The He/Ne beam diagnostic for active emission spectroscopy in the island divertor of Wendelstein 7-X

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Wendelstein 7-X stellarator recently completed its first divertor campaign (OP1.2a). For this phase ten test carbon divertor units with passive cooling were installed in the five modules that compose the device. The magnetic configuration is based on the island divertor concept for power and particle exhaust. In the standard 5/5 configuration five large magnetic islands are intrinsically present in the scrape-off layer: their inner sides define the separatrix and their intersections with the plates define the position of the strike lines.

In order to characterize the plasma parameters (electron temperature T_e and density n_e) in the island divertor, the He/Ne beam diagnostic has been extensively upgraded since the first limiter campaign at W7-X [1]. The injection system consists of two boxes with 5 fast piezo valves each, mounted directly behind the divertor plates in one upper and one lower divertor module, which are magnetically connected in the standard configuration [2]. The new observation system includes 54 horizontal lines-of-sight which are channelled to a 19cm and a 32cm focal length Czerny-Turner spectrometer allowing observation of the He and Ne lines as well as impurities and hydrogen lines with high spectral resolution (dispersion down to 1.3 nm/mm).

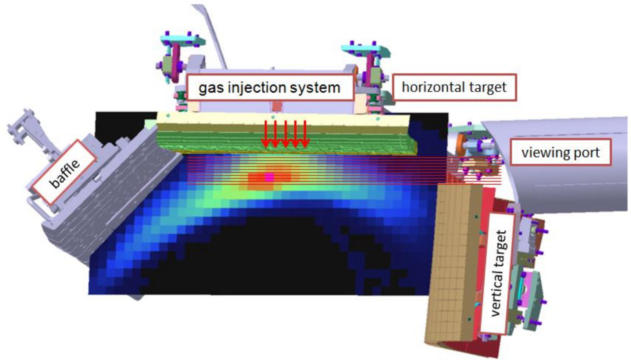

Figure 1. View of the upper divertor with the gas injection system and its 5 nozzles and the horizontal lines-of-sight intersecting the beam. The colored area represents a sample EMC3-EIRENE simulation of the He line emission (λ = 706.5) [3].

In the first divertor campaign of W7-X solely He has been used to deduce T_e and n_e profiles measuring the emissions of three He I lines: the singlet $\lambda_1 = 667.8$ and $\lambda_2 = 728.1$nm as well as the triplet $\lambda_3 = 706.5$nm visible lines. A state-of-the-art collisional-radiative model (CRM) is applied to compute T_e and n_e from the ratios of these three lines [4]. The solution of the model can be computed in both a stationary and a time-dependent way taking the beam propagation into account. With the time-dependent solution, we avoid unphysical high electron temperature measurements in the SOL region that could appear when using the stationary model. The time dependent solution is performed at low densities ($\leq 1\times10^{18}$ m^{-3}) where the relaxation time of the triplet spin term (^3S) becomes comparable with the beam propagation time (~ tens of µs). This time dependent solution is then overlapped with a stationary solution, which is applicable to the higher electron density regimes where the triplet spin system relaxation times are no longer significant compared to the beam propagation time scales.

The T_e and n_e profiles are measured in front of the horizontal divertor target, across the 5/5 island in the standard magnetic configuration, covering the full radial width of the scrape-off layer (~9cm). The spatial resolution of the diagnostic is 2.5mm and the time resolution is 25ms. Edge parameter measurements with the He-beam have been carried out in different magnetic configurations. In Fig.2 we show an example of T_e/n_e profiles in the standard 5/5 configuration with reversed field.

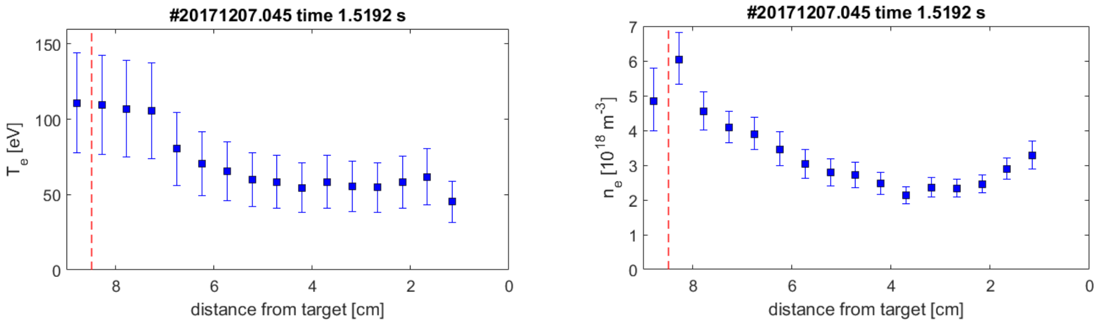

Figure 2. Typical temperature and density profiles for a medium power (P_{ECRH}=3MW) medium density (n_e=1.8×10^{19}m^{-2}) discharge in the standard field-reversed configuration. Separatrix is shown as a red dashed line. Distances are from the horizontal target.

Temperature and density are quite flat inside the island, density is slightly hollow, then they become steep when approaching the separatrix.

Uncertainties for T_e and n_e are normally computed by propagating the line-ratio uncertainties to the derived electron temperatures and densities. In our case these uncertainties are almost entirely given by the experimental uncertainties (deviations from the Gaussian fit of the line intensities) with a small contribution coming from the uncertainties of the CRM. The latter are not yet rigorously calculated but roughly estimated to be 2.5%. They don't include a major contribution coming from the collision cross-sections. Since at the moment the errors from this CRM are not properly calculated, we assume a constant systematic error of 30% for T_e and 10% for n_e which were derived for the CRM used at TEXTOR [5]. We consider these as upper limits, independent of the measurement inaccuracies.

In parallel with the exploitation of the He-beam line-ratio spectroscopy diagnostic another one is currently under development. This is based on the injection of thermal neon and on the determination of temperature and density from the ratio of some selected neutral neon lines. The need of the change from helium to neon occurs when the temperature drops below 10eV and the He lines are so weak (or not detectable for $T_e < 5$eV) that the T_e/n_e measurement becomes very problematic. Ne has lower excitation energy and can provide stronger emission lines at low temperatures. This condition is expected to happen during detachment which is planned to be achieved in the next campaign. Initial neon test injections were already carried out in the last campaigns and the dominant Ne lines were identified. At the same time a new dedicated collisional-radiative model for Ne I is under development in collaboration with Auburn University.

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