Initiation of the plasma jet of the magneto-plasma compressor by the external plasma source

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Abstract. The results of a preliminary study of the interaction of supersonic gas-plasma flows created by a magneto-plasma compressor and a pulsed erosion plasma jet are presented. Stable initiation of the MPC discharge at atmospheric pressure was achieved for the first time. The advantage of using the coaxial arrangement of plasma jets sources for MPC discharge initiation is shown. A noticeable change in the shock wave front velocity and pressure (up to 20%), created during the MPC discharge and dispersed powders and liquid mixtures interaction, is discovered.

1. Introduction

The report presents the results of a preliminary study of the interaction of supersonic gas-plasma flows created by a magneto-plasma compressor (MPC) and a pulsed erosion plasma jet (EPJ). It is necessary to note the design simplicity of these plasma sources and the possibility of obtaining high-speed jets with highly ionized plasma for their practical use (they have a characteristic speed of the order of units-tens of kilometers per second). Currently, such plasma sources are widely used [1]. In particular, it was noted that the successful use of MPC was demonstrated as a high-brightness optical source in the visible and UV ranges, a plasma source for exciting microplasma discharges, a shock-compressed plasma layer shaper for processing material surfaces, an ignition device for igniting gas-fuel flows, etc. In our work, the use of these devices was developed in the radio-physical and gas-dynamic experiment [2,3], where it was shown that the plasma flow of the MPC can be successfully used both for studying the flow around the testing bodies and for creating plasma layers. And, finally, this year's search experiments with the initiation of an MPC discharge by an erosive plasma jet showed another possible direction of research. This is the study of ways to achieve detonation modes by compressing the energy-saturated plasma of an erosive plasma jet with the magnetic field produced MPC. The energy saturation of the plasma is provided both by its own discharge of the EPJ [4], and by the introduction of fine powder and liquid mixtures into the discharge region. This area of research relates to optimizing the effectiveness of achieving detonation or its suppression when the volume concentration of particles in the gas changes. In addition, the heat treatment of the gas mixture improves the conditions for the occurrence of detonation at higher gas pressures [5,6]. These factors contributed to the development of the experiment with the initiation of an MPC discharge at air pressures close to atmospheric. During the work, various variants of experimental conditions were tested, which also ensured the creation of a new device called a combined MPC.
experiments have revealed the importance of understanding the conditions of initiation of the breakdown of the MPC by a third-party plasma jet, their synchronization in time and in space. The method of supplying dispersed mixtures to the required discharge region also turned out to be quite complex. Therefore, in general, these works are of a search nature, but taking into account the above, the relevance of this area of work is quite obvious.

2. Initiation of an MPC discharge by a pulse erosive plasma jet

At the first stage, the methods of initiation of the MPC by an external plasma jet were studied, which were compared with those where the MPC discharge was initiated by an auxiliary spark. It should be noted that stable operation mode of the MPC discharge initiated by an auxiliary spark can be achieved at low pressures only (P≤50 Torr). The use of a plasma jet instead of an auxiliary spark makes it possible to expand the operating pressure range of the MPC discharge up to 1 atm. At the first stage, we studied the methods of initiation of MPC by an EPJ with different mutual orientation of the EPJ and MPC jets – coaxial or orthogonal. An important role in the MPC discharge operation plays the choice of distance between the plasma sources and of optimal parameters of the switching power supplies of the MPC and the EPJ. To understand these factors, the discharge processes were recorded by means of high-speed imaging. Pressure sensors were used to record shock-wave processes accompanying the pulsed plasma flows formation. Later, pilot experiments were conducted to study the interaction of the plasma jet with various working mixtures. Pressure sensors were also used here to study the possibility of detonation in various powder and liquid mixtures under study. In these experiments, various systems for injecting powders and liquid mixtures into the discharge region of the MPC were tested. The experiments were carried out in a vacuum chamber, where the MPC and EPJ were located figure 1. Switching power supplies were installed outside the vacuum chamber and were synchronized relatively the moment of EPJ initiation. All trigger signals, source voltage, speed camera control (PCO SENSICAM with an exposure of up to 100 ns) and pressure sensors (ΔP) were recorded using a Tektronix TDS 3014B 4-beam oscilloscope. MPC and EPJ were mounted in a vacuum chamber with the help of special devices. A general view of the experiment with orthogonal initiation of the MPC discharge is shown in figure 1. The detailed design of the MPC arrester is presented in figure 2.

Figure 1. The experiment scheme. Photo of MPC and EPJ in the vacuum chamber: (1) MPC, (2) EPJ. A variant of the orthogonal arrangement of plasma sources.

Figure 2. The design of the MPC arrester: (1) MPC insulator, (2) anode block, (3) anode rods, (4) cathode, (5) cylindrical igniting electrode, (6) insulator of the ignition channel (alundum ceramics), (7) electric supply of the igniting voltage, (8) power supply cable.
The photo in figure 1 shows the lateral location of the EPJ. However, the initiating plasma jet of the EPJ can also be disposed above the MPC. Then, in the first variant, the plasma jet streams are perpendicular, and in the second variant, they are coaxial. The distance between the central cathode of the MPC and the section of the EPJ nozzle varied up to ~7 cm to achieve a stable formation of a powerful MPC jet.

3. The results of the experiments
Spectral measurements of the MPC plasma jet were performed using a multichannel gated spectrometer AvaSpec-ULS-2048-XL-UA-50 in the range of 300÷1000 nm with spectral resolution of 2.4 nm. The lines of O I, O II, N I, N II were detected in the plasma jet spectrum. The Cu I lines appearing as a result of the cathode erosion processes are very weak. The flow temperature was estimated by selecting the synthesized spectrum that best coincides with the experimental one and contains all the spectral lines observed in the experiment, taking into account their Doppler and Stark widenings. This procedure shows that the electron temperature of the plasma is $T_e \approx 3 \pm 0.5$ eV, and the electron concentration is $n_e \approx 10^{16}$ cm$^{-3}$. Such a plasma flow created by the MPC accelerates to high speeds of about 10 km/s or high. The lifetime of the jet in the range of air pressure from 30 Torr to atmospheric is $\sim 50\div100$ microseconds. To obtain these parameters, it is necessary to provide the experiment with reliable switching power sources that allow obtaining a high energy storage of the order of $1\div10$ kJ. At the same time, the supply voltage of the capacitive storage device is $5\div7$ kV, and the values of the pulse current are in the range of $50\div70$ kA. The parameters of the erosion plasma jet were as follows: the pulse discharge current - up to 100 A, the discharge voltage - from 600 to 800 V, the pulse duration - $1\div10$ ms. The examples of an MPC plasma jets initiated by an external energy-saturated EPJ in various disposition relatively MPC are presented in figure 3.

The completed cycle of experimental studies has shown the advantage of using coaxially positioned sources of plasma jets. Stable initiation of a powerful MPC jet is achieved at relatively low source voltage levels in the range of up to $\sim 5$ kV. The optimal distance between the MPC and the EPJ does not exceed $3\div5$ cm.

![Image](image.png)

Figure 3. An (1) MPC plasma jet initiated by (2) EPJ disposed in (a) orthogonal and (b) coaxial direction relative to MPC axis. The frame exposure time is 100 ns. Discharge in the air at $P=750$ Torr.

4. The results of the study of shock-wave effects
In this cycle of work, shock-wave (SW) processes were studied in the selected coaxial version of the arrangement of plasma flows created by EPJ and MPC. In addition, methods of injecting working substances into the discharge region of the MPC, including water, alcohol mixtures and dispersed powders of aluminum and nickel, were studied. It is obvious that these methods were aimed at studying the possibility of increasing the energy properties of the erosive plasma jet created by the
EPJ. Therefore, the injection of various additives was carried out both in the cathode region of the MPC and in the zone developed by a heterogeneous plasma jet of the MPC. For this purpose, single-layer and multi-layer targets made of thin foil were installed on the path of the plasma jet created by the MPC, on which dry or wet powders were poured.

Powder and liquid additives (alcohol and water) were placed along the jet axis at various distances above the cathode in the range of 0÷4 cm. Simultaneously with the photoregistration, the signals from the pressure sensor were recorded, radiation in the visible range was recorded by a photoelectronic multiplier (PEM) and the voltage on the capacitive storage device was also recorded using a high-voltage probe. The pressure sensor was mounted in a vacuum chamber the distance of 5 cm from the MPC axis. This allowed us to estimate the relative change in the amplitude of the pressure signal, and the time delay of the arrival of a gas-dynamic disturbance from a high-speed plasma flow. According to the time delay, the average speed of the SW was determined depending on the parameters of the MPC.

The analysis of the waveforms showed that the presence of a dispersed powder leads to an increase in the pressure signal behind the SW front by about 20%. The arrival SW to the pressure sensor also occurs faster than in the control case without powder. The speed of SW in the presence of powder also increases to 6 km/s (without powder it is about 4 km/s). These experiments were performed at a reduced pressure (P ~ 50 Torr).

5. Conclusions
The experiments has been carried out to study the initiation of a powerful supersonic plasma jet of MPC by means of a pulsed erosive plasma jet. Stable initiation of the MPC discharge at atmospheric pressure was achieved for the first time. The completed cycle of experimental studies has shown the advantage of using the coaxial arrangement of plasma jets sources.

Based on the obtained results, a new device was created - a combined erosion MPC, in a single design of which the MPC and the erosion plasma torch are combined and work.

The study of shock-wave effects from the MPC using dispersed powders and liquid mixtures showed a noticeable change in the velocity of the shock wave and the pressure at its front (up to 20%).

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