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Two stage plasma gun as the fuelling tool of Globus-M tokamak

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Development of an efficient fuelling method for the thermonuclear reactor allows controlling the ignition, burning and mitigation of the discharge in the magnetic plasma confining system. For the reactor the source has to generate a number of particles $10^{20} \div 10^{23}$, density $>10^{22}m^{-3}$, flow velocity 100 ÷ 800 km/s. Fuelling system has to inject low impurity fuel. The method of high kinetic energy jet injection into a tokamak is developed and tested at the Ioffe Institute. Two stage plasma gun with explosive method of gas feeding a coaxial accelerator generates clean plasma jet of high velocity and density [1]. Experiments with injection of the dense fast plasma jet into Globus-M have demonstrated the viability of such fuelling method with minimum plasma perturbations [2-4].

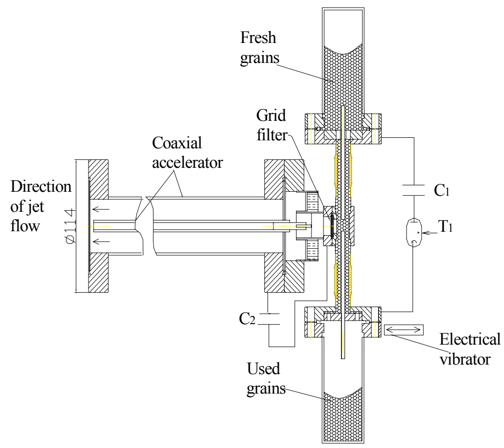


Fig.1: Two stage plasma gun, with explosive method of gas feeding a coaxial accelerator

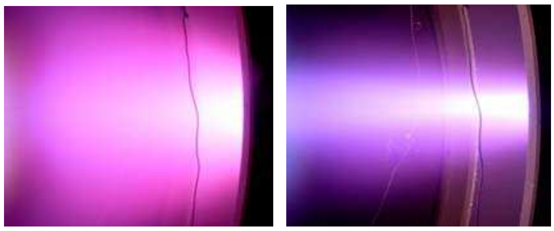
Plasma gun investigation at the test facility

The source consists of two stages - gas generating and plasma accelerating (Fig.1). The gas generating stage contains titanium grains loaded with hydrogen. An electric discharge passing through the grains releases high-pressure hydrogen. Neutral hydrogen passing through a specially designed grid fills the accelerator electrode gap to a high pressure in a few tens of microseconds. Due to replacement of the granules in the discharge gap of the gas stage before each shot, the latest version is able to produce more then 1000 shots with satisfactory reproducibility without recharge. The plasma generating stage is actually a system of coaxial electrodes. Electric

Table 1

Parameter/ year	Jet density, m^{-3}	Jet velocity, km/s
1999	10^{21}	15-20
2003	10^{21}-10^{22}	30
2008	$>2x10^{22}$	>200

discharge fired through the gas between the coaxial electrodes provides gas ionisation and plasma acceleration in the classical "Marshall gun scenario". The external circuit inductance was reduced which helped to increase accelerating current in a shot pulse of 10 μs.



Jet energy 20 J   Jet energy 200 J

Fig.2: Photos of the jet for different energies

Considerable increase of plasma jet parameters was obtained (Table 1) at limited power supply energy (2 kJ) to minimize impurity generation.

A pictures of the jet made with photo camera testifies the smaller divergence in comparison with the previous gun modification (Fig.2). The jet energy measured with a calorimeter was increased up to ~200 J. The jet propagation speed was measured by means of streak-camera. Photo in fig.3 proves the fact that the plasma jet consists of several components (clusters), each of them propagates with its own speed. Investigation showed that the jet velocity depends on capacitor voltage squarely (Fig.4). Also the jet was observed with a frame camera (Fig.5). The pictures show that typical cluster length fluctuates in few centimetres.

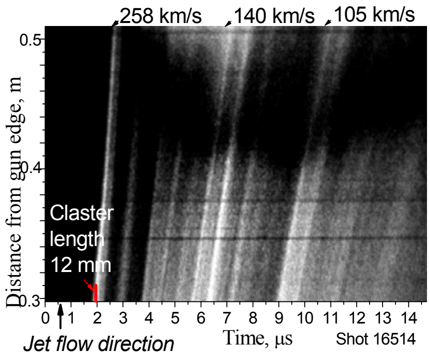


Fig.3: Propagation of the jet radiation recorded with a streak-camera

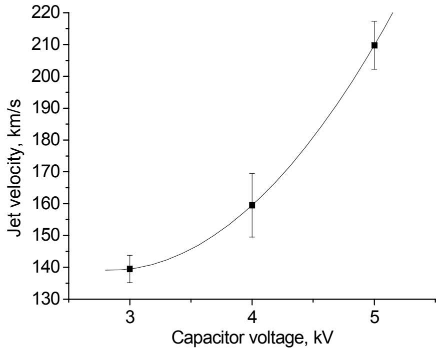


Fig.4: Dependence of the jet velocity on voltage at the capacitor

Intensive plasma jet injection experiments at Globus-M

The design description, operational principles and experimental program of Globus-M are described in [5]. The basic design characteristics are as follows: aspect ratio A=R/a=1.5, major plasma radius R=0.36 m, minor plasma radius a=0.24 m, toroidal magnetic field at the vessel axis B_T = 0.2 – 0.5 T, plasma current I_p = 0.1 – 0.35 MA, average plasma density $n_e = (1 - 10) \times 10^{19}$ m^{-3}, pulse duration with inductive current drive $\tau_{pulse} \leq 0.15$ s. The jet was injected into Globus-M at the equatorial plane along the major radius from the low field side through 0.5 m recombination chamber. So, the dense and cold (1÷10 eV) plasma jet did not recombine completely into neutrals and may be deflected by the magnetic field.

Jet interaction with toroidal magnetic field for velocity ≤ 250 km/s was investigated. Injection into the tokamak magnetic field confirmed presence of components with different speeds registered by earlier measurements with streak camera. The deeper penetration was recorded in comparison with previous experiments at injection into the tokamak toroidal field [2]. Photos of the jet propagation through the tokamak chamber at the magnetic field on, but without plasma are shown in Fig.6. It is seen that the components with different speeds deviate for different angles.

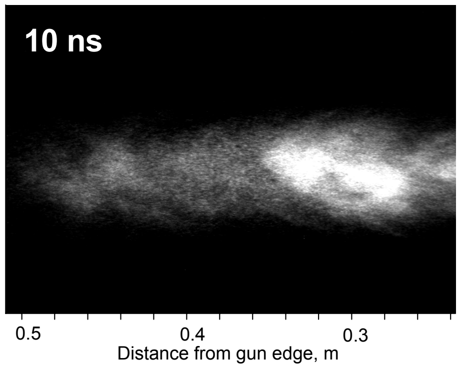


Fig.5: The jet observed with frame camera

Experiments with injection of the dense fast plasma jet into Globus-M plasma have demonstrated the viability of such method of fuelling with minimum perturbations. A video frame of the jet injection into the tokamak plasma discharge recorded by means of a fast camera (4000 frames/s) is shown in Fig.7b. Deep jet penetration into the plasma core of Globus-M was observed. The fast density increase and temperature drop in the shot was recorded by means of multi-pulse Thomson diagnostics during the first millisecond after the injection (Fig.7a). The measurements showed that already in 50 µs after the start of the plasma jet injection into the target plasma with the current of 0.2 MA and density of (2-6)×10^{19} m^{-3} the plasma density at the magnetic axis increases and the temperature drops, at that, changes in the central region are stronger than at the periphery (details see in p2.108, this conference).

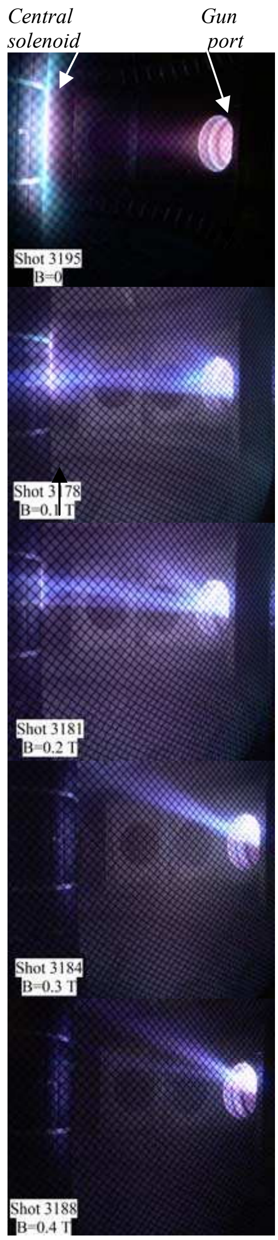


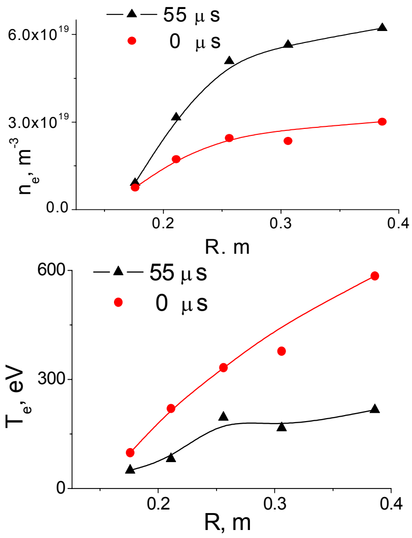
Fig.6: Jet deviation in toroidal magnetic field

Conclusions

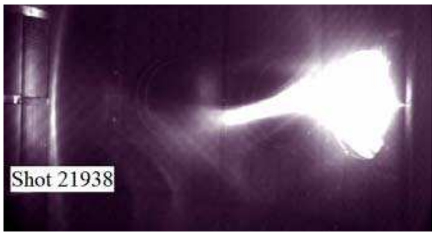
Further results on optimisation of the source parameters to provide higher values of plasma jet appropriated for large-scale tokamak feeding are reported. The clean hydrogen plasma jet with a density >2×10^{22} m^{-3}, total number of accelerated particles (1-5)×10^{19} and a flow velocity >200 km/s is developing for the density control in the

Globus-M spherical tokamak. The source produces stable gas and plasma flow for many shots (>1000 pulses) due to modification of gas and plasma generating stages. Kinetic energy of the jet was increased by higher power of the discharge at limited capacitor storage energy (2kJ). A calorimeter registered several times higher energy of the jet flux as compared with energy obtained in earlier gun modifications.

Behaviour of the jets in vacuum magnetic field and in the Globus-M plasma was investigated. Video and streak cameras registered that the jet consists of different components with separate velocities. Deep jet penetration into the plasma core of Globus-M was observed and plasma density profile modification was achieved. This fact seems to testify that the significant part of the injected particles is stopped just in the central region of the plasma column. Investigation, optimisation and further employment of the source at Globus-M permitted to confirm its efficiency as a tool for plasma fuelling and control of the parameter profiles.



a *Shot 21660*



b

Fig.7: Jet injection into plasma core
a) Electron density and temperature profiles before and after 55 μs the gun shot;
b) Jet penetrating in Globus-M plasma core; toroidal magnetic field 0.4 T

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