Magneto-plasma compressor for radiophysical study of supersonic flows around bodies

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Abstract. One of the promising applications of magneto-plasma compressor (MPC) may be the use of plasma jets generated by MPC for experimental study of hypersonic flow around the models. For the study the MPC was developed with a caliber of 24 mm with internal initiation of discharge, working in "submerged" mode. The maximum operating value of the discharge current in this MPC corresponds 29 kA, the duration of the current pulse is not less than 90 μs. Jet quasi-stationary mode is set when the discharge current reaches of about 12–15 kA, that gives an estimate of the jet lifetime about 55–60 μs. To estimate the abilities of MPC the tests were conducted with Teflon conic models with a diameter of 10 mm and a height of 30 mm at a distance from the edge of the cone to the MPC nozzle exit 30–50 mm. Experiments have shown that the studied type of the MPC could serve as a basis for creation of the experimental stand for the radio physical researches of the processes in hypersonic flows in the ranges of pressures and flow rates of interest.

The compact magneto-plasma compressor (MPC) is the result of further development of large-scale MPC, developed for the injection of pre-accelerated and heated plasma in installations type TOKAMAK [1,2]. As a generator of high-speed plasma jets, the MPC has been long studied both for technological purposes and for the purposes of applied plasma dynamics. One of it promising applications can be the use of jets generated by MPC for experimental studies of the processes of hypersonic flow around the models.

The range of speeds of the plasma streams generated by such MPC shall be 2–10 km/s, the jet lifetime should not be less than 50 μs, in the range of the surrounding gas (air) static pressures from 10 to 500 Torr. The electron density reaches values of 10^{16}–10^{17} cm^{-3} at a temperature of about 3 eV.

The diameter of the jet should be not less than 5mm in focus with it further extension under angle 10 degrees. Since the implementation of the "large-scale" MPC with an output diameter of 0.5–0.8 m is a complex engineering task, the relatively miniature versions of MPC with an output diameter of 1–5 cm. could be more suitable for practical applications. The reduction of the output caliber for MPC in variant of the compact geometry allows essentially simplify the design of electrodes, and in particular, to use of the monolithic cathode with cathode
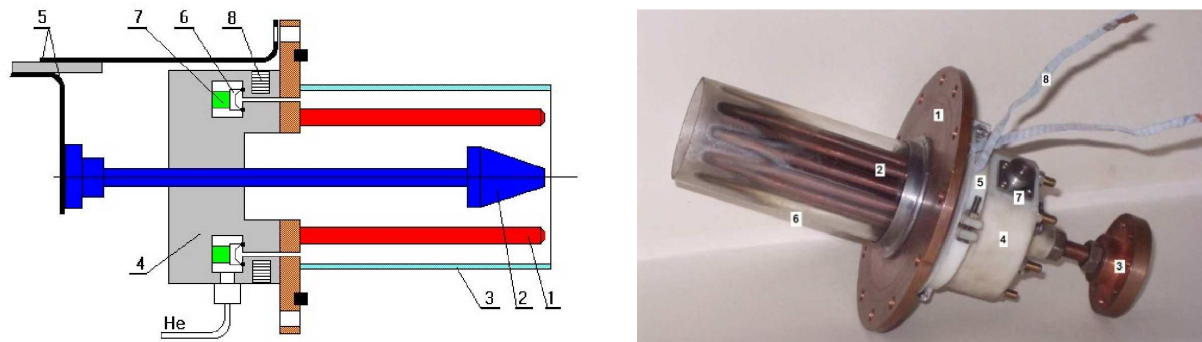
Figure 1. (On the left-hand side) The scheme of magneto-plasma compressor of compact geometry in a "vacuum" design: 1—rod anode system (the diameter on which the centers of anodes are located is 44 mm), 2—cathode, 3—glass tube, limiting the expansion of the injected gas, 4—insulator, compressor, 5—lead current bus, a cup of the electromagnetic valve 7—is an elastic seal, 8—the pulse inductor valve.

Figure 2. (On the right-hand side) Total view of the vacuum MPC of the compact geometry.

divertor [3–5]. A sample implementation of the MPC, a large enough caliber (44 mm), forming a compression jet in vacuum 10^{-5}–10^{-6} Torr is shown in figures 1 and 2.

High-speed of the compression plasma jet is formed in the MPC at high current (from 20 to 200 kA), pulsed (50–200 μs) and distributed arc discharge between the central cathode and series of the accelerator rod anodes [3, 4]. The most important factor determining the jet formation process in this accelerator is it self-magnetic field, which could be above than several of Tesla. Such MPC in the future we will call "vacuum", as for the injection accelerated gas to MPC it is necessary to use the pulse valve with a operation time of 50–80 μs and large massflux.

One of the great features of the considered accelerator is it ability to operate in the mode of the surrounding gas acceleration (submerged MPC). In this mode MPC can operate at comparatively high pressures (up to 100–120 Torr).The possible application of MPC in these modes as applied to high-speed plasma dynamics had been demonstrated in the works [3, 6]. If the physics of the processes of jet formation in vacuum MPC was investigated comparatively carefully [4, 5], the "submerged-type" MPC so far been studied rather poorly. Unfortunately, at present time there is no adequate analytical or numerical models for the calculations of processes in such MPC and creation of accelerators for this mode is based on the existing experimental experience [3, 6].

Figures 3 and 4 show photographs of the jets generated by this compressor. In figure 3, free jet at a gas pressure of 0.6 Torr is shown; in figure 4, there is a flow around a wedge with an angle of 50 deg. All photos were taken with an exposure of 1 ms (integrated all stages of development of the discharge and the flow around a body) through the interferential filter 630 nm with bandwidths of 10 nm. Change the image color is associated with features display large intensities of the used CCD camera.

The caliber reduction of the used MPC leads to a decrease in the size and level of operating currents, which makes possible its flexible application in the experiment. Account of the reasonable characteristics of storage battery, (800–3000 μF, 5000 V), the minimum required lifetime of the jet (30–50 μs) leads to a range of possible calibers 20–30 mm. In the present work describes the properties of the "submerged" MPC with caliber of 24 mm.

MPC working in this mode is started due to the gas self-breakdown between the electrodes. When the desired range of pressures and electrode distances, corresponding to a caliber of 24 mm self-breakdown voltage of this accelerator is 3–5 kV. The calculations show that given the initial
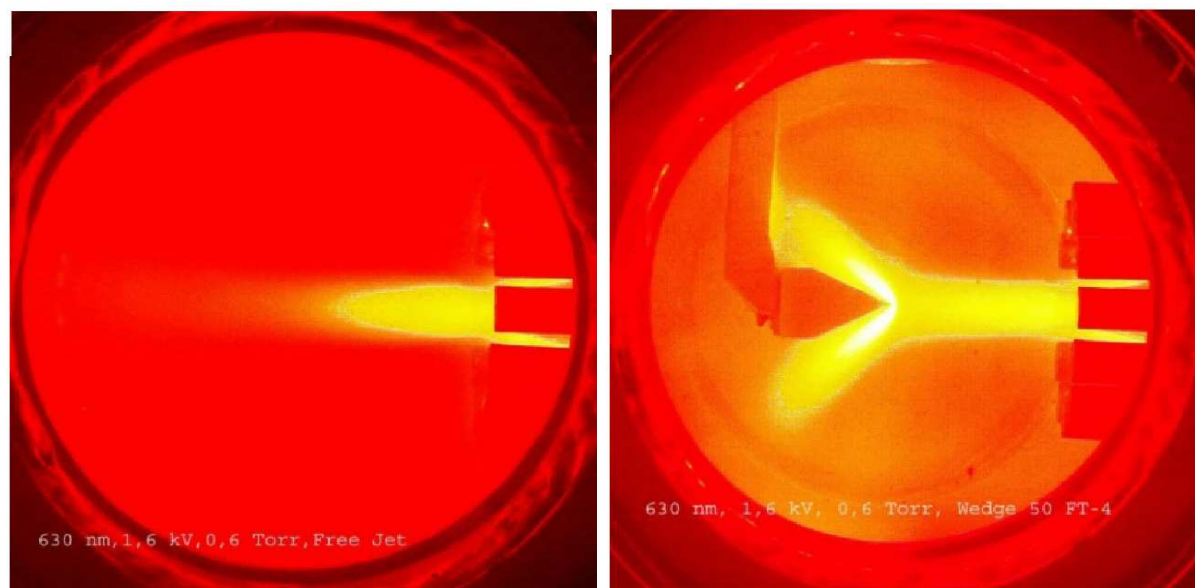
Figure 3. (On the left-hand side) Free jet "submerged" MPC of caliber 44 mm.

Figure 4. (On the right-hand side) Flow by jet of the wedge 50°: interferential filter is of 630 nm, the ambient gas pressure is 0.6 Torr.

voltage and the minimum inductance of the supply chain, the amplitude of the current in this IPC can reach values of 100–150 kA. While tearing stresses acting on the electrode system by the electrodynamic forces begin to exceed the limits of the structural strength of the anode system and it can be damaged.

To avoid such modes, the initial electric strength of the electrode gaps of the MPC decreases due to the organization of the duty of special high-voltage discharge generated by a additional voltage source. The discharge has a sliding nature and occurs on the dielectric surface between the igniting electrode and the cathode in the area of the critical section of the MPC nozzle.

The developed design of "submerged" MPC caliber 24 mm with internal initiation is presented in figure 5 and 6.

Created MPC pre-tested at the stand of the SPBSU in a small vacuum chamber with static pressures 38–40 Torr. Determined allowable range of currents debugged ignition system and evaluated the geometric characteristics of the resulting jets. In figure 7, presented is the integrated in time picture of the jet made with 1000 μs exposure through a interference filter 480 nm. The air pressure in the chamber 38 Torr. The discharge current and the voltage at MPC and the connecting cable length of 1.7 m are presented in figure 8. The conversion factor for the current channel (channel 1, 0.75 mOm shunt)—6.7 kA/div, the conversion factor for the channel voltage is 111 V/div. The maximum current value in this example corresponds to 29.5 kA, the duration of the current pulse is not less than 90 μs. The quasi-stationary regime of the jet in this MPC is set when the discharge current is of about 12-15 kA, that for the excess discharge duration gives an estimation of the jet lifetime about 55 to 60 μs.

For estimation of MPC abilities to create streams, in which may be carried out the radiophysical researches of the flow processes around models, the tests were performed at SPBSU with using Teflon cones with a diameter of 10 mm and a height of 30 mm. as a tested body The result of this test is presented in figure 9. Conditions for jet formation are the same as previously, the exposure time is 4 μs, the time delay of the exposition from the start of discharge in the MPC—
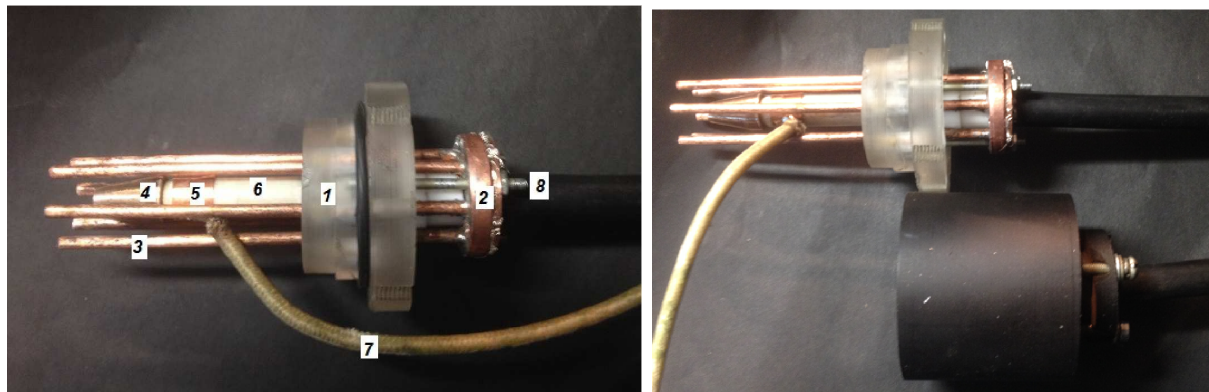
Figure 5. (On the left-hand side) Design of developed "shipped" in-chamber of the MPC: 1—MPC insulator, 2—anodic block, 3—rods of anodes, 4—cathode, 5—the ignition cylindrical electrode, 6-insulator of the ignition channel (corundum ceramics), 7—electric supply of igniting voltage, 8—lead cable.

Figure 6. (On the right-hand side) Design of developed "shipped" in-chamber of the MPC. form-chamber MPC with an external sealing sleeve.
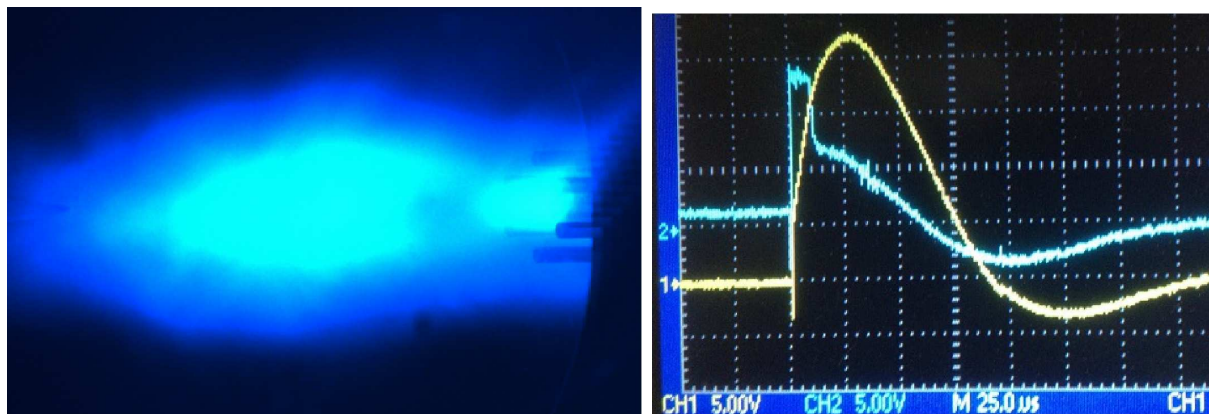

Figure 7. (On the left-hand side) Integral in time picture of the jet made at the exposition time of 1000 μs using an interference filter 480 nm. The pressure is 38 Torr.

Figure 8. (On the right-hand side) The discharge current and the voltage at MPC and the connecting cable length of 1.7 m. Conversion factor for the current channel (channel 1, 0.75 mOm shunt)—6.7 kA/div, the conversion factor for the channel voltage is 111 V/div.

50 μs, the distance from the edge of the cone to the nozzle exit MPC—30 mm. On the figure the head of the shock wave flow is clearly visible, and the region of existence of quasi-stationary plasma jet generated by the MPC at 50 μs of discharge.

The experiments demonstrate that investigated type of the MPC could be used as a basis for creation of the experimental setup for the study of the radio physical processes above and hypersonic flow over combined models in the most useful ranges of pressures and flow rates $V = 2$–10 Km/s, $N_e = 10^{16}$–10^{17} cm^{-3} at $T_e = 3$ eV, the lifetime of the jet is 50 μs, in the range of static pressures of the surrounding gas (air) 10–500 Torr.
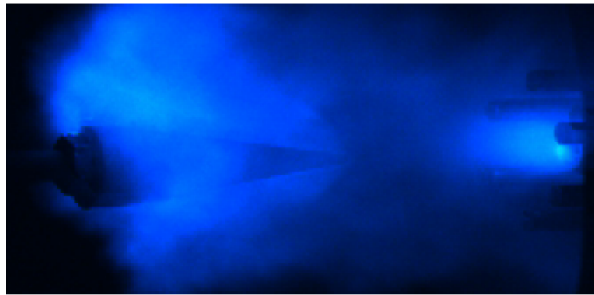
Figure 9. The flow around the cone by MPC jet: the gas pressure is 38 Torr; the delay from the start of discharge is 50 μs; exposure is 4 μs, the filter is of 480 nm.

Of course, more detailed metrological characterization of the flows generated by this MPC requires further careful study.

Acknowledgments

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