

An Impulsive High-Pressure Gas Valve for Plasma Devices

V. V. Staltsov^{a,*}, V. V. Chebotarev^a, N. V. Kulik^a, and V. A. Makhraj^a

^a *Institute of Plasma Physics, National Science Center Kharkiv Institute of Physics and Technology,
National Academy of Sciences of Ukraine, Kharkiv, 61108 Ukraine*

**e-mail: staltsov@ipp.kharkov.ua*

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Abstract—An impulsive gas valve with an electrodynamic drive of the locking element is described. The valve is designed to inject working gases into a discharge channel of plasma devices of the compression and acceleration types. The key gas-dynamic and electrical characteristics of the impulsive gas valve are presented. The valve is capable of forming gas pulses with a wide range of gas-dynamic parameters: the supplied volume of the working gas is 30–540 cm³ per pulse (at atmospheric pressure) and the gas pressure in the flow is as high as 760 Torr.

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INTRODUCTION

Analysis of the current state of plasma technologies and their further development, as well as the solution of the problem of controlled thermonuclear fusion, allows us to conclude that the prospects for the development of plasma technology in the near future will be determined by the requirement to increase the power and duration of plasma flows generated by plasma-dynamic systems [1–4]. The investigations carried out in this field have shown that the final parameters of the plasma strongly depend on the gas-dynamic characteristics of the working-gas flow, which is injected into the discharge space of the plasma-dynamic system for the purpose of its ionization. Such gas dynamic characteristics include the velocity, gas pressure in the flow, its gradient in the axial and radial directions of the accelerating channel, and the mass flow [5–8].

The “potential jump” is a physical phenomenon near the surface of the electrodes that is observed in powerful plasma-dynamic systems, which is caused by a lack of discharge-current carriers in these regions [1, 5–7]. Therefore, in the formation of plasma flows with a high energy content, it is important that a sufficient number of charge carriers be provided in near-electrode flow regions. A lack of charge carriers in the plasma leads to phenomena that make it impossible to effectively convert the energy of the feeding storage into the energy of the plasma flow. As a result, the efficiency of the plasma accelerator is reduced and the lack of charge carriers is partially replenished by the extraction of metal atoms from the surface of the electrodes; i.e., erosion of electrodes occurs in the plasma accelerator [1, 8].

High-speed impulsive valves play a decisive role in feeding the near-electrode regions of the plasma flow [1, 5–8]. In connection with this, the creation of gas-injection systems is an important and urgent task for high-power plasma technology. At the same time, gas valves with an electrodynamic drive are the most suitable for this purpose in terms of their performance characteristics.

AN IMPULSIVE HIGH-PRESSURE GAS VALVE

An impulsive high-pressure gas valve (IHGV) with an electrodynamic drive of the locking element was designed and manufactured to supply gas into the interelectrode space of a high-power plasma accelerator with a plasma-pulse duration of more than 100 μs. The construction of such a valve is shown in Fig. 1 and the exploded view of the valve is shown in Fig. 2.

The locking plate 2 (see Fig. 1) is concentrically set inside the body 1 of the valve. In the closed position, it is supported by its sealing bands on the sealant 3 of the valve 4 on one side and on the surface of the elastic reflector 5 on the other side. The other end of the elastic reflector 5 is located in the groove of the base 6, which is screwed onto the internal thread of the body 1. The end surface of the plate 2 is in contact with the ridge of the pusher 7. The steering electromagnetic coil 8 is concentrically placed on the opposite side of the pusher 7. The elastic ring 9 is installed between the working surfaces of the pusher 7 and the coil 8. At the opposite end of the coil 8, there is a flange 10 that fixes this coil inside the body 1 and, at the same time, secures the sealing of the communicating booster gas cavities 11 and 12 by means of gaskets 13 and 14.

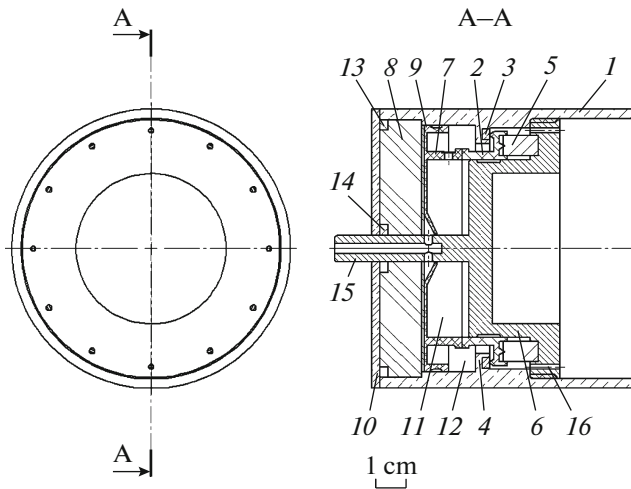


Fig. 1. The impulsive high-pressure gas valve: (1) body, (2) locking plate, (3) gasket, (4) valve seat, (5) elastic reflector, (6) base, (7) pusher, (8) steering electromagnetic coil, (9) elastic ring, (10) flange, (11, 12) booster gas cavities, (13, 14) gaskets, (15) stock, and (16) gas supply channels.

At base 6, there is a rod 15, whose axial and radial channels are used to supply gas from the gas supply system to booster cavities 11 and 12 with a total volume of 95 cm³. Gas accumulates in these cavities before its injection into the ionization zone of the plasma device. The gas accumulates before the injection into the ionization zone of the plasma device.

The valve body is made of brass; the base, the locking plate, and the pusher are made of D16T aluminum alloy; the elastic reflector, the elastic ring, and the seals are made of vacuum rubber. The steering electromagnetic coil is an assembly unit, in the body of which an electric winding is wound and fixed in place with a hot-curing epoxy compound. The body of the coil is made of fiber-glass plastic, the winding is made of copper busbar wire with a cross section of 3 × 1 mm² and a fiberglass insulation.

When a current pulse is applied to the winding of the electromagnetic coil 8, the magnetic field of the coil induces eddy currents in the pusher 7, as a result of which it is thrown away from the coil together with the plate 2. The plate 2 moves away from the gasket 3, releasing the gas-supply channels 16 and simultaneously compressing the elastic reflector 5. After the electromagnetic coil 8 has stopped acting on the pusher 7, the elastic reflector 5 returns the plate 2 with the pusher 7 to the starting position. The elastic ring 9 protects the working surface of the coil 8 from the impact of the pusher 7.

In the valve, the parameters of the gas flow introduced into the discharge channel are controlled by changing the following quantities: the current in the winding of the electromagnetic coil, the initial gas

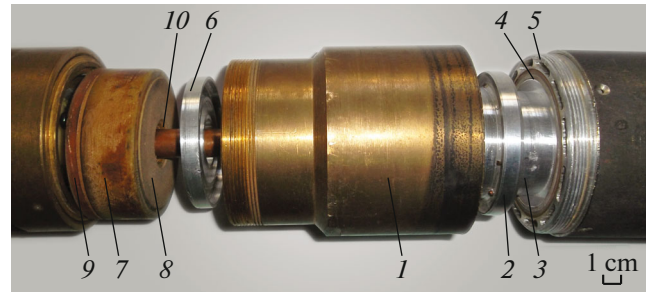


Fig. 2. A photograph of the impulsive high-pressure gas valve when disassembled: (1) body, (2) locking plate, (3) base, (4) elastic reflector, (5) gas supply channels, (6) pusher, (7) steering electromagnetic coil, (8) elastic ring, (9) gasket, and (10) stock.

pressure in the booster cavities, and the compression force of the elastic reflector.

INVESTIGATION OF THE GAS-DYNAMIC AND ELECTROTECHNICAL CHARACTERISTICS OF THE IMPULSIVE HIGH-PRESSURE GAS VALVE

Investigation of the gas-dynamic characteristics of the gas valve was carried out using piezoelectric pressure sensors (with an operating speed of 2.5–3 μs). The measurement of the current in the winding of the electromagnetic coil was carried out using calibrated Rogowski loops. The volume of gas injected by the impulsive valve per pulse was determined by calculation based on the results of measurements of the pressure difference in the vacuum chamber of the setup using the VT-3 vacuum gauge before and after its filling with gas.

Figure 3 shows the time dependences of the current pulse I in the winding of the steering electromagnetic coil of the impulsive valve and the gas pressure p in the flow. The dependencies were obtained for voltages $U = 1, 1.5, \text{ and } 2 \text{ kV}$ at the battery supply of the valve when hydrogen was fed with a volume of 66, 102, and 130 cm³ per pulse, respectively, at atmospheric pressure. The initial pressure of the working gas in the booster cavities was 4 atm. The gas pressure in the flow was measured at a distance of 4 cm from the gas-supply channels.

According to the dependences in Fig. 3, an increase in the voltage applied to the winding of the gas-valve coil leads to an increase in the gas pressure in the flow and to the extension of the gas pulse. The above dependences allow us to determine the gas distribution and its gradient in the accelerating channel, as well as to select the optimal mode of gas filling in terms of the gas pressure in the flow. This is important both for creating the edge of a gas pulse with optimal gas-dynamic parameters and for forming the optimal gas-pressure gradient in the accelerating channel for timely replen-

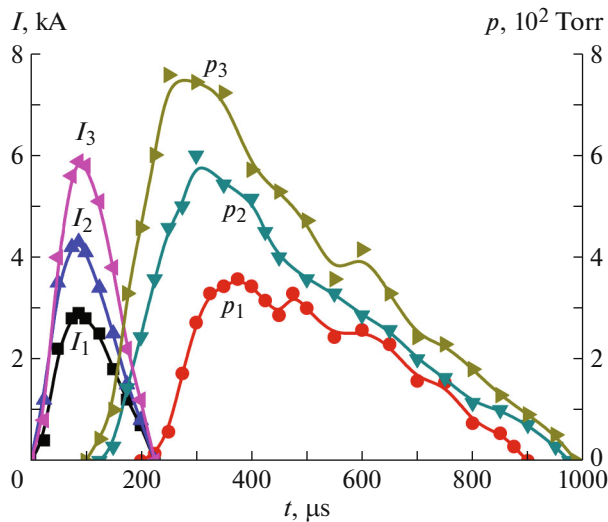


Fig. 3. The time dependences of the current pulse I in the winding of the steering electromagnetic coil of the impulsive gas valve and the hydrogen pressure pulse in the flow: (I_1, p_1) for the 1-kV voltage at the supply battery of the valve (the integral hydrogen flow per pulse is 66 cm^3 under atmospheric pressure); (I_2, p_2) 1.5 kV (102 cm^3) and (I_3, p_3) 2 kV (130 cm^3).

ishing the plasma flow with missing charge carriers. As an example, according to Fig. 3, for the given operation modes of the valve, the maximum gas pressure in the flow is achieved in the interval of 250–350 μs . Therefore, it is advisable to apply the voltage between the electrodes of the plasma device for plasma generation with the same delay after the current pulse is applied to the coil winding. In this case, the ionization of the working gas in the discharge space occurs at a maximum pressure in the flow.

The effect of the voltage U at the winding of the coil control, as well as the initial pressure of the working gas in the booster cavities of the gas valve, on the value of the hydrogen inlet is shown in Fig. 4. From these dependences, it follows that an increase in the voltage at the winding of the valve coil and the initial gas pressure in its booster cavities leads to an increase in the volume of gas injected into the discharge channel. The above dependences allow us to select the optimal operation mode of the valve, which provides the necessary amount of working gas for the plasma generation process. It should be emphasized that the described gas valve allows the formation of gas pulses with a wide range of gas dynamic parameters: the supplied volume of the working gas inlet is 30–540 cm^3 (at atmospheric pressure), and the gas pressure in the flow varies from a few to 760 Torr. The valve is used to inject the working gas in the high-power plasma injector [5]. The described valve can be used both in systems with a short pulse and a small mass flow of the

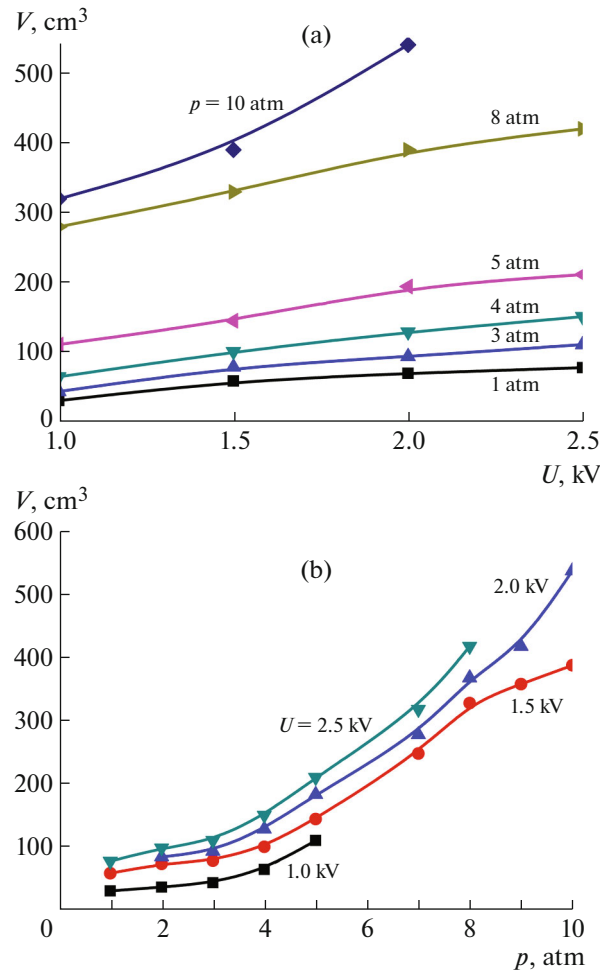


Fig. 4. The dependence of the volume V of the supplied hydrogen (at atmospheric pressure) by the gas valve per pulse: (a) on the voltage at the winding of the steering electromagnetic coil at different values of the initial gas pressure in the booster cavity (designated by numbers) and (b) on the initial gas pressure p in the booster cavity for various voltages applied to the winding of the steering electromagnetic coil (designated by numbers).

working gas, where the duration of the flow generation is only a few microseconds, and in powerful plasma-dynamic systems in which the duration of plasma generation is hundreds of microseconds.

REFERENCES

1. Morozov, A.I., Tereshin, V.I., Stal'tsov, V.V., Shcurov, O.A., Pavlichenko, O.S., Chebotarev, V.V., Volkov, Ya.F., Kovalenko, V.I., Kulik, N.V., Manojlo, V.S., Marinin, V.V., Solyakov, D.G., Tashchev, Yu.I., Tsupko, B.Yu., et al., *Plasma Devices Oper.*, 1992, vol. 2, p. 155.
2. Garkusha, I.E., Aksenov, N.N., Byrka, O.V., Makhlij, V.A., Herashchenko, S.S., Malykhin, S.V., Petrov, Yu.V., Staltsov, V.V., Surovitskiy, S.V., Wirtz, M., Linke, J., Sadowski, M.J., Skladnik-Sadowska, E., et al., *Phys.*

- Scr.*, 2016, vol. 91, p. 094001. doi 10.1088/0031-8949/91/9/093001
3. Makhlay, V.A., Garkusha, I.E., Aksenov, N.N., Bazyleva, B., Byrka, O.V., Chebotarev, V.V., Landmana, I., Herashchenko, S.S., Staltsov, V.V., et al., *J. Nucl. Mater.*, 2015, vol. 463, p. 210. doi 10.1016/j.jnucmat.2014.12.057
 4. Garkusha, I.E., Cherednychenko, T.N., Ladygina, M.S., Makhlay, V.A., Petrov, Yu.V., Solyakov, D.G., Staltsov, V.V., Yelisyeyev, D.V., Hassanein, A., et al., *Phys. Scr.*, 2014, vol. T161, p. 014037. doi 10.1088/0031-8949/2014/T161/014037
 5. Staltsov, V.V., Chebotarev, V.V., and Makhlay, V.A., *Probl. At. Sci. Technol.*, 2015, vol. 95, no. 1, p. 118.
 6. Staltsov, V.V., *Probl. At. Sci. Technol.*, 2015, vol. 98, no. 4, p. 140.
 7. Stal'tsov, V.V., *Instrum. Exp. Tech.*, 2016, vol. 59, no. 4, p. 609. doi 10.1134/S0020441216030106
 8. Marchenko, A.K., Garkusha, I.E., Staltsov, V.V., Ladygina, M.S., Petrov, Yu.V., Solyakov, D.G., Cherednichenko, T.N., Makhlay, V.A., Chebotarev, V.V., Yelisyeyev, D.V., Krauz, V.I., et al., *Probl. At. Sci. Technol.*, 2014, vol. 94, no. 6, p. 83.

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