*29th EPS Conference on Plasma Phys. and Contr. Fusion Montreux, 17-21 June 2002 ECA Vol. **26B**, P-5.049 (2002)*

Quasi-Stationary High-Current Plasma Accelerator as Plasma Injector for Fusion Devices

S.I.Ananin[1], V.M.Astashynski[1], V.S.Burakov[1], E.A.Kostyukevich[1], A.M.Kuzmitski[1], N.V.Tarasenko[1], I.Dojcinovic[2], M.M.Kuraica[2,3], J.Puric[2,3], I.R.Videnovic[2,4]

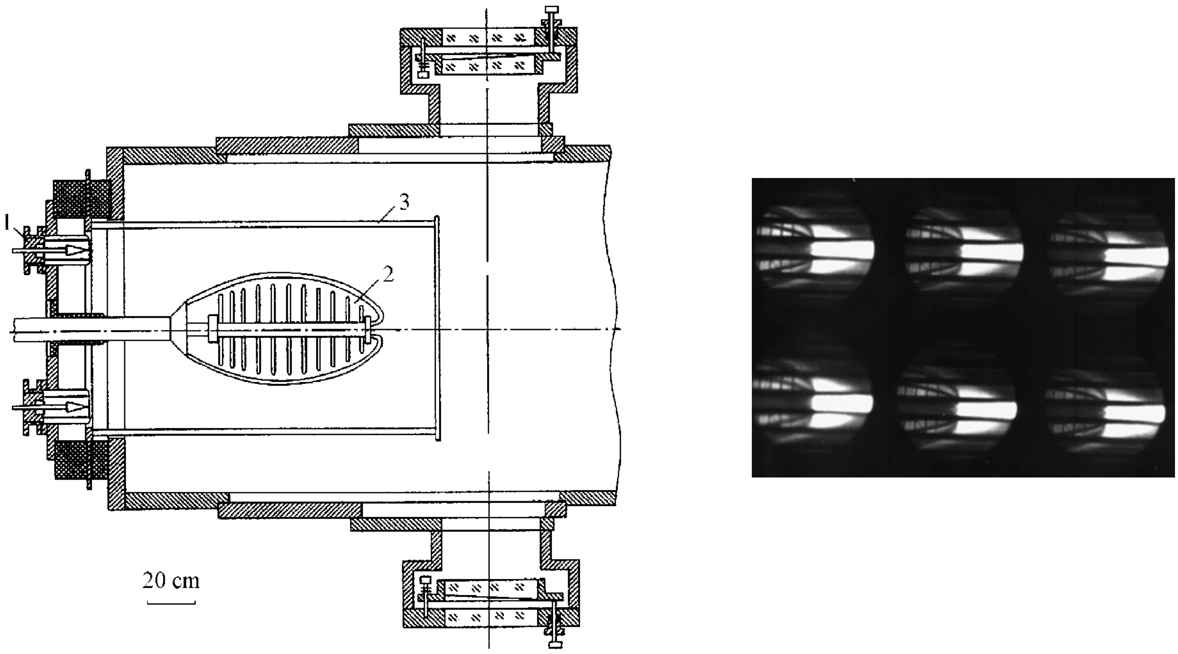
[1] *Institute of Molecular and Atomic Physics of National Academy of Sciences of Belarus, Minsk, Belarus; E-mail: ast@imaph.bas-net.by*
[2] *Faculty of Physics, University of Belgrade, P.O. Box 368, 11001 Belgrade, Yugoslavia*
[3] *Center for Science and Technology Development, Obilicev Venac 26, Belgrade*
[4] *Institute of Physics, University of Basel, Switzerland*

Introduction. Much attention is given to development of various fueling methods (such as gas-puffing and ice pellet injection, neutral beam injection and compact toroid injector) for fusion devices. The most advanced of them seems to be compact toroid injection (CTI) [1-3]. However, even CTI has essential problems associated with the necessity to considerably increase lifetime of compact toroid and its electron density as well as to substantially reduce CTI impurity level.

In this paper the capabilities of a new generation plasma accelerator – quasi-stationary high-current plasma accelerator (QHPA) – as plasma injector for stellarator and tokamak fueling are considered.

The QHPA, unlike other accelerators, represents two-stage plasmadynamic system operating in an ion current transfer mode and providing ion-drift acceleration of magnetized plasma [4]. The function of the QHPA first stage is to inject completely ionized plasma flows into the second stage, i.e. in the main accelerating channel formed by so called anode and cathode transformers (electrodes). The anode transformer emits into the accelerating channel the ion stream equal to the discharge current of the second stage, while the cathode one accepts this stream. The magnetic systems of both anode and cathode transformers protect solid elements of their constructions from exposure to powerful plasma flows.

Experimental setup. One version of such plasmadynamic system is QHPA of P50M type (50 is characteristic scale equal to the external electrode diameter in centimeters), in which both anode and cathode transformers are formed by copper rods [5]. The Fig. 1a schematically shows an accelerator discharge device. The QHPA first stage (the input ionization block) consists of four units, which construction is developed on a basis of a magnetoplasma compressor of a compact geometry with the electromagnetic valve for delivery of working gas (hydrogen) [6,7].



a b

Fig. 1 a – diagram of the discharge device of the QHPA: 1 – input ionization chamber; 2 –cathode transformer; 3 – anode transformer;
b – sequence of photos of plasma flow; frame frequency – 125000 frame/sec

The anode transformer is formed by 36 copper rods each measuring 120 cm in length, symmetrically located along a circle of 50 cm in diameter. The semi-active cathode transformer consists of two coaxial cylinders separated by insulators and connected by 16 copper rods forming an ellipsoid of revolution. Copper needles, located in a gap between rods on the inner cylinder, act as current collectors. Accelerating channel elements are shielded by magnetic field of intrinsic current flowing along rods of anode and cathode transformers.

Three sectioned capacitor banks served as energy storages feeding the accelerator main stage (W_0 = 150 kJ), the input ionization block (W_0 = 45 kJ), and the valves (W_0 = 5 kJ).

Results and discussion. The discharge duration in the QHPA amounts to 500 μs and the peak value of discharge current, depending on initial parameters of discharge, ranges from 200 to 450 kA. Under these conditions, a compression plasma flow 50 cm in length and with a diameter of 3 cm in the maximum compression zone is formed downstream of inner electrode (cathode) tip (Fig. 1b). The compression of plasma flow takes place due to interaction of longitudinal component of discharge current “swept away” from the discharge device, with the intrinsic azimuth magnetic field. The presence of the “swept-away” current in plasma flow is a direct consequence of magnetic field freezing in plasma [4].

As follows from our experiments carried out by high-speed methods of photo-registration, interferometry and spectroscopy, plasma velocity in compression flow is $2 \cdot 10^7$ cm/s, electron density – up to 10^{17} cm^{-3} (Fig. 2), and electron temperature – 10-15 eV [8,9]. These results are consistent with data of numerical simulation of physical processes in QHPA carried out by large particles method [10].

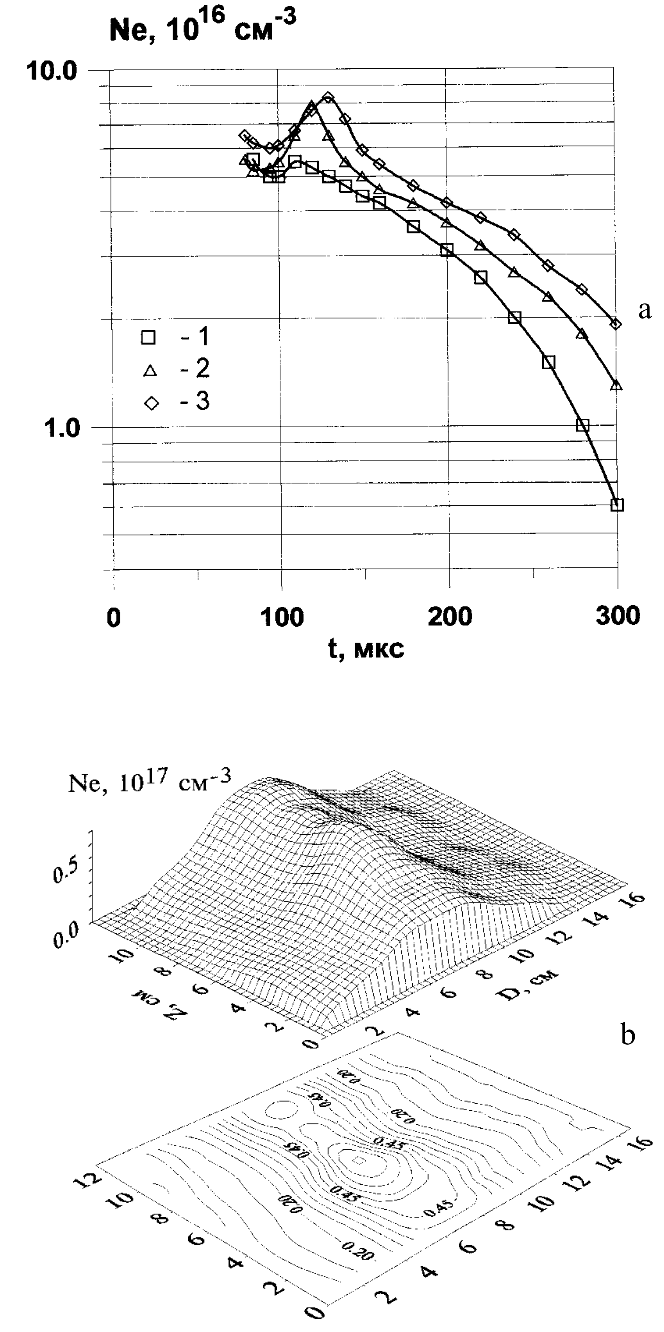


Fig. 2. Temporal evolution (a) and spatial distribution (b) of the electron density in the compression plasma flow in QHPA

As to design features of QHPA discharge device, impurity level in plasma flow is considerably less compared to any other type of accelerators. Amount of impurities in compression plasma flow can be monitored by method of laser-induced fluorescence spectroscopy (LIF). The LIF method has advantages of high sensitivity combined with good spatial and temporal resolutions. LIF is often the only diagnostic technique which can provide the desired information without perturbing the plasma parameters.

In our early experiments the LIF method was successfully employed to study spatial profiles of atomic and ionic densities in plasma of hollow cathode discharges [11], as well as for determining the density of hydrogen atoms and metal impurities in high-temperature tokamak plasmas [12-14]. From the estimation of detection limits and from the discussion of properties of available laser system it appears that LIF satisfies the most of existing requirements for in situ diagnostics of impurities in QHPA plasma. We assume for our estimate that the limitations are mainly imposed by the strong background (primarily Bremsstrahlung) radiation from plasma. The detection limits for metal atoms such as copper and iron has been estimated to be of the order of 10^7–10^8 cm^{-3}.

Conclusion. A distinctive feature of QHPA is large (as compared to compact toroid injector) duration of existence of plasma flow with high parameters and low in impurity content. It should be noted that QHPA enables discharge duration to be extended substantially by a mere increase in energy storage capacity.

References

[1] J. Miyazawa, H. Yamada and O. Motojima. Jpn. J. Appl. Phys. **37** (1998) 6620.

[2] T. Ogawa, H. Ogawa, Y. Miura et al. J. Nucl. Mater. **290-293** (2001) 454.

[3] J. Miyazawa, H. Yamada, K. Yasui et al. Fusion Engineering and Design **54** (2001) 1.

[4] A.I. Morozov. Sov. J. Plasma Phys. (Engl. transl.) **16** (1990) 79.

[5] S.I. Ananin, V.M. Astashinskii, G.I. Bakanovich et al. Sov. J. Plasma Phys. (Engl. transl.) **16** (1990) 102.

[6] V.M. Astashinskii, V.V. Efremov, E.A. Kostyukevich et al. Sov. J. Plasma Phys. (Engl. transl.) **17** (1991) 545.

[7] I.P. Doichinovich, M.P. Gemishich, B.M. Obradovich, M.M. Kuraitsa, V.M. Astashinskii, J. Puric. J. Appl. Spectroscopy **68**, (2001) 529.

[8] V.M. Astashinskii, A.A. Man'kovskii, L.Ya. Min'ko, A.I. Morozov. Sov. J. Plasma Phys. (Engl. transl.) **18** (1992) 47.

[9] S.I. Ananin, V.M. Astashinskii, E.A. Kostyukevich et al. Plasma Physics Reports **24** (1998) 936.

[10] S.I. Ananin, V.M. Astashinskii. Plasma Physics Reports **23** (1997) 37.

[11] V.S.Burakov, P.A.Naumenkov, N.V.Tarasenko. J. Appl. Spectroscopy **50** (1989) 140.

[12] V.S.Burakov, and G.T.Razdobarin. Izv. Akad. Nauk SSSR 46 (1982) 957.

[13] V.S.Burakov, G.T.Razdobarin, N.V.Tarasenko et al. Sov. J. Experimental and Theoretical Physics, Letters **37** (1983) 308.

[14] V.S.Burakov, G.T.Razdobarin, N.V.Tarasenko. J. Appl. Spectroscopy **53** (1990) 547.