TECHNOLOGICAL COAXIAL PLASMA ACCELERATOR

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Plasma sources for accelerators intended for separation processes and surface treatment have been investigated. The conditions for the choice of system parameters, as well as plasma flux, injection system, and power source have been discussed. These parameters have been obtained experimentally. A conclusion about the role of metal erosion products of the electrodes has also been drawn.

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1. INTRODUCTION

This paper gives a comparative analysis of plasma electromagnetic separators with ion-cyclotron (IC) heating [1]. It should be noted that in one case, the IC radiation was brought in from outside at a strictly fixed frequency to separate isotopes. In the other case, the ion-cyclotron radiation was originated under the definite parameters of plasma rotated in the crossed electrical and magnetic fields. The investigation of discharges of such a kind (plasma systems) was carried out in the past and the physical effects, in particular, an IC instability, which leads to a selective heating of ions of a different mass were also investigated [2, 3]. A similar mechanism is embedded into physical principals of an experiment [4] carried out according to the American program known as Archimedes, plasma mass filter. The task was set to investigate the possibility of heavy masses separation in case of IC instability in a rotated plasma. The work on plasma separators done over the last years by NSC KIPT is oriented at a magnetic system available at the present time. It has such parameters that allow us to work in the range of light atomic masses up to 10 at outer cyclotron heating and in the range of heavy masses of 100 to 200 in case of ICR instability.

When developing a separator that operates using any of the mentioned ICR methods much attention is paid to the selection of a plasma source, in which the plasma is formed and then it is transported into a magnetic field with further IC-heating and separation of hot and cold ions. For industrial mass separators the steady mode of operation is a normal one. Thus, the Archimedes project envisages the possibility of using the steady-state HF-plasma source of 4MW. However, for demo simulation experiments it is reasonable to use quasi-steady, i.e. pulse mode, which allows the reduction of capital and operating costs. However, the pulse power and pulse duration should be such that physical interpretation of the data obtained and possible technical and economic application could cause no doubts. The plasma pulse duration should be equal to about or more than $\tau \approx L/v_p$, where L is a system length, v_p is a plasma velocity. According to our evaluation, the pulse duration should be at the level of 1 to 10ms, and the plasma density should be in the range of 10^{10} to 10^{13} cm^{-3}; this in certain way prescribes the plasma sources parameters. In this case, the plasma should have optimal parameters to escape collisional effects. At the present time, a variety of plasma sources are available, however only some of them are capable of providing the above mentioned modes, i.e. can be used for the isotope separation. This paper tries to determine requirements set to the plasma injectors that should provide the injection of multi-component plasma fluxes suitable for the plasma separation in the crossed E and H fields, as distinct from [2,4], where plasma was formed directly inside a trap. We employ the sources of a coaxial type in a steady-state and pulse mode. This paper gives the preliminary experimental results.

2. PLANT DESCRIPTION

The experiments were carried out using the plant with a vacuum chamber that had an evacuation system and a magnetic system generating a longitudinal field, Fig.1. This figure shows also the magnetic field topography in the discharge area. The vacuum chamber of a separator consists of two parts. The first part of the chamber has a calorimetric transformer 2 installed on a bracket 1 that can move along the magnetic system axis. The gas is evacuated using a diffusion pump. The second part of the chamber is a separator magnetic system that consists of a long solenoid 3 and a plug solenoid 4.

A coaxial plasma source 5 is installed at the rear end of the magnetic plug 4. It consists of a core electrode 6 that is located inside a hollow cylinder 7. The cylinder and the electrode are made of stainless steel. A radial gap between them is 40 mm.

A cylinder-core discharge is initiated by a pulse inlet of gas into the working area through a valve 8 applying a triggered voltage to the electrodes.

A power supply circuit of the plant includes a rectifier that feeds the magnetic system and two pulse systems that provide operation of the plasma accelerator and pulse gas inlet system.

A capacitor bank that provides operation of plasma source is assembled of capacitors IM 2-5-140 U4 with a total capacity of 1400 μF. A maximum charging voltage is of 5 kV. The discharge was initiated from the additional chamber by the pulse gas inlet through the valve KMPN-10 (Pos.8, Fig.1) powered by the pulse power supply source with a pulse duration of 20 ms from an additional chamber with gas pressure of 15…50 Torr.

During the gas inlet the pressure in the main chamber was rising up to $(3…6)\cdot10^{-3}$ Torr and the particles in amount of $(1.7…3)\cdot10^{19}$ cm^3 were injected. The air was used as the inlet gas. The calorimeter was a copper plate of 0.1 mm thick, ∅120 mm on the back of which the thermocouple chromel-allimel was welded. The calorimeter mass was of 5.09 g. The distance to the plasma source was variable in the range of 70 mm to 600 mm.

The chamber was evacuated down to the pressure of $4\cdot10^{-5}$ Torr.

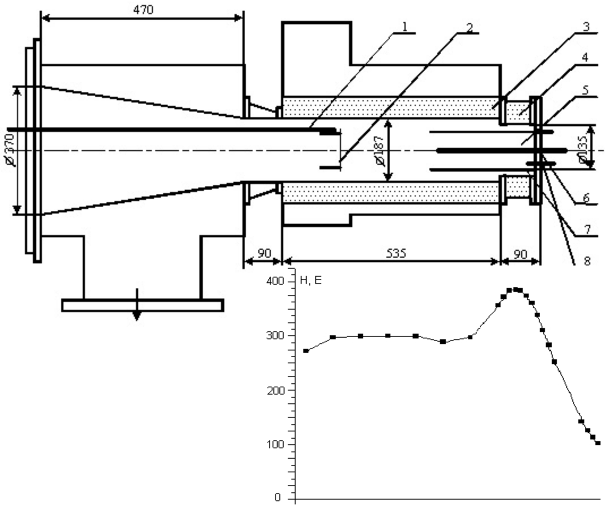


Fig.1. General view of the chamber and distribution of magnetic field within the system
1 – bracket; 2 – calorimeter; 3 – solenoid; 4 –magnetic plug; 5 – plasma source; 6 – core electrode; 7 – cylinder; 8 – inlet valve

3. CARRYING OUT AN EXPERIMENT

The plasma energy ΔQ supplied to the calorimeter by a plasma flux that is oriented along the magnetic field axis with N particles per $1 cm^2$ is equal to

$$\Delta Q = 4.186 \cdot M_c \cdot C_p \cdot \Delta T = N \cdot W_x \cdot A \cdot f \quad (1)$$

where ΔQ is an energy, J; M_c is a mass of calorimetric element, g; Cp is a specific heat capacity of the calorimeter material equal to 0.385 kJ (kg·K); ΔT is an observed increase in temperature, °C; A is an area of the calorimetric element, equal to 452, 39 cm^2; N is a number of particles per 1 cm^2; W_x is an average kinetic energy of the particles, J; f is an amount of energy absorbed by calorimeter, equal to 0.5.

The current discharge oscillogram with the battery charged up to 2 kV is shown in Fig.2. The measurements were taken using the noninductive shunt of $1.08\cdot10^{-3}$ Om. The pulse duration makes up 140 µs and the maximum current is equal to 46.2 kA.

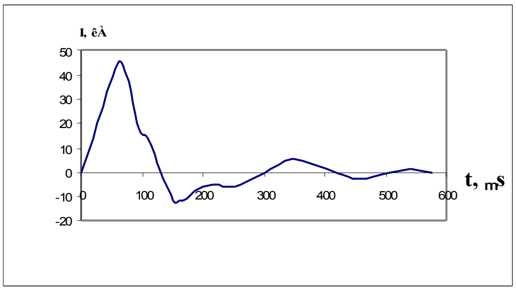


Fig.2. Current pulse oscillogram

The calorimetric measurements were made at different distances from the plasma source at different voltages of the power supply source.

Fig.3 shows the graph of the calorimetric measurements.

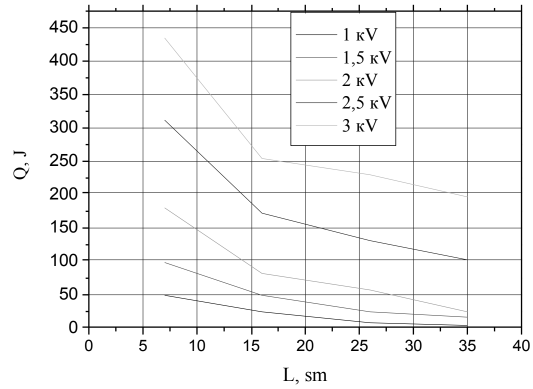


Fig.3. Dependence of the energy transferred to the calorimeter upon the distance and voltage

The energy dependence liberated by the internal electrode on the value of magnetic field and polarity is shown in Fig.4. This resultant dependence shows that the system should be cooled in quasi mode and steady – state mode.

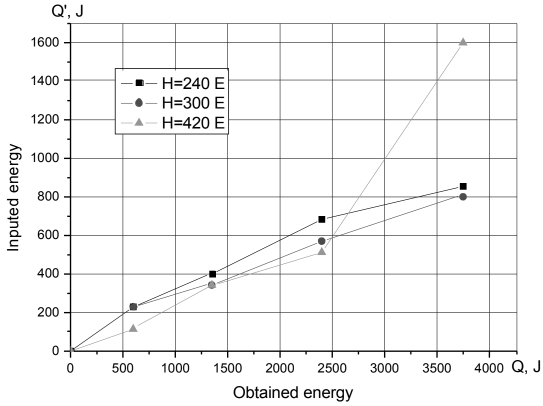
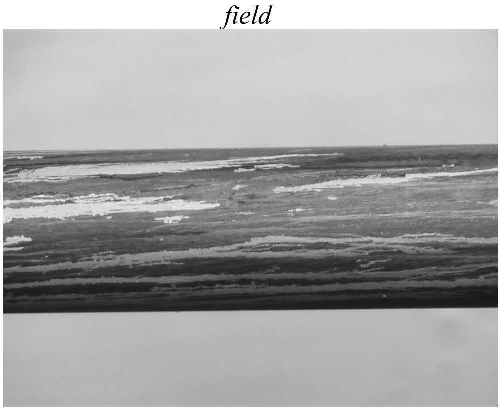


Fig.4. The dependence of the extracted energy on the central electrode upon the battery power and magnetic field



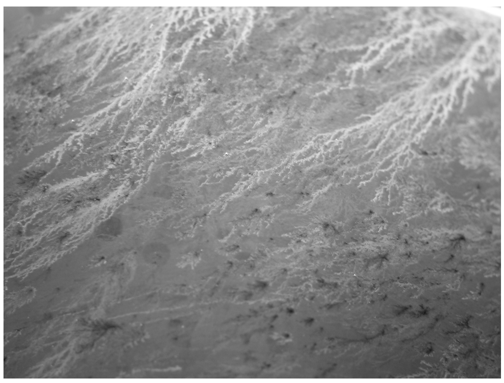


Fig.5. Erosion characteristics of electrodes

The erosion characteristics of a discharge, see photo in Fig.5, are of great importance. This photo shows the trails of cathode-anode spots on the central electrode which is called cathode 6 and on the internal anode surface of the cylindrical electrode 7. Those spots deliver a great amount of metal ions into discharge plasma.

However, it should be noted that during the experiments conducted using the Xe-Kr-Ar mixtures the metal admixtures will add the atomic numbers between 80 and 30, i.e. between Kr-Ar. to the mass-spectrum; that should not affect the result of an experiment.

CONCLUSIONS

The results show that the obtained plasma is quite suitable for the demo simulation experiment on separating Xe-Kr-Ar-Me mixtures. To increase the pulse duration it is necessary to increase the battery capacity. It is reasonable to conduct an experiment on using lower discharge voltages.

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ТЕХНОЛОГИЧЕСКИЙ КОАКСИАЛЬНЫЙ ПЛАЗМЕННЫЙ УСКОРИТЕЛЬ

В.Б. Юферов, Ю.В. Ковтун, В.И. Ткачев, В.А. Сероштанов, Е.И. Скибенко, С.В. Шарый, Д.В. Винников, О.С. Друй, В.Ф. Тихонов, Н.А. Косик, А.Н. Пономарев, Л.Г. Сороковой

Исследуются плазменные источники-ускорители для процессов сепарации и обработки поверхностей. Обсуждаются условия выбора параметров системы, плазменного потока, системы напуска газа, источника питания. Экспериментально получены их параметры. Сделан вывод о роли металлических продуктов эрозии электродов.

ТЕХНОЛОГІЧНИЙ КОАКСІАЛЬНИЙ ПЛАЗМОВИЙ ПРИСКОРЮВАЧ

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Досліджуються плазмові джерела прискорювачів для процесів сепарації та обробки поверхонь. Обговорюються умови вибору параметрів системи, плазмового потоку, системи напуску газа, джерела живлення. Експериментально одержані їх параметри. Зроблені висновки щодо металевих продуктів ерозії електродів.