PULSED ELECTROMAGNETIC GAS VALVES FOR HIGH-CURRENT PLASMA ACCELERATORS

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The paper describes the design features of a gas valve for the axial (parallel to the axis of the accelerator) working gas supply into the accelerator channel. The results of gas-dynamic studies of the injectors are presented. The amount of the working gas inlet was investigated as a function of gas pressure under the blocking valve element. A strong dependence of the amount of the injected working gas on the electric current value in the control coil was found.

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INTRODUCTION

The studies of high-power plasma streams have shown a substantial effect of the parameters of the neutral gas injected into the accelerator channel on the finite energy parameters of the plasma [1-6]. For realizing a regular plasma flow in the accelerator channel, it is necessary to provide the assigned working gas pressure gradient in the accelerator channel, and also, to ensure the required mass flow rate of the working substance during the whole period of plasma existence [3-6]. This is necessary primarily to eliminate the crisis phenomena of the discharge current [1, 2]. To meet these requirements, various modifications of high-speed gas injectors with a wide range of functional properties have been developed [3-8]. After the ionization of the working substance in the discharge space of the accelerator, the positively charged ions start moving towards the cathode. Due to this fact, a zone with the deficit of positively charged ions and, hence, with the excess of negatively charged particles is formed near the surface of the anode. This forms a near-anode potential jump. As a result, the symmetry of the plasma flow is violated, thus leading to instability of the ionization zone of the working gas and preventing the efficient conversion of the stored energy into the kinetic energy of the plasma flow [1, 2]. To overcome this drawback, substantially new approaches to organizing regular plasma flows and developing adequate designs of plasma-dynamic systems and their valves of the operating substance are necessary.

In this paper, the new design of the pulsed electromagnetic gas valve for high-power plasmodynamic systems is presented. The main features of the valve are discussed.

THE PULSED ELECTROMAGNETIC GAS VALVE (PEGV)

In order to ensure a high mass rate of working gas flow in the accelerator channel in combination with a high gas flow pressure, a Pulsed electromagnetic gas valve (PEGV) has been developed. The injector supplies the working gas directly to the ionization zone, enabling the formation of the required gas pressure gradient along the radius of the accelerating channel. Fig. 1 shows the 3D model of the PEGV, Fig. 2 – component parts of the PEGV.

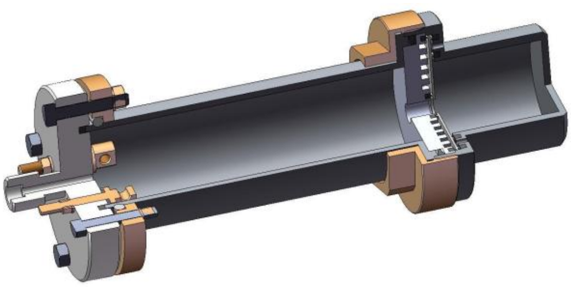

Fig. 1. The 3D model of the PEGV

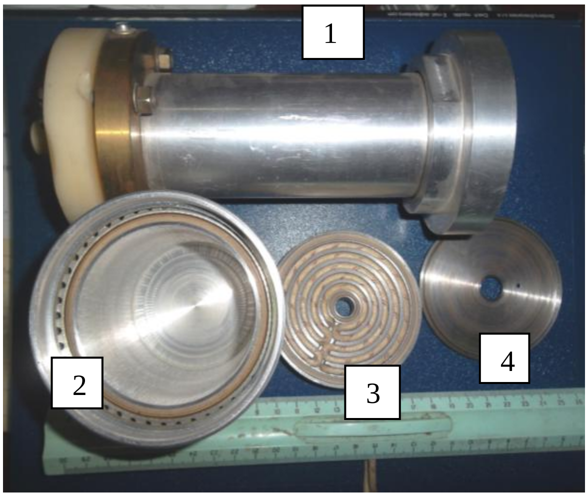

Fig. 2. Component parts of the PEGV: 1 – housing; 2 – saddle of the valve; 3 – electromagnetic coil; 4 – locking element

Fig. 3 illustrates the design of the PEGV. In particular, the electromagnetic coil 1 is placed in the booster gas chamber A, and it acts directly on the locking element 3. Such a location of the electromagnetic coil holds significance for enhancing the operation speed of the valve. The locking element 3 moves along the saddle of the valve 4 surface. Sealants protrusions of the locking element 3 are in contact with sealants 5, 6, 7. Locking element 3 cuts off a booster gas chamber A from the vacuum chamber B and from the channels of gas inlet 8. The working gas is fed into the booster gas chamber C and A through the nozzle 9. The sealants 11, 12 are located between the housing 2 and flange 10. They seal gas booster chamber C. When triggered, gas from the booster chamber A enters the vacuum chamber B through the channels of gas inlet 8.

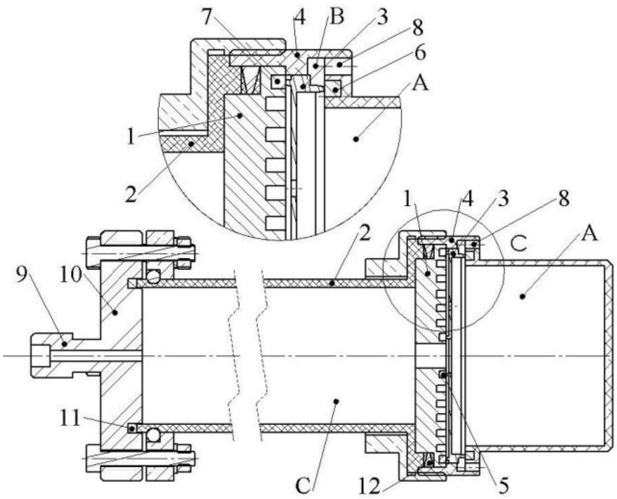

Fig. 3. Design of the PEGV. 1 – electromagnetic coil; 2 – housing; 3 – locking element; 4 – saddle; 5, 6, 7, 11, 12 – sealants; 8 – channels of gas inlet; 9 – nozzle; 10 – flange; A, C – booster gas chamber; B – vacuum chamber

The locking element of the valve is free of working gas pressure, i.e., with a variation of the gas pressure in the booster gas chamber the clamping pressure of the locking element on the sealants remains unchanged. This enables one to change the inlet gas flow parameters by varying the gas pressure in the gas chamber without changing the parameters of the drive current of the coil. The factor of relieving the moving elements from gas-pressure-induced forces also has its positive effect on the operation speed of the system and the service life of the magnetic coil, considering that with increasing gas pressure this factor permits opening of inlet channels at the same high rate without increasing the current intensity in the coil winding. The same factor permits an essential range extension of initial operating gas pressures in the booster chamber, at which the injector shows a stable and reliable operation.

One should note that this construction scheme of the pulse gas valve ensures a higher speed of operation, since here the only moving element is the locking plate, directly on which the electromagnetic coil acts.

The described gas valve variant supplies to the discharge space of the plasma injector in the form of an annular jet. In addition, the annular jet is injected along the surface of the outer electrode (in this case, anode). Such a scheme of the working gas is preferable if a problem of eliminating the near-anode potential jump solved. Hence, the injector variant with an axial inlet was created by changing the embodiment of gas inlet channels. Different injection schemes of the working gas into the accelerating channel of the plasma-dynamic system is an important factor of controlling the working gas dynamics in the accelerating channel, and, hence, the parameters of the plasma flow and their optimization.

In the valve, the parameters of the gas flow, admitted into the discharge channel, are regulated by changing the current in the winding of the control electromagnetic coil, the initial gas pressure in the booster cavity, and the force of compression of the elastic shock absorber.

STUDIES OF GAS-DYNAMIC AND CURRENT-VOLTAGE CHARACTERISTICS OF THE PEGV

Gas-dynamic and current-voltage characteristics of the PEGV have been made. The study of the gas-dynamic characteristics of the working-substance valves was performed using piezoelectric pressure detectors (the speed of their operation is 2.5…3 μs). The current value in the winding of the coil was measured using calibrated Rogowski coils. The volume of the gas, which is admitted by the pulse valve of the working substance for one pulse, was determined by the calculation method after the VIT-3 vacuum-gauge measurement of the pressure difference in the vacuum chamber of the plant before and after the inflow.

Fig. 4 shows the dependences of the current for a voltage in the winding of the electromagnetic coil of the PEGV.

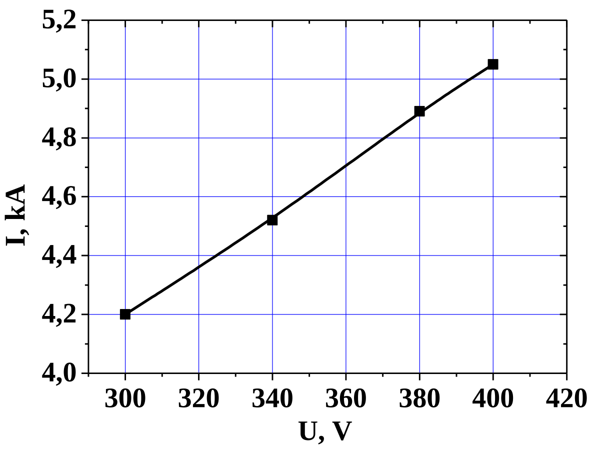

Fig. 4. Dependences of the current from the voltage in the winding of the electromagnetic coil of the PEGV

Fig. 5 shows the time dependences of the current pulse I in the winding of the electromagnetic coil of the PEGV at the voltage of 400 V at the power-supply bank and a gas-for different initial pressure in the booster chamber: p_1 = 1 atm; p_3 = 3 atm. The pressure of the gas flow was measured at a distance of 40 mm from the gas inlet channels. The gas-pulse duration is 900 μs. In all the modes, a pressure peak with a duration of 100…300 μs is observed at the beginning of the gas pulse after which the hydrogen pressure in the flow decreases. For the stated operation modes of the cutoff valve, 800…900 μs is the time gap, when the nitrogen pressure in the flow is close to its maximum and, in addition, does not substantially change. Therefore, it is expedient to switch-on the voltage between the electrodes of the plasma injector for the discharge formation and plasma generation with a delay of ~850 μs after the supply of a current pulse. In this case, the ionization of the working gas occurs at the maximal pressure and is relatively stable during the plasma existence time.

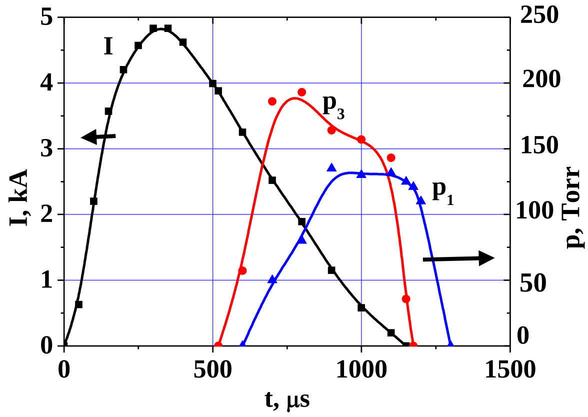

Fig. 5. Time dependences of the current pulse I in the winding of the electromagnetic coil of the PEGV at the voltage of 400 V at the power – supply bank and a gas – for different initial pressure in the booster chamber: p_1 = 1 atm; p_3 = 3 atm

It is important both for the creation of the leading edge of the gas pulse with the optimal gas-dynamic parameters and formation in the gas flow of an optimal pressure gradient along the radius and length of the accelerating channel for the timely supply of the plasma flow with lacking carriers of the discharge current. This injection scheme of the working gas allowed us to eliminate the near-electrode potential jump and, as a result, obtain a plasma flow with high energy characteristics.

Fig. 6 shows the integrated working gas inlet (gas volume under atmospheric pressure injected per pulse) from the voltage in the winding of the electromagnetic coil of the PEGV at initial booster-chamber gas pressures of 1 atm (1), 2 atm (2), 3 atm (3). It follows from the dependencies that an increase of the voltage in the electromagnetic coil of the gas valve and the initial pressure of the working gas in the booster chamber leads to an increase in the volume of the working-gas inflow. The analysis of the curves shows that the gas inlet for the PEGV is essentially dependent on the voltage supplied to the electromagnetic coil winding (hence, on the current value in the coil winding), and on the initial gas pressure in the booster chamber of the valve. Thus, with an increase of the coil voltage from 250 up to 400 V, the operating gas inlet increased from 24 up to 38 cm^3·atm per pulse at an initial gas pressure of 1 atm in the booster chamber. For an initial gas pressure of 3 atm the gas inlet at the same voltage values has increased from 37 up to 79 cm^3·atm.

The described gas valve allows one to admit the working gas in a wide range of 24 to 79 cm^3 per pulse (at the atmosphere pressure) for hydrogen. It can be used both in high-power plasma-dynamic systems, in which the duration of the plasma generation is hundreds of microseconds and in systems with a short pulse and small mass flow of the working gas, where the duration of the flow generation is only several microseconds.

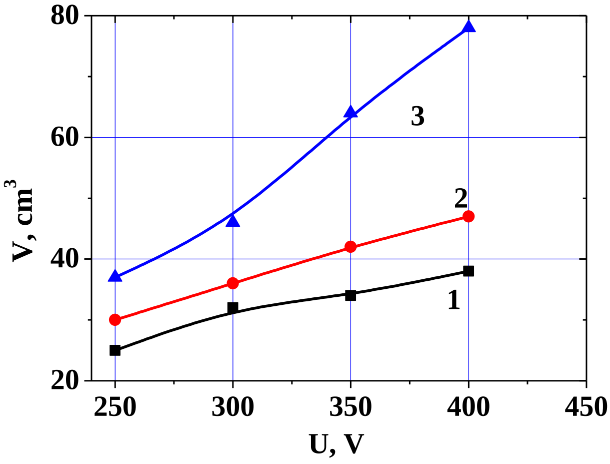

Fig. 6. Integrated working gas inlet by the PEGV versus control – coil winding voltage at initial booster – chamber gas pressures: 1 atm (1); 2 atm (2); 3 atm (3)

The performed studies of the basic electrical characteristics of the gas valve and dynamics of the gas-flow generation open up possibilities for the efficient matching of the gas injection processes and development of the discharge in the accelerating channel of the plasma injectors. In the optimal case, the ionization of the working gas in the discharge gap occurs at the moment, when the flow of the plasma-forming gas has the maximal pressure and is stable during the whole discharge existence time in the plasma accelerator.

CONCLUSIONS

Pulsed electromagnetic gas valve (PEGV) has been developed and tested for high-power plasmodynamic systems. The PEGV makes it possible to form the gas pulse with required gas-dynamic parameters both in the radial direction and along the length of the accelerator channel. It has been shown the injectors provide a metered integrated inlet of the working gas ranging from 24 to 79 cm^3·atm per pulse. The maximum gas flow pressure varies from 3 to 190 Torr. A wide range of gas flow parameters permits the efficient variation in the energy parameters of plasma. During the process of plasma acceleration, the action of the injector PEGV provides the plasma stream stabilization and an efficient feed of current carriers to the zone.

The obtained results are important for high energy density plasmadynamics. Plasma streams with optimized parameters are going to be used in technological applications for surface modification [7-11] and in further studies of plasma-surface interactions simulating fusion reactor conditions [12-18].

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ИМПУЛЬСНЫЙ ЭЛЕКТРОМАГНИТНЫЙ ГАЗОВЫЙ КЛАПАН ДЛЯ СИЛЬНОТОЧНЫХ ПЛАЗМЕННЫХ УСКОРИТЕЛЕЙ

В.В. Стальцов, В.В. Чеботарёв, С.С. Геращенко, Н.В. Кулик

Описываются особенности конструкции клапана газа с электромагнитным приводом запирающего элемента для осевой (параллельной оси ускорителя) подачи рабочего газа в ускорительный канал плазмодинамических систем. Представлены результаты газодинамических исследований клапана. Исследована зависимость количества напускаемого рабочего газа в зависимости от давления газа под запирающим элементом клапана. Показана существенная зависимость количества инжектированного рабочего газа от величины тока в электромагнитной катушке.

ІМПУЛЬСНИЙ ЕЛЕКТРОМАГНІТНИЙ ГАЗОВИЙ КЛАПАН ДЛЯ СИЛЬНОСТРУМОВИХ ПЛАЗМОВИХ ПРИСКОРЮВАЧІВ

В.В. Стальцов, В.В. Чеботарьов, С.С. Геращенко, М.В. Кулик

Описуються особливості конструкції клапана газу з електромагнітним приводом запираючого елемента для осьової (паралельної осі прискорювача) подачі газу в прискорювальний канал плазмодинамічних систем. Представлено результати газодинамічних досліджень клапана. Досліджена залежність кількості робочого газу, що напускається, залежно від тиску газу під запираючим елементом клапана. Показана істотна залежність кількості робочого газу, що напускається, від величини струму в електромагнітній котушці.