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A three-point ignition of ablative pulse discharge in vacuum

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Abstract. In this paper, the method of ignition of a discharge in ablative pulsed plasma accelerators is investigated. One of the options for using such devices is their use as a propulsion system for small spacecraft – nanosatellites (total mass no more than 10 kg). Traditional methods of ignition in such devices face high overvoltage problems, which reduces reliability and increases energy consumption. In response, a three-point ignition discharge has been proposed, which uses three electrodes instead of one to create a more uniform electric field and improve the ionization of the gas.

Experiments have shown that three-point ignition provides a more uniform flow rate of the working substance and coaxial plasma flow, which leads to a decrease in the weight of the working substance and an increase in reliability. The results of the experiments demonstrate that the new ignition method significantly improves the performance of the accelerator in vacuum, providing a more stable discharge and reduced energy consumption compared to single-point ignition.

Keywords: ablative pulsed plasma accelerator, three-point ignition, energy efficiency

1. Problem statement

Ablative pulsed plasma accelerators (APPA) have a good prospect of being used as a propulsion system for small spacecraft – nanosatellites (with a total mass of no more than 10 kg) [1]. However, traditional methods of ignition of APPA discharge [2, 3] in a vacuum have a number of disadvantages associated with high overvoltage at the initial stage of ignition. This problem is solved either by applying a voltage to the discharge interval of 3–10 mm, exceeding the breakdown [4], or by creating a seed plasma in the discharge channel using an ignition device. A high overvoltage of 15–20 kV leads, on the one hand, to low reliability due to low electrical compatibility, on the other hand, to high power consumption due to the need to break through the trained electrodes. Thus, the possibility of increasing the reliability and uniformity of ignition for the stability of plasma streams of accelerators of the APPA type was investigated.

2. Considered options for ignition

Let us consider the most common variants of initiation of the main interelectrode discharge in the coaxial geometry of APPA electrodes.

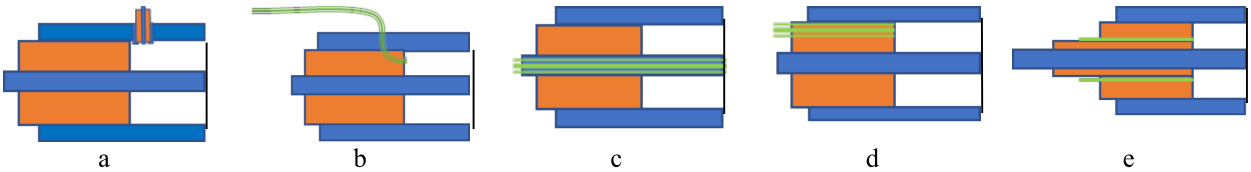

Fig. 1. The variants of initiation APPA: a - by an ignition candle [5], b – with external electrode input, c – with input through the internal electrode, d – with input through an insulator, e – coaxial electrode.

These ignition options have both advantages and disadvantages, these are uneven ignition (Fig. 1a), difficult supply of the working substance (Fig. 1b and d), complexity of design (Fig. 1c and e), and duplication is not provided.

3. Proposed solution

In the presented work, a gas stove ignition plug (Gorenje) with a ceramic electrode insulator (cathode) in a copper cup (anode) with rolling at the end of the spark plug to provide a gap of approx. 0.5 mm was used as an ignition device.

The spark plugs were installed directly behind the cut of the working substance in the direction of the cathode (Fig. 2). Three such spark plugs were installed evenly around the circumference of the anode. The command to ignite the spark plugs was given when the operating voltage on the capacitor C was reached.

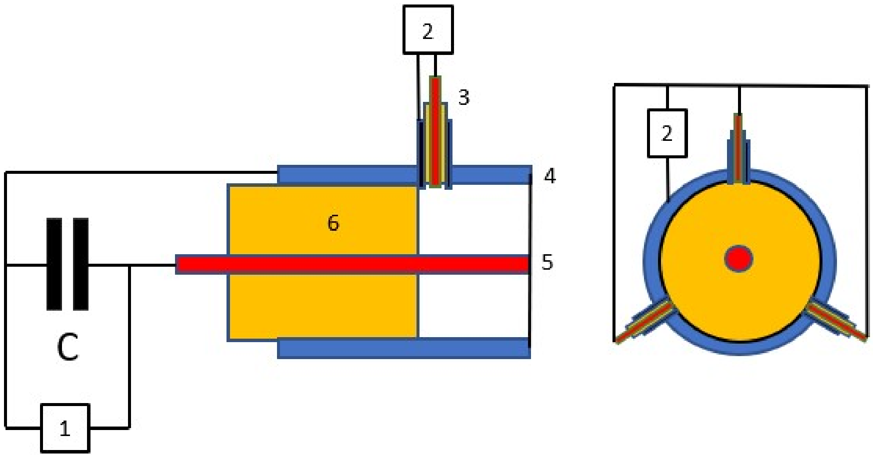

Fig. 2. Connection diagram of the APPA model with three-point ignition: 1 – main capacitor charging unit, 2 – spark plug ignition unit, 3 – ignition plug, 4 – external electrode, 5 – internal electrode, 6 – APPA working substance.

4. Technical implementation and preliminary tests

For such a discharge channel scheme, a prototype was made with dimensions close to 1U format (1U is a cube measuring 10×10×10 cm), Cube Sat (Fig. 2), and a series of experiments was carried out. At first, the discharge clearances of all spark plugs were trained in the air from one high-voltage transformer connected in parallel according to the scheme (Fig. 2). After achieving a statistically uniform and alternate operation, the plugs were ignited in a vacuum (residual pressure of 5 mPa) with constant pumping (Fig. 4–5).

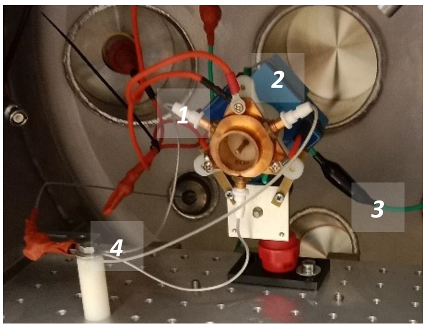

Fig. 3. Photo of the installation in a vacuum chamber: 1 – ignition candles, 2 – capacitors, 3 – charge wires, 4 – ignition wires.

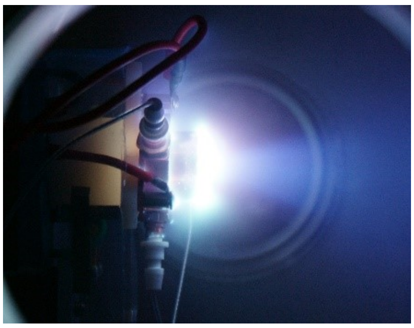

Fig. 4. Integral photo of the AIPD discharge from the side.

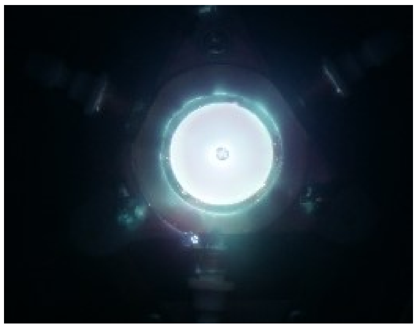

Fig. 5. Integral photo of the AIPD discharge from the end.

At the next stage, the breakdown of a coaxial ablative pulsed accelerator with a discharge energy of about 5 J with ignition from candles (pulse repetition rate of about 2 Hz) was checked upon reaching the operating voltage (about 1.5 kV).

The place of reference of the discharge was recorded by a bright spot on the central electrode on the storyboard of the video recording of the discharge (Fig. 6) and visually during the discharges through the filters (Fig. 7). At the same time, in the course of long-term observation and analysis of the data obtained, the alternating and random nature of the spark plug lighting and the corresponding discharge binding was established. An increase in the discharge voltage on it, while conductive carbon deposits are layered on non-working plugs, which contributes to the priority operation of one of the two non-working plugs, its self-cleaning and cycle renewal.

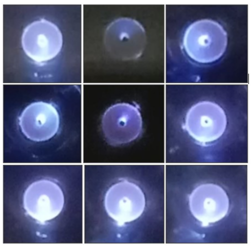

Fig. 6. Integral photos of discharges taken through the ND 3.0 filter.

Fig. 7. Integral photo of the AIPD discharge from the side.

5. Conclusions

Experiments have shown that three-point ignition of the discharge due to the uniformity of ignition along the azimuth of the working substance significantly improves the characteristics of the APPA in vacuum, such as the uniform flow rate of the working substance and, consequently, the coaxial plasma flow, which in turn leads to a decrease in the required mass of the working medium.

Three-point ignition accelerators exhibit higher ignition reliability, lower power consumption, and more stable discharge compared to single-point ignition.

Acknowledgement

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6. References

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