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The diagnostic system for the characterisation of ITER Neutral Beam Injectors

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ITER Neutral Beam Injectors (NBI) are based on the acceleration of negative hydrogen (deuterium) ions, which exhibit a constant neutralisation efficiency up to 1 MeV [1,2].

Some of the target parameters of ITER NBI [3] have already been attained in various test stands around the world; however several issues are still open [4]. A NBI test facility will be realised, to assess the operational window of the system and to optimise its performances [5]. Specifically a negative ion source test facility (IS-TF) will be devoted to the investigation of negative ion yield, electron co-extraction, caesium consumption, resilience to impurities, source uniformity and long time operation. The main phenomena occurring in the ion source are as follows: eight RF drivers, located on the rear side of the source, generate a plasma, which expands until ions and neutrals impact on the plasma grid, producing negative ions; the process is aided by a layer of evaporated caesium; despite magnetic fields (current in plasma grid; permanent magnets) and a bias plate in front of the plasma grid, some electrons get co-extracted and are deflected onto the extraction grid; a last grid accelerates the negative particles up to 100 kV; the beam is finally dumped onto a calorimeter.

In the following, an overview of the implementation of the diagnostic system which will be used in the IS-TF is given, aiming at the characterisation and improvement of the performances of the injector [6]. Protection and operation diagnostics are also planned.

Since the parameters of the accelerated negative beam are the ultimate goal, the most important region for diagnosing plasma parameters is the vicinity of the plasma grid. The measured parameters should be distinguished from the aims of the IS-TF. In Table 1 the measured parameters are reported, along with the aims of the IS-TF. Some of the parameters must be measured, because they give direct measurements of the aims (red colour); some measurements have links with the aims and can provide information about them (blue).

The diagnostics can be grouped in few wide categories as follows: thermocouples (in driver plate, RF drivers, grids), electrical measurements (grid currents and voltages, electrostatic probes, plasma grid filter current), emission spectroscopy (line spectroscopy in source, line spectroscopy of beam, beam tomography, source tomography), absorption spectroscopy (cavity ring-down, laser photodetachment, laser induced fluorescence), radiation measurements (X-ray, neutron), inspection (visible radiation, infrared radiation), mechanical measurements (gas pressure, coolant parameters, residual gas analysis, inlet gas parameters, caesium level). Some of these diagnostics will be described herein.

	aims of ISTF						beam-characterising parameters			
measured parameters	H^-/D^- current density	co-extracted electron current	unifor-mity	Cs control	impu-rities	protec-tion	*beam diver-gence*	*max particle energy*	*energy spread*	*beam position*
electron density	blue	blue	blue							
electron temperature	blue	blue								
electr. energy distrib.	blue	blue	blue							
neutral H/D density	blue		blue							
neutral H/D temperature	blue									
H^-/D^- density	blue		blue							
impurities	blue	blue			red					
caesium density	blue		blue	red						
plasma grid work function	blue		blue	blue						
magnetic field (PG current)	blue	blue	blue			red				
gas pressure in source	blue	blue				red				
RF measurements	blue		blue			red				
current from extraction grid		red				red				
X-rays		red						blue	blue	
return currents	red					red				
grid voltages						red	blue	blue		blue
gas pressure in accelerator	blue					red	blue		blue	
breakdown					blue	red				
Doppler shifted H_α/D_α	blue		red					red		red
Doppler width of H_α/D_α line							red		red	
calorimeter temperature	red		red				red			red
IR calorimeter observation	red		red				red			red
surface temperature				blue		red				
coolant temperature						red				
coolant flow/pressure						red				
residual gas analysis						red				
inlet gas flow	blue	blue				red				
inspection						red				
neutron detectors						blue		blue	blue	
light emission from source						red				
oven temprtr,current;Cs	blue			blue		red				

Table 1: Aims of the ion source test facility and measured parameters.

Spectroscopy allows monitoring key parameters involved in negative ion formation and in neutralisation: temperature and density of electrons, temperature and density of atoms and molecules, density of caesium. Spectroscopic equipment can involve high resolution spectrometers to analyse molecular spectra, in order to evaluate: gas temperature, vibrational temperature, molecular density, and ionisation degree. Low resolution spectrometers can be used for monitoring single outstanding emission lines, such as the Balmer series, caesium lines and doping gas lines (typically N or Ar) and any line due to impurities coming from a vacuum leak; in those cases when real time evaluations (caesium density), occurrence of arcing inside the source or leaks are important, photomultipliers, coupled to interference filters might be adopted. CCD arrays, combined to interference filters, can be used to build a tomographic mapping of certain processes, with the purpose of assessing source symmetry through the detailed space behaviour of Balmer lines. Spectroscopic data interpretation may be quite sophisticated, but significant development has been achieved in the recent past on this subject [7].

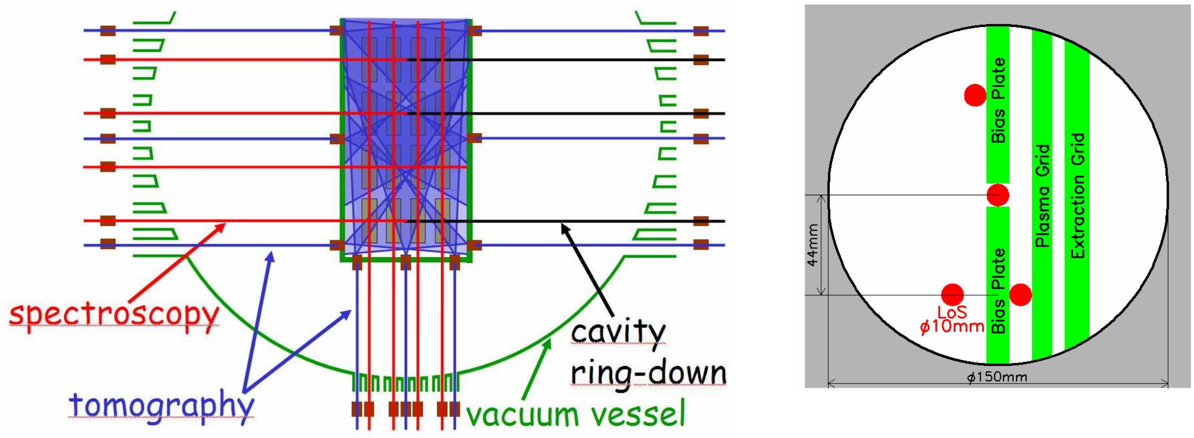

Fig. 1: Arrangement of spectroscopic LoS on a plane parallel to the plasma grid (left) and axially (right).

Cavity ring-down consists in the decay of a short laser pulse injected into the cavity between two highly reflective mirrors. Light losses are due to: leakage through mirrors, scattering, diffraction and photodetachment (photon absorption by negative ions with electron liberation); the last allows the measurement of negative ion density. Nd:YAG lasers at 1.06 μm, with photon energies of 1.2 eV, are commonly used to this end [8]

Fig. 1 sketches the geometry adopted for emission and absorption spectroscopy: three horizontal lines-of-sight (LoS) close to the plasma grid are used for cavity ring-down (black lines); the mirrors will be installed in vacuum. Emission spectroscopy is in the visible range, so the same LoS can be shared between cavity ring-down and emission spectroscopy (red lines); the latter will also employ four vertical LoS. Each horizontal line corresponds to four LoS located in slightly different axial positions (Fig. 1, right hand side); analogously, the vertical lines represent two LoS, axially spaced. The overall arrangement allows investigating top-bottom and left-right asymmetries, as well as axial decays of the parameters. Suitable accesses are also provided in case a finer investigation of source uniformity might be necessary, requiring tomographic analyses (blue fans of LoS).

Electrostatic probes will provide local plasma parameters in the source (electron density, temperature and energy distribution function). They will be embedded in the bias plate and in the plasma grid. Suitable locations of the probes around the holes in the plasma grid are being decided to obtain information on spatial uniformity. The effect of magnetic fields, negative ions, surface contamination due to caesium and grid temperature will be accounted for.

Source efficiency will be studied also in terms of beam parameters. Common techniques include Doppler spectroscopy [9], applied to the radiation emitted after charge-exchange reactions of the beam with the background gas. The energy distribution of particles gives information about undesired neutralisations, whereas the Doppler width is a measure of the beam divergence. The LoS will be arranged along the beam line so as to allow tomographic reconstructions of the beam position and of the beam uniformity [10].

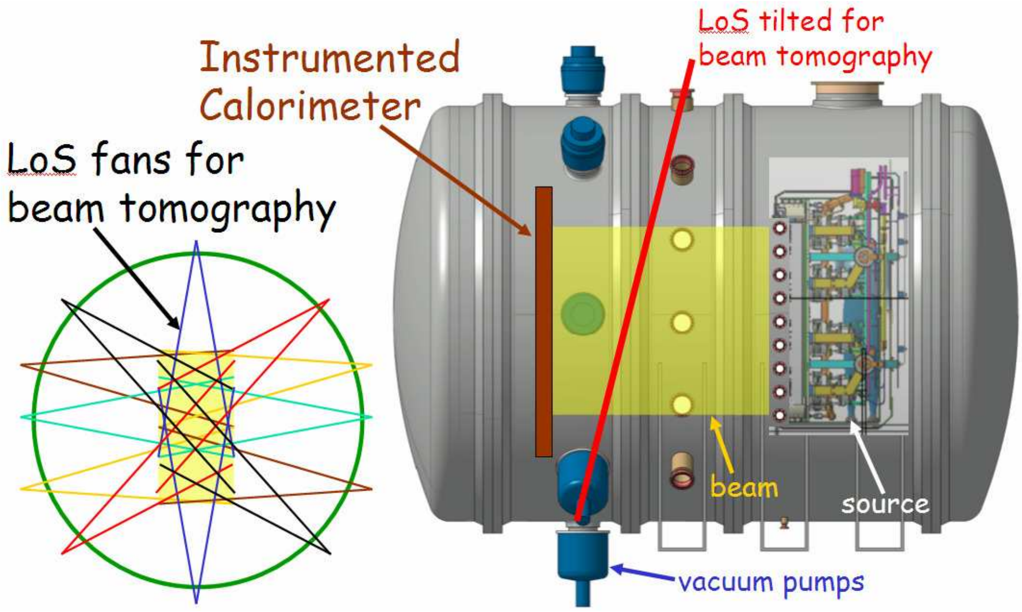

Fig. 2: Arrangement of spectroscopic LoS on a plane parallel to the plasma grid (left) and axially (right).

During short low-power pulses the use of an instrumented calorimeter [11,12] is proposed. The calorimeter will be equipped with thermocouples and will be viewed by infrared cameras in order to investigate beam position and uniformity, thus complementing beam tomography. The arrangement of the LoS for beam tomography and of the instrumented calorimeter is sketched in Fig. 2.

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