пражњења као Марковљеви процеси, док се промена димензија бројачке цеви разматра преко просторно-временског закона пораста. Случајна променљива "струјни импулс у бројачкој цеви" (то јест, електрични пробој електродне конфигурације), статистички се посматра и на основу тога одређује се одговарајућа теоријска расподела. Теоријски добијени резултати упоређени су са одговарајућим експерименталним резултатима добијеним под добро контролисаним лабораторијским условима.

Кључне речи: ГМ бројач, закон пораста, мерна несигурност