The first experiments on lithium dust injection into T-10 tokamak plasma

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Introduction

Lithium technologies are extensively developed and frequently used for discharge control in contemporary magnetic confinement devices including tokamaks and stellarators [1]. Various technical approaches exploring lithium are applicable for wall conditioning, heat and particle control in edge and core plasmas [2-4].

A new rotary feeder has been designed, tested and commissioned at T-10 tokamak for controllable injection of lithium dust, which is industrially produced [5]. In this paper, we present the results of its first application in T-10 tokamak experiments.

Experimental setup

The lithium dust injector is described in details in Ref. [6]. The layout of T-10 experiments with Li dust injection is shown in Fig. 1. Tokamak T-10 is a rail limiter device with the major radius of 150 cm and the minor radius of 38 cm. The graphite limiter radius was 30 cm in these experiments. The injector was fixed in a horizontal position and connected to the tokamak structure. The bellows were used for mechanical decoupling of the injector from the tokamak vacuum vessel. The dust flow rate was measured by means of optical barriers.

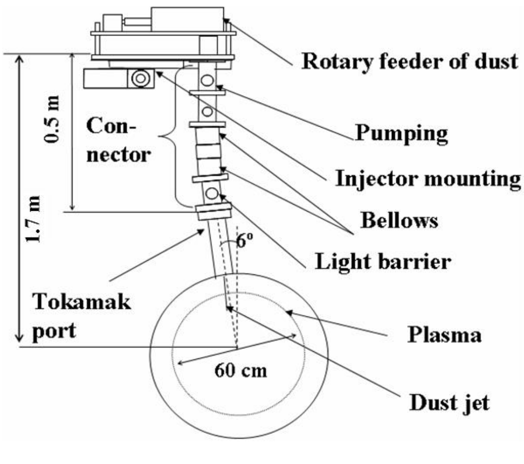

Fig.1. T-10 experimental layout.

The axis of dust jet falling down vertically due to the gravity force was tilted to the axis of tokamak port at the angle of 6 degrees. Therefore, a system was used that was composed of three subsequent funnels, which were placed inside the connector. This system makes the dust jet cross-section profile shrink and can change essentially the temporal behavior of the flow rate of dust particles leaving the rotary feeder.

Results and discussion

The first experiments with Li rotary feeder were aimed at determining the range of dust

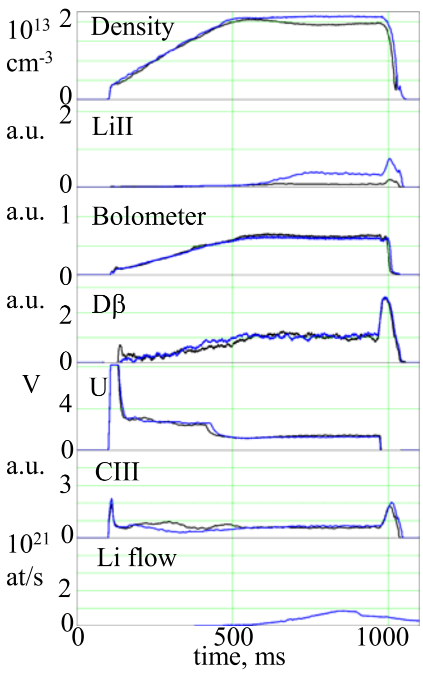

Fig.2 Li dust injection, OH. Black - #59471 without Li, blue - #59481 with Li.

injection rate compatible with the plasma performance. The temporal evolution of main plasma parameters (the line averaged electron density, LiII line intensity, the bolometer (AXUVD) channel corresponding to the middle of the minor radius, D_β line intensity, loop voltage, CIII line intensity) and the dust flow rate are shown in Figs. 2, 3.

The injection was carried out at the steady-state stage of the discharge and dust-plasma interaction started at a time of 550 ms from the beginning of the discharge. The Li injection with different dust flow rates were realized in OH plasma shots with $\langle n_e \rangle \approx 2\text{x}10^{13}$ cm^{-3}, $I_p \approx 250$ kA, B_T = 2.4 T. The injection was also performed in OH + ECRH (130-140 GHz, 1.5 MW) plasma shots (Fig. 3).

In typical OH shot #59481 (Fig. 2), a steady-state behaviour of LiII radiation in plasma was observed. Plasma density slightly increased under a small (up to 8×10^{20} atoms/s) lithium flow rate. The loop voltage, D_β and CIII signals are practically undisturbed in these conditions. A slight decrease of the radiation level from plasma (bolometer signal) at higher plasma density may be considered as footprints of discharge conditioning.

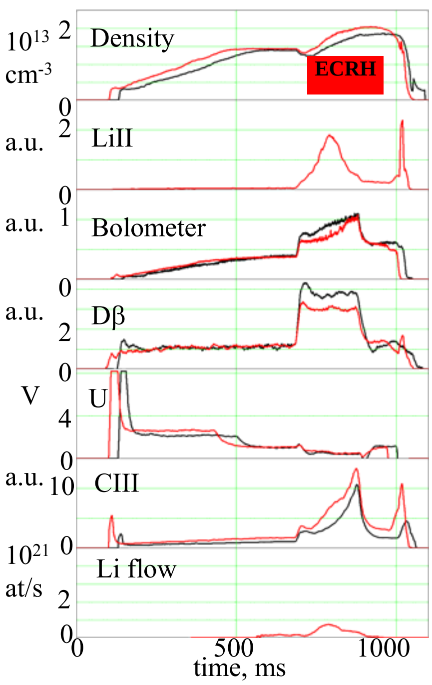

Fig.3 Li dust injection, OH+ECRH. Black - #59660 without Li, red - #59711 with Li.

The discharge conditioning effects are also evident in the case of dust injection into shots with an auxiliary ECR heating (see Fig. 3). Namely, the increase of electron density and reduction of both bolometer and D_β signals due to Li injection can be seen when comparing the ECRH pulse with corresponding signals in the reference shot. It should be noted that a rise of carbon amount in plasma (CIII signal in Fig. 3) after the start of ECRH pulse is caused by additional impurity flows initiated by the gyrotron power. The series of experiments with different injection and plasma heating modes (OH, OH+ECRH) shows that injection with the

Li flow rate up to 2×10^{21} atoms/s is compatible with disruption free plasmas.

A simple 0D balance equations for lithium and electrons has been used to reveal an effect of lithium influence on the wall recycling of hydrogen:

$$\frac{dN_e}{dt} = -\frac{N_D}{\tau_{pD}^*} - Z_{Li}\frac{N_{Li}}{\tau_{pLi}^*} + F_D + Z_{Li}F_{Li} \quad (1) \qquad \frac{dN_{Li}}{dt} = -\frac{N_{Li}}{\tau_p}\left(1-R_{Li}\right) + F_{Li} \quad (2)$$

where N_e, N_D and N_{Li} are total amount of electrons, deuterium and lithium, $\tau_{pLi}^* = \frac{\tau_p}{1-R_{Li}}$ and $\tau_{pD}^* = \frac{\tau_p}{1-R_D}$ are effective confinement times of deuterium and lithium, τ_p is particle confinement time (assumed to be equal for all species), R_D and R_{Li} are effective recycling coefficients, F_D is deuterium flux from gas puffing, F_{Li} is a flux of injected lithium, Z_{Li}=3 is being assumed overall the plasma volume and other impurities were not taken into account for simplicity.

The total amount of electrons N_e was evaluated as $N_e=V_p n_e$, where V_p is a plasma volume and n_e is a line-averaged density which has been measured in experiment. The particle confinement time τ_p was assumed to be equal to energy confinement time $\tau_E \approx 30ms$ which was estimated using scaling for ohmic heated plasmas [7]. The D_2 flow from the gas puff into plasma F_D was proportional to the voltage on the gas valve V_G with the coefficient A_D ($F_D = A_D \cdot V_G$).

The lithium dust flow was measured by means of the optical barrier which had been calibrated in atoms per second. This data was used for estimation of F_{Li}. The flux of lithium ions, entering the plasma F_{Li} is equal to a number of ionizations of Li per second in all tokamak volume which should be proportional to the LiII intensity. Actually, the evolution of LiII intensity differs from evolution of optical barrier signal (Fig. 2). Although reasons of this difference are not clear yet, we suppose that at the initial stage of the injection all injected lithium reaches the plasmas. Under this assumption it is possible to find the proportionality coefficient between the LiII intensity and F_{Li}. Since approximately 750 ms the LiII intensity normalized by this coefficient is lower than the optical barrier signal (Fig. 4).

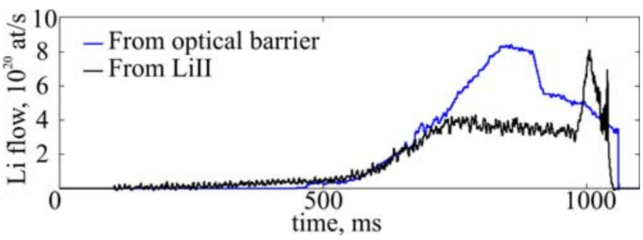

Fig.4 Estimation of dust injection flow rate by means of optical barriers (blue) and Li ions entering the plasma by means of LiII (black, normalized to optical barrier signal at the beginning of injection)

We also assumed that R_{Li}=0.1 as was done in Ref. [2], then the equation (2) was solved numerically to obtain $N_{Li}(t)$. Using $N_e=N_D+Z_{Li}N_{Li}$, τ_{pD}^* can be found from (1) depending on experimental data and the parameter A_D:

$$\tau_{pD}^* = \frac{N_e - Z_{Li}N_{Li}}{A_D V_G + Z_{Li}F_{Li} - \frac{dN_e}{dt} - Z_{Li}\frac{N_{Li}}{\tau_{pLi}^*}} \quad (3).$$

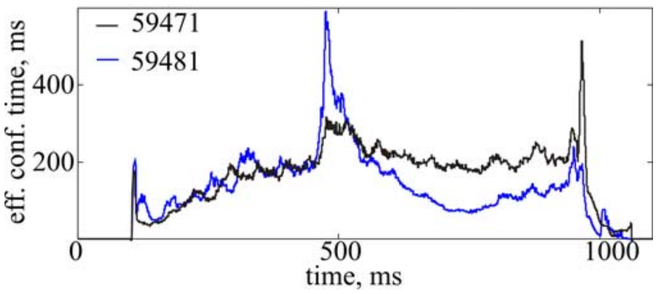

Fig.5 Evaluation results of the deuterium effective confinement time using eq. (3). Black - #59471 without Li, blue - #59481 with Li.

The temporal evolution of τ_{pD}^* in discharges 59471 and 59481 is shown in Fig. 5. The coefficient A_D was chosen to be that preventing an essential time variation of τ_{pD}^* in shot 59471 without lithium injection. It is seen from Fig. 5 that the effective confinement time for deuterium decreases by a factor of 2 during the Li injection. If the particle confinement time is assumed to be unchanged during lithium injection this results in a decrease of the effective deuterium recycling coefficient R_D from 0.85 to 0.7.

Summary

The first experiments on lithium dust injection into T-10 tokamak plasma have been carried out using a novel rotary feeder. Quasi steady-state and pulse regimes with the Li flow rate up to 2×10^{21} atoms/s are found to be compatible with both OH and OH+ECRH disruption free plasmas. A simple estimation of effective confinement time for deuterium allows might be interpreted as decreasing the deuterium recycling coefficient from 0.85 prior to 0.7 during Li injection.

References

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