Plasma gun with super fast gas feeding in fusion research

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One of the problems of controlled fusion is fuelling of the reactor plasma. To allow central penetration to ITER-like plasma core fuel jet injection technique with density $>10^{22}$m^{-3} and flow velocity up to 1000 km/s should be used. The improved gun produces a fully ionised clean hydrogen jet with the density up to 3×10^{22} m^{-3}, kinetic proton energy up to 300 eV and minimal number of particles 5×10^{18}. Intense electric discharge passing through the titanium hydride grains releases the high pressure gas, which is feeding coaxial plasma accelerator [1]. Latest gun modifications were directed on: a) reduction of impurities and the number of accelerating particles in the jet; b) improving reproducibility of the gun; c) plasma parameter control in tokamak Globus-M with intensive jet without discharge degradation; d) investigation of fusion grade materials irradiated by the jet.

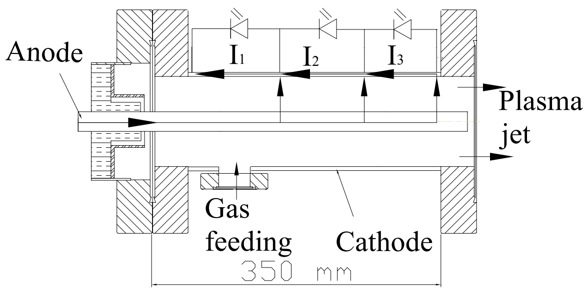


Fig. 1: Coaxial plasma gun equipped with radial gas feeding and current layer detectors

The present accelerator has radial gas feeding instead of axial one used in earlier versions (Fig.1). Electrode polarity was reversed similar to the plasma focus scheme. The gun was equipped with diagnostics allowing regular measurements of energetic and spectral characteristics both at the tokamak and test bench

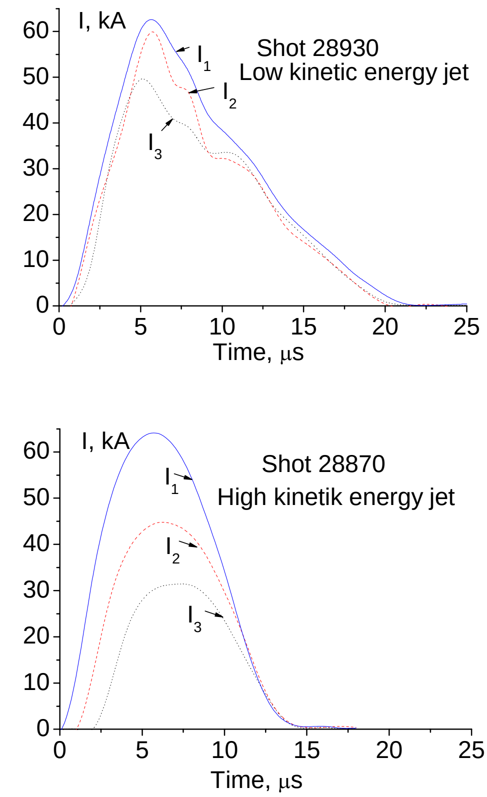


Fig.2: Time dependence of current distribution along muzzle at low and high kinetic energy jet

facility. Light diodes placed along the outer electrode registered current distribution along the muzzle. It was found that only a movable current layer may produce the clean and high kinetic energy jet. The gun generates low energy jet if the current is mainly localised near inlet and/or outlet gun edge (Fig.2 upper curves). Contrary, high energy is generated when the current is running along the muzzle (light diodes signals are delayed one to another, Fig.2 lower curves). Better reproducibility of the output gun was achieved by optimisation of the gap between electrodes. These modifications allowed us twice increasing the gun efficiency. The gun can generate 200 J plasma flow at 1280 J capacitor storage energy (compare to 2500 J for earlier gun versions). This gun has a perspective for raising the jet parameters.

Investigations of the jet injection dynamics in the plasma discharge of the Globus-M spherical

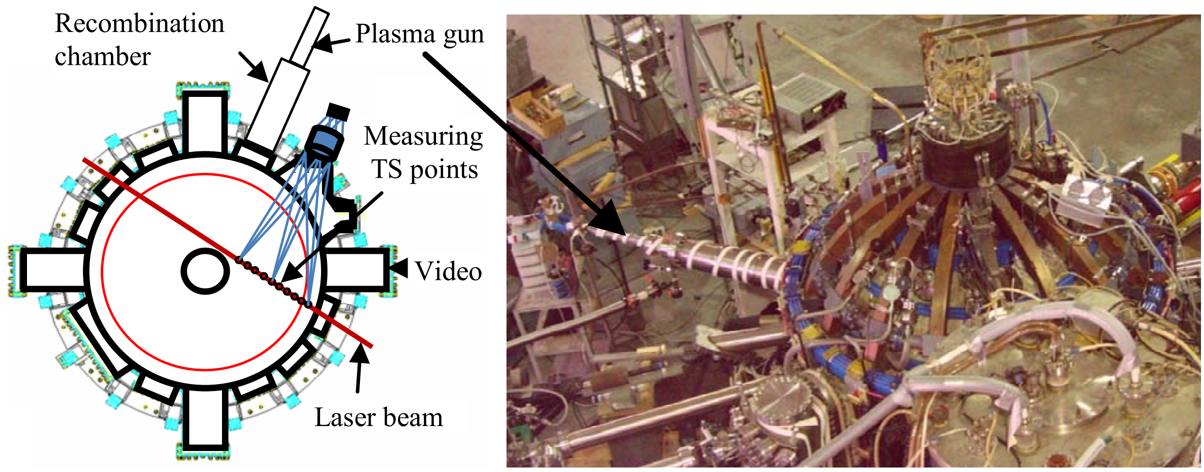


Fig.3: Top view of plasma jet injection experiment at the Globus-M

tokamak were carried out (Fig.3) [2-6]. The jet was injected through 1.5 m recombination chamber, where the plasma jet performs time-of-flight recombination into the neutral flux and may avoid interaction with tokamak magnetic field. Toroidal field B_T = 0.4 T was chosen for the experiments. Video camera Olympus i-speed 2

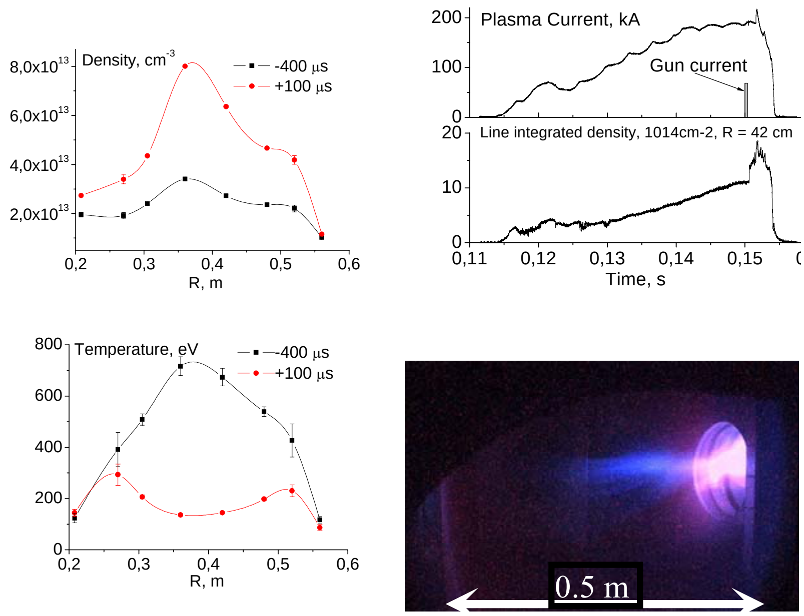


Fig. 4; Strong jet penetration inside Globus-M plasma column; shot 26900; accelerating voltage 4.4 kV monitored the jet radiation during injection in the target tokamak plasma. Upgraded for 10 spatial points, a multi-pulse TS system measured density and temperature distribution across the plasma column. Jet penetration and propagation inside the Globus-M plasma column for different conditions was recorded.

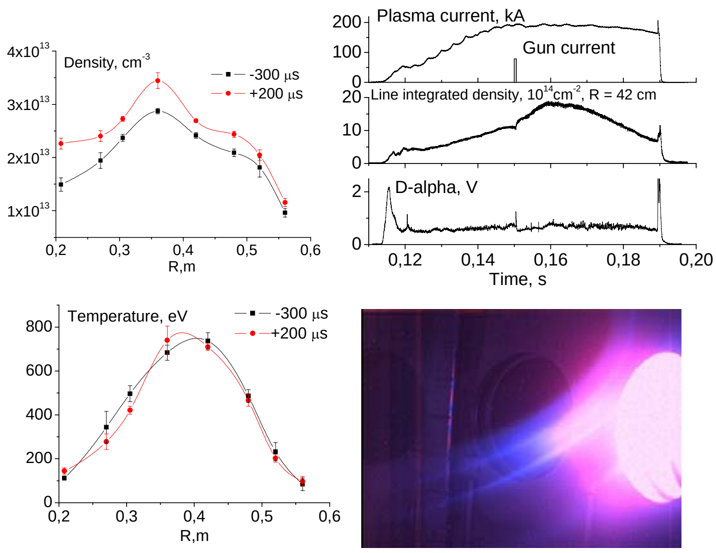


Fig.5: Lower jet energy injection into the Globus-M plasma column; shot 26836; accelerating voltage 4.2 kV

Strong jet penetration inside column at high accelerating voltage (high jet energy) was observed (Fig4). The tokamak plasma density increased 2 -3 times but the temperature decreased about 7 times. Discharge survived during only a few milliseconds after such injection. Video frame demonstrated jet penetration into the plasma column (exposition time 250 μs). At lower accelerating voltage (4.2 kV - the jet energy is lower) the discharge survived until the end of the tokamak shot (Fig.5). In this case the density raised about 25 % and temperature didn't change in the range of accuracy of measurements. Jet penetration into the plasma column after H-mode initiated with NBI was investigated (Fig.6). After jet injection the density increased and temperature decreased by 40 %. The discharge lived many milliseconds after injection.

The pure hydrogen jet of the gun was used for irradiation of fusion reactor material (ferrite steel 10Cr9WVTa). A sample was located perpendicular to the gun axes at distance 50 mm from gun edge and irradiated by 10 μs pulse flux. The surface structure of the irradiated samples was analyzed with a scanning electron microscope (SEM). Modification

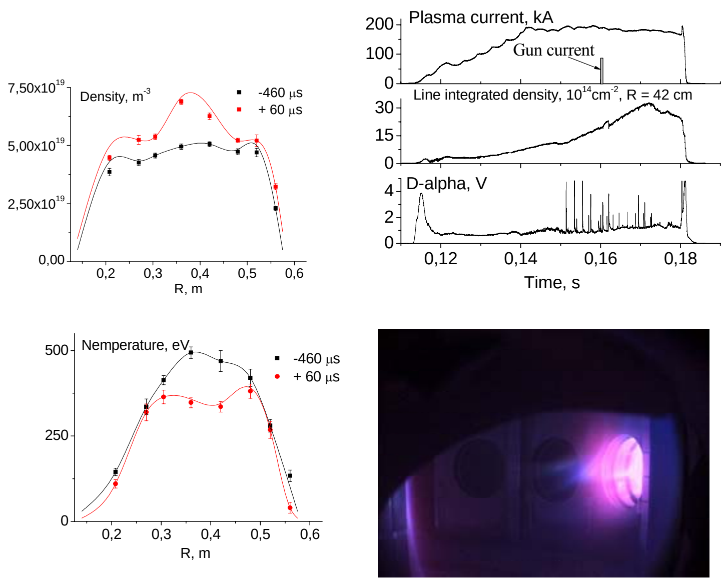
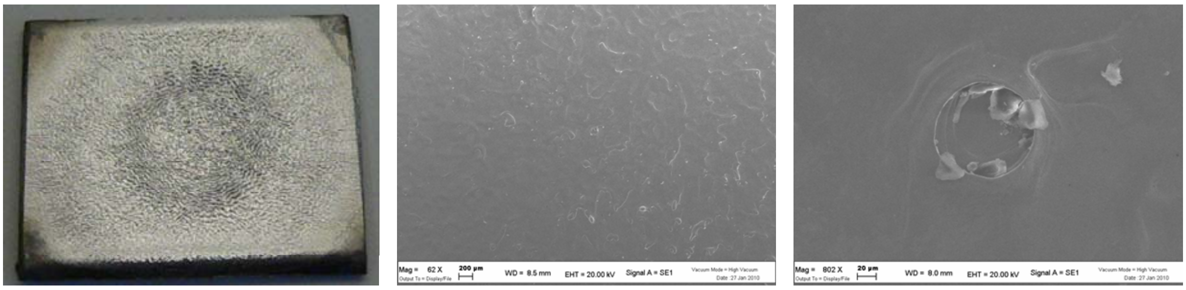


Fig.6: Jet penetration in plasma column after H-mode initiation with NBI; shot 26896; accelerating voltage 4.4 kV



10 mm a 200 µm b 20 µm c

Fig.7: Photo of ferrite steel 10Cr9WV surface irradiated by pulse hydrogen plasma jet for different space resolution: a-sample 24x30 mm, 15 shots; b – SEM, 200 µm; ***c*** *– SEM, 20 µm*

of the ferrite steel surface after irradiation was observed. Topographical structure had central symmetry ≈ 15 mm in diameter with a deep relief (Fig.7a). Actually the wave relief arises at power density > 1 MW/cm^2. The surface had no structural defects such as bobbles, craters, pores, microcracks. Such defects usually happen at higher fluxes 10-100 MW/cm^2 typical for plasma focus with pulse duration 0.1 – 1 µs (Fig.7b) [6]. Only some open bubbles large diameter ~ 50 µm were observed (Fig.7c). These results confirm both the better perspectives of 10Cr9WVTa steel like Eurofer97 as comparison with austenite steels for fusion application and the fact that the gun produces power density flux > 1 MW/cm^2.

The achieved results approve a perspective of upgraded plasma gun in fusion application. The gun can produce clean hydrogen jet with density up to 3×10^{22} m^{-3} and kinetic proton energy up to 300 eV in Globus-M like plasmas. The jet is able to penetrate into the central region of the plasma column without discharge degradation. Non destructive surface influence of the jet flux with the power density 1 MW/cm^2 on fusion reactor materials was demonstrated. The results confirm the better perspectives of ferrite steel as comparison with austenite steels for fusion application. At the test bench facility the gun had a better reproducibility than in the tokamak experiments. Fine gun positioning at the tokamak porter is planning.

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