HIGH-SPEED GAS INJECTOR FOR POWERFUL PLASMADYNAMIC SYSTEMS

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The paper describes the design features of gas injectors for the axial (parallel to the axis of the accelerator) and radial (perpendicular 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 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. For realizing a regular plasma flow in the accelerator channel, it is necessary to provide the assigned working gas pressure gradient in the radial direction and along the length of the accelerator channel, and also, to ensure the required mass flow rate of the working substance during the whole period of plasma existence. 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].

THE AXIAL GAS FEED INJECTOR (AGFI)

For feeding the working substance to the discharge space of the plasmodynamic system parallel to its axis, a gas injector with axial gas feed (AGFI) has been developed. The injector supplies the working substance directly to the anode region of the accelerator channel in order to feed it with missing current carriers. Besides, this scheme of working substance delivery allows one to stabilize the back edge of the ionization region by gas-dynamic pressure. All these factors together make it possible to stabilize the plasma stream, to reduce substantially the potential jump, and to improve the energy characteristics of the plasma.

Fig. 1 depicts the integrated working gas inlet (gas volume under atmospheric pressure injected per pulse) as a function of voltage supplied to the control coil winding at initial pressures of the gas (4 and 8 atm) in the booster cavity. The analysis of the curves shows that the gas inlet for the AGFI is essentially dependent on the voltage supplied to the control coil winding (hence, on the current value in the coil winding), and also, on the initial gas pressure in the booster cavity of the injector. Thus, with an increase of the coil voltage from 2.2 up to 3 kV, the operating gas inlet increased from 1.5 up to 8 cm^3·atm per pulse at an initial gas pressure of 4 atm in the booster cavity. For an initial gas pressure of 8 atm the gas inlet at the same voltage values has increased from 2.5 up to 33 cm^3·atm. Here, it should be noted that a two-fold increase of the initial gas pressure in the booster cavity leads to an increase in the gas inlet by factors of 4 to 5.

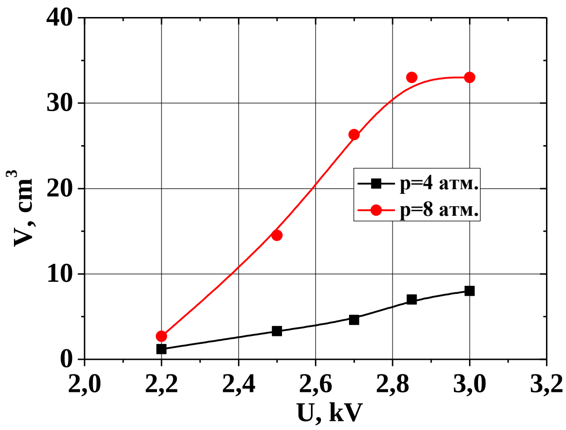

Fig. 1. Integrated working gas inlet versus winding lead voltage of the AGFI control coil

Fig. 2 illustrates the maximum gas flow pressure versus initial gas pressure in the booster cavity of the AGFI. The gas flow pressure was measured at 1 and 5 cm from the nozzle exit section. It is shown that at 1 cm from the nozzle section the gas pressure increase in the booster cavity from 2 atm up to 6 atm leads to the increase in the maximum gas flow pressure from 9 up to 42 Torr. It should be noted that with a distance away from the nozzle section a thermal expansion of the gas flow takes place, and the flow pressure sharply decreases. Thus, with the distance from the nozzle section increasing from 1 cm up to 5 cm, the maximum gas flow pressure decreases by factors of 4 to 5, all other conditions being the same. This should be taken into account when forming the required working gas pressure gradient along the length of the accelerating channel. It should be also noted that the variation in both the control coil winding voltage (current intensity) and the initial working gas pressure in the booster cavity of the injector provides an efficient control of the gas flow parameters.

THE RADIAL GAS FEED INJECTOR (RGFI)

For feeding the working substance to the discharge space of the plasmodynamic system perpendicularly to its axis, a gas injector with radial gas feed (RGFI) 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.

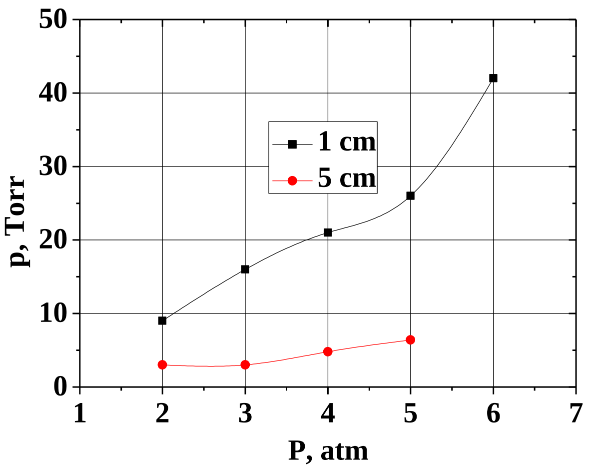

Fig. 2. Maximum gas flow pressure versus initial gas pressure in the booster cavity of the injector AGFI

The special design feature of the RGFI is that its locking cup is fully discharged of the gas pressure. The working gas supply by the injector RGFI directly to the near-electrode zone of the accelerator in order to feed it with missing current carriers, enables one to reduce substantially the potential jump and to improve the energy characteristics of the plasma.

Gas-dynamic studies of the RGFI injector were made. Fig. 3 gives the integrated working gas inlet as a function of voltage supplied to the control coil winding at initial pressures of the gas (4 and 8 atm) in the booster cavity. It is shown that the gas inlet for the RGFI injector is essentially dependent on the voltage supplied to the control coil winding (hence, on the current value in the coil winding), and also, on the initial gas pressure in the booster cavity of the injector. Thus, at an initial gas pressure of 4 atm in the booster cavity, with an increase of the coil voltage from 1.8 up to 2.4 kV, the operating gas inlet increased from 2 up to 42 cm^3·atm per pulse. For an initial gas pressure of 8 atm the gas inlet at voltage values ranging from 1.8 to 2.4 kV has increased from 2.5 up to 116 cm^3·atm. Here, it should be noted that a two-fold increase of the initial gas pressure in the booster cavity leads to an increase in the gas inlet by factors of 2 to 3, the winding currents of the control coil being equal.

The maximum gas flow pressure versus initial gas pressure in the booster cavity of the RGFI is given in Fig. 4. The gas flow pressure was measured at 1 cm from the inlet hole. It is shown that at a distance of 1 cm from the hole the gas pressure increase in the booster cavity from 2 up to 12 atm. leads to the increase in the maximum gas flow pressure from 215 up to 1350 Torr. From the analysis of the experimental data it follows that the design features of the RGFI provide an efficient wide-range control of the gas flow parameters. The locking cup of the injector, freed from pressure, permits operation at high initial gas pressures in the booster cavity. This provides a means of forming the gas pulse with a steep leading edge and a high gas flow pressure, that being of importance for generation of plasma streams with high energy parameters. It should be noted that in powerful plasmodynamic systems it is most reasonable to use the gas injectors IAF and IRF in combination. It is the combined action of the two injectors that makes it possible to form the gas pulse with specified parameters along both the radius and the length of the acceleration channel. Moreover, in the plasma acceleration process, the combined action of the injectors permits an efficient current-carrier feeding to the zones, which show the carrier deficiency.

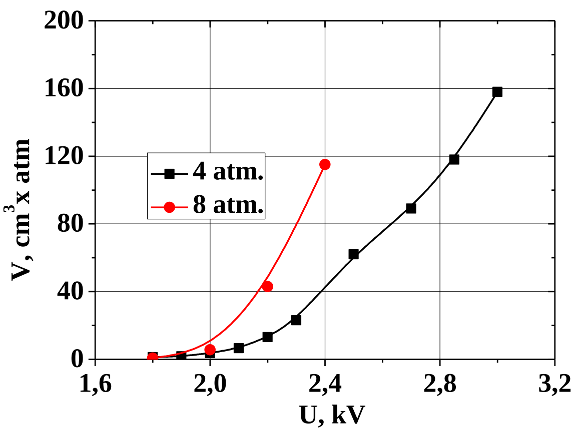

Fig. 3. Integrated working gas inlet by the RGFI injector versus winding voltage of the control coil at initial gas pressures of 4 and 8 atm in the booster cavity

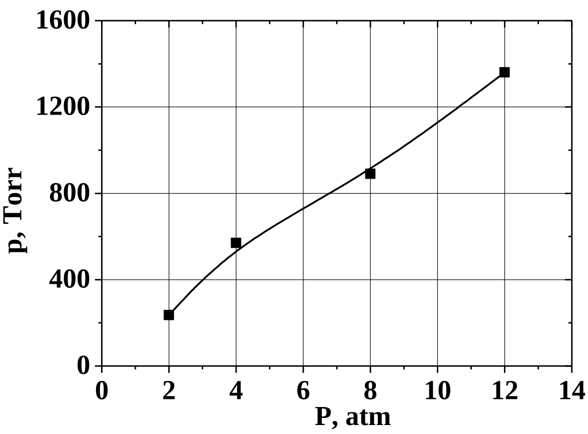

Fig. 4. Maximum gas flow pressure versus initial gas pressure in the booster cavity of the injector RGFI

THE HIGH-PRESSURE GAS INJECTOR HPGI

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 high-pressure gas injector (HPGI) has been developed. The control magnetic coil in this injector is located in the booster gas cavity, and it acts directly on the locking element not involving intermediate pieces. This holds significance for enhancing the operation speed of the injector. The locking element of the injector is free of working gas pressure, i.e., with variation of the gas pressure in the booster gas cavity the clamping pressure of the locking element on the seals remains unchanged.

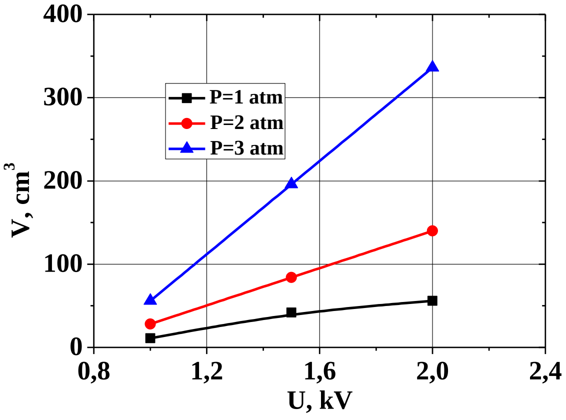

Fig. 5. Integrated working gas inlet by the HPGI versus control-coil winding voltage at initial booster-cavity gas pressures of 1, 2 and 3 atm

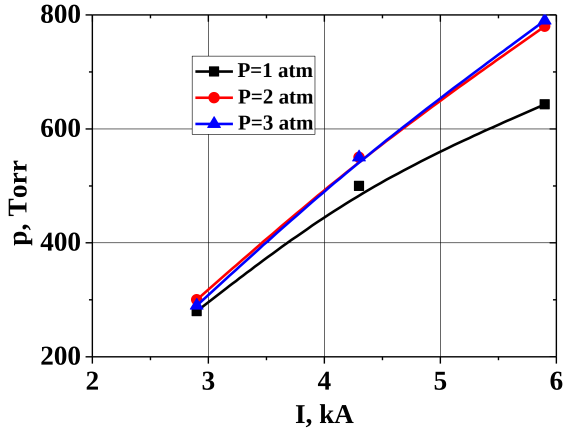

Fig. 6. Maximum gas flow pressure versus control-coil winding current for initial pressures of 1, 2 and 3 atm. in the HPGI booster cavity

This enables one to change the inlet gas flow parameters by varying the gas pressure in the gas cavity 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 cavity, at which the injector shows a stable and reliable operation.

Gas-dynamic tests of the HPGI have been made. Figure 5 shows the integrated working gas inlet versus voltage applied to the control-coil winding at initial booster-cavity gas pressures of 1, 2 and 3 atm. It is seen that the gas inlet for the HPGI is essentially dependent on both the voltage applied to the control-coil winding (hence, on the current value in the coil winding) and the initial gas pressure in the booster cavity of the injector. Thus, at the initial booster-cavity gas pressure of 1 atm, with the coil voltage increase from 1.0 up to 2.0 kV the working gas inlet increased from 4 up to 53 cm^3·atm. per pulse. At initial gas pressure of 3 atm., the gas inlet at the same voltage values increased from 53 up to 330 cm^3·atm. Here it should be noted that a 3-fold increase of the initial gas pressure in the booster cavity leads to the increase in the gas inlet by factors of 5 to 6.

Fig. 6 gives the maximum gas flow pressure as a function of the control-coil winding current for initial gas pressures of 1, 2 and 3 atm. in the HPGI booster cavity. The gas flow pressure was measured at a distance of 20 cm from the inlet channels. It is obvious that in this section the current increase in the coil winding from 2.9 to 5.9 kA leads to the increase in the maximum gas flow pressure from 280 to 640 Torr for initial gas pressures of 2 and 3 atm. It should be noted that the increase in the initial gas pressure from 1 to 3 atm. at low currents in the control coil winding brings no essential change in the maximum gas flow pressure. However, with the increase in current up to 5.9 kA, the maximum gas flow pressure increases from 640 to 790 Torr, i.e., by more than 20%.

It should be also noted that variously designed inlet channels of the injector provide for varying (axial, radial or combined) inlet of the working substance.

CONCLUSIONS

The developed gas injectors make it possible to form the gas pulse with required gas-dynamic parameters at the input of the accelerator channel and along its length by varying the working gas inlet and the gas-flow pressure gradient radially and along the length of the accelerator channel.

The experiments have shown an essential dependence of the integrated working gas inlet and the gas flow pressure on the voltage (current) value of the control electromagnet coil winding and on the initial gas pressure value in the booster cavity of the injector. The injectors provide a metered integrated inlet of the working gas ranging from 1 to 158 cm^3·atm. per pulse. The maximum gas flow pressure varies from 3 to 1350 Torr. A wide range of gas flow parameters permits the efficient variation in the energy parameters of plasma.

In high-power plasmodynamic systems, a combined use of the IAF, IRF, HPGI gas injectors appears most reasonable. It is just their combined action that makes it possible to form the gas pulse with assigned parameters both in the radial direction, and along the length of the accelerator channel. And in the process of plasma acceleration, the joint action of the injectors provides the plasma stream stabilization and an efficient feed of current carriers to the zone, which shows their deficiency.

The obtained results are important for high energy density plasmadynamics. Plasma streams with optimized parameters are going be used in technological applications for surface modification [4-7] and in further studies of plasma-surface interactions simulating fusion reactor conditions [8-12].

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БЫТРОДЕЙСТВУЮЩИЕ ГАЗОВЫЕ ИНЖЕКТОРЫ ДЛЯ ПЛАЗМОДИНАМИЧЕСКИХ СИСТЕМ БОЛЬШОЙ МОЩНОСТИ

В.В. Стальцов, В.В. Чеботарёв, В.А. Махлай

Описываются особенности конструкции газовых инжекторов для осевой (параллельной оси ускорителя) и радиальной (перпендикулярной оси ускорителя) подачи газа в ускорительный канал. Представлены результаты газодинамических исследований инжекторов. 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 управляющей катушке.

ШВИДКОДІЮЧІ ІМПУЛЬСНІ ІНЖЕКТОРИ РОБОЧОЇ РЕЧОВИНИ ДЛЯ ПЛАЗМОДИНАМІЧНИХ СИСТЕМ ВЕЛИКОЇ ПОТУЖНОСТІ

В.В. Стальцов, В.В. Чеботарьов, В.О. Махлай

Описуються особливості конструкції газових інжекторів для вісьової (паралельної осі прискорювача) і радіальної (перпендикулярної осі прискорювача) подачі газу в прискорювальний канал. Представлені результати газодинамічних досліджень інжекторів. Досліджена залежність кількості робочого газу, що напускається, залежно від тиску газу під замикаючим елементом клапана. Показана істотна залежність кількості робочого газу, що напускається, від величини струму в котушці, що управляє.