Lifetime of Vacuum Arc Triggering System Based on Surface Discharge

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Abstract – The development of ion sources is governed by the possibilities to employ them in technologies of surface modification. At the High-Current Electronics Institute sources of this type have been developed which provide generation of intense metal ion beams in the repetitively pulsed mode. The most efficient vacuum arc triggering systems are based on the initiation of a cathode spot by the surface discharge plasma. Among the advantages of this method are simplicity, relative stability of operation, and low trigger energy, as compared to the main arc discharge energy. However, the lifetime of these triggering systems is limited by dielectric erosion and metal film deposition on the insulator surface. This paper presents the results of experimental studies on determination of the optimal parameters of a vacuum arc triggering system. The optimum parameters should provide stable ignition of a vacuum arc and increase the lifetime of the triggering system.

1. Introduction

Plasma ion sources based on a vacuum arc discharge are employed for ion implantation and for injection of metal ions in heavy particle accelerators. In sources of this type, it is practice to use the repetitively pulsed mode of the arc operation. The operation of a vacuum arc in steady-state conditions is rather difficult to realize due to comparatively high values of its threshold current, which can reach tens of amperes. The threshold current of the arc determines the minimum power of the ion beam. In steady-state conditions of the discharge operation this power makes up tens of kilowatt that may far exceed the parameters of a technological ion source.

The use of the repetitively pulse mode imposes a number of requirements on triggering systems, among which the most important are the following:

– initiation processes may not affect the parameters of a vacuum arc and, consequently, the output parameters and characteristics of an ion source;

– to maintain the low “ion cost” the energy expended in initiating the main discharge should be minimum, as compared to the energy which goes into its operation;

– the lifetime of the triggering system may not severely limit the time of the ion source operation;

– the design of the triggering unit should be simple and reliable, and its cost should make up a small portion of the general expenses of developing an ion source.

All these requirements limit the use of methods based on a vacuum breakdown [1], effects of laser radiation [2] or charged particle beams [3] on the cathode surface, mechanical approach of electrodes [4], and initiation of an auxiliary gas discharge [5, 6] in technological ion sources.

In the majority of ion sources which employ a vacuum arc discharge, the arc is initiated by an auxiliary surface discharge [7]. The advantages of this method are the design simplicity, the low trigger voltage, and also the absence of gas supply into the discharge gap. However when broken down, the dielectric is intensively destroyed in the region of the cathode spot operation, being metallized due to spattering of the cathode material. This decreases the ultimate lifetime of such triggering systems to 10^5–10^6 pulses [7, 8].

The main objective of this work was to optimize the parameters of a trigger surface discharge to increase the lifetime of the triggering system of a vacuum ion source.

2. Experimental Chamber Design

The system to be tested was based on a vacuum arc initiated by a surface discharge. The circuit of this system is shown in Fig. 1. The discharge chamber is a coaxial electrode system. Cylindrical cathode *1* of diameter 6 mm is located inside ceramic tube *2* of length 1 mm which separates the cathode from ring trigger electrode *3*. The cathode unit is on the axis of cylindrical hollow anode *4*. The discharge chamber is mounted on the face of the vacuum chamber evacuated to a residual pressure of the order of 10^{-3} Pa by a turbomolecular pump.

The insulator material was chosen to be Al_2O_3 ceramics because of its high specific resistance (10^{19} Ω/cm) and high mechanical strength. The cathode material was aluminum due to a large droplet fraction in the cathode spot and, consequently, to a rather short lifetime of the cathode unit. Such a choice was made to reduce the time of the experiment.

The trigger discharge current was varied by selecting the capacitance of a discharge capacitor in the power supply unit. The variation of the capacitance from 1 to 8 μF corresponded to the increase in trigger discharge current from 3 to 25 A. The currents of trigger and main discharges were measured with Rogowskii coils of sensitivity 20 and 120 A/V. The voltage of the trigger discharge was measured by a voltage divider with a ratio of 1:100.

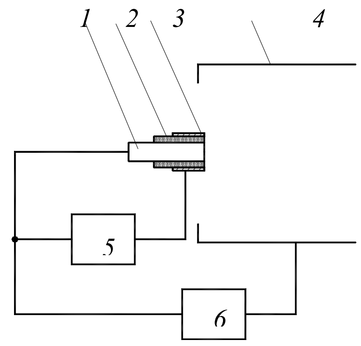

Fig. 1. Circuit of the experimental setup: *1* – cathode, *2* – ceramic tube, *3* – trigger electrode, *4* – hollow anode, *5* – power supply of the trigger discharge (*V* – 3 kV, *I* – 25 A), *6* – power supply of the vacuum arc (*V* – 1 kV, *I* – 500 A)

A forming LC line switched by a thyristor served as the power supply. The line provided quasirectilinear discharge current pulses of duration up to 1 ms and amplitude up to 500 A.

3. Determination of the Optimal Voltage of the Trigger Discharge Operation

To determine the optimal voltage at which there will be a maximum number of pulses of the vacuum arc discharge the amplitude of the trigger discharge pulse was varied from 500 V to 3 kV. At a specified voltage of the trigger discharge, the number of triggered and lost pulses of the vacuum arc was determined.

Figure 2 shows the ratio of triggered pulses of the vacuum arc to the total number of pulses applied versus the discharge voltage between the cathode and the trigger electrode for an insulator width of 1 mm.

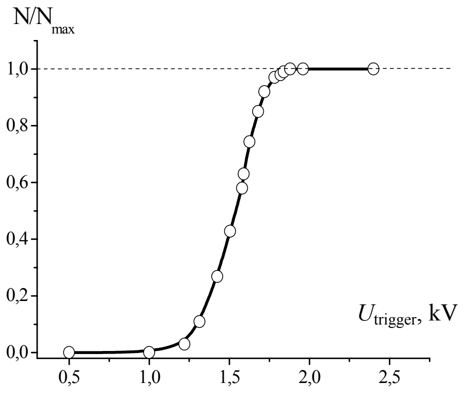

Fig. 2. Ration of the number of triggered vacuum arc pulses N to the total number of the pulses applied N_{max} versus the trigger discharge voltage $V_{trigger}$. The range of vacuum arc currents 100–200 A. The insulator width between the cathode and the trigger electrode 1 mm

It can be seen from this dependence that at a trigger discharge voltage higher than 2 kV stable triggering of all applied pulses of the vacuum arc takes place. Therefore further experiments were performed at a voltage of 2.5 kV.

4. Determination of the Optimal Current of the Trigger Discharge

Figure 3 shows the dependence of the lifetime of the discharge system (i.e., the number of stably triggered pulses of the vacuum arc without reassembling the cathode unit) on the trigger discharge current at different arc currents. The pulse duration of the vacuum arc was 1 mc at current amplitudes of I_{arc}= 200 A и 120 A (curves *1* and *2*, respectively). It is seen that the dependences reveal a clearly defined optimal value of the trigger discharge current at which the maximum lifetime of the cathode unit is attained.

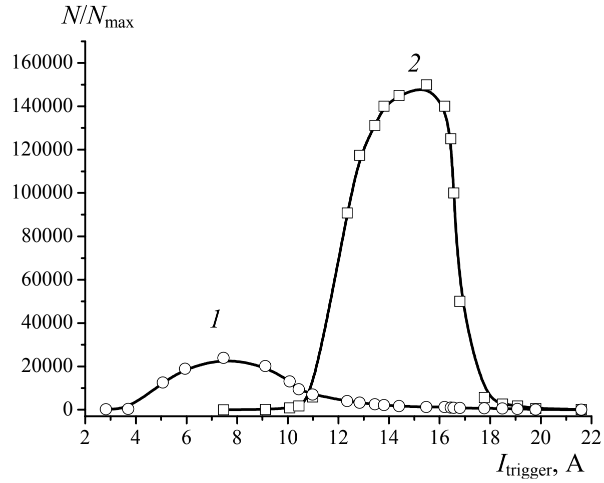

Fig. 3. The lifetime of the trigger system versus the trigger discharge current $I_{trigger}$. N – number of initiated vacuum arc pulses without reassembling the cathode unit. The vacuum arc current: *1* – 200 A, *2* – 120 A. Arc pulse duration 1 mc

The presence of such a value can be explained as follows. As the trigger discharge current is increased the products of cathode erosion, which are formed during the operation of the vacuum arc and deposited in the form of film on the working face of the ceramic insulator, becomes more and more sputtered by the trigger discharge. This slows down the formation of the metal film on the ceramics that may close the cathode and the trigger electrode. As a result, the lifetime of the cathode unit increases (the left branch in Fig. 3). At the point of maximum the amount of products of the cathode erosion deposited during the operation of the vacuum arc equals the number which is efficiently evaporated within each successive period of the discharge over the ceramics surface [9]. In such a mode the cathode erosion determines the time of operation of the discharge system to a greater extent, than the lifetime of the ceramic insulator does.

However, further increasing the trigger discharge current causes the destruction of ceramics by this discharge to become more and more pronounced and the lifetime starts to decrease (the right branch in Fig. 3).

The fact that the curves for the lifetime at different vacuum arc currents are shifted relative to each other is governed by the trigger voltage in the vacuum arc circuit, which is set at the output of the forming line. Therefore to initiate a discharge with a current of 200 A at a no-load voltage of 500 V a lower energy is required, as compared to the initiation of a discharge with a current of 120 A at a no-load voltage of 300 V.

The obtained findings on determination of the optimal parameters of the trigger discharge were used in experiments aimed to increase the surface conductivity of ceramic insulators by implanting Pt ions with an energy of 100 keV.

Thus, the experiment has made it possible to optimize the parameters of the trigger system of the vacuum arc discharge and, thus, to increase the lifetime of the cathode unit. So, in the case of a Pt cathode the cathode unit displayed stable operation at the parameters of the vacuum arc pulse $\tau = 400$ μs, $I_{arc} = 100$ A, $f = 10\ s^{-1}$ within more than $1.3 \cdot 10^6$ pulses. In so doing the lifetime of the cathode unit was governed to a greater degree by erosion of the cathode itself.

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