LIFETIME CHARACTERISTICS OF GAIGER-MULLER COUNTERS

by

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This paper discusses the process of functional aging of Geiger-Muller counters. Two types of Geiger-Muller counter chambers were characterized in an experiment using a combined constant voltage. Chamber A had a coaxial geometry and chamber B had a plan-parallel geometry. The experimental results indicate that the aging process was faster in the case of chambers with a coaxial geometry. The results are explained based on the process of electrical discharges in gasses.

Key words: Geiger-Muller counter, electrical discharge in gasses, lifetime characteristic

INTRODUCTION

The Geiger-Muller counter is a gaseous detector of ionizing radiation whose principle of operation is based on gas multiplication. In the process of gas multiplication 10^9-10^{10} ion pairs are formed from a single quantum of radiation. Because of that, the amplitude of the output signal is very high (~1 V). An amplitude of this magnitude enables the use of simple measuring instrumentation, which usually does not include a preamplifier. However, the large concentration of ion pairs leads to energy-specific plasma-chemical conversions. The released energy determines the amount of the remaining charge in the gas after the discharge and the total permanent changes of the insulation structure of GM counters during usage. The remaining charge affects the next result outcome, the recovery time of the insulation and the dead time of the counter. Total permanent changes of insulating structures of GM counters affect its lifetime [1-4]. There are many papers in which the dead time of GM counters is examined, but not so many on the topic of GM counter lifetime [5-9]. The purpose of this paper is to determine the characteristics of lifetime of commercial GM counters.

The determination of lifetime characteristics of GM counters was done by examining the interdependence of the distribution function of the breakdown time t_{dp} and the breakdown voltage u_{dp} of the GM counter chamber. For that purpose, a comparison of the results obtained using a constant voltage and the theoretical expectations were carried out. The selection of the test technique was determined by the goal of the experiment. Constant voltage testing gives reliable and detailed data about the distribution function of the breakdown voltage, but the determination of the lifetime characteristics requires a lot of time.

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DISTRIBUTION FUNCTION OF THE BREAKDOWN TIME AND THE BREAKDOWN VOLTAGE

Studies have shown that random statistic samples of variables such as the breakdown times and the breakdown voltages, in coaxial geometries insulated with noble gasses at low pressure, belong to the Weibull distribution. Based on the selected quantiles of those distributions, a so-called lifetime characteristic can be constructed. Experience has shown that the lifetime characteristic forms a straight line on a double logarithmic scale [10-12]. If the confidence intervals of the used quantiles are known, they can be transferred to the lifetime characteristic. For each quantile order p (in eqs. 2 and 3, p = 0.1 and p = 0.63) of the breakdown time, the lifetime characteristic is described in the following way

$$u_{\mathrm{dp}} \quad k_{\mathrm{dp}} t_{\mathrm{dp}} \mathrm{e}^{\;1/r} \qquad (1)$$

where k_{dp} is a constant which characterizes the geometry structure, and r is the lifetime exponent which depends on the insulation material and its condition.

Changes (like curving) in the lifetime characteristic indicate to changes in the aging mechanism (electrical aging mechanism) [13, 14].

Based on the validity of the Weibull distribution for random statistical samples of variables of the breakdown time and the breakdown voltage, the probability for the breakdown voltage and the fixed breakdown time must be equal to the probability for the fixed breakdown voltage and the breakdown time, $F(u_{\mathrm{d}}, t_{\mathrm{d}_1}) \quad F(t_{\mathrm{d}}, u_{\mathrm{d}_1})$. Starting from the Weibull distribution

$$F(x, y_1) \quad 1 \quad \exp \quad \left(\frac{x}{x_{63}(y_1)}\right)^{\delta_t} \qquad (2)$$

and the assumption that the lifetime exponent r can be applied to all the quantiles, it can be derived

$$u_{d_{63}}(t_{d_1})\sqrt{t_{d_1}} \quad k_{d_{63}} \qquad (3)$$

which is also valid for the dependence on the r values $(u_{d_{63}}, t_{d_1})$.

On the basis of the expression (3), there is a relationship between Weibull's exponents for statistical samples of random variables of breakdown time (δ_t), breakdown voltage (δ_{u}) and the lifetime exponent r

$$r \quad \frac{\delta_{\mathrm{u}}}{\delta_{\mathrm{t}}} \qquad (4)$$

It should be repeated that expression (4) applies only if the random variables of the breakdown time and breakdown voltage belong to the Weibull distribution and that the lifetime exponent is equally true for all distributions.

EXPERIMENT

The experiments were carried out under constant voltage with two types of commercial GM chambers. Type A has a coaxial electrode configuration, fig. 1(a), and type B has a plan parallel electrode configuration, fig. 1(b). In the experiment, the GM chamber was at an operating voltage (400 V DC voltage for both type A and type B chamber), and the electrical discharges were simulated by superimposed impulse voltage. Namely, if the pulse voltage caused a breakdown, it was equivalent to the GM counter operating mode, and if the impulse voltage did not cause a breakdown, it was equivalent to an electric discharge in the GM chamber that was not self-sustaining. On fig. 2 the scheme of the measuring system is shown.

The amplitude of the impulse voltage ranged from a minimal value of 10 V (at which a breakdown almost never occurs) to a maximal value of 250 V (at which a breakdown almost always occurs). The number of voltage steps was 10 and the number of applied voltages per step was 100. The difference in the amplitude of the impulse voltage per step was 25 V. The interval between two impulse voltages was 1 minute.

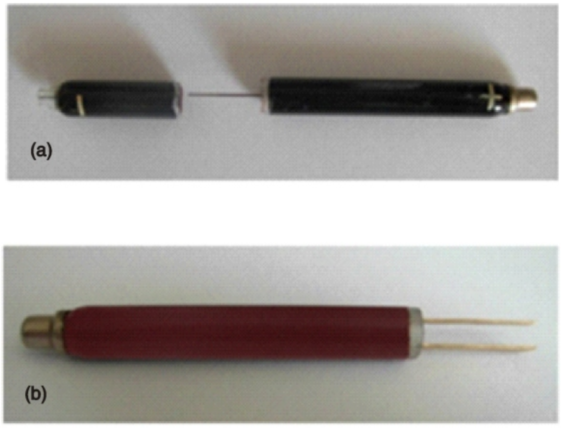

Figure 1. GM counter with coaxial electrodes (chamber A) (a), and GM counter with plan-parallel electrodes (chamber B) (b)

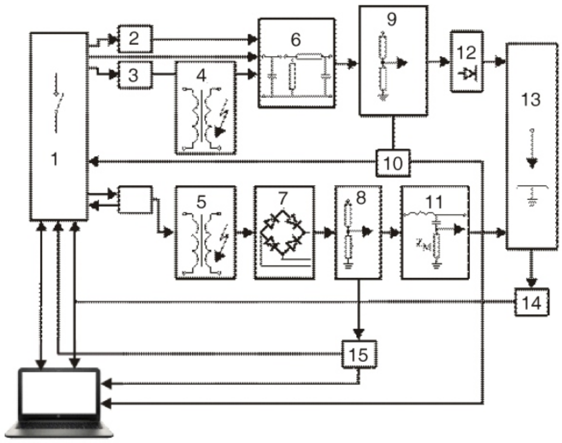

Figure 2. The measuring system scheme; *1 – adjustment, 2 – triggering level, 3 – actuator, 4 – DC voltage generator, 5 – test transformer, 6 – impulse generator, 7 – Graetz circuit, 8 – divider, 9 – divider, 10 – measuring unit, 11 – capacitor and measuring impedance, 12 – adapter, 13 – test sample, 14 – breakdown indicator, and 15 – measuring and control unit*

The measuring system was designed so that it automatically determined a statistical sample of 1000 random variables of the breakdown time and the breakdown voltage. The obtained statistical samples were graphically tested and using the test to see if they belong to the Weibull distribution. After that, the parameters of the adequate distributions were derived using the momentum method and the lifetime characteristics were plotted. The combined measurement uncertainty of the procedure was less than 3 % [15, 16].

RESULTS AND DISCUSSION

The lifetime characteristics of type B and type A GM chambers are represented in fig. 3 and fig. 4, respectively.

In fig. 3 the lifetime characteristic of the type B GM chamber is a straight line which means that there were no irreversible changes in the breakdown mechanism during the experiment. Figure 4 shows that the lifetime characteristic of the type A GM counter is curved which means that there were irreversible changes in the aging mechanism of the insulation chamber.

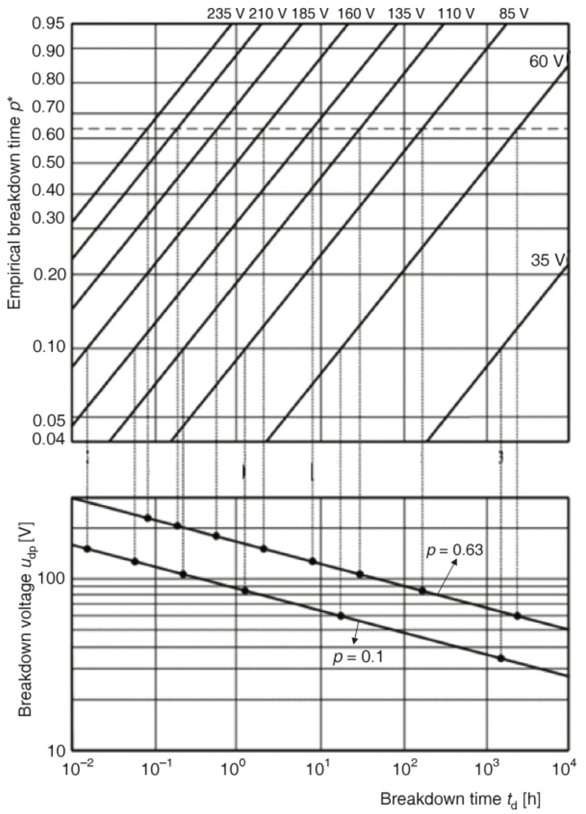

Figure 3. Lifetime characteristic of chamber B

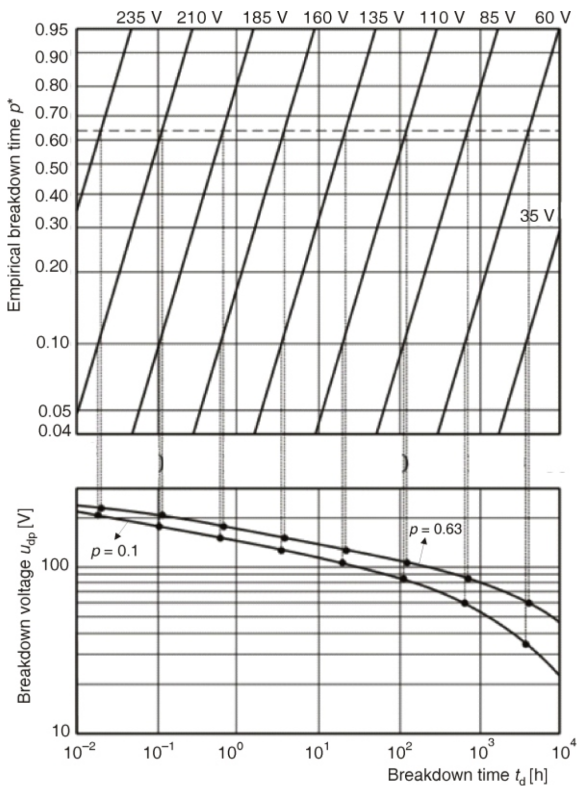

Figure 4. Lifetime characteristic of chamber A

The obtained results can be explained by changes on the electrodes and in the gas due to long-term electrical discharges. Changes occur on the electrodes due to partial discharges and breakdowns. Electrodes with small curvature radiuses are particularly prone to erosion. Also, electrodes with small areas are prone to roughness increasing and formation of non-metallic coating. However, a similar phenomenon can be seen on electrodes with larger areas. Firstly, regarding the changes in the gas, one must keep in mind that electric discharges lead to chemical reactions and thus to changes in the gas composition. Secondly, the electric discharge leaves behind spatial charges which recombine relatively slowly. If the following voltage application occurs after the discharge, before the spatial charges recombine, there will be a different distribution of the critical electric field, which will either speed up or slow down breakdown process, in comparison with the case without spatial charge. If there are solid dielectric boundary layers in the insulation system (due to support elements for example) firmly adhering, surface charge may be formed which affects the distribution of the critical field.

These mechanisms are responsible for the differences in the lifetime characteristics of GM counting chambers type A and type B. Namely, the type A counting chamber has a coaxial geometry with a small radius central electrode. In the case of the type A counting chamber, the process of charge deposition on the insulation carriers significantly affects the changes of the critical field with time. Unlike the type A counting chamber, type B has electrodes with an infinite radius of curvature and electrode supports with negligible dimensions. Regarding the processes in the gas, they are the same for both observed chambers and they do not lead to irreversible changes in the aging mechanism. This is due to the fact that the insulation gas in both of the used chamber is a dominantly noble gas (He).

CONCLUSION

Based on the consideration of the lifetime characteristics of GM counters with radial homogenous fields in the counting chambers, it was found that irreversible changes first appear in tubes with radial fields. This means that in conditions of long-term usage, GM counting chambers with electrodes less susceptible to changes caused by electrical discharge should be used. Such electrodes have larger curvature radiuses and are made of materials with a lower work function, higher melting temperature and a better thermal conductivity.

AUTHOR CONTRIBUTION

Experiments were carried out by N. Kartalović. All authors analysed and discussed the results. The manuscript was written by all authors.

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КАРАКТЕРИСТИКЕ ВЕКА ТРАЈАЊА ГАЈГЕР-МИЛЕРОВОГ БРОЈАЧА

У раду се разматрају процеси функционалног старења коморе Гајгер-Милеровог бројача. На основу експеримената са комбинованим сталним напоном одређене су карактеристике два типа комора. Комора типа А била је са коаксијалном, а типа Б са план-паралелном геометријом. Добијени резултати објашњени су на основу процеса електричног пражњења у гасовима.

Кључне речи: Гајгер-Милеров бројач, електрично пражњење у гасовима, карактеристика века трајања