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The energy of the surface discharge in the electrode system of parallel stripes

© A.V. Lazukin, A.M. Nikitin, G.A. Romanov

National Research University Moscow Power Engineering Institute, Moscow, Russia
E-mail: lazukin_av@mail.ru

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The results of an experimental study of the dependence of the energy of a surface barrier discharge on the value of the supply sinusoidal voltage with a frequency of 4 and 20 kHz in the electrode system of parallel stripes with a distance between them of 5 and 30 mm are presented. At a distance of 5 mm between the strips, there is a self-limited surface discharge in the electrode system. Self-limiting of the discharge leads to the fact that with an increase in the applied voltage, the energy invested in the electrode system increases more slowly than in the case when the discharge exists without restrictions. The energy of a self-limited discharge is 15−40% lower than the energy of a discharge that exists without restriction.

Keywords: surface discharge, energy, volt-coulomb characteristic, self-limited discharge.

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Surface discharge is a type of atmospheric pressure gas discharge that develops near the surface of a dielectric near an electrode of a small curvature radius. A dielectric separates the small-curvature electrode from the second electrode of the system and an alternating voltage is fed to them. Surface discharge is currently used to build a number of low-temperature plasma electrical technologies, the electrode systems and power sources being quite simple and reliable, free of any vacuum part and needing no inert gases for their operation. The most complete list of technological solutions using surface discharge and other barrier discharges can be found in overview [1] and introductory parts of studies [2,3].

To cope with a technological task (e.g., when treating the surface of polymer or wood, seed layer, etc.) one needs to scale the electrode system of surface discharge. In that case, a system of parallel strip electrodes or grid electrodes is used (a comparison of such systems for a number of parameters is made in [2]). Neighboring strip electrodes or cell boundaries (in the case of a grid) are under the same potential. When this potential exceeds some initial value, a group of microdischarges starts from the electrode edges (as illustrated by high-speed photography, see study [3] for example). However, if the neighboring electrodes are close enough, the counter groups of microdischarges prevent each other from developing, and the surface discharge becomes self-limited. The distance of „self-limitation" is determined by the electrode configuration and supply voltage parameters [4]. The developing self-limitation should be reflected in the discharge energy.

The purpose of the present study is to retrieve the dependence of surface discharge energy on voltage and frequency in electrode systems of self-limited discharge.

The surface discharge energy invested in the electrode system over a single period of supply voltage was measured using the volt-coulomb characteristics (VCC) technique. The measurement scheme and the electrode system are shown in Fig. 1, *a*. A view of VCC at 4 kHz and 30 mm spacing between the stripes is shown in Fig. 1, *b*.

The electrode system is built on a dielectric barrier of VK-96 corundum ceramic of $\Delta = 1$ mm thickness in the shape of two parallel stripes of aluminum foil (20 μm thick). Two systems with a strip spacing of 5 and 30 mm were produced. The opposite side of the dielectric barrier is occupied by a grounded return electrode, in which a 10 mm wide measuring section is located. The measuring section is grounded via a $C1$ capacitor. Parallel to the arm formed by the geometric capacitance of the electrode system and capacitance $C1$, a „compensating" arm, consisting of a vacuum capacitor of variable capacitance C_v and capacitance $C2$ is connected (capacitances $C1$ and $C2$ are nominally equal: 4 nF). A DP high voltage differential probe (DP-150, Pintek) is connected to the middle points of the formed bridge. This way only the energy of discharge existing over the measuring section is measured, without the contribution of the energy introduced into the geometric capacitance of the electrode system. Voltage is controlled by a P6015A high voltage mixed divider (Tektronix). A sinusoidal voltage of 4 or 20 kHz is fed from a high voltage source HV. The source is designed as a half-bridge transistor inverter with its output stage built on a high-voltage transformer and choke. The inductance of the output stage is selected so as to provide conditions close to the resonant discharge of the circuit to its load.

Fig. 2 shows the results of measuring energy at 4 and 20 kHz while voltage is increased from 1.5 to 4 kV (effective value). The initial voltage was 1.4 kV. The

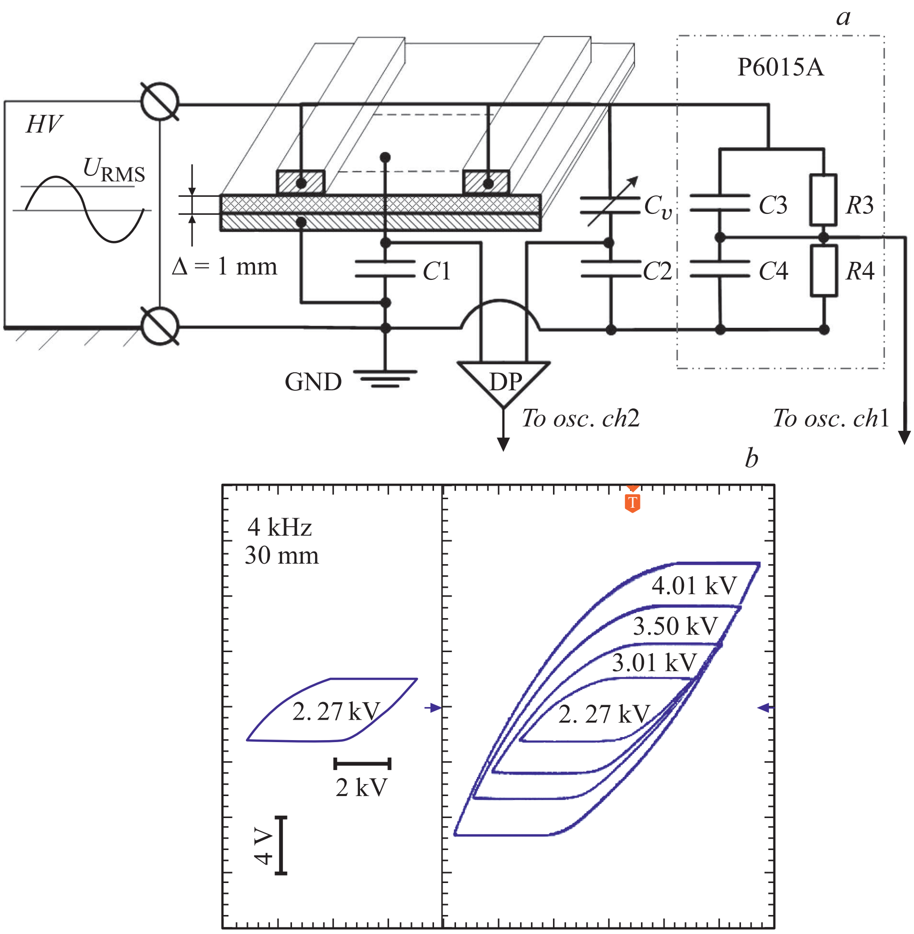

Figure 1. *a* is the electrode configuration and measurement scheme; *b* is the view of VCC at 4 kHz for different effective voltages.

energy grows with increasing voltage applied following the power dependence characteristic of atmospheric pressure discharges, which agrees with the published data [2,5]. The discharge energy depends on the frequency of the voltage fed too, which contradicts the data given in [2]. According to data from study [2], where a system was used with 3 mm spacing between 35 μm thick copper foil stripes, when fed 4.7 kHz and 10 kHz sinusoidal voltage, such a system remained almost independent of frequency in the energy invested into its discharge across the supply voltage period. Probably, when the distance between parallel stripes is 3 mm, combustion zones of counter discharges merge at practically the ignition voltage.

Discharge zone lengths in such systems are given in [4], the circumstances of self-limitation of surface discharge estimated from high-speed photographs. In a system of parallel stripes spaced 5 mm from each other, counter microdischarges start to affect each other at a voltage of 2.5 kV. Frequency of the supply voltage affects the self-limitation mode as well. At 20 kHz discharge zones merge at 2.5 kV. At 4 kHz a complete closure of discharge zones is observed around 3 kV. That feature should be reflected in frequency dependence of the discharge energies ratio.

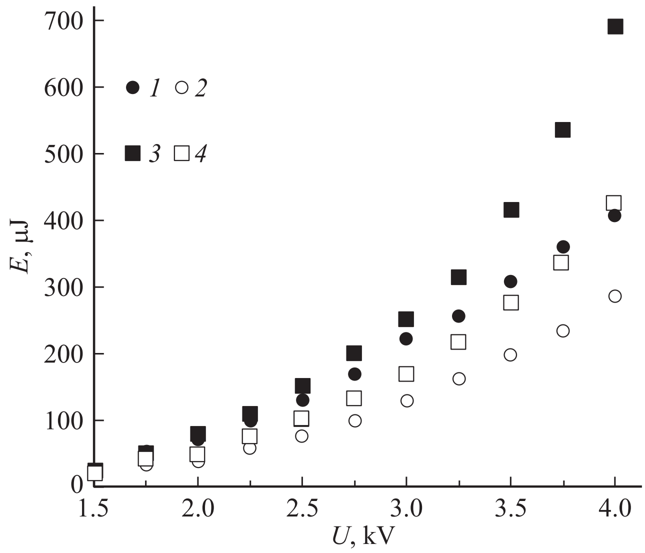

Figure 2. Surface discharge energy as a function of voltage. Dark characters refer to 20 kHz, light characters refer to 4 kHz. *1, 2* are for 5 mm spacing between the stripes; *3, 4* are for 30 mm spacing between the stripes.

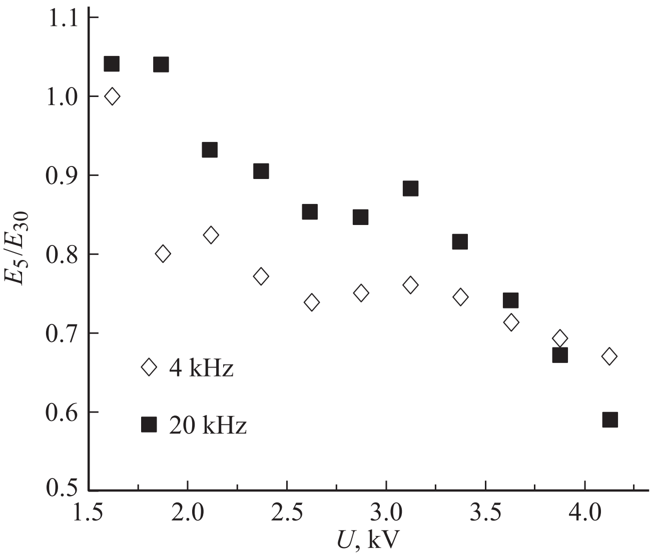

Figure 3. Discharge energy at strip spacing 5 mm (E_5) ratio to that at strip spacing 30 mm (E_{30}), for 4 and 20 kHz.

The 5 and 30 mm strip spacing ratio of discharge energies as a function of voltage is shown in Fig. 3. When switching to the electrode system of surface discharge of 5 mm spaced parallel electrodes, the discharge energy appears lower than that for 30 mm spaced electrodes. As the voltage increases, the energy ratio decreases by 15−40%. The character of the decrease depends on the frequency. At 20 kHz the energy ratio drops to 0.8−0.9 and stays in that range as the voltage rises from 2 to 3 kV. With further increase in voltage from 3 to 4 kV, the energy ratio decreases linearly to 0.6. At 4 kHz, except for the initial stage when the energy ratio decreases from 1 to 0.8 as the voltage increases from 1.5 to 1.75 kV, the energy ratio decreases almost linearly from 0.8 to 0.67 following the increase in the applied voltage.

The obtained dependencies may entail the following conclusions. The energy invested in self-limited discharge systems does not go to saturation as a function of voltage; however it does not grow as fast as the energy of a free-developing discharge. It is likely that the number of individual microdischarges along the edge increases, but the charge carried in the individual pulse does not. At 4 kHz such reorganization of the discharge structures goes better than at 20 kHz. Consequently, low frequencies of supply voltage are preferable for self-limited discharge systems.

From the point of view of technological application of surface discharge, not only the discharge energy is important, but also other electrophysical characteristics, such as the intensity of volumetric charge formation or the UV flux density. A detailed study of the relationship between the energy of self-limited surface discharge and key technological characteristics of the electrode systems is seen as the future thrust.

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Conflict of interest

The authors declare that they have no conflict of interest.

References

[1] R. Brandenburg, Plasma Sources Sci. Technol., **26**, 053001 (2017). DOI: 10.1088/1361-6595/aa6426
[2] S. Pekárek, J. Mikeš, Eur. Phys. J. D, **74**, 59 (2020). DOI: 10.1140/epjd/e2020-100332-3
[3] I. Selivonin, I. Moralev, Plasma Sources Sci. Technol., **30** (3), 035005 (2021). DOI: 10.1088/1361-6595/abe0a1
[4] A.V. Lazukin, I.V. Selivonin, M.E. Pinchuk, I.A. Moralev, S.A. Krivov, Izv. VUZov. Physics, **61** (9-2), 152 (2018). https://elibrary.ru/item.asp?id=36614175
[5] J. Kriegseis, B. Möller, S. Grundmann, C. Tropea, J. Electrostat., **69**, 302 (2011). DOI: 10.1016/j.elstat.2011.04.007