STATISTICAL REVIEW OF THE INSULATION CAPACITY OF THE GEIGER-MUELLER COUNTER

by

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This work considers the manifestation of spontaneous breakdowns of Geiger-Mueller counters. This is an experimental type of work. The reasons leading to the spontaneous breakdowns of Geiger-Mueller counters have been analysed under controlled laboratory conditions. The experiments were carried out under the "constant voltage". The tested Geiger-Mueller chambers were commercial chambers of the radial electric field and homogenous electric field. The experimental-statistical methods were used in order to choose the chambers with identical features (with 0.1 % of statistical reliability).The results of experiments showed that the spontaneous breakdown of the Geiger-Mueller counter happens even in the conditions of shielding. They also showed that those breakdowns have cumulative features. The reason for that is a positive feedback between the spontaneous breakdowns. The explanation is confirmed and quantified by the working gas filtering experiments.

Key words: Geiger Mueller counter, spontaneous breakdown, gas filtering experiment

INTRODUCTION

The Geiger-Mueller counter (GM counter) is a gas detector working on the basis of gas multiplication, as well as the work of the proportional counter. Every primary electron in the proportional counter creates an avalanche that is independent from the other avalanches. Since all avalanches are approximately the same, the gathered electric charge is proportional to the number of primarily generated electrons. The GM counter uses the stronger electric field which makes the avalanches more intense. One avalanche can cause another somewhere else in the tube. Above the critical value of an electric field, each avalanche causes at least one more avalanche and that is how self-maintained electric discharge happens and it is known as Geiger discharge. By further expanding the electric field, the number of avalanches during the discharge grows. When a certain fixed number of avalanches is reached within one discharge, the collective effects of all avalanches terminate the chain reaction and the discharge quenches. Since approximately the same number of avalanches quenches every discharge, all the impulses of the GM counter have the same amplitudes, irrespective of the number of primarily generated ion couples which start the process. The GM counter can function only as a counter of the events caused by the action of ionizing radiation and not as a spectrometer, because the information about the energy that the entering radiation quantum transfers to gas gets lost [1-4].

In order for the GM counter to function in the described manner, certain conditions need to be fulfilled so that the entering ionizing radiation starts the avalanche which will, by a self-maintaining mechanism, lead to the breakdown. That, primarily, means that the working point of the GM counter tube, determined by the tube voltage N and the product of stress and interelectrode distance, is in a state of unstable balance. Ionizing radiation, in spite of the great energy it has on the microscopic scale, is not capable of causing any effect on the macroscopic energy scale. That is why the GM counter tube has to be in the state of unstable balance, *i. e.*, its voltage should be less than the value of the breakdown voltage, but still very close to the value so that the breakdown can be triggered by the energies of the microscopic scale [5, 6].

However, the breakdown voltage is by its nature a statistical value, which means that the working point that is not properly set can cause great measuring uncertainties type A [7-9]. In order for that to be prevented, the minimization of uncertainty type A must be taken into consideration when determining the working point of the GM counter (*i. e.*, operating voltage).

The goal of this paper is to experimentally determine the existence of spontaneous breakdowns in the

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GM counter tube without the influence of outer radiation. The experiments are performed by the long-term method of "constant voltage" without the presence of sources of ionizing radiation. Such results shall be interpreted using the Theory of the Electric Discharge Through Gases. Theoretically expressed explanations of the results shall be additionally checked by other types of experiments.

THE CHOICE OF VARIATE

The choice of variate to describe the breakdown process depends on the incurred physical or technical problem. In most experiments random variate breakdown voltage U_d is directly investigated. If the experiments relate to the measurements on insulating arrangements to be installed in the system of a certain operating voltage, then it is recommended that it stays with the random variate breakdown voltage. The performance function of the breakdown voltage will then be comparable with the insulation level, the test voltages or the distribution functions of the overvoltages. The voltages with clear, unambiguous parameters must be used in the experiment. Breakdown voltage performance functions for different stress durations are needed for statistical consideration of the time effect [10].

In the case of slightly non-uniform insulation arrangements (one of which is the GM counter chamber), we are often interested in breakdown voltage generalization. The Schwaiger relationship can be used for simple calculation of the variate maximum breakdown field-strength from the variate breakdown voltage for an insulation arrangement with an electrode gap d and degree of uniformity η

$$E_{dh} \quad \frac{U_d}{d\eta} \tag{1}$$

If curvature factor e_h, which describes the influence of electrode curvature on the breakdown process, is also known for the insulation arrangement concerned, then the variate dielectric strength E_d can be introduced as a material property

$$E_d \quad \frac{E_{dh}}{e_h} \quad \frac{U_d}{d\eta e_h} \tag{2}$$

This strength is also a function of the duration of the applied stress, fig. 1(c). It is sometimes technically expedient (and physically meaningful) to use a random time factor to describe the random nature of the breakdown process

$$K_t \quad \frac{E_d(t)}{E_{d0}} \tag{3}$$

where E_{d0} is the strength at a given time.

Such an approach proves satisfactory when considering a breakdown which is the result of random processes (which is the case with the GM counter). By analogy to time factor K_t, it is always recommended to introduce the selected variates if they can be used to describe the random breakdown process and permit the generalization of the test results.

Finally, it is advantageous in many problem situations to consider the variate breakdown time T_d empirical distribution functions $F(T_d)$. In special cases, it also seems quite reasonable to deteremine breakdown time performance functions.

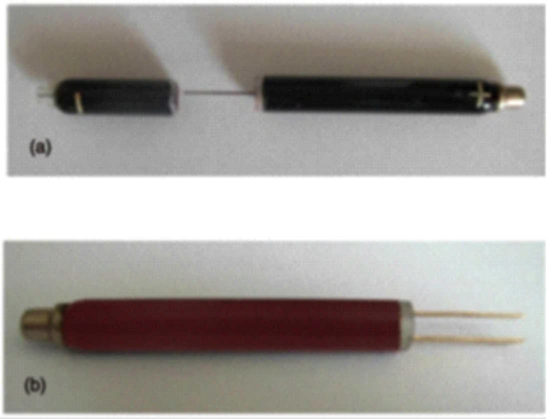

Figure 1. GM counter with coaxial electrodes (chamber A) (a), and GM counter with plan-parallel electrodes (chamber B) (b)

EXPERIMENT

The investigation of the stability of the working point stochasticity of the GM counter was performed by the constant voltage method [11, 12]. The commercial types of GM tubes were used: type 1 with a coaxial electric field and type 2 with a homogenous electric field, fig. 1.

The experiments were done on 20 GM tubes of type 1 and the same number of GM tubes of type 2 chosen by preliminary examination from a much greater number. The tubes used were new, commercial, GM tubes as well as 5 years old, 1 year old tubes, and tubes of the same types were used. Also, the experiment was carried out on the tubes after the working gas filtration. The working gas was filtrated by a paper filter which contained particles of zeolite 1. Figure 2 shows the working gas filtrating system for the GM counter.

The preliminary examination was carried out by measuring 50 values to breakdown voltage of each individual GM tube where the speed of voltage increase was 8 Vs^{-1}. The interval between the two consequent breakdowns was 1 minute. Based on the resulting values, the unique, statistical sample of random variate d. c. breakdown voltage was formed. From such a formed sample, by further application of the U-test, 20 GM tubes were chosen for type 1 and the same number of tubes for type 2 whose values of the breakdown voltage differed less than 0.1 %.

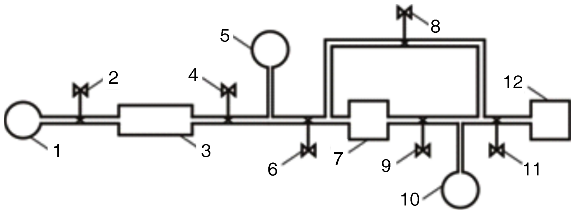

Figure 2. The working gas filtrating system for the GM counte; *1, 5, 10 – pressure gauges, 2 4, 6, 8, 9, 11 – two-way valves, 3 – GM counting tube, 5 – pressure gauge, 7 – filter, 12 – compressor*

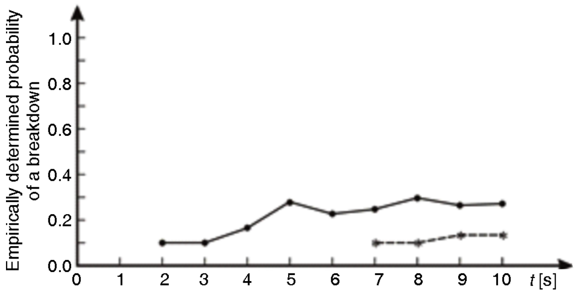

Figure 3. Empirically determined probability of a spontaneous breakdown of the commercial GM tube depending on time; non-uniform geometry (cylindrical); homogeneous geometry (plate-plate), breakdown time in days; non-uniform geometry, --- homogeneous geometry

The process of statistical determination of spontaneous breakdown of GM tubes was measured by a measuring circle shown in fig. 3. The measuring was entirely automatized. Simultaneously, 20 GM tubes of the same types were positioned in the measuring system. All the examined tubes were set in a lead box with 15 cm thick sides (to prevent the possibility of breakdown of the tubes due to secondary cosmic radiation). The value of the d. c. voltage for each tube was equal to the value of the voltage at a working point. Whenever a breakdown happened in a GM tube, the time of the breakdown was marked. After 50 breakdowns the value of the d. c. voltage increased by 10 % and the measurement was repeated. This procedure was repeated until the d. c. voltage of GM tubes reached the value of the d. c. breakdown voltage of GM tubes. The same procedure was practiced with alleviating values of the d. c. breakdown voltage. The minimizing of the d. c. braeakdown voltage value was repeated until the situation when 100 hours passed without spontaneous breakdown [13, 14].

For each value of the d. c. breakdown voltage, the statistical sample of the random variate spontaneous breakdown time was formed. Such a statistical sample was tested for qualification for Normal, Weibull and double-exponential distribution. The testing was done graphically by the Hi square test. The analysis of such results enabled the determination of frequency of possibility for spontaneous breakdown of the GM counter tube.

RESULTS AND DISCUSSION

Noble gases with the addition of a mixture for quenching are, conditionally, a completely renewable insulation. However, the initiation of electric discharge within the GM tube requires the existence of free electrons, the formation of which is the biggest problem for obtaining and interpretation of the results associated with the statistical overview of the insulation properties of the GM counter in the conditions of the descriptive experiment. Namely, secondary cosmic radiation is considered responsible for the formation of the largest number of free electrons in gases. This source is impossible under the experimental conditions due to the shielding. Other free electron sources (neutral atom vessels from Maxwell's distribution tail, collisions of metastables are also impossible or have a negligible efficiency). Therefore, a spontaneous breakdown of GM tubes would be unlikely if there were perfectly cooled electrode surfaces and a new one. This is confirmed by the results shown in fig. 3.

Figure 3 shows the empirical probability of a spontaneous breakdown of a new commercial GM tube, depending on the time.

Figure 4 shows the empirical probability of a continuous breakdown of the used GM tube depending on time.

Figure 5 shows the dependence of the spontaneous breakdown empirical probability of the new commercial GM tube, non-uniform geometry (cylindrical) on the time, with a percentage increase in operating voltage as a parameter.

Figure 6 shows the dependence of the spontaneous breakdown empirical probability of the new commercial GM tube of homogeneous geometry (plate-plate) on time, with a percentage increase in operating voltage as a parameter.

Figure 7 shows the dependence of the spontaneous breakdown empirical probability of the commer-

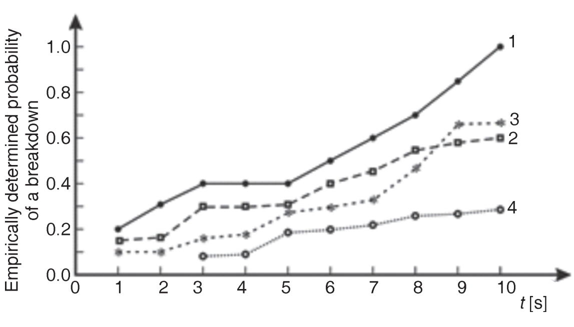

Figure 4. Empirically determined probability of a spontaneous breakdown of used GM tubes depending on time; 1 – GM tube of non-uniform geometry (cylindrical) used for five years; 2 – GM tube of non-uniform geometry (cylindrical) used for one year; 3 – GM tube of homogeneous geometry (plate-plate) used for five years and 4 – GM tube of homogeneous geometry (plate-plate) used for one year

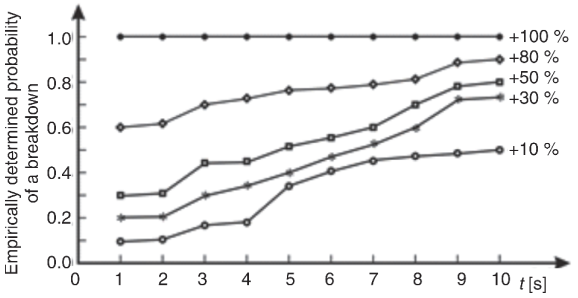

Figure 5. The dependence of the spontaneous breakdown empirical probability of the new commercial GM tube, non-uniform geometry (cylindrical) on the time, with a percentage increase in operating voltage as a parameter

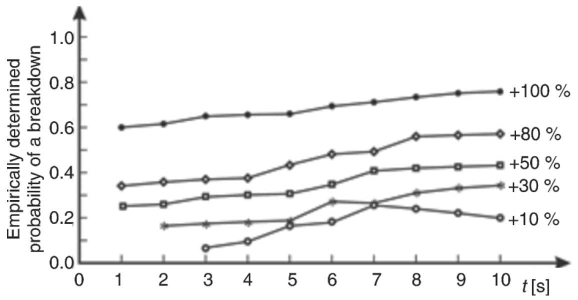

Figure 6. Dependence of the spontaneous breakdown empirical probability of the new commercial GM tube of homogeneous geometry on time, with a percentage increase in operating voltage as a parameter

cial GM tube used for five years on time, with a percentage increase in operating voltage as a parameter.

Figure 8 shows the spontaneous breakdown empirical probability of the commercial GM tube used for five years of homogeneous geometry (plate-plate) depending on time, with a percentage increase in operating voltage as a parameter.

Figure 9 shows the breakdown empirical probability of the new GM tube of non – uniform geometry (cylindrical), depending on time with a percentage increase in operating voltage as a parameter.

Figure 10 shows the breakdown empirical probability of a GM tube used for five years of non-uniform geometry (cylindrical), depending on time with a percentage increase in operating voltage as a parameter.

Figure 11 shows the breakdown empirical probability of a GM tube used for five years of homogeneous geometry.

Figure 12 shows the determined probability of spontaneous breakdown of a GM tube used for five years of homogeneous and non-uniform geometry before and after filtering of operation gas.

The obtained results show that there is a spontaneous breakdown of the GM counter tube in the conditions of a long-term experiment. Since the operating point of the GM counter tube is chosen so that the tube can hold in conditions of a labile balance, the spontaneous breakdowns could be explained by small voltage fluctuations and/or pressure in the tube. However,

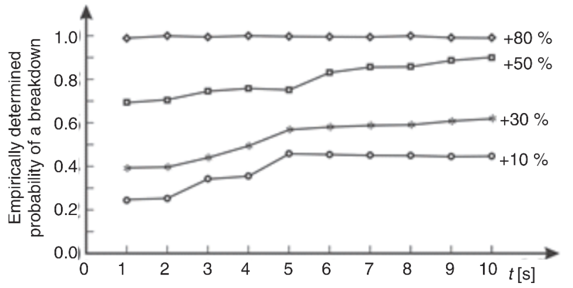

Figure 7. Spontaneous breakdown empirical probability of a commercial GM tube used for five years non-uniform geometry (cylindrical), depending on time with a percentage increase in operating voltage as a parameter

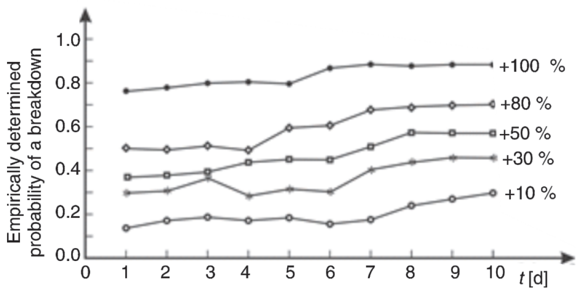

Figure 8. The spontaneous breakdown empirical robability of the commercial GM tube used for five years of homogeneous geometry (plate-plate) depending on time, with a percentage increase in operating voltage as a parameter

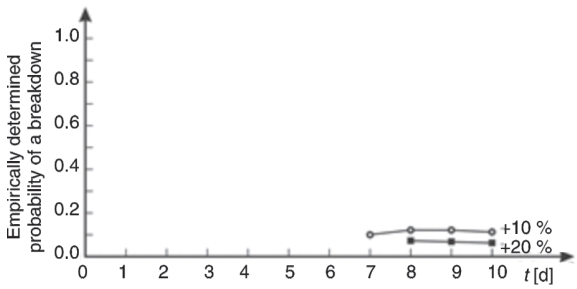

Figure 9. The breakdown empirical probability of the new GM tube of homogeneous geometry (plate-plate), depending on time with a percentage increase in operating voltage as a parameter

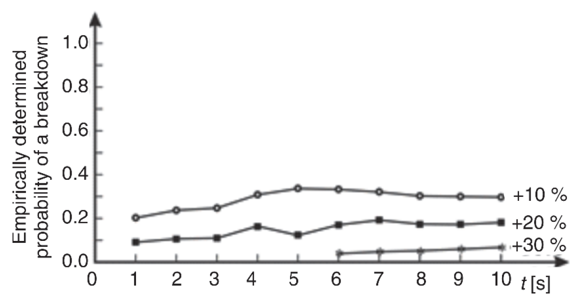

Figure 10. The empirically determined breakdown probability of the GM tube used for 5 years of non-uniform geometry, depending on time

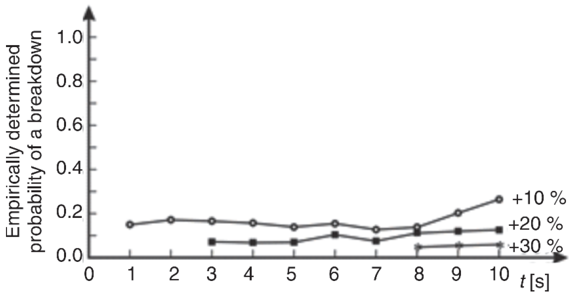

Figure 11. Empirically determined breakdown probability of the GM tube used for 5 years of homogeneous geometry (plate-plate) depending on time with a percentage increase in operating voltage as a parameter

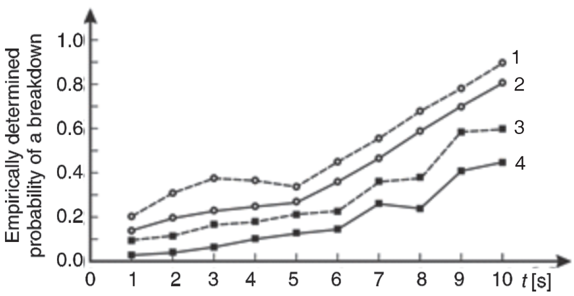

Figure 12. Empirically determined probability of spontaneous breakdown of a GM tube used for 5 years 1 – non homogeneous ( ) geometry before filtering, 2 – homogeneous (x) geometry before filtering, 3 – non homogeneous ( ) geometry after filtering, and 4 – homogeneous (x) geometry after filtering

for this kind of explanation, the existence of a higher density of free electron gas in the GM tube would be required. Since free electrons (potentially initial) occur mostly as a consequence of secondary cosmic radiation, it can not be expected in the case of the shielding around the GM tube.

The occurrence of free electrons as a result of a collision of noble gas neutral atoms from the Maxwell's distribution tail can be the cause of ionization and the emergence of a free electron that can, under the aforementioned conditions, initiate a spontaneous breakdown. The probability of such a process is not big, and it should not have a cumulative nature which is noticeable in the experimental results (*i. e.*, such an initiated occurrence of spontaneous breakdowns should depend on time).

Based on the increase in the number of GM counter tube spontaneous breakdowns, it can be concluded that there is positive feedback between the breakdowns (chronologically observed). That positive feedback, which leads to an increase in the number of spontaneous breakdowns over time, may be the consequence of the appearance of conductive particles in the gas and/or electrode topography changes due to previous breakdowns. Namely, the spark by which the breakdown is carried out is in the state of thermo-ionized plasma. Due to the high temperature, the spark is also subject to high pressure (in accordance with the gas state equation). The high temperature leads to melting of the electrode surfaces at the point where the spark is formed. At the moment of spark-suppression, there is an explosion of a sparkle channel under high pressure (this explosion is the source of sound that can be heard during the occurrence of any spark). Explosion of the spark channel causes the molten electrode material scattering into the inter-electrode space and creates a crater at the site of the explosion. The discharged electrode material in the inter-electrode space is cooled in droplet form (due to the effect of surface voltage). The formed craters usually have sharp edges [15, 16]

The appearance of conductive particles in the electrode space perturbs the electric field, and they can become the source of new free electrons by the effect of cold emission. The resulting craters with their sharp edges can also create free electrons by cold emission, but also by the emission of photons that can ionize atoms of noble gas. The results of fig. 12 indicate that both of these phenomena are present in commercial GM tubes and that the particle appearance in the gas inter-electrode space contributes to 40 % of spontaneous breakdowns, and the electrode topography changes by about 60 %. These phenomena are more expressed with GM tubes with non-uniform fields due to a larger increase in the local field near the particles, or the crater. Regarding the change in the number of spontaneous breakdowns with the increase or decrease in operating voltage, this is in line with the previous consideration.

CONCLUSION

Based on the results of long-lasting experiments, it was found that the occurrence of spontaneous breakdowns of the GM counter tube caused a positive feedback. This feedback leads to an increase in spontaneous breakdowns over time. As a cause of the formation of this feedback, irreversible changes of the GM counter tube insulation system were identified, during the breakdown. These changes are the result of punctual melting of electrode surfaces during breakdowns. The melting of electrodes leads to the appearance of conductive particles in the inter-electrode space and crater formation on electrode surfaces. These changes create new free electrons in the zone of high values of the electric field, which initiates spontaneous discharges. In order to reduce the effect of spontaneous emission, it is recommended to: (1) use GM tubes with a lower degree of non-uniformity of the electric field; (2) use material for the production of electrodes with a lower output operation value, greater melting point value, and higher thermal conductivity values.

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AUTHORS' CONTRIBUTIONS

Theoretical and experimental analysis was carried out by M. D. Obrenović. Calculations were carried out by M. D. Obrenović. All authors analysed and discussed the results. The manuscript was written by M. D. Obrenović.

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СТАТИСТИЧКИ ПРИКАЗ ИЗОЛАЦИОНЕ СПОСОБНОСТИ ГАЈГЕР-МИЛЕРОВОГ БРОЈАЧА

У раду експерименталног типа разматра се појављивање спонтаних прорада Гајгер-Милеровог бројача. Под добро контролисаним лабораторијским условима испитивано је који разлози доводе до спонтаног отказа Гајгер-Милеровог бројача. Експерименти су обављани под “сталним напоном”. Испитиване Гајгер-Милерове коморе биле су комерцијалне коморе радијалног електричног поља и хомогеног електричног поља. Гајгер-Милерове коморе су експериментално-статистичким методама изабране да имају идентичне карактеристике (са 0,1 % статистичке поузданости). Експериментално добијени резултати показали су да и под условима заштите долази до спонтаног отпуштања Гајгер-Милеровог бројача. Такође је показано да ти откази показују кумулативни карактер. То је објашњено позитивном повратном спрегом између спонтаних покрета. Објашњење је потврђено и квантификовано експериментима са филтрирањем радног гаса.

Кључне речи: Гајгер-Милеров бројач, спонтани отказ, експеримент са филтрирањем радног гаса