PLASMA DYNAMICS AND PLASMA WALL INTERACTION

THE EXPERIMENTAL RESEARCH OF THE ELECTRIC CHARACTERISTICS OF DISCHARGE IN THE QUASI-STEADY PLASMA ACCELERATOR WITH THE LONGITUDINAL MAGNETIC FIELD

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Installation of the coaxial quasi-steady high-current one-stage plasma accelerator with a longitudinal magnetic field is created. The lead experiments have shown an opportunity of realization of the discharges, formation of the ionization front and generation of the plasma streams at the presence of a longitudinal field in the accelerator channel. The current-voltage characteristics of the discharge at the presence and absence of a longitudinal field are measured. It is established that a weak longitudinal field does not render the appreciable influence on the integrated characteristics of discharge in the accelerator with the rod anode in an ion current transport regime.

PACS: 52.25.Xz; 52.30.-q; 52.50.Dg

1. INTRODUCTION

One of actual problems of the modern plasma physics is the creation of the powerful plasma accelerators which are capable to generate the plasma streams with the average directed energy of ions up to tens keV and with the full energy capacity up to tens MJ. The research of such streams is of the great importance for the solution of problems of the plasma injection in the thermonuclear installations, of the interaction of plasma with a surface, of realization of the various technological applications, and also for creation of the electrojet plasma engines.

The main principles of the coaxial quasi-steady plasma accelerators (QSPA) are stated in works [1-2]. In the two-stage QSPA systems it was offered to carry out the regular ion current transport by means of the special blocks of the anode and cathode transformers to overcome the near electrode irregularities, in particular, to eliminate the near anode jump of potential. The numerous experiments on the QSPA [3-6] have confirmed as a whole the basic ideas realized in the given installations. The mechanism of the plasma acceleration in all QSPA is based on the Ampere force and the use of the mainly azimuthal component of a magnetic field in the basic stream of the QSPA second stage and in the small coaxial plasma accelerators forming the QSPA first stage. For today the QSPA problems still assume the researches of the some principle questions of plasma dynamics.

The new direction of the QSPA researches is connected with introduction of a longitudinal magnetic field in the system of the plasma accelerator. The theoretical and numerical models of the plasma dynamics in a three-component magnetic field are at present developed and the bases of the QSPA theory with a longitudinal magnetic field are created [7-10]. The additional longitudinal field opens the new opportunities to operate the plasmadynamic processes in the QSPA channel, to overcome the phenomenon of the current crisis, to solve the near electrode problems and the problems of the additional isolation of the design elements from the high-energy plasma streams.

The separate experiments [6] on the two-stage QSPA have been carried out earlier to investigate the influence of the channel geometry and of an external magnetic field on a compression zone. Now the new QSPA installation with a longitudinal magnetic field is created in the laboratory of the pulse power systems at the Institute for Innovation and Fusion Research. The installation consists of the one-stage coaxial plasma accelerator and the system of coils with a current to create an additional longitudinal field. The first experiments are carried out on the given installation to investigate an influence of a longitudinal field on the discharge characteristics, the gas ionization and near electrode processes [10].

2. EXPERIMENTAL INSTALLATION

The plasma accelerator with the coaxial electrodes and the system of rings to create of a longitudinal field is schematically represented on Fig. 1. The rod anode serves as the external electrode of the accelerator. Eight rods are in the regular intervals located at diameter. The cathode in a working zone has the form of the rotation ellipse. The length of the cathode profiled part is equal 62 cm, the maximal diameter of ellipse in critical section is 48 cm.

The accelerator is placed at an end face of the working chamber with the current-bringing cables and with the system of the gas pulse pump. The length of the working chamber is equal 70 cm, the diameter is 40 cm. The working chamber through a gate valve is connected to a receiver which has a volume in 30 times more chambers that allows to pump out it quickly enough.

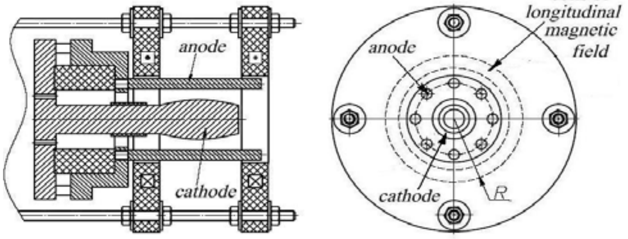

Fig. 1. The scheme of accelerator

The gas moves into a gap between the anode and cathode filling it regularly. When a voltage arises between the electrodes of the accelerator we observe a breakdown of gas, the ionization front is formed and the appeared plasma is accelerated in a longitudinal direction due to the Ampere force. The gas inflow system allows to vary the gas flux within the limits of 0.5…20 g/s. The standard technique of the definition of the gas flux based on the measurement of dependence of the dynamic pressure $p(t)$ of gas filling the interelectrode gap from time was used.

The mass flux of gas can be calculated by means of the formula $\dot{m} = S\ p(t)/V$ where the cross-section square of an interelectrode volume is S, the velocity of the gas outflow is V. The dynamic pressure of gas was measured in work by means of the pressure gauge on the basis of the piezoceramics. The gauge was located in an interelectrode gap. Hydrogen is used as the working gas.

The electric scheme of the accelerator is presented in Fig. 2. The power of the basic discharge of the accelerator includes a section of the condenser battery C. The maximal working voltage on the condenser battery is equal $U_m = 5\ kV$. The maximal discharge current makes 100 kA. The characteristic dependences of the discharge current and voltage on the time and also the current derivative on the time are presented in Fig. 3. These data allow to measure such parameters of the discharge as the inductance L_p and the active resistance of the plasma volume R_p. As a first approximation it is possible to consider these parameters not dependent on time. We use following relation $U_p(t) = R_p\ I_p(t) + L_p\ d\ I_p(t)/d\ t$. As result we find for hydrogen $R_p = 0.01\,(Om)$ and $L_p = 18 \cdot 10^{-9}$ (Hn) taking into account the obtained dependences. The found discharge parameters allow to choose in turn the parameters of the coils to maintain a longitudinal magnetic field of the required value.

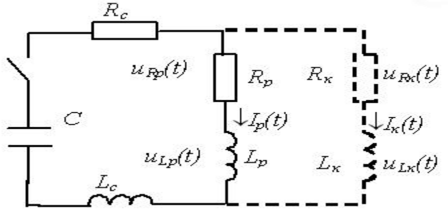

Fig. 2. Electric scheme of accelerator: R_c, L_c –resistance and inductance of the cable; R_k and L_k mark the coils

3. CALCULATION OF COIL PARAMETERS OF A LONGITUDINAL FIELD SYSTEM

To provide the necessary value of a longitudinal magnetic field and its coordinated change together with an azimuthal magnetic field it has been decided to connect the coils of a longitudinal field in parallel a discharge gap. The corresponding section of an electric circuit is represented the dashed curve in Fig. 2 where we have $I_k(t) = \beta\, I_p(t)$ and $\beta = const$. We place I_k into the second Kirchhoff's law for a contour including a discharge branch and the coils of a longitudinal magnetic field. As a result we obtain the relations of the active resistance $R_K = R_p / \beta$ and inductance $L_K = L_p / \beta$ in the system of a longitudinal magnetic field. We can find the parameters of the system determining the value $\alpha = H_z / H_\varphi$. If $\alpha << 1$ the inductance of an external longitudinal field system is small enough. Therefore it has been decided to use a magnetic system close to a system of the Helmholtz coils (Fig. 1) instead of a long solenoid.

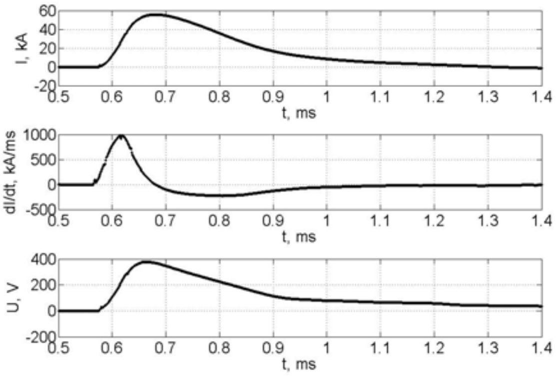

Fig. 3. The current, the current derivative and voltage of discharge

The azimuthal component of a magnetic field in the $H_\varphi(t) = \mu_o\, I_p(t)/2\pi r$. In turn the value of a longitudinal magnetic field in the vicinity of the middle part approximately can be found by means of the relation $H_z(t) = N \mu_o I_k R^2 A$ where $A = (R^2 + h^2)^{-3/2}$, μ_o is the magnetic constant, N is the ring number of one coil, R is the coil radius, h is half of a distance between the coils. The following approximate expression $L_1 = 14.8 \cdot 10^{-9}\, \pi\, R(cm) N^2(Hn)$ is connected the ring number of one coil with its inductance. The inductance of system is equal $L_k = 2\, L_1$ at a consistent connection of coils. Using the resulted relations it is possible to calculate the ring number in the coil $N = 0.07 \cdot L_p(nHn) \cdot r \cdot R \cdot A / \alpha$. If $\alpha = 0.1$, $h = 3.5\ cm$ and $R = 4.3\ cm$ then each of two coils should consist of one ring at the consistent connection. The comparison of the oscillograms of a discharge current and the Helmholtz coil current has shown that they are well coordinated.

4. THE INTEGRATED CHARACTERISTICS OF DISCHARGE

The current-voltage characteristics of the discharge were under construction at the time moment corresponding a maximum of a discharge current for the various values of a mass flux $\dot{m}$. The characteristics corresponding to the greater flux are more to the right, i.e. discharge resistance is in inverse proportion to a flux. The dependence of a voltage on a current is close to linear. It corresponds to the known results according to which the current crisis is absent in classical understanding in accelerators with the rod anode and continuous cathode.

The current-voltage characteristics of the discharge at $\dot{m} = 0.7$ (g/s) in the absence and the presence of the longitudinal magnetic field $H_z = 0.1\, H_\varphi$ are presented in Fig. 4. It is shown that within the limits of measurement errors a weak longitudinal magnetic field does not influence on current-voltage characteristics of discharge.

In a sense the current-voltage characteristics are the integrated parameters of the discharge. In such treatment the obtained result will be coordinated with the conclusions of the work [10]. In the given work it has been shown that an integrated plasma stream through a surface ($r = r_o$, $0 \le z \le 1$) of the penetrate anode

$$\dot{m}_a = 2\pi r_o \int\limits_{z=0}^{z=1} \rho V_r \, dz\,, \quad \dot{m}_{(z=0)} = 2\pi \int\limits_{r_k}^{r_a} r \rho V_z \, dr \ -$$

the plasma flux in the accelerator channel and the integrated parameter of exchange $\xi_o = |\dot{m}_a| / \dot{m}$ practically do not vary in a ion transport regime in the presence of a longitudinal field. It has appeared that the decrease of the normal or radial component velocity of the plasma inflow V_r is observed at an introduction in a system of a longitudinal field simultaneously with increase in density in a vicinity of the anode due to the arising rotation. Thus the longitudinal field does not worsen the integrated parameters of the accelerator.

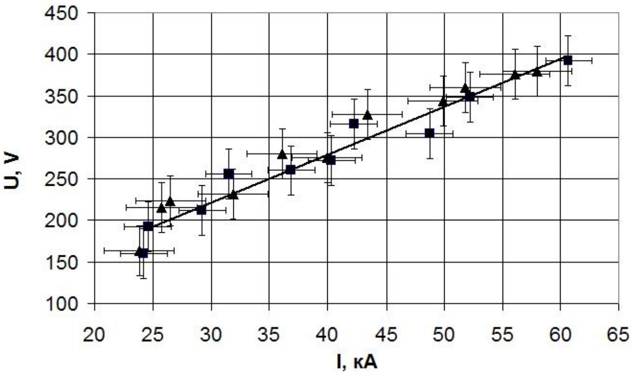

Fig. 4. Current-voltage characteristics of discharge:
■ - $H_z = 0$, ▲ - $H_z = 0.1 H_\varphi$

The weak longitudinal field allows to change the plasma dynamics in a vicinity of electrodes not rendering the appreciable influence on the basic stream. This result has been obtained for the plasma stationary streams calculated by a relaxation method in view of that the characteristic flight time t_o of system and relaxation time is significantly lower than the time interval corresponding to a discharge t_p in the quasi-steady systems ($t_o << t_p$).

5. CONCLUSIONS

Installation of the coaxial plasma accelerator for research of influence of an additional longitudinal magnetic field on the electric characteristics of the discharge and on the parameters of a plasma stream is created. The current-voltage characteristics of the discharge are measured in the absence of a longitudinal magnetic field for the various values of the gas mass flux. The parameters of the coil are calculated and the system of a longitudinal magnetic field is created. The scheme of connection provided the synchronous change of a longitudinal field and own azimuthal field of plasma.

The measurements of the current-voltage characteristics of the discharge for the fixed gas mass flux are lead in the presence of an external longitudinal magnetic field within the limits of 10 % from the own azimuthal magnetic field of the discharge. It is found that the weak longitudinal magnetic field does not render the appreciable influence on the current-voltage characteristic of the accelerator with the rod anode.

The authors are grateful to Professor A.I. Morozov from the Kurchatov Institute for the universal support, helpful discussions and valuable comments.

This work is supported by RFBR (N 06-02-16707).

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Article received 24.09.08
Revised version 14.10.08

ЭКСПЕРИМЕНТАЛЬНОЕ ИССЛЕДОВАНИЕ ЭЛЕКТРИЧЕСКИХ ХАРАКТЕРИСТИК РАЗРЯДА В КВАЗИСТАЦИОНАРНОМ ПЛАЗМЕННОМ УСКОРИТЕЛЕ С ПРОДОЛЬНЫМ МАГНИТНЫМ ПОЛЕМ

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Создана установка коаксиального квазистационарного сильноточного одноступенчатого плазменного ускорителя с продольным магнитным полем. Проведенные эксперименты продемонстрировали возможность осуществления разрядов, формирования фронта ионизации и генерации потоков плазмы при наличии продольного поля в канале ускорителя. Измерены вольтамперные характеристики разряда при наличии и отсутствии продольного поля. Установлено, что слабое продольное поле не оказывает заметного влияния на интегральные характеристики разряда в ускорителе со стрежневым анодом в режиме ионного токопереноса.

ЕКСПЕРИМЕНТАЛЬНЕ ДОСЛІДЖЕННЯ ЕЛЕКТРИЧНИХ ХАРАКТЕРИСТИК РОЗРЯДУ У КВАЗІСТАЦІОНАРНОМУ ПЛАЗМОВОМУ ПРИСКОРЮВАЧІ З ПОДОВЖНІМ МАГНІТНИМ ПОЛЕМ

А.М. Козлов, С.П. Друкаренко, М.С. Клімов, А.А. Москачова, В.Л. Подковиров

Створено установку коаксіального квазістаціонарного сильнострумового одноступеневого плазмового прискорювача з подовжнім магнітним полем. Проведено експерименти, які продемонстрували можливість здійснення розрядів, формування фронту іонізації й генерації потоків плазми за умови існування подовжнього магнітного поля в каналі прискорювача. Виміряні вольтамперні характеристики розряду при наявності та відсутності подовжнього поля. Встановлено, що слабке подовжнє поле не створює значного впливу на інтегральні характеристики розряду в прискорювачі зі стрижневим анодом в режимі іонного струмопереносу.