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THE ELECTRICAL BREAKDOWN TIME DELAY DISTRIBUTIONS IN “GE 155/500” GAS DIODE (STARTER)[*]

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Abstract. The results of the electrical breakdown time delay statistical investigations in the “GE 155/500” gas diode (manufactured in factory General Electric) by the time delay measuring method are presented in this paper. This diode is usually used as a “starter” (with one bimetal electrode) whose function is electrode heating regularization in fluorescent tubes. The experimentally obtained Laue distributions for different voltages (from 240 V to 500 V) and different relaxation times (from 1 ms to 1500 ms), as well as the memory curves for different overvoltages (from 240 V to 500 V), are presented. The results indicate that time delays in the “GE 155/500” diode don’t depend on the number of switches, and that have god characteristic for commercial using.

Key words: breakdown time delay distributions, Laue distributions, statistic breakdown voltages, electrical breakdown, commercial gas diode GE 155/500.

1. INTRODUCTION

Investigation of electrical breakdown in gases is important for describing processes and characteristics of gases as well as their practical applications [1, 2]. The electrical breakdown time delay method, used in this experiment, gives very useful information about electrical breakdown, cathode effects, concentration of ions, electrons and neutral active particles in the afterglow [3, 4], as well as about reliable of commercial gas components [5], which are very significant in practical applications.

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The electrical breakdown of gases is of a stochastic nature as the result of the statistical behaviour of the processes, which lead to it. The statistical theory of the electrical breakdown is described on the base of Townsend breakdown mechanism [6]. Breakdown criterion according to Townsend theory (for small pressure and small overvoltages, when the influence of the space charge is neglected) is:

$$\gamma\left[\exp\left(\int_0^d \alpha \mathrm{d}x\right)-1\right]=1, \tag{1}$$

where α is the primary ionization coefficient and γ the effective secondary ionization coefficient (this coefficient includes all secondary processes).

One of the important electrical breakdown characteristics is the time delay t_D, the time from the moment when the sufficient voltage U_W is applied on the gas diode up to the electrical breakdown. The time delay is also of the statistical nature and consists of a statistical time delay t_S and the discharge formative time t_F, ($t_D = t_S + t_F$) [7]. Statistical time delay t_S represents time from the moment when voltage U_W is applied until the occurrence of the initial electrons causing the breakdown. Statistical time delay is characterized with the exponential distribution [7]. The discharge formative time t_F is the time from occurrence of initial electrons to electrical breakdown. The formative time delay is defined by the process of ionization and carrier multiplication in the gas, leading to the development of a low impedance conducting plasma. The formative time delay is characterized with the Gaussian distribution [8–10].

The electrical breakdown time delay distributions are investigated in many papers. In some papers, the convolution model of time delay distribution are developed [9, 10, 11]. This model the statistical and the formative time delays treated as sum of two independent random variables, with exponential (statistical time delay) and Gaussian (formative time delay) distribution. In contrary, in the reference [12] the authors claim in the case of the small relaxation time, the mutual dependence of the statistical and the formation time delay, as well as, that for different relaxation times, total time delay has Gaussian, Gauss-exponential and exponential log-normal shape.

Beside of that, in great number of papers are shows that formative time delay has not statistical behavior, and can be treated as constant value. In that case formative time delay value represent only shifted parameter in shifted exponential distribution. In these cases time delay distributions can be described with Laue diagrams (Lauegrams), as shown by von Laue [7, 13]

$$\ln\frac{N_i}{N}=-\frac{t_D-t_F}{\overline{t_S}}, \tag{1}$$

where N_i is the number of the time delays t_D greater than the actual time values, N is the total number of measured values (N_i/N represents $1-F(t_D)$, where $F(t_D)$ is time delay distribution function), and t_S is the mean value of the statistical time delay. The distribution (3) is attained from the presumption of constant formative time value. This distribution is the subject of interest in many papers [14, 15].

The aim of this work was to investigate the stationary current reach rate in diode, the breakdown time delay and to notify the regularity of this events, with accidental select diode.

2. EXPERIMENT

For measuring of the electrical breakdown time delay t_D, the *gasmem v1.0* system [16] is used. This system time delay treated as interval, between the moment when the U_W voltage is applied (turned) on the gas tube and the moment when the desirable current I_0 (90% of I_G, i.e. the total current through gas) appears in the gas. This measuring system can controlled relevant experiment parameters during the experiment relaxation time τ, glowing time t_G and current through the gas I_G flows. During the time delay period t_D period, the current in the gas is initially zero and then rapidly increases for a few ns until the gas breakdown occurs and the current reaches the I_G value. During the τ period, there is no voltage ($U_W = 0$), but during the t_G period, there is the U_W voltage on the tube and the I_G current flows through the tube. A diagram of the *gasmem v1.0* system is shown in Fig. 1.

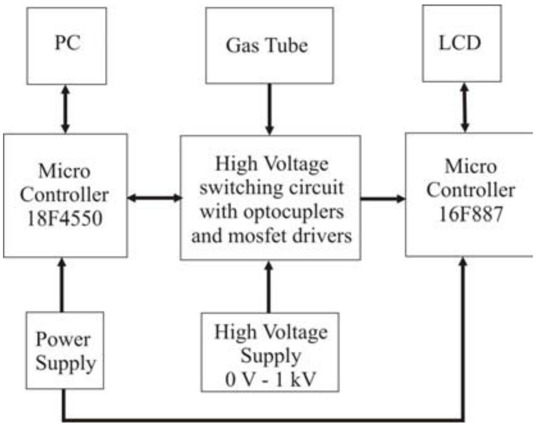

Fig. 1 – The block diagram of the measured system *gasmem v1.0* [14].

The *gasmem v1.0* system is composed of three modules: (1) the control module (CM), (2) the analog switch module (ASM) and (3) the voltmeter module (VM). The CM is based on PIC18F4550 MCU that has internal hardware timers for time interval measurements and integrated USB2.0 module for interfacing with a personal computer (PC). A main function of the CM is to control the ASM that turns the gas tube voltage *on* or *off,* and to measure t_D. The CM is electrically isolated from the ASM by optocouplers. Electrical details of the measuring system *gasmem v1.0* and the experimental procedures are described with more details in references [16].

The maximal rise time of the desired voltage U_W in the *gasmem v1.0* system is 400 ns for U_W = 900 V, and the the hardware limit of the t_D measurement is about 800 ns, which is absolutely sufficient for the main gas discharge conditions. The values ot τ and t_G could be changed in the wide range from 1 to 232 ms and (≈50 days), respectively.

The measurements are done on the commercial gas tube, "GE 155/500" gas tube (manufactured in factory General Electric). This diode is usually used as a "starter" (with bimetal) whose function is electrode heating regularization in fluorescent tubes. The diode volume is 2 cm^3, with wolfram electrodes (one of them is bimetal bearer) and parallel connected condensator capacity 6 nF (used for radio-interference elimination). Comparation of spectroscopic pure argon spectrum and the "GE 155/500" gas diode spectrum, show that the diode is filled with argon, as can seen from Fig. 2. The spectral analyzation was perform with SP1-USB spectrometer (Thorlabs).

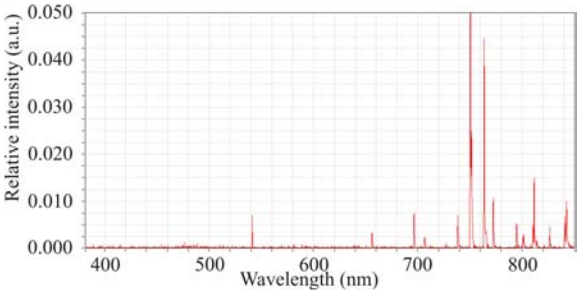

Fig. 2 – Spectar of the comercial "GE 155/500" gas tube.

3. RESULTS AND DISCUSSION

The results of the investigation of the breakdown time delay distribution in starter GE 155/500, for different overvoltages, and relaxation times are given in Figs. 3–7.

3.1. STATIC BREAKDOWN VOLTAGE DETERMINATION

The static breakdown voltage is determined according to the definition where the static breakdown voltage is highest voltage at which breakdown did not take a place [14]. The estimations of the static breakdown are represented in Fig. 3. Each point in this figure represents mean value of 100 consecutive and independent measurements. Thus, the estimated static breakdown voltage values are $U_S = 219$ V as indicated in Fig. 3.

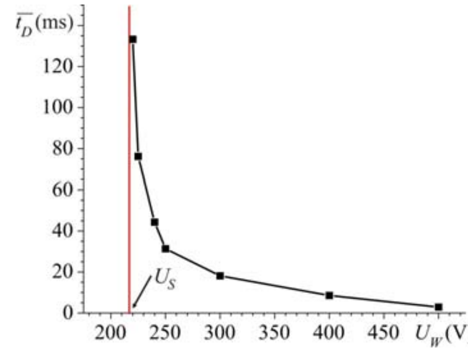

Fig. 3 – Time delay *versus* applied voltage.

3.2. MEMORY CURVES

The memory curves for the “GE 155/500” gas diode are given in Fig. 4. Each point corresponds to the mean value of 100 measurements, for voltages 240 V, 250 V, 300 V, 400 V and 500 V. From this figure it can be seen that memory effect exist up to 1 s for lower voltages, and that decrese with increasing the voltages. For voltage values of 500 V, memory effect exists up to 150 ms.

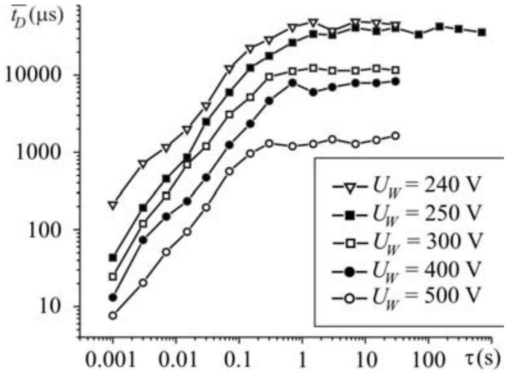

Fig. 4 – Memory curve for indicated overvoltages.

Usually, the memory curves have the expected shapes within three parts [17]: (1) the plateau region (for small values of relaxation time τ); (2) the region with increase of time delay values, with increase of τ, and (3) the saturation region. The shape of the memory curve is a consequence of different mechanisms which predominantly influence the secondary electron emission process from the cathode.

The memory curves presented in Fig. 4 are characterized with absence of plateau (1). This plateau of memory curve is a consequence of the presence of positive ions in the early afterglow (up to approximately $\tau \approx 80$ ms for rare gases) [10, 11]. This shape of memory curves are probably caused by nonstandard geometry of starter (GE 155/500 gas tube), which cause quenching of positive ions from previous discharge.

The increase of t_D values (from $\tau \leq$ 1s for U_W = 240 V, up to $\tau \leq 150$ ms for U_W = 500 V) in Fig. 4 is a consequence of the change in the mechanisms which dominate the process of the secondary electron emission. The emission of secondary electrons from the cathode is mostly induced by neutral active states. However, in literature the character of neutral active states which are the most involved in memory effect in rear gases is doubtful. The neutral active states are $^3P_2$ and $^3P_0$ metastable atoms of Ar (and other rare gases) [10, 11, 17, 18] which de-excite at the cathode surface and release the secondary electrons. On the contrary, in References [19] and [20] the remanent nitrogen atoms states initiate secondary electron emission. They exist in gas diodes after manufacturing. However, this dilemma does not influence the statistical approach applied in this paper, since it detects the secondary electrons without considering the mechanisms of their creation.

The third part of memory curve (from $\tau \geq$ 1s for U_W = 240 V, up to $\tau \geq$ 150 ms for U_W = 500 V) represents the saturation. This saturation is a consequence of the significant decrease of concentrations of the neutral particles. Thus, the number of secondary emitted electrons from the cathode is strongly reduced, and, hence, the breakdown is initiated by cosmic rays. Since the flux of cosmic rays during the experiment varies insignificantly, the breakdown time delay values are approximately constant [17].

3.3. INVESTIGATION OF MEASUREMENT RANDOMNESS

In goal of investigation of statistical analyze of time delay values in commercial gas tube GE 155/500, two set of experimental results are obtained, with variation one of experimental parameter. One set of experimental results are obtained for constant parameters: glow time t_G = 2 s, relaxation time τ = 1.5 s, current through gas diode I_G = 0.2 mA, and for different voltages (U_W = 240 V; 250 V; 300 V; 400 V and 500 V), and second set of experimental results are obtained for constant parameters: glow time t_G = 2 s, current through gas diode I_G = 0.2 mA, voltage U_W = 3 000 V and for different relaxation times (τ = 1 ms, 15 ms, 150 ms, 1500 ms and 15000 ms).

Before we concentrate on the statistical analysis of the experimental results, it is necessary to check their randomness (potential existence of some systematic trend). Because of that, each series of 1000 measurements obtained for the same experimental conditions was divided into 50 groups with 20 successive data. As an example, the groups mean values as the function of the group ordinal number are given in Fig. 5, for the voltages and relaxation times indicated on the same figure. The overall mean values of 1000 measurements are given by solid lines.

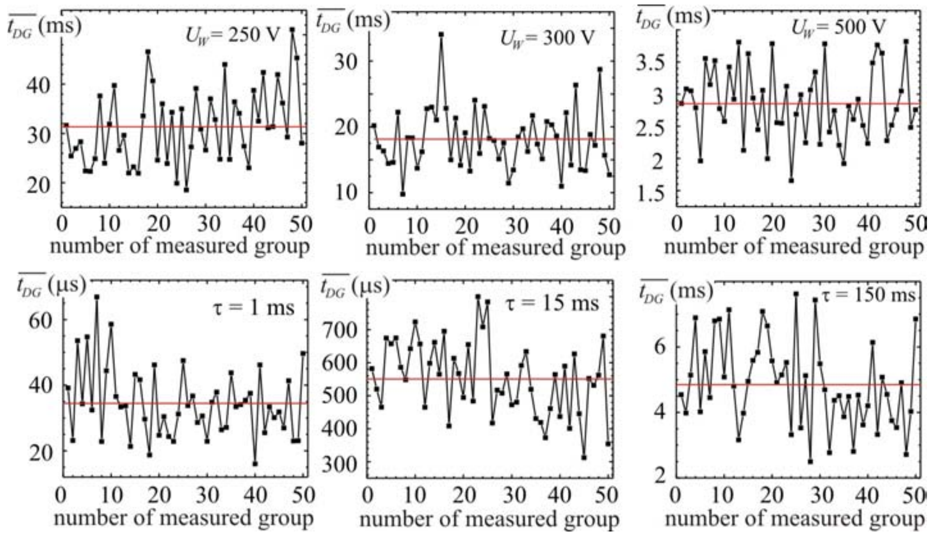

Fig. 5 – The mean values of the groups of 10 measurements $\overline{t_{DG}}$ (dots) as the functions of the group ordinal number; lines represent total mean values, for indicated voltages and relaxation times.

For investigating the randomness of the group mean values $\overline{t_{DG}}$ distribution around the total mean value $\overline{t_D}$ Wilcoxon or Mann-Whitney's test [9, 21–24] was used. As the illustration of this test, some dependencies of the group mean values $\overline{t_{DG}}$ as the function of the group ordinal number are given in Fig. 5, for the voltages and relaxation times indicated on the figure. In this test, every $\overline{t_{DG}}$ value is replaced with the zero or unity: if $\overline{t_{DG}} < \overline{t_D}$ it corresponds to 0, and if $\overline{t_{DG}} > \overline{t_D}$, 1 appears. In that way a series of zeros and unities is obtained. Now, it is possible to define an inversion as the number of unities that precedes each zero in the series. Statistics V represents the total number of inversions, *i.e.* the sum of inversions for all zeroes in the series. Total number of inversions is $0 \leq V \leq n_1 n_2$, where n_1 is the number of zeros and n_2 is the number of unities ($n = n_1 + n_2$). The initial hypothesis is the randomness of 0 and 1 appearance. If the initial hypothesis is valid, and if $n_1 \geq 4$, $n_2 \geq 4$ and $n_1 + n_2 \geq 20$, statistics V has the distribution which is very close to the normal distribution N, with the expected value of the number of inversions $E(V) = (n_1 n_2)/2$ and their variance $D(V) = E(V)(n + 1)/6$ [25]. It is common to normalize statistics V to obtain statistics Z_0

$$Z_0 = \frac{V - E(V)}{\sqrt{D(V)}}, \tag{3}$$

which has the normal distribution $\mathbf{N}(0,1)$. The hypothesis of the randomness is accepted at the confidence level p if $| z_0 | < z_p/2$ is valid. Value z_0 is the realized value of statistics Z_0 and $z_p/2$ is the corresponding value of the normal distribution $N(0,1)$ [21].

Table 1

Values of V, V, $E(V)$, $D(V)$ and z_0 in Wilcoxon's test

$\tau = 1.5$ s				
U_W (V)	V	$E(V)$	$\sqrt{D(V)}$	z_0
240	364	312	51.4976	1.0097
250	229	312	51.4976	-1.6117
300	348	312	54.4976	0.6991
400	341	312	54.4976	0.5631
500	396	312	54.4976	1.6311
U_W = 300 V				
τ (ms)	V	$E(V)$	$\sqrt{D(V)}$	z_0
1	349	312	54.4976	0.6789
15	398	310.5	51.3736	1.7032
150	410	312	54.4976	1.7982
1500	332	312	54.4976	0.3670
15000	303	304.5	50.8748	-0.0294

The realized values z_0 of the statistics Z_0 are given in Table 1. These values are compared with the values $z_{0.95/2} = 1.96$ and $z_{0.99/2} = 2.58$ from the normal distribution, at the confidence levels of 95% and 99%, respectively, showing that the hypothesis of the randomness is valid on the given confidence levels. Thus, it is possible to conclude that the significant systematic trend is not present during the measurements of the breakdown time delay.

3.4. TIME DELAY DISTRIBUTIONS

Statistical analysis of time delay distributions for commercial gas tube GE 155/500 are perform for variation of relaxation time and voltages. Each of distribution is obtain from 1000 measurement. First set of experimentally distributions are obtained for different voltages, U_W = 240 V; 250 V; 300 V; 400 V and 500 V. Other experimental parameter are keep constant (glow time t_G = 2 s, relaxation time τ = 1.5 s, current through gas diode I_G = 0.2 mA). Experimentally obtained Laue distributions, for indicated voltages, are presented in Fig. 6.

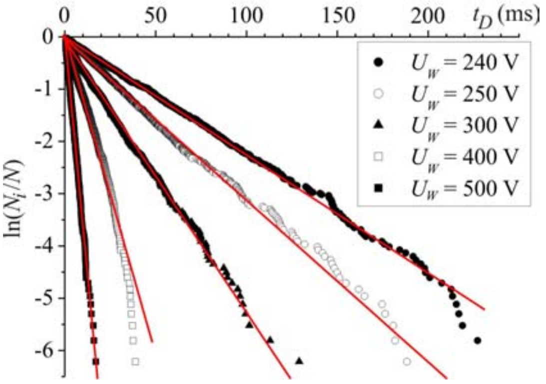

Fig. 6 – Laue diagrams for indicated overvoltages.

The Laue diagrams, which are presented in Fig. 6, are fitted by straight line, with standard equations $y = a + bx$, using least square method, where parameter y presents the values of $\ln(N_i/N)$, and x presents the time delay values t_D. Obtained parameter A and B in linear regression equation are presented in Table 2, where are given and regression coefficient r, for each regression lines [21]. The regression coefficient represents the measure of linearity of experimental results. Values of regression coefficients almost equal one indicated good linear fit. These results indicated the exponential form of the time delay distributions.

Table 2

Values of V, V, $E(V)$, $D(V)$ and z_0 in Wilcoxon's test

U_W (V)	A	B	r
240	-0.00102 ± 0.0029	$-2.2582\cdot10^{-5} \pm 4.68515\cdot10^{-8}$	-0.99786
250	-0.03134 ± 0.00262	$-3.09543\cdot10^{-5} \pm 5.88321\cdot10^{-8}$	-0.9982
300	-0.05692 ± 0.00202	$-5.21625\cdot10^{-5} \pm 7.75525\cdot10^{-8}$	-0.9989
400	0.0442 ± 0.00577	$-1.22237\cdot10^{-4} \pm 4.9389\cdot10^{-7}$	-0.99197
500	0.03875 ± 0.00162	$-3.65148\cdot10^{-4} \pm 4.13958\cdot10^{-7}$	-0.99937

The second set of experimentally distributions are obtained for different relaxation times, τ = 1 ms, 15 ms, 150 ms, 1500 ms and 15000 ms. Other experimental parameter are keep constant (glow time t_G = 2 s, current through gas diode I_G = 0.2 mA, voltage U_W = 3000 V). Experimentally obtained Laue distributions, for indicated relaxation times, are presented in Fig. 7. The Laue diagrams for Fig. 7 are fitted by straight line. The values of parameter A and B, and regression coefficient r in linear regression equation, for best agreement with experimental results are presented in Table 2. All values of regression coefficients are almost equal to one, which indicated good linear fit. These results indicated the exponential form of the time delay distributions.

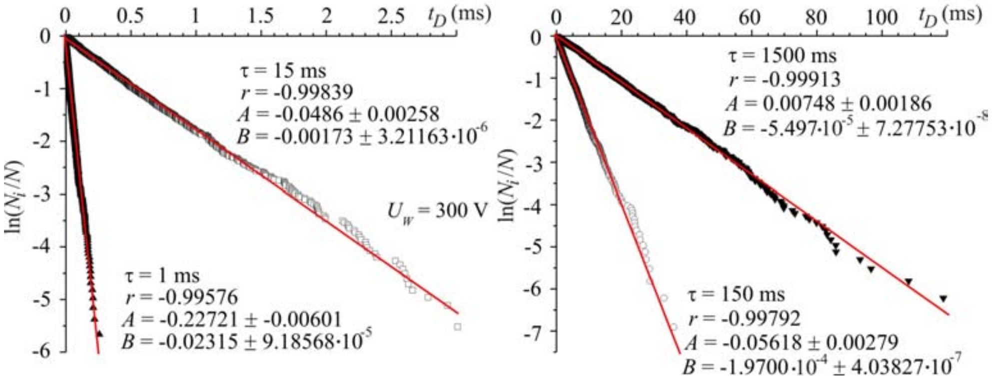

Fig. 7 – Laue diagrams for indicated relaxation time.

All Laue diagrams start from zero values (for all values of voltages and relaxation times), which are caused with negligible values of formative time delay in order to statistical time delay. Beside of that, good agreement straight lines with experimentally obtained Laue diagrams clearly indicated the exponential shape of all time delay distributions.

4. CONCLUSIONS

In this paper, the results of investigations of commercial gas tube GE 155/500 (starter), are presented. For investigations the time delay method is used. The Laue diagrams are obtained on the base of 1000 measurements, for different relaxation times and applied voltages. As the results of analysis of Laue diagrams is concluded that distributions of time delay is the exponential. On the base of these conclusions, it can be assumed that time delays in the GE 155/500 diode don't depend on the number of switches.

Beside of that, the memory curves, for different applied voltages are investigations. The values of the time delay on the plateau of memory curves for great relaxation times values are relatively small (order of 100 ms for smaller values of applied voltages). The gas tube GE 155/50 in commercial using as starter, in AC voltage circuit (U_{EFF} = 220 V, 50 Hz), where voltage approximately 15 time exchange polarity. With every voltage cycle, the ionization in diode increase, and the condition for the breakdown become better and better. When the GE 155/5 tube had to start again (for little values of τ) time delay is very short (order of few ms).

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