# AGING OF THE GEIGER-MULLER COUNTER DUE TO PARTICLE CONDUCTANCE IN AN INSULATING GAS

by

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**In this paper, the aging effect of commercially available Geiger-Muller counters under working conditions is being considered from both theoretical and experimental point of view. In the experimental part lifetime curves for the commercial Geiger-Muller counter chamber are first recorded. After detection of the aging phenomena, the commercial chamber response to an impulse voltage is tested along with recording of the same response of the Geiger-Muller chamber model with conductive particles included. The law of similarity for the gaseous discharge is fulfilled both by the commercial Geiger-Muller chamber and by the chamber model with conductive particles. The results obtained from the U-test indicate that the aging of the Geiger-Muller chamber is mainly caused by the occurrence of a great number of conductive particles hovering inside the chamber. Some suggestions of how to reduce the aging effect due to conductive particles inside the Geiger-Muller chamber are given in the conclusion.**

*Key words: Geiger-Muller counter, aging, conductive particle*

## INTRODUCTION

Geiger-Muller (GM) counter is a gaseous detector whose working principle is based on the electrical breakdown of the gases. In the gas chamber, each and every electron avalanche launches at least one such additional avalanche. This leads to the self-sustaining chain reaction, known as the Geiger discharge. During the discharge, approximately $10^9$-$10^{10}$ ion pairs are created inside the counter chamber. As a consequence, the amplitude of the output impulse is very high (~1 V). Such high voltage level enables the usage of the simple measurement instrumentation that, in most cases, does not need to include a preamplifier stage [1, 2].

As the GM counter works on the principle of the electrical breakdown of gasses, the presence of the electronegative gases inside the chamber should be avoided. Consequently, the noble gasses such as helium or argon are most often used for counter chambers filling. Along with those gases, another component needed for the extinguishing is also added [3, 4]. Namely, if the chamber of the GM counter is filled only with one of the gasses, then all the positive ions are the ions of that gas. Neutralization of these ions is being conducted on the cathode and during this process releasing of free electrons from the cathode surface can occur. Every single free electron can start up new avalanche, thus preventing the stabilization of the counter. The false impulses occurring in this way have the same amplitude as the real ones. In order to avoid this an extinguishing gas is added, along with noble gases. This gas has lower ionization energy and more complex molecular structure than the noble gases and its percentage content in the mixture varies from 5 to 10 %. Using the mechanism of collision with charge transfer, the role of the extinguishing gas is to secure that all the positive ions that reach the cathode are exclusively its own ions. During a neutralization of the extinguishing gas ions, the obtained energy is spent on molecule dissociation, and not on the release of secondary free electrons. The most commonly used extinguishing gases are ethyl alcohol, chlorine and chromium [5, 6].

The degradation of GM counter parameters can be caused by the noble gas diffusion from the chamber and by accumulation of sparking created impurities inside the chamber. The both effects are macroscopically manifested as aging of the GM counter. The diffusion effect of the noble gas is controlled by the sealing of the chamber. The impurities formation is impossible to

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control. Impurities inside the chamber are mainly the spherical shape metallic particles, created when the part of the anode, melted by a spark, is ejected into the interelectrode space forming a spherical shape under the influence of the surface tension [7-9].

The aim of this paper is to determine the influence of the spherical shape conductive particles inside the interelectrode space on the aging process of the GM counter.

## LIFETIME CHARACTERISTIC OF THE GM COUNTER

If *n* samples are tested with a constant voltage, at the level $U_{\mathrm{d}}$, then *n* samples of breakdown time are obtained. Empirical function of the breakdown time distribution is suitably described by the Weibull distribution [10]

$$F(t_{\mathrm{d}}, u_{\mathrm{d1}}) \quad 1 \quad \exp \quad {\frac{t_d}{t_{\mathrm{d63}}(u_{\mathrm{d1}})}}^{\delta_t} \tag{1}$$

Breakdown voltage/breakdown time diagram, the so called "lifetime characteristic" can be drawn using the chosen quantiles of this distribution. The experience shows that diagram forms a straight line on the double logarithmic scale. If the confidence intervals for the given quantiles are known, then they can be transferred on the lifetime characteristic. For each quantile of order *p* of the breakdown time, the lifetime characteristic is described as

$$u_{\mathrm{dp}} \quad {k_{\mathrm{dp}} t_{\mathrm{dp}}}^{1/r} \tag{2}$$

where $k_{\mathrm{dp}}$ is a constant that describes the geometry of the structure, and *r* is an exponent of the lifetime that depends on the tested insulation. Deflection (deviation from a straight line) of the lifetime characteristic indicates that there are some changes in the mechanism of aging (breakdown process).

If, according to the eq. 1, the Weibull distribution is adopted for the breakdown voltage $U_{\mathrm{d}}$ with fixed breakdown time $t_{\mathrm{d1}}$

$$F(u_{\mathrm{d}}, t_{\mathrm{d1}}) \quad 1 \quad \exp \quad {\frac{u_{\mathrm{d}}}{u_{\mathrm{d63}}(t_{\mathrm{d1}})}}^{\delta_u} \tag{3}$$

then, for the same breakdown probabilities, the following is obtained

$$u_{\mathrm{d63}}(t_{\mathrm{d1}})[t_{\mathrm{d1}}]^{\delta_t/\delta_u} \quad u_{d1}[t_{\mathrm{d63}}(u_{\mathrm{d1}})]^{\delta_t/\delta_u} \tag{4a}$$

According to the law of lifetime (2), and assuming that the exponent *r* is applicable to all quantiles, one can write

$$u_{\mathrm{d63}}(t_{\mathrm{d1}})[t_{\mathrm{d1}}]^{1/r} \quad k_{\mathrm{d63}} \tag{4b}$$

Comparison of the coefficients on the left parts of the eqs. (4a) and (4b) yields

$$r \quad \frac{\delta_{\mathrm{u}}}{\delta_{\mathrm{t}}} \tag{5}$$

## LAW OF SIMILARITY

The so called "law of similarity" provides the engineers with the opportunity to check the features of the original system on appropriate model during the system development. This law is of a particular importance in the natural sciences where the required values cannot be, or can hardly be, numerically determined. Similarity in physics assumes the proportionality of two homogenous physical values that are given in two geometrically similar systems, with proportionality coefficient that depends on those two systems. Such similar physical values are called homologous [11-13].

Two gas-insulated electrical systems are similar in the case when the same gas and the same building materials are used, along with the consistency of the mutual geometric relations, including the mean free path length of the elementary particles. If the same voltage is applied to such two similar systems, the ratio of the electrical field intensities at corresponding points 1 and 2 is

$$\frac{E_1}{E_2} \quad \frac{1}{a} \tag{6}$$

Analogous, the ratio of surface charge densities is

$$\frac{\sigma_1}{\sigma_2} \quad \frac{1}{a^2} \tag{7}$$

the ratio of volume charge densities

$$\frac{\eta_1}{\eta_2} \quad \frac{1}{a^3} \tag{8}$$

the ratio of current intensities

$$\frac{i_1}{i_2} \quad 1 \tag{9}$$

the time ratio

$$\frac{t_1}{t_2} \quad a \tag{10}$$

and the ratio of the rates of current change is

$$\frac{\frac{di_1}{dt}}{\frac{di_2}{dt}} \quad \frac{1}{a} \tag{11}$$

where *a* is geometrical similarity parameter.

All these equations are valid assuming neglection of space charges and are derived from the potential fields similarity as a result of geometrical similarity. The research works conducted in this field have pointed out that space charges created as a result of first order elementary processes do not have a major influence on the validity of the above expressions [14, 15].

## EXPERIMENT AND EXPERIMENTAL RESULTS PROCESSING

The experiments were performed using commercially available GM chambers and models. Models of

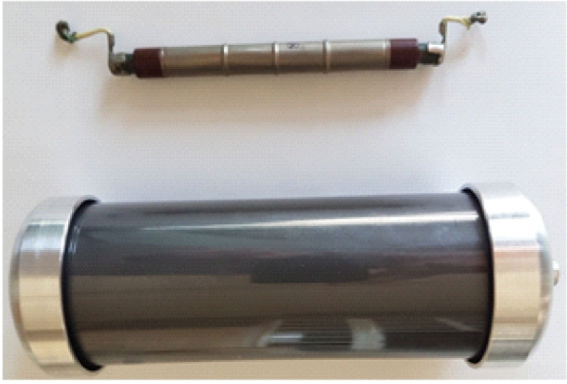

**Figure 1. Photography of the commercial GM chamber (upper) and of a chamber model (lower)**

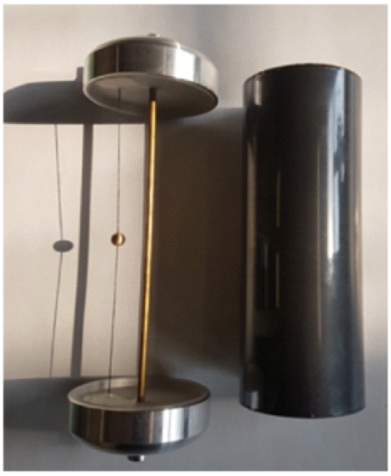

**Figure 2. Photography of the GM chamber model with a conductive particle**

GM chambers were identical to the commercial chambers, and were enlarged 10 times, as shown in fig. 1.

This enlargement made it possible to put magnified conductive particles inside the model. These conductive particles were magnified according to the law of similarity and increase, with respect to the particles whose appearance is expected in the commercial GM chambers. The metal particles, 2 mm in radius, were put on a fireproof thread and placed in a model of the GM chamber, as shown in fig. 2. The thread that carried the conductive particles was strained and parallel to the axial axis of the chamber. At the same time, it was possible to place three threads at the following positions: $r = R/6$, $r = R/2$, $r = 2R/3$. GM chamber model was attached to a gas circle (depicted in fig. 3), thus ensuring a constant working gas pressure during the experiment. The working gas pressure was 10 times lower than the pressure in the commercial chambers, allowing so the usage of the law of similarity. Namely, such pressure value provides 10 times increase in the mean free electrons path, thus fulfilling the geometrical similarity to the commercial GM chamber [16]. Inside the commercial GM chamber and inside chamber model was the same gas mixture of 0.95 He + 0.05 Cl. The pressure of the mixture was 1400 Pa. Percentage composition of the gas mixture was adjusted according to the principle of partial pressures additivity.

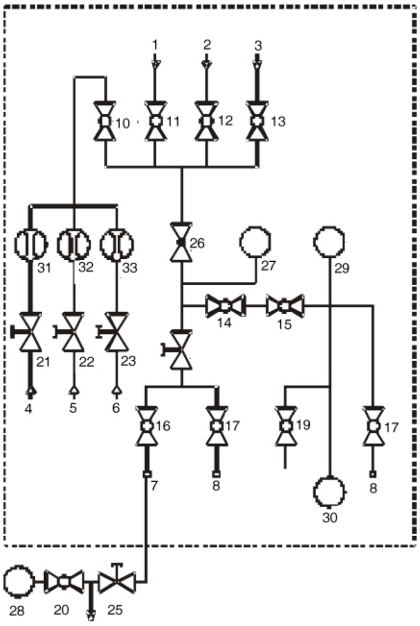

**Figure 3. Gaseous circle**
*(1-9 – gas inflows, 10-20 – dual-position valves, 21-25 – dosing valve, 26 – pressure reducer, 27-29 – vacuum gauge, 30 – vacuum pump, 31-33 – relative pressure gauge)*

Because of the long-term nature of the measurement procedure, the gas pressure in the chamber model was regularly checked every 24 hours (and in case of unstable atmospheric conditions even more frequently). This ensured the constancy of a gas pressure inside the GM chamber model (which is a problem due to small dimensions of noble gas atoms).

During the measurement process, the lifetime curve of the commercial GM chambers was first recorded. After that, the commercial GM chambers, where the aging effect was detected, were isolated (*i. e.* the chambers whose lifetime curves were bended), and the statistical sample of 1000 values of the impulse breakdown voltage was determined. The same statistical sample was determined for the new commercial GM chambers, too. Afterwards, the same statistical sample was determined for the model of the GM chamber with and without metal particles inside. Thereby, the number and the position of metal particles varied during these measurements. Different dispositions of the conductive particles inside a chamber model during the experiment were outlined in fig. 4.

The determination of the distribution functions of the breakdown time and the breakdown voltage was performed using the combined *dc* + pulse constant voltage. Figure 5 outlines the block diagram of the test circuit [17]. Applied *dc* voltage had the ripple less than 3 %. The amplitude of the *dc* voltage was adjusted to be 20 % lower than the *dc* breakdown voltage at the operating point of the GM counter chamber. Impulse voltage, superimposed on *dc* voltage, was the switching voltage with 250/2500 μs shape. Amplitude of the

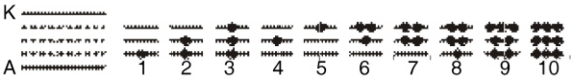

**Figure 4. Dispositions of the conductive particles inside a GM chamber model**

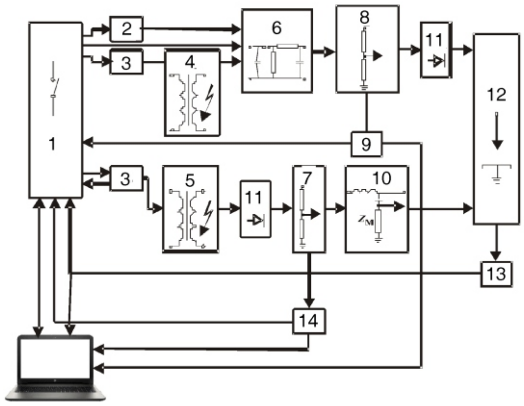

**Figure 5. The measuring system scheme**
*1 – adjustment, 2 – triggering level, 3 – actuator, 4 – dc voltage generator, 5 – test transformer, 6 – impulse generator, 7 – divider; 8 – divider, 9 – measuring unit, 10 – capacitor and measuring impedance, 11 – adapter, 12 – test sample, 13 – breakdown indicator,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

impulse voltage was 10 % of the dc breakdown voltage at the operating point of the GM counter. The number of voltage steps in the experiment of lifetime curve determination was 6, the number of voltage changes per one step was 1000 and the time interval between two consecutive voltage applications was 60 s. Statistical sample recording of the impulse breakdown voltage was performed in the same way as in the case of the lifetime (duration) curve determination. The measurement process was planned and conducted in such a way that it provided the mutual independence of the individual tests, the possibility of repetition and the general usability of the test results. Combined measurement uncertainty of the measurement procedure was less than 5 % [18, 19].

The test results were gathered automatically and statistical samples of the random variables breakdown voltage and breakdown time were formed. Thus, obtained statistical samples were automatically processed using the developed application. The processing of the experimental data was carried out through the following steps: (1) – Application of the modified Chauvenet's criterion in order to reject the suspicious measurement results, (2) – Testing statistical samples of the random variables towards the Weibull distribution affiliation (according to the Kolmogorov criterion and using the graphical method), (3) – Parameters determination of the corresponding Weibull distributions (using moment method), (4) – Drawing the lifetime curves, (5) – Determination of the lifetime exponent using lifetime curve and eq. (4) and the application of the U-test.

The U-test has been used to test the affiliation of the statistical sample of 1000 random variables breakdown voltage obtained on the GM chamber model (with different conductive particles positions) to the same statistical sample of 1000 random variables acquired on the commercial GM chamber after the aging effect has been occurred.

## RESULTS AND DISCUSSION

Figure 6 shows commercial GM chambers lifetime characteristics, where $p^*$ is probability. Figure 7 depicts the U-test diagram for the 1000 impulse breakdowns of the GM chamber for which, according to the lifetime characteristic, the aging process has already occurred. Figure 7 also outlines the same number of impulse breakdowns of GM chamber model with conductive particles disposed as in fig. 3.

Results obtained from the U-test point out that the aging process in the commercial GM counters is mainly caused by the appearance of the conductive particles inside the chamber. These conductive parti-

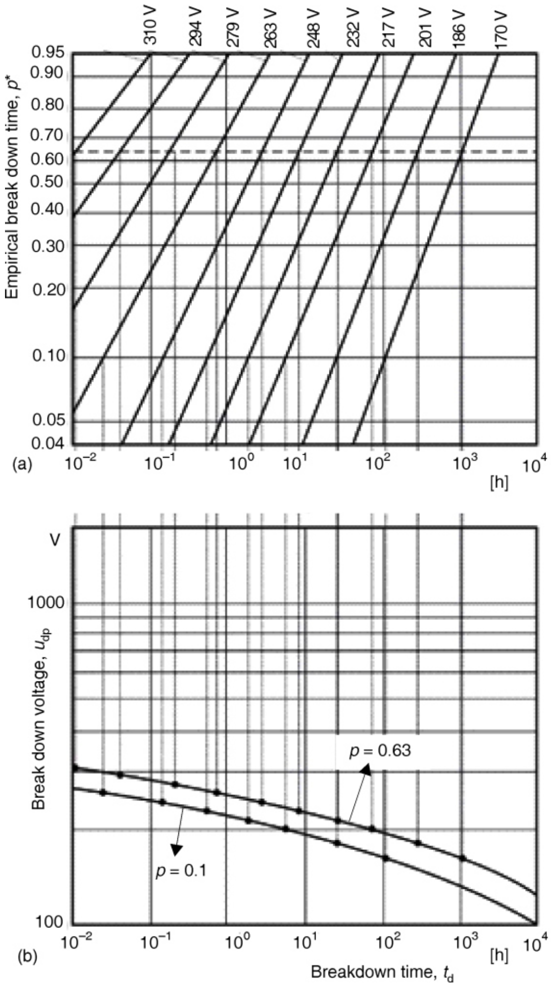

**Figure 6. Determination of lifetime characteristic of the commercial GM chambers, gas He, $p$ = 1400 Pa;**
*(a) distribution function of breakdown time, (b) lifetime characteristic*

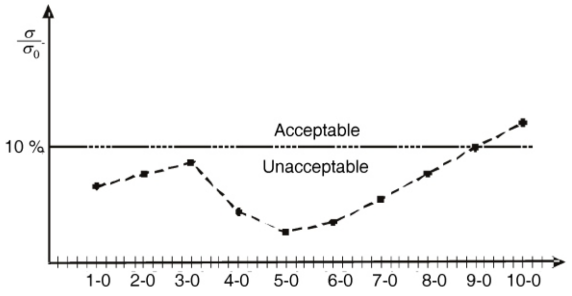

**Figure 7. The results of the U-test**

cles are hovering freely inside the chamber and their impact is greater as they are closer to the anode.

One possible solution for the reduction of this unwanted effect is in manufacturing the GM chamber anode using the materials with higher thermal conductivity and with higher melting temperature. It is also possible to reduce the total dissipated energy inside the chamber by increasing the total resistance of the discharging circuit.

## CONCLUSION

The results of the experiment with the constant voltage undoubtedly point out that there is an aging process of the commercial GM counter chambers. The comparison of the random variable impulse breakdown voltage of the commercial GM chamber, where the aging process has already taken place, with the random variable impulse breakdown voltage of the GM chamber model with conductive particles in the gaseous insulator, indicates that the aging process of the GM chamber is dominantly caused by the appearance of conductive particles as a result of the working process in the chamber. The gas pressure change through time can be neglected as the cause of the aging process. In order to slow down the aging process, the manufacturing of the chamber anode using the materials with higher thermal conductivity and with higher melting temperature can be recommended. For this purpose, an increase of the resistance of the circuit branch, in which the gaseous discharge is taking place, can also be used.

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## AUTHORS' CONTRIBUTIONS

All authors performed theoretical analysis. Experiments were carried out by D. Arbutina. Literature research was carried out and manuscript was written by all authors. The figures were prepared by T. M. Stojić. All authors analyzed and discussed the results.

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# СТАРЕЊЕ ГАЈГЕР-МИЛЕРОВОГ БРОЈАЧА УСЛЕД ПОЈАВЕ ЧЕСТИЧНЕ ПРОВОДНОСТИ У ИЗОЛАЦИОНОМ ГАСУ

У раду се разматра старење комерцијално доступних Гајгер-Милерових бројача у условима експлоатације са теоријског и експерименталног аспекта. У експерименталном делу најпре се снимају криве века трајања за коморе комерцијалних Гајгер-Милерових бројача. Након детекције појаве старења комерцијалне коморе, врши се тестирање њеног одзива на импулсни напон заједно са снимањем истог одзива за модел Гајгер-Милерове коморе. И комерцијална комора и модел коморе са проводним честицама задовољавају закон сличности и за гасна пражњења. Подаци добијени из У-теста показују да старење Гајгер-Милерових комора углавном наступа због појаве већег броја проводних честица које лебде унутар коморе. У закључку су наведене смернице како се може умањити ефекат старења због настанка проводних честица унутар коморе бројача.

*Кључне речи: Гајгер-Милеров бројач, старење, проводна честица*