§19. Helium Exhaust with Closed Helical Divertor in LHD

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The intrinsic level of helium exhaust with the closed helical divertor at LHD was studied and an attempt was made to gain active control by means of resonant magnetic perturbations. The impact of RMP field which excites a core and an edge magnetic island was considered and RMP currents were selected such that the island does not penetrate (called "healed state"). The basic methodology was puff/pump studies in which the location of the helium puff was varied with respect to the activated cryo-absorption pump. A three step density scan was planned to alter the recycling conditions from low to high recycling and finally into detachment. We use the outward shifted configuration at R_0=3.9m where stabilization of radiative edge layer with 1/1 RMP fields and evidence for a resonant edge magnetic island was found. Three steps in density (2.0 x $10^{19}m^{-3}$, ~3.5 x $10^{19}m^{-3}$, and 5.0 x $10^{19}m^{-3}$) were accomplished and for all three density values, a noRMP reference discharge and also both 1/1 RMP cases (at 1.9kA (healed state) and at 3.3kA (penetrated case)) were obtained. This represents an excellent data basis for a thorough initial assessment of helium exhaust with RMP fields at LHD.

The full set of appropriate visible spectroscopy was applied. We obtained data from spectroscopy on neutral helium providing H_α and He-I intensities in the plasma edge and accordingly He/H ratios. The CXRS system was set to He-II line (468.6nm), which enables to obtain an active spectroscopy for ionized helium in the plasma edge and towards the plasma core. The spectroscopically assisted Penning gauges were operated to enable together with the Asdex gauges measurement of neutral pressures and fractional He and H neutral pressures. The new 2D imaging spectrometer was operated and will be used to map 2D emission patterns from He and H. An attempt to extract 2D maps of n_e and T_e based on line ratio spectroscopy on helium will be made.

The initial analysis shows two promising observations. First, it is noted that using the 9.5L gas puffer at maximum throughput (5V on piezo valve) at low density (2.0 $10^{19}m^{-3}$), no helium exhaust at all can be detected. As analysis method, we observed the He/H and H/(H+He) ratios obtained from He-I and He-II lines. For the low-density configuration, no gradual decrease of the helium injected in either signal was seen. This corresponds to an effective helium confinement time $t_{p,He}$* -> infinity. Application of RMP in this setup did not change anything on this initial observation.

On the contrary, we have found substantial evidence for the first time that helium is screened by presence of an edge magnetic island. The He/H ratio increases after the He injection. However, the case with m/n=1/1 edge island present features a helium concentration at the island position which is as low as the one in the standard scrape-off layer further outside. This provides evidence for a strong local helium depletion due to the edge island. Considering the plasma density response inside of the resonance layer as well as the decay of the helium emission (He-II at 468nm was used as a proxy), show a stronger decay of these emission lines with RMP field. This faster decay is most noticeable for the low current 1/1 case and the 2/1 case. Both are considered as being "healed island states", i.e. the RMP field is shielded out by poloidal flows. Magnetic analysis in the control room suggests this classification. The 1/1 RMP case with 3.3kA of current shows field penetration, which was confirmed, based on magnetic analysis and also based on a flat profile in T_e around the relevant resonant surface in the plasma edge. While the decay rate of the He-I line is hardly really visible for 1/1 RMP field at 3.3kA, a clear difference appears in comparison to the other RMP cases and the noRMP case when discussing the He-II emission time traces. Here it is obvious that for the 1/1 RMP case at 3.3kA with an edge magnetic island present a significant reduction of the He-II emission at this radial location is seen.

To summarize this result, the effective helium confinement time was calculated using the helium emission signal and calculating an exponential fall off time. The result is shown in figure 1. The healed m/n-1/1 (edge) and 2/1 (core) island actually yields a significant increase of τ_p*_{He} while for the case with penetrated edge island, a clear reduction of nearly 30% is measured. The edge island is found to be effective for avoiding helium penetration into the deeper plasma and for enhancing the helium exhaust capacity. These results show the capacity of the RMP field to act as a fine actuator on the helium confinement and exhaust. This message is quite relevant for burning plasma experiments as here the helium ash has to be prevented from re-entering the plasma, which was successfully accomplished by a well-dosed amount for RMP field evoking a magnetic island in the very plasma edge.

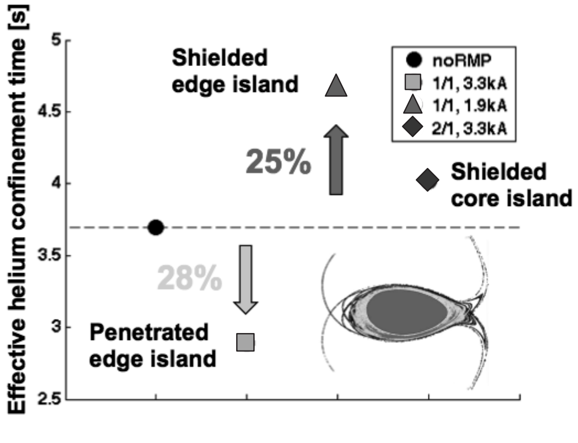

Fig.1. Effective helium confinement time for different RMP applications in the coil currents and the mode number m/n.