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INJECTOR OF LITHIUM JET FOR T-10 WALL CONDITIONING

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Introduction. Optimization of the operation regimes of magnetic confinement machines is still an important problem of high temperature plasma physics. It is well known that a solution of the problem distinctly reduces expenses of achievement of quasi-stationary thermonuclear reaction at laboratory conditions [1]. The operation regimes depend crucially on the first wall condition and processes at peripheral plasma. It was shown in experiments [2] that covering the first wall by a few mono-layers of a light impurity (Li, B, C) gains the absorption property and essentially reduces heavy impurities fluxes into the plasma core. A wall conditioning effect leads to significant improvement of general plasma parameters (effective charge, electron temperature, density, energetic confinement time, neutron flux etc.), which may essentially decrease the ignition threshold [3].

The first experiments with injection of lithium pellets of about 1 mm in size and $(1.6–2.2)\cdot 10^{19}$ atoms contents into T-10 plasmas have demonstrated the initial weak signs of the Li discharge conditioning only [4] due to a lack of the injected lithium quantity. Furthermore, the deep penetration of Li pellet could hinder from obtaining the scenario favorable for wall conditioning. It was proposed to increase the amount of injected lithium with simultaneous decrease of its penetration depth. This injection method can be realized by delivering the lithium into the plasma in the form of liquid metal jet.

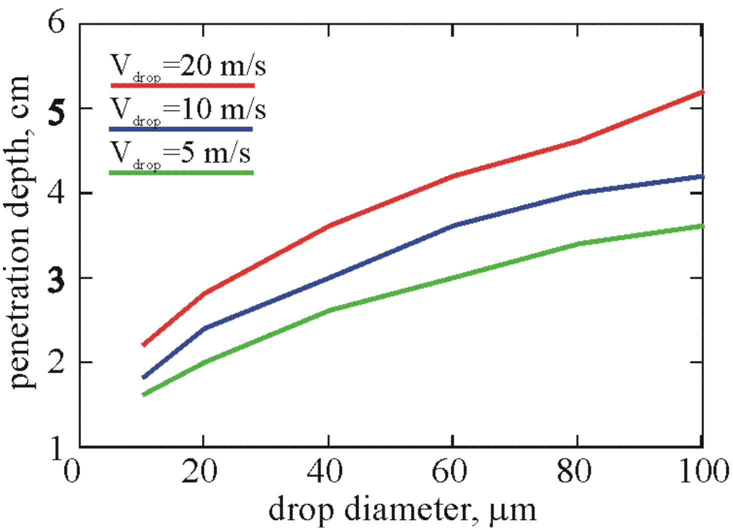

Fig.1. Simulated penetrations of Li droplets in T-10 plasma

Estimations and simulations. Jet velocity and diameter can be estimated assuming that for wall conditioning the plasma by Li it is necessary to cover T-10 vessel surface in 3-4 monolayers of lithium ($\sim 2\cdot 10^{20}$ atoms content). So one could create annular lithium domain in the plasma edge with the 10^5 cm^2 surface area, 1 cm thickness and

10^{13} cm^{-3} densities (~10^{18} Li atoms content). If we estimate the lifetime of these atoms as the leaving time along the magnetic field lines $2\pi Rq / V_{Ti} \approx 5$ ms, the necessary lithium flux is required $2\cdot10^{20}$ atoms per one-second discharge duration. As the lithium atomic density is $5\cdot10^{21}$ at/cm^3, this leads to 40 mm^3 of lithium input into plasma per second. This Li supply can be realized by injection in T-10 discharge the lithium jet 50 μm in diameter with velocity 20 m/s or 100 μm in the jet diameter with velocity 5 m/s.

A simulation of lithium droplets penetration in typical T-10 plasma (central electron temperature and density are 1 keV and $4\cdot10^{13}$ cm^{-3} correspondingly, parabolic-like profiles) has been performed. A scaling based on the neutral shielding model was used (see Ref. [5]). Simulation results are presented in Fig.1. It is seen that even for fast (20 m/s) and big (100 μm) drops penetration the depth does not exceed 5 cm. That fact coincides with a presumed peripheral Li deposition assumed above.

Lithium jet injector schematic, principle of operation and technical parameters. A sketch of the lithium jet injector, which satisfies the requirements listed above, is shown in Fig. 2. The injector consists of the following main components: 1 – stepping motor, 2 – system of the transition movement into vacuum, 3 – piston, 4 – lithium syringe, 5 – heater, 6 – lithium chamber, 7 – removable nozzle, 8 – thermocouple. The formed lithium jet is shown as well (9). Injector elements that are in a contact with melted lithium are produced using materials with adequate rustproofing coating.

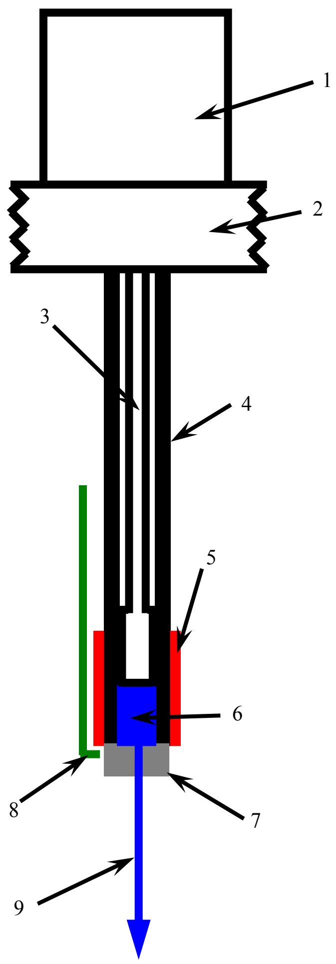

Fig. 2. Lithium jet injector sketch

The principle of injector operation is as follows. Motion of the stepping motor (1) is transferred to the lithium syringe piston (3) by the system of the transition movement into vacuum (2). The lithium, which is melted by the heater (5), escapes through the nozzle (7), forming the lithium jet (9). The lithium temperature in the chamber is measured using the thermocouple (8). For stepping motor and heater control and also for the operation triggering with T-10 tokamak discharge the injection control system was developed and fabricated. Using this system one can handle the operating regime of lithium jet injector. The injected jet diameter is determined by the nozzle cross-section. These nozzles can be changed. The jet velocity and injection duration can be varied using different stepping motor operation regimes.

The main technical parameters of the described lithium jet injector are following.

The complete volume of injected lithium – 300 mm^3 ($1.4 \cdot 10^{22}$ atoms content)

The injected jet minimal diameter – 50 m

The injected jet velocity – 10-100 m/s (can be regulated by the motor step duration 1-10 ms depending on nozzle cross-section)

The injection pulse duration – $5 \cdot 10^{-3}$ – 8 s

Number of injections (standard regime ~10 mg) – 12-15

Test-bed experiments with lithium jet injector. For testing the developed injector the test bed imitating the T-10 experimental geometry was assembled. The injection test bed experiments were carried out in the direction of plastic target placed at the 1 m distance from the injector nozzle under forevacuum conditions. The space between the target and the injector was fabricated using a transparent material pipe that allows us to make visual control of lithium jet over the whole its trajectory. Firstly, experiments were carried out with water for testing the system work capacity. During these experiments it was observed that only high enough fabrication accuracy nozzles could form not the spray but the jet with small deviation from the injector axis.

During the preliminary Li test-bed experiments the developed injector was equipped by 100 μm nozzle orifice. The critical 10 m/s velocity of lithium flow through this nozzle was determined experimentally. Below this value the jet forming is impossible. Instead of a jet the melted lithium forms a ball on the outer (bottom) side of the nozzle. In the case of higher velocities the lithium jet is forming correctly and reaches the target. In Fig. 3 picture of the Li jet that hints the test-bed target is shown. One can see

Fig.3. Photo of the test-bed target hinted by a Li liquid jet.

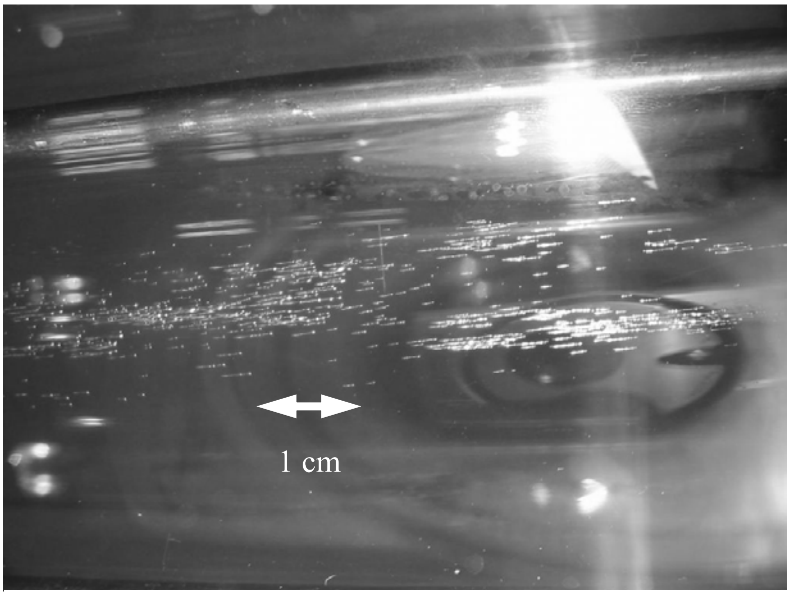

Fig. 4. Photo of the test-bed transparent wall hinted by a Li liquid spray.

that a vertical deviation of the Li jet axis is about of 1 cm on the 1 m base, i.e. the deviation angle is about 10^{-2} rad. This picture confirms that at certain regime Li is not sprayed and is injected as an unbroken liquid jet mainly. Minor amount of lithium reached the target as dust. It is seen in the photo as small dark spots over the whole area of the target. It is not clear at the moment whether this dust is a result of a hint of the jet at the target or it is formed during the injection.

On other hand the injection mode, which sprays the Li into dust, has been observed as well. Presumably this mode is connected with high speed of lithium outflow through the nozzle. Only a few events of such injection have been observed. In this case part of injected Li hints to the test-bad wall due to higher scattering angle. The result of such injection is shown at Fig. 4. It is seen that Li sprays into huge amount of droplets with sizes less than 100 μm. It is not clear yet which regime of injection (spray of dust or liquid jet) is more preferable for wall conditioning purposes. The certain data (see Ref. [6] for instance) denotes to prospects of dust injections mode. Anyway this problem needs additional experiments.

The obtained critical 10 m/s velocity for the 100 μm nozzle orifice is 2 times bigger than that estimated above. This requires additional studies of dependence of the Li jet flow on the nozzle orifice diameter. Further test-bed experiments with 50 μm nozzle orifice equipped by snapshots system for measuring the forming lithium jet are foreseen. The developed injector is planned to be installed and operated during the fall 2007 experimental cycle of T-10 machine.

References

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