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Decrease of the air breakdown threshold by the subcritical streamer discharge when the initiator is placed near the metal screen

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The influence of the screen size on the air breakdown by an induced subcritical streamer discharge is discussed based on the data of physical and computational experiments. A cylindrical metal vibrator mounted at a certain distance from the screen is used to initiate a streamer discharge. The initiator length is comparable with the half wavelength of electromagnetic field. Data on the effect of the distance from the emitting aperture to the screen and its width on the breakdown pressure are given. The dependence of the field amplification factor at the poles of a linear vibrator on the size of the reflector screen is obtained.

Keywords: breakdown, streamer discharge, microwave discharge, plasma-assisted combustion.

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One of the advantages of the subcritical microwave discharge initiators mounted in parallel to the flow near a metal screen–reflector is that they enable generation of discharges in very weak microwave fields with intensities below 100 V/cm. The best–studied type of the microwave discharge initiator is the linear electromagnetic initiator. Among its advantages there are a simple design, known dependences of the field at the ends on various factors, and also the possibility of providing the breakdown of medium at high values of the indicator of the initial field subcriticality.

The adjoint deeply subcritical streamer discharge is efficiently heatable with the microwaveradiation [1]. Under the resonance conditions, a large induced current emerges in the conductor, while near the initiator gas ionization takes place, and plasma channels heating the surrounding gas are formed [2]. Generally, the smaller is the end radius and shorter is the resonator–to–screen distance, the higher is the field amplification factor [3]. In the case of a dielectric screen, the resonator is placed directly on its surface. In this case, the maximum field intensity is observed in the space limited by the screen surface and rounded end of the resonator [3].

The performed studies showed that, if the electromagnetic vibrator is mounted at a small distance from the metal screen, it becomes possible to realize the air breakdown at the radiation power considerably lower than that necessary to realize the breakdown in an unlimited space [4] (deeply subcritical streamer discharge).

If the initiator length is comparable with the electromagnetic field half wavelength, the initiator gets resonance properties. The initiator placed in the radiation field with the linear polarization parallel to the electric field has maxima of the induced field at both ends. For instance, the air breakdown occurs at the atmospheric pressure when the discharge initiator is above the metal screen by $h = \lambda/4$ (where λ is the microwave radiation wavelength). The field amplification factor increases with respect to that in case the initiator is located in the free space, if the initiator approaches the screen to $h \ll \lambda/4$. Concurrently, the initiator resonance length increases.

To make possible application of the subcritical discharge in practice (e.g., for the fuel mixture ignition in advanced engines), it is necessary to determine the minimal screen area at which the medium breakdown occurs. The theory and methods for calculating various–design initiators are presented in [5]. The influence of conductivity, geometric size and shape of the initiator and their group on the local characteristics of the induced electromagnetic fields is considered in [6]. Paper [7] proposed an energetically efficient method for controlling the boundary layer by creating on the model surface a regular system of localized microwave discharges formed in the field of a quasi–optical electromagnetic beam from a remote microwave energy source.

The goal of this study was to experimentally confirm the effect of reduction of the air breakdown threshold in using the subcritical streamer discharge when the discharge initiator is located at a short distance from the metal screen.

The experimental investigation was performed by using a bench designed and developed at MRTI RAS. The measurements were carried out at a setup with the microwave radiation wavelength $\lambda = 12.3$ cm. To initiate the deeply subcritical discharge in the quasi–optical microwave beam, an electromagnetic vibrator located near the screen (at $h \ll \lambda/4$) was used. The details of the experimental setup, as well as the experience in creating microwave discharges

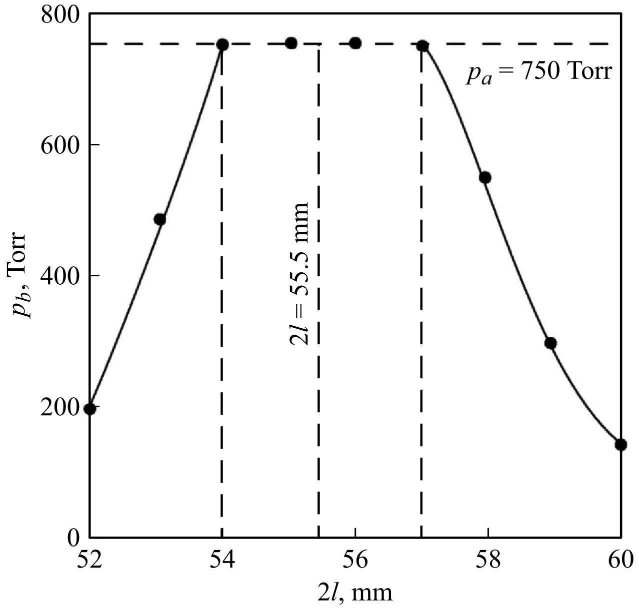

Figure 1. Determination of the initiator resonance length.

Table 1. The influence of the distance between the emitting aperture and screen on the breakdown pressure

H, mm	p_b, Torr
70	750
90	750
125	600
130	540

in motionless air and in a high–speed air flow are discussed in papers [8,9].

The vibrator resonance length was determined experimentally. The atmospheric pressure was assumed to be $p_a = 750$ Torr. The vibrator was made from a duralumin rod $d = 2.25$ mm in diameter and had rounded ends. Its length $2l$ decreased stepwise. The vibrator was located on a foam–plastic base; the distance from it to the screen sheet surface 110×110 mm in size was kept equal to $h = 5$ mm. Fig. 1 presents the experimental results. Based on the obtained data, further theoretical and experimental investigations were performed at the vibrator length $2l = 56$ mm.

In the next experiments there was determined distance H between the emitting aperture and screen, at which the air breakdown pressure p_b initiated by the resonance–length vibrator was lower than the atmospheric pressure of 750 Torr. The experiments employed a cone microwave–emitting trumpet 140 mm long with the inlet cross section of 90×45 mm and outlet cross section of 90×90 mm. In these experiments, the vibrator was placed on a foam-plastic base ensuring the distance to the screen of $h = 5$ mm at the duralumin sheet screen size of 100×100 mm. The obtained results show that the experiments are to be conducted at $H > 125$ mm (Table. 1).

The main parameter of the discharge initiator is the electric field amplification factor $K = E/E_0$, where E is the maximal field amplitude at the end of the initiator, E_0 is the amplitude of the initial microwave field at the point where the initiator is located. The field amplification factor depends not only on the initiator length but also on the size of screen near which it is installed.

The maximal field amplification factor is observed near the initiator ends. At a sufficiently large initiator–to–screen distance, the distribution of the electric field intensity appears to be almost symmetrical about the initiator axis. As the initiator approaches the screen, the field is concentrated between the initiator pole surfaces turned to the screen and the screen. The points of maximal field intensity on the initiator surface shift from its axis towards the screen and conjugation lines between the basic cylindrical surface of the vibrator and its end hemispheres [6].

The field amplification factor at the poles of the resonance–length vibrator at $h = 5$ mm in the linearly polarized initial field of the travelling TEM wave at different screen lengths $b$and widths c was calculated theoretically (Fig. 2). When dimension b or c was decreased, the other dimension remained constant and equaled 100 mm. To complete the picture, in a number of experiments the screen dimension b was made less than the vibrator resonance length ($2l = 56$ mm).

The experiments showed that while dimension $c = 100$ mm remains constant, pressure p_b begins decreasing only at $b < 62$ mm; therefore, dimension c was varied

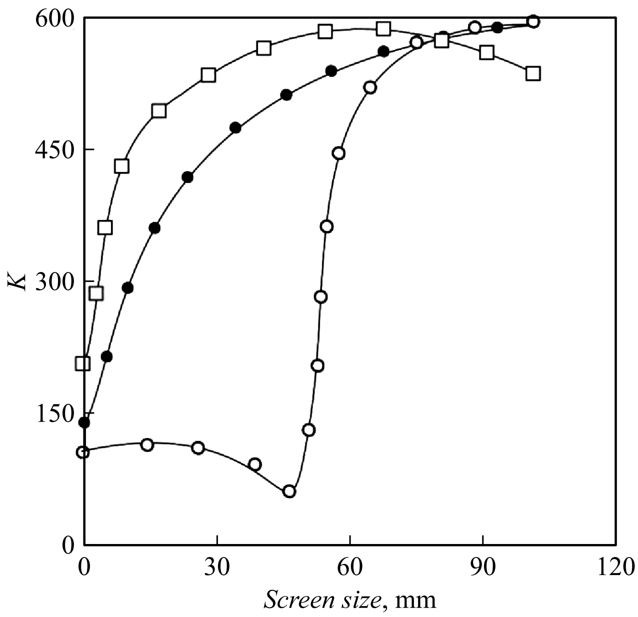

Figure 2. The dependence of the field amplification factor at the poles of a linear vibrator on the size of the screen–reflector. Open circles represent the $K(b)$ dependences at $c = 100$ mm, dark circles correspond to dependence $K(c)$ at $b = 100$ mm, open squares correspond to dependence $K(c)$ at $b = 62$ mm.

Table 2. The influence of the screen width on the breakdown pressure

c, mm	p_b, Torr
100	615
40	600
20	600
10	480

in experiments at $b = 62\,\text{mm} = \text{const}$ (the same variant was calculated theoretically). Fig. 2 presents the calculation and experimental results.

The experimental results are listed in Table 2. They were obtained at $H = 110\,\text{mm}$ and screen length $b = 62\,\text{mm}$. The screen was set on a carbon−ceramic microwave absorber $140 \times 140\,\text{mm}$ in cross section and 80 mm in thickness.

The obtained results are of interest for creating the non−equilibrium microwave discharge and applying it for fuel ignition and enhancement of fuel combustion in high−speed flows [10,11]. The deeply subcritical discharge adjoint to the initiator located near the metal screen does not undergo blowout with the high−speed flow and enables ignition of the fuel mixture. The use of initiated microwave discharges for ignition of the fuel mixture in the high−pressure chamber allows not only creation of such discharges at a significantly lower power of the microwave energy source but also their localization in the operating chamber at the necessary place.

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Conflict of interests

The authors declare that they have no conflict of interests.

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