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ELECTRONICS AND RADIO ENGINEERING

Influence of an External Magnetic Field on the Switching Mode of a Compact Triggered Vacuum Gap

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Abstract—The possibility of excluding the binding of discharge cathode spots in a small-size pulse vacuum gap by placing the latter in a magnetic field is shown. The probable physical mechanism of this phenomenon is presented.

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The idea of using a controllable breakdown of a vacuum gap (VG) for creating a high-voltage small-size pulse VG, as well as the first design variant and the scheme for connecting this device to the switched circuit were proposed in [1]. At present, controllable small-size VGs are used in logging equipment, high-speed photography, devices for illumination of fast processes with optical and X-ray radiation pulses, and in other fields, in which the decisive requirements are the absence of filament circuits, small dimensions, a wide range of switched currents, and the resistance to external effects.

The authors of this study investigated the possibility of influencing the regime of a discharge, which occurs in a compact VG, by applying a magnetic field produced in the volume of the device by external sources in order to extend the service life and increase the VG operation stability. In the performed studies, a triggered VG was used, which represented a three-electrode coaxial system (the cathode, anode, and igniter electrode) that was placed inside a hermetically evacuated sealed-off shell manufactured of a dielectric material (Fig. 1).

The cathode, the igniter electrode, and a 0.1-mm-thick dielectric (mica) washer, which is tightly compressed between them, form the ignition system. The dielectric that fills the gap between the cathode and the igniter electrode serves for reducing and stabilizing the voltage of the igniting breakdown, which initiates a breakdown between the cathode and anode. The latter leads to operation of the VG as the switching element of the external electric circuit. The cathode–anode gap value is 1 mm. The aluminum-cathode diameter is 5 mm.

The cathode is grounded, and the anode before the switching process has a positive potential of 2–3 kV. In this case, the self-breakdown voltage is at least 10 kV. The VG operates at a frequency of ~1 Hz (this actually means that the VG operates in the single-pulse mode), when a positive (relative to the cathode) voltage pulse with an amplitude of 3.5 kV and a rise rate of (1–2) × 10^{10} V/s is fed to the igniter electrode. The spread of the delay time of the cathode–anode gap breakdown relative to the moment of application of a control voltage pulse to the igniter electrode does not exceed 50 ns.

The current that is switched in the cathode–anode gap has a duration of 3 × 10^{-5} s and an amplitude of 200–300 A. The current-pulse parameters are determined by a forming line with respect to which the VG serves as the electric-circuit-closing switch. The circuit of the triggered VG is shown in Fig. 1. Figure 2 shows oscillograms of a control voltage pulse at the igniter electrode and the discharge current in the cathode–anode gap.

When a voltage pulse is fed to the igniter electrode and the voltage increases, the electric-field strength near the cathode edge, which is adjacent to the dielectric washer, reaches values at which field-electron-emission currents arise. The values of these currents are sufficient for evaporation of micropoints from the

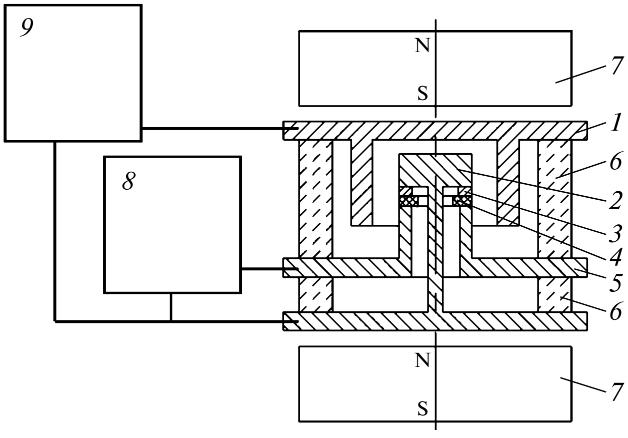

Fig. 1. Schematic diagram of the triggered VG: (*1*) anode, (*2*) cathode, (*3*) sealing metal gasket, (*4*) dielectric washer, (*5*) igniter electrode, (*6*) hermetic dielectric shell, (*7*) permanent magnets, (*8*) unit of control voltage pulses, and (*9*) forming line in the discharge-current circuit.

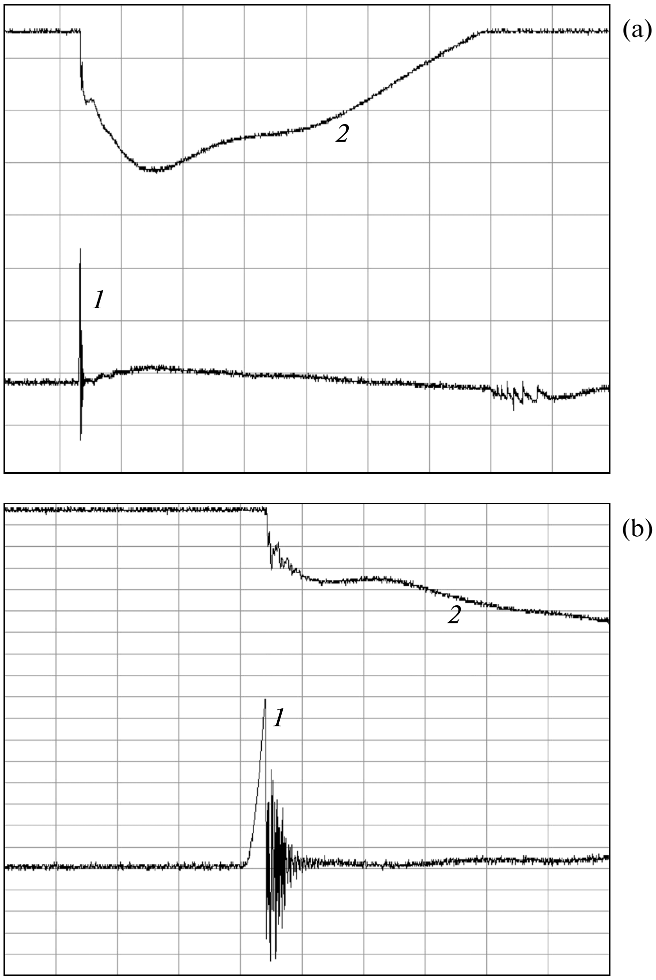

Fig. 2. Oscillograms of a control voltage pulse (*1*) at the igniter electrode and (*2*) a discharge current in the cathode–anode gap for different time sweeps: (a) 5 and (b) 0.5 μs/division.

cathode surface and ionization of forming vapors of the cathode substance and gas molecules that were sorbed on the cathode and dielectric-washer surfaces. A cathode spot and a plasma cloud are formed. The latter expands into the ambient space both under the action of a voltage applied to the cathode–anode gap and owing to the high electron mobility and propagates towards the anode. A cathode flame is formed, which closes the cathode–anode gap, and the spark-discharge stages transforms into the arc stage [2].

A disadvantage of the above-described switching device is the asymmetry (over the system perimeter) of the action of the discharge, which is burning in the device, on the surfaces of the electrodes and dielectric washer or so-called binding of the discharge cathode spots, which leads to an inhomogeneous erosion of the electrode (primarily, their edges adjacent to the dielectric washer) and dielectric-washer surfaces. This phenomenon also causes an intensified transfer of the conducting electrode substance to the dielectric-washer surface on a localized segment of its perimeter. All these processes as a whole lead to disturbances in the stable VG operation. It should be noted that careful preliminary cleaning of the electrode surfaces and centering of the electrodes with respect to the VG symmetry axis do not allow one to eliminate the discharge binding.

In order to control the conditions of an occurring discharge and increase the symmetry of its action on the electrodes and dielectric washer, two cylindrical permanent magnets were coaxially placed from the outside of the hermetic housing of the VG. The magnet dimensions were 12 (diameter) × 15 mm, and their opposite poles faced each other (Fig. 1). The magnets created a magnetic field with an induction of ~0.1 T in the VG volume. The force lines of this field were parallel to the VG axis of symmetry.

Tests were performed for two identical VGs: two series of switching events with 1000 operations in each in the absence and presence of a magnetic field. The tested VGs were visually examined using an МБС-9 microscope at a magnification of $14^{\times}$–$100^{\times}$. The following results were obtained (Fig. 3).

In the absence of a magnetic field, an area of 25–33% of the cathode lateral surface was subjected to appreciable erosion. The same refers to the dielectric washer. The localizations of the areas where the most intense erosions of the cathode and dielectric washer are observed spatially coincide. A transfer of the cathode substance is observed in the direction of the dielectric washer and partially to its surface. No erosion is observed on the end surface of the cathode.

When a magnetic field was present, the erosion was observed over the entire lateral surface of the cathode and was visually uniform. The erosion of the dielectric washer was uniform over the perimeter. In this case, no erosion of the flat end surface of the cathode was observed as well, but an erosion (mainly in the form of individual craters, which were traces of cathode spots that appeared at the stage of an arc discharge) was observed at the boundary between the lateral cylindrical and flat end surfaces of the cathode, i.e., where the electrode surface noticeably protrudes to the region of the electric field and the electric-field strength near the cathode surface has an increased value. The anode erosion that was observed in our experiments was insignificant (Fig. 4).

Thus, placing a small-size triggered VG in a magnetic field with the technologically easily realized strength and configuration provided conditions for improving the symmetry of the vacuum-discharge action on the electrodes and dielectric washer of the VG ignition system. This resulted in a lower and more uniform erosion of these elements and in turn increased the service life and stability of the VG operation stability.

Let us consider the possible mechanism of the magnetic-field influence on the conditions under which a discharge occurs. According to the data from

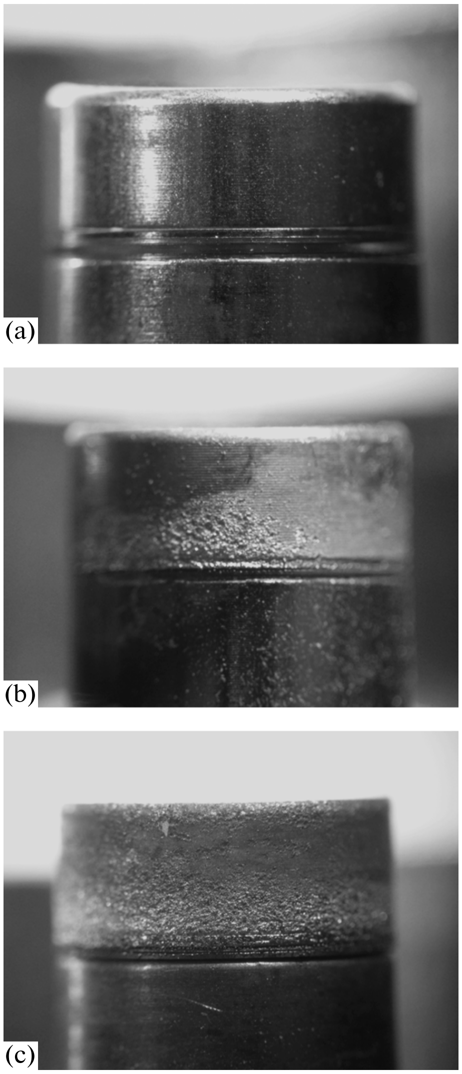

Fig. 3. Photographs of the cathodes: (a) before tests, (b) after tests in the absence of a magnetic field, and (c) after tests in the presence of a magnetic field.

[3], the cathode-flame propagation velocity in the cathode–anode gap under our experimental conditions (a small gap and the presence of a transverse magnetic field) can be ~10^4 m/s. Hence, the expected closure time for the cathode–anode gap will be ~10^{-7} s.

Under the action of a magnetic field, the cathode spot at the spark-discharge stage will move in the direction of the action of an Ampere force at a velocity of ~10^4 m/s [3]. Within a time of ~10^{-7} s, the displacement will be ~1 mm. Upon a change to the arc-discharge stage, the cathode-spot displacement velocity will decrease by two orders of magnitude (in this case, the cathode-spot movement direction in the magnetic field will be reversed). However, the duration of the arc stage (~3×10^{-5} s) is such that the displacement value will be about several millimeters. This is comparable to the linear dimensions of the cathode.

Fig. 4. Photograph of the inner cylindrical surface of the anode that was exposed to a discharge.

In addition, because the duration of the cycle of the explosive-electron-emission centers (10^{-8} s) [3] is much shorter than the spark-discharge development time in the cathode–anode gap, under the action of, e.g., radiation emitted by cathode-flame plasma and bombarding the cathode surface, new cathode spots may be formed under the conditions of a high voltage maintained across the cathode–anode gap. This probably accounts for the presence of an erosion at the boundary between the lateral cylindrical and flat end surfaces of the cathode, where the electric-field strength has an increased value.

It can be stated in conclusion that the use of a magnetic field, which is produced in the working volume of a small-size vacuum pulse gap using simple engineering means, showed its efficiency as a tool for controlling the discharge-process conditions. In a homogeneous magnetic field, we managed to eliminate the binding effect of the discharge cathode spots, i.e., the localization of the region of the switched-current flow under multiple repetitions of the working VG cycle. As a result, the degree of the discharge effect on the elements of the VG ignition system per unit surface was reduced, thus providing the conditions for increasing the VG service life and operation stability.

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