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BREAKDOWN ENERGY OF GASES AND THE SURFACE LAW

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Abstract. Energy of electrical breakdown of gases (breakdown energy) is a stochastic variable and its distribution is determined by the statistics of the breakdown time delay and the breakdown voltage. The surface law stating that voltage pulses applied to the gas diode cover a constant area in the voltage-time coordinates (*U-t* plane) can be derived as a linear approximation of the breakdown energy for the linear temporal current growth and it is not valid for electrical breakdowns by linearly rising (ramp) pulses.

1. INTRODUCTION

The energy imported into a discharge can be calculated by an integration of synchronized oscilograms of current and voltage (Podgorni 1968). Accordingly, the energy of electrical breakdown of gases (breakdown energy) transferred to the gas during its transition from un-conducting to conducting state, can be calculated by integration of synchronized oscilloscopic waveforms of current and voltage:

$$E = \int_0^{t_d} i(t)U(t)\,dt \,, \tag{1}$$

where $i(t)$ is the current, $U(t)$ the voltage and t_d is the breakdown time delay (Morgan 1978). The breakdown energy is a stochastic variable and its distribution is determined by the statistics of the breakdown time delay and the dynamic breakdown voltages when the linearly rising (ramp) pulses are applied to the discharge tube. Therefore, great number of measurements is necessary to obtain the mean value of breakdown energy as well as its corresponding distribution under given experimental conditions. Some experiments for the measurements of gas breakdown statistics and their applications to study relaxation processes in gases are described in Marković et al. (2005, 2006).

The validity of the surface law stating that voltage pulses applied to the gas diode cover a constant area in the voltage-time coordinates ($U-t$ plane) is studied by Maluckov and Radović (2002). It was claimed that the surface law is valid, which for the mean values of dynamic breakdown voltages $\overline{U_b}$ reads $S = (\overline{U_b} - U_s)^2 / 2k = const$, where U_s is the static breakdown voltage and k is the rate of voltage rise. However, a more careful and better founded analysis of data from Maluckov and Radović (2002), as well as similar data for nitrogen and argon shoved that the surface law is not valid (Marković et al. 2005). In this paper the surface law is derived as a linear approximation of the breakdown energy and some characteristic items related to electrical breakdowns by linearly rising (ramp) pulses in argon are discussed.

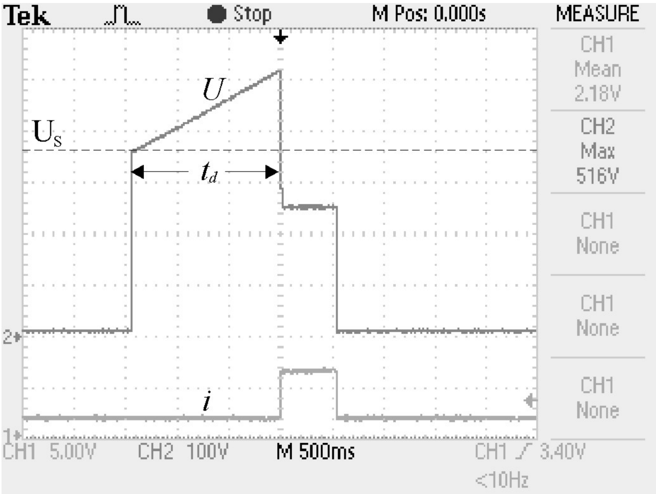

Figure 1: The oscilloscopic waveforms: CH2 - the ramp voltage, CH1 - the discharge current, measured by TDS 2000 digital oscilloscope.

2. THE EXPERIMENTAL DETAILS

The measurements of dynamic breakdown voltages U_b have been performed for a gas tube made of borosilicate glass (8245, Schott technical glass) with volume of $V \approx 300cm^3$ and gold-plated copper cathode (copper rods of 99.98% purity and diameter $D = 6\,mm$ and gap $d = 4.5\,mm$). The tube was evacuated down to $10^{-7}\,mbar$, baked at $600\,K$ and filled with argon with an oxygen impurity level below $1\,ppm$ (Matheson Co.) at the pressure of $1.33\,mbar$. The static breakdown voltage was $U_s = 370\,V$ DC. The measurements consisted of 200 single shots in series by using the computer guided electronic automatic system (Marković et al, 2005, 2006). The measurements were carried out at glow current $I_g = 0.1\,mA$, glow time $t_g = 5\,s$ and the relaxation (afterglow) time $\tau = 7\,s$. More details about experimental procedure can be found in Marković et al. (2005, 2006).

3. RESULTS AND DISCUSSION

The breakdown energy for linearly rising (ramp) pulses can be expressed by relation:

$$E = \int_0^{t_d} i(t)\; k\,t\,dt\,, \tag{2}$$

where $U(t) = kt$ is the ramp pulse voltage starting at the static breakdown voltage U_s (Marković et al. 2005, 2006). Taking into account that the temporal current growth is exponential $i = i_0 \exp(\lambda t)$, where i_0 is its initial current and λ is the rate of current growth, after integration it is obtained:

$$E = \int_0^{t_d} i_0 \exp(\lambda t) k\,t\,dt = \frac{i_0 k}{\lambda}[(t_d - \frac{1}{\lambda})\exp(\lambda t_d) + \frac{1}{\lambda}]. \tag{3}$$

By using linear approximation for the temporal current growth $i_0 \exp(\lambda t_d) \approx i_0(1 + \lambda t_d)$, the approximate value of the breakdown energy is obtained:

$$E_0 = i_0 k t_d^{\;2}\,, \tag{4}$$

or after averaging over the series:

$$\overline{E_0} = i_0 k \overline{t_d^{\;2}}\,. \tag{5}$$

In order to compare with the surface law, the above equation is more convenient if expressed by the dynamic breakdown voltage $\overline{U_b} = U_s + k\overline{t_d}$:

$$\overline{E_0} = i_0 (\overline{U_b} - U_s)^2 / k\,, \tag{6}$$

that is different from the surface $S = (\overline{U}_b - U_s)^2 / 2k = const.$ by a factor of $2\,i_0$.

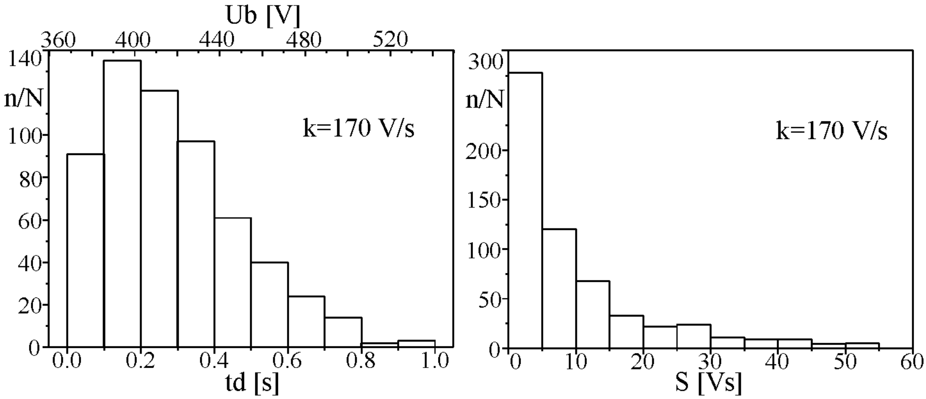

Figure 2: The distributions of the breakdown time delay t_d, the dynamic breakdown voltage U_b and the surface S.

As it has already been said, the breakdown energy and the surface are stochastic variables and their distributions are determined by the statistics of the breakdown delay times and the dynamic breakdown voltages. It is demonstrated in Fig. 2, where the distributions of the breakdown time delay t_d, the dynamic breakdown voltage U_b and the surface S are presented.

In Fig. 3, the surface S is presented as a function of the rate of voltage rise k ranging from $62-800Vs^{-1}$, as well as a function of the dynamic breakdown voltages. Thus, the surface S is not constant, but have a minimum at about $170Vs^{-1}$ and about $\overline{U_b} \approx 418V$, respectively (Fig. 3). Further considerations are in due coarse (Marković et al. 2010).

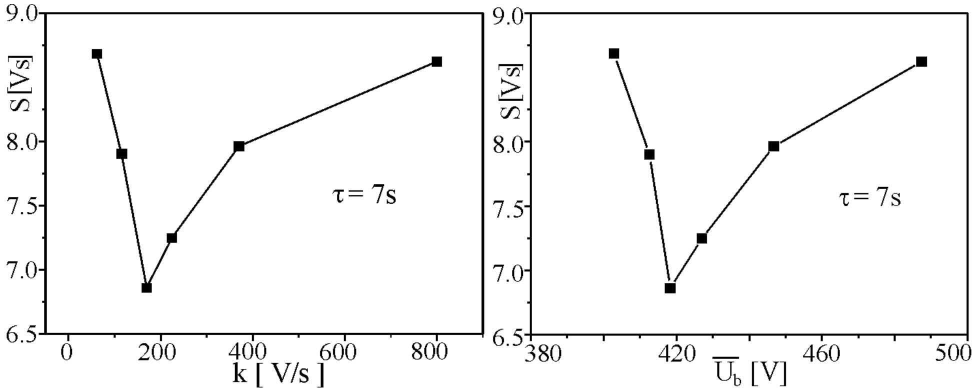

Figure 3: The surface S as a function of the rate of voltage rise k and the dynamic breakdown voltage $\overline{U_b}$.

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