OPTIMIZATION OF A VACUUM SPARK DISCHARGE AS AN X-RAY SOURCE

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The paper reports on the results of experimental investigation of the influence of the trigger location relative to the discharge gap and the trigger energy on spatial and temporal stability and emission parameters of the X-ray sources, formed in low-inductance vacuum spark discharge. The investigations corroborated the influence of initial plasma characteristics on vacuum spark evolution. The conditions for primary forming of the hot spots radiating the X-ray within the spatial region less than 500 μm and with a temporal jitter less than 300 ns were defined.

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1. INTRODUCTION

High temperature and density of plasma formed in pulse pinch discharges such as a plasma focus and a vacuum spark set conditions for a big part of X-ray in the total plasma radiation. The hot spots, the regions of high temperature and dense plasma with size less than 100 μm, are the most intense sources of this X-ray. Therefore use of such type of discharges as X-ray sources for feasible applications is of interest. In this case such parameters as intensity, size and spectrum of the emitting source, its spatial and temporal stability are essential. Information about radiating plasma parameters obtained from X-ray emission measurements allows to optimize source operating conditions.

The initial plasma in vacuum spark discharges is usually produced by the additional trigger electrode. In a number of papers [1, 2, 3] the influence of the trigger discharge energy and of the trigger location relative to the cathode on the variation of generation time and on the amplitude of the X-ray pulse were considered. In this works the trigger electrode was placed either in the cathode centre or at the edge of a plate cathode. In these cases the trigger durability was limited by erosion action of the main discharge. Increase of trigger operating life may be achieved when the trigger is removed from the region of main discharge current flow [4].

In this paper we present the experimental investigation of influence of initial plasma injection location and trigger energy on both the X-ray pulse time stability and on the spatial location, dimension and energy range of the X-ray sources.

2. EXPERIMENTAL SETUP

The investigations were carried out on the micropinch setup Zona-2 [4]. The cathode is a 20 mm diameter plane iron cylinder with a 3 mm hole in its centre. The anode has a form of a 3 mm peaked iron rod. The initial distance between electrodes is 5 mm. The capacitance of the main capacitor is 20 μF. The discharge period is 8,5 μs. The discharge current runs up to 100 kA under the charging voltage of 10 kV.

The trigger electrode was produced in the form of a 2 mm molybdenum rod with a ceramic insulator. It was placed either on the edge of the cathode surface radially to the discharge axis or it was moved 25 mm away from the discharge axis on the lateral side of the external electrode opposite to the discharge gap midpoint. The voltage of the trigger capacitor was switched to the trigger electrode by the thyratron either directly or by means of high-voltage transformer operating as a current limiting device.

3. EXPERIMENT DESCRIPTION

Trigger discharge energy was variated by means of the trigger capacitor change from 14 to 147 nF with constant charge voltage of 7 kV. In such case trigger pulse amplitude was variated from 20 A to 1.8 kA, and pulse duration was variated from 500 ns to 1.6 μs with rise time from 100 to 600 ns respectively. The measurements were carried out under both polarities of the trigger pulse. The duration of the trigger pulse was changed by variation of the trigger capacitor magnitude. High-voltage ferrite transformer working in saturation mode was used to limit the current amplitude. The measurements were carried out for a row of ten discharges for each value of trigger energy, trigger pulse polarity and trigger location.

Time characteristics and intensity of the X-ray within the range over 4 keV were recorded to oscillograph TDS-3054 with the help of X-ray pin-diode. Spatial position and energy range of X-ray sources were tested in real-time mode by three-channel pinhole camera with 150 μm diameter holes. The central hole was free, the right-hand and the left-hand holes were covered by 210 μm and 420 μm thick aluminum filters respectively. The pinhole was placed inside the vacuum chamber 6 cm away from discharge axis to increase its efficiency. Image recording techniques were disposed outside of the setup vacuum chamber. Therefore, the registered radiation additionally passed through a 50 μm mylar filter placed on a diagnostic window of the vacuum chamber and through an 11 cm thick air slab. The dependence of total transmission coefficient on energy for each several pinhole channel is shown in Fig. 1.

The pinhole image was formed in 150 μm thick ZnS·CdS-Ag luminescent layer split out of X-ray multiplying screen. The luminescent layer was attached directly to the input window of electron-optical image intensifier with multialcaline photocathode. The image from the output screen was registered by high-sensitivity CCD camera Videoscan-205, transmitting this image to computer display. As a result it was possible to control the setup operating regime directly in the measurement process. Stationary conditions of pinhole image registration provide the possibility of correct comparison of the X-ray sources location and their emission intensity for several discharges.

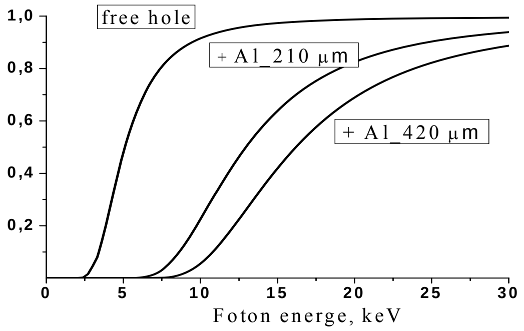


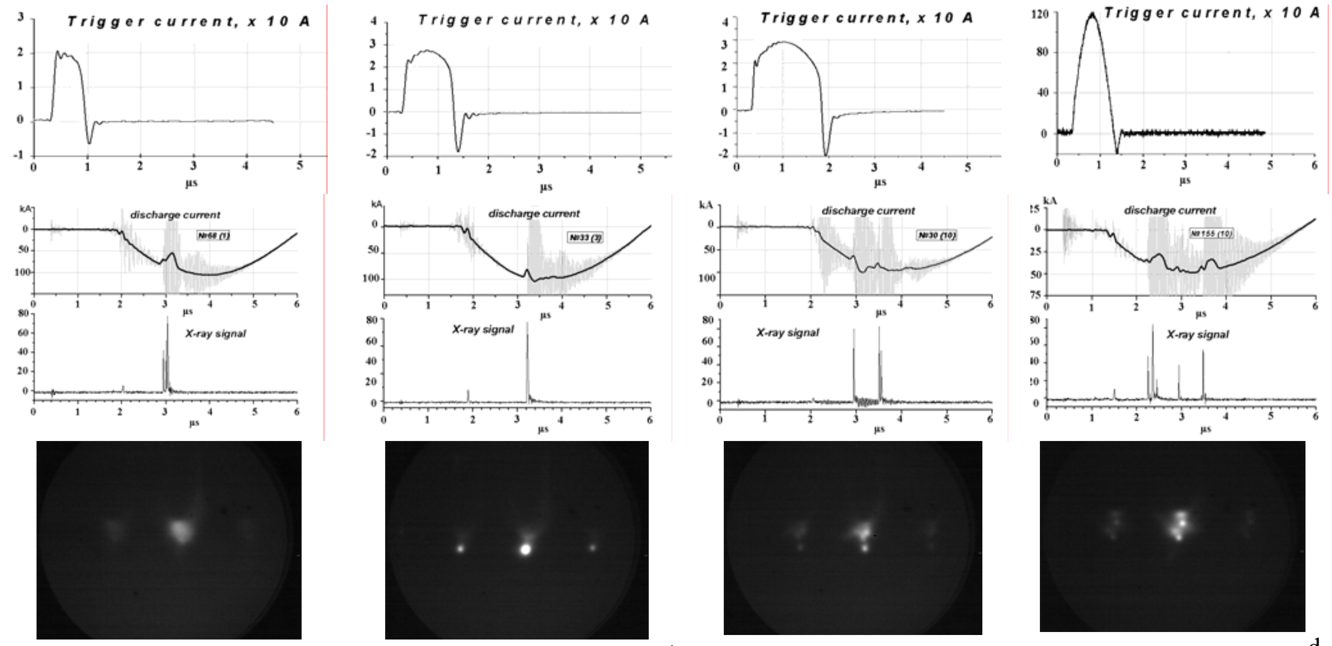
Fig. 1. Transmission curves of X-ray for several pinhole channel including 50 μm mylar film and 110 mm air slab

4. RESULTS AND DISCUSSIONS

Our investigations had shown the substantial dependence of emission instant, amplitude of X-ray pulses, and spatial location of radiation sources on trigger discharge conditions. Typical oscillograms of discharge current, pin-diode signal and pinhole images under different trigger discharge energy corresponding to them are shown in Fig. 2. Enumeration presented on the current oscillograms signifies the discharge sequential number. Optimum results of hot spot formation stability and X-ray intensity were obtained when the trigger electrode was placed on the edge of the cathode surface and when this electrode was supplied with the positive current pulse with the amplitude of $I_{tr} \approx 30$ A, duration $t_{tr} = 900$ ns and rise time 100 ns (Fig. 2, b). In this case about 70 % of the hot spots were formed within a 500 μm range of interelectode gap with a 300 ns time jitter. Changes of trigger pulse polarity with the same other discharge parameters resulted in drastic fall of plasma point formation probability. And the most intensive X-ray emission was observed from a diffuse cloud near the anode end.

Almost double decrease in the trigger pulse duration leads mainly to diffuse X-ray glow of several areas within the discharge gap and near the anode without noticeable hot spots formation (Fig. 2, a). Such behavior of the discharge is explained, in all appearances, by insufficient plasma density forming near the anode under the influence of the electron flow and radiation from the trigger plasma. Double increase in the trigger pulse duration relative to optimum value with constant amplitude increases the initial plasma concentration near the anode. In consequence the X-ray anode glow rises. However, the density of remainder plasma in the discharge gap increases simultaneously. It shunts the main discharge channel and reduces the degree of plasma contraction, which results in the decrease of the X-ray pulse amplitude in the pinching moment and of hot spot glow intensity in X-ray range (Fig. 2, c).

Increasing of the trigger pulse amplitude up to 1 kA provides the sufficient plasma density for repeated pinching along discharge axis. This results in increasing of a total X-ray yield and in extension of X-ray generation area (Fig. 2, d). As a case described above are created conditions for current flow in peripheral plasma, that reduce the pinching efficiency. A quantity of registered X-ray pulses not always coincide with number of observed X-ray sources. This fact indicates on repeated pinching in the same regions of discharge gap.



a b c d

Fig. 2. Oscillograms of trigger current, discharge current, X-ray pulse and the pinhole images corresponding to them under various trigger pulse parameters: a) $I_{tr} \approx 20$A, $t_{tr} = 500$ ns; b) $I_{tr} \approx 28$ A, $t_{tr} = 900$ ns; c) $I_{tr} \approx 30$ A, $t_{tr} = 1{,}6$ μs; d) $I_{tr} \approx 1200$ A, $t_{tr} = 900$ ns

Stable X-ray emission was registered only with trigger current more than 1 kA when the trigger electrode was placed out of the discharge gap. In this case the X-ray characteristics substantially coincide with the case when the trigger with such current was placed on the cathode surface. The trigger life was increased more than three times at the same time.

We should note that the anode length was reduced by 5 µm in a single discharge at the average because of the anode end erosion. Therefore additional displacement of the hot spots is to be taken into account in the case of large shots quantity in test series.

Comparison of X-ray glow intensities from the same discharge gap regions on pinhole images obtained behind different filters makes it possible to estimate the X-ray energy. The analysis of the pinhole images shows that main part of the registered X-ray emission fits to the energy range from 3 to 10 keV. Unfortunately deficiency of reference point made it impossible to estimate the share of multiply charged ion line emission in registered X-ray radiation.

5. CONCLUSIONS

Our investigations corroborate the existence of optimal value of the trigger current and the trigger pulse duration ensuring the primary formation of hot spots with small spatial and temporal spread for vacuum spark discharge. The trigger space position relative to discharge gap also has effect on the optimal energy of the trigger discharge. The mode of discharge triggering when up to 70 % of the X-ray pulses were generated within the 500 µm region of the interelectode gap with 300 ns time jitter was found.

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REFERENCES

1. Ch.K. Erber, O.H. Herzog, et al. Optimization of micropinch plasmas produced by vacuum spark discharges// *Plasma Sources, Science and Technology*. 1996, v. 5, N 3, p. 436 – 441.
2. Ch.K. Erber, K.N. Koshelev, H.-J. Kunze. Time development of Mg micropinches in a low-inductancevacuum spark discharge // *J. Quantitative Spectroscopy & Radiative Transfer (65)*. 2000, p. 195-206.
3. N. Georgescu, C.G. Serbãnescu, G. Sandolache. Reproducibility conditions for the pulsed X-ray emission in a vacuum spark discharge// *Nukleonika*. 2001, v. 46, suppl. 1, p.17-20.
4. A.P. Kuznetsov, O.A. Bashutin, et al. Interferometric studies of the electron density dynamics at the periphery of a micropinch discharge //*Plasma Physics Reports*. 2008, v. 34, N 3, p. 193-198.

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ОПТИМИЗАЦИЯ ВАКУУМНОГО ИСКРОВОГО РАЗРЯДА КАК ИСТОЧНИКА РЕНТГЕНОВСКОГО ИЗЛУЧЕНИЯ

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Представлены результаты экспериментального исследования влияния расположения триггера относительно разрядного промежутка и энергетики триггера на пространственную и временную стабильность эмиссионных параметров источников рентгеновского излучения, образующихся в низкоиндуктивном вакуумном искровом разряде. Подтверждено влияние характеристик инициирующей плазмы на эволюцию вакуумной искры. Определены условия для преимущественного формирования горячих точек, испускающих рентгеновское излучение, в пределах локальной области размером менее 500 мкм с временным разбросом менее 300 нс.

ОПТИМІЗАЦІЯ ВАКУУМНОГО ІСКРОВОГО РОЗРЯДУ ЯК ДЖЕРЕЛА РЕНТГЕНІВСЬКОГО ВИПРОМІНЮВАННЯ

О.А. Башутін, Є.Д. Вовченко, А.С. Савелов, С.А. Саранцев

Представлено результати експериментального дослідження впливу розташування триггера щодо розрядного проміжку й енергетики тригера на просторову і часову стабільність емісійних параметрів джерел рентгенівського випромінювання, що утворюються в низькоіндукційному вакуумному іскровому розряді. Підтверджено вплив характеристик ініціюючої плазми на еволюцію вакуумної іскри. Визначено умови для переважного формування гарячих точок, що випускають рентгенівське випромінювання, у межах локальної області розміром менш 500 мкм із часовим розкидом менш 300 нс.