Investigation on the beam homogeneity in large sources for negative hydrogen ions

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Introduction

The ITER neutral beam injection (NBI) will deliver up to 33 MW of heating and current drive power [1]. Due to the required particle energy (see Table 1) the system is based on the acceleration of negative hydrogen ions as their neutralisation efficiency is still 60 % at these high energies.

Table 1: Required parameters for accelerated current density, total current, particle energy, co-extracted electron to ion ratio and pulse length for the ITER NBI heating beam.

Parameter	H	D
j_{acc} [A/m^2]	240	200
Acc. Current [A]	48	40
Particle energy [keV]	870	1000
j_{e-}/j_{H-}	< 1	< 1
Pulse length [s]	600	3600

Table 1 shows the main parameters that have to be provided by the negative ion source. Due to the low current density that can be achieved [2] compared to positive ion systems, the net extraction area is 0.2 m^2 and the whole source 2x1 m^2, in order to achieve the required currents.

The beam has to have a divergence of less than 7 mrad and an inhomogeneity of the extracted current density across the large grid of less than 10% in order to minimise transmission losses in the accelerator and the beam line.

Experiment setup

At IPP Garching the small test facility BATMAN with a well diagnosed ⅛ ITER-size source is in operation to gain a better understanding of the source and beam physics [2,3] and to benchmark models, which can then be transferred to the large ion source (extraction area 0.1 m^2; whole source 1x1 m^2) at ELISE [4]. One task is to investigate the beam homogeneity.

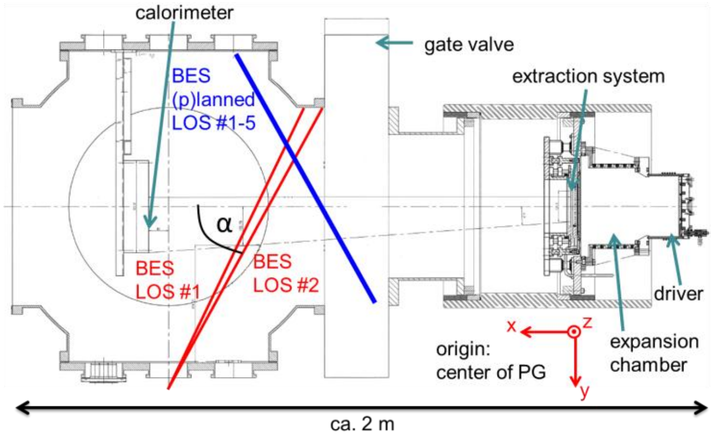

Figure 1: schematic drawing of the ion source and beamline at BATMAN with the current and planned BES experiment setup.

Figure 1 shows schematically the ion source and the beam tank at BATMAN. Hydrogen/deuterium atoms and positive ions are generated in the driver and get to the plasma grid surface, where they are converted into negative ions by the so-called surface effect. This effect, dominated by neutral hydrogen [5], is optimised by evaporating caesium into the source by using a caesium oven [6]. Caesium lowers the work function of the surface and increases the negative ion production yield. In order to reduce the negative ion destruction and therefore to minimise the co-extracted electron current, a magnetic filter is used on order to decrease the electron temperature in front of the plasma grid.

The extraction is done in a three-grid-extraction system containing 126 apertures. The system consists of the plasma grid, the extraction grid and the grounded grid [7]. The grids itself have an upper and lower half, which are inclined by a small angle of approximately 0.88° to focus the beam. Due to this breakup of the grids in two halves, two sub-beams are formed merging to the final beam.

In order to get information on the beam parameters, for example beam homogeneity, Beam Emission Spectroscopy (BES) downstream the extraction system comes into operation.

With BES, the Doppler-shifted H_α Balmer line radiation of the fast beam particles is detected. The averaged divergence ε of the beam can be determined from the width of the Doppler-shifted line by the formula

$$\varepsilon = \frac{\sqrt{2}\sigma}{\Delta\lambda \tan(\alpha)}$$

where σ the standard deviation of the Doppler-shifted peak, derived from a Gaussian fit to the peak, Δλ is the Doppler shift and α the observation angle of the LOS with respect to the beam axis [8].

For the BES at BATMAN two horizontal Lines-of-sight (LOS) are currently installed, while for fall 2013 an update with five new LOS for the experiment setup is planned (pLOS) (see Table 2), to measure the beam homogeneity of the source within the requested accuracy of less than 10%.

Table 2: Position and observation angle of the current LOS and the planned LOS setup.

	x [m]	y [m]	z [m]	α [°]
LOS #1	1.5	0.6	-0.05	63.58
LOS #2	1.5	0.6	0.015	61.06
pLOS #1	1.3	0.5	-0.08	57
pLOS #2	1.3	0.5	-0.04	57
pLOS #3	1.3	0.5	0	57
pLOS #4	1.3	0.5	0.04	57
pLOS #5	1.3	0.5	0.08	57

An important question is to find out the sensitivity of beam homogeneity determination with the new experiment setup, which will also be used at ELISE and is planned for the

ITER NBI full size sources at the testbeds SPIDER and MITICA. For this task calculations with the trajectory code BBC-NI (Bavarian Beam Code for Negative Ions) were performed. The code is able simulate the whole beam from plasma grid to calorimeter, including all diagnostic tools, also BES. For the studies, the calculations where done with the starting point at the grounded grid, for the sake of simplicity. The particles of each beamlet at BATMAN are assumed to have a Gaussian angle distribution within a given divergence angle (input parameter).

Table 3: Extracted current j_{extr} and the associated divergence ε.

j_{extr} [A/m^2]	ε [°]
136	5
156	4.3
176	4
194	3.5
214	3.1
233	2.9

For the parameter variation, the extracted current of the upper grid half was kept constant, while the current of the lower grid half was changed. The extracted current at fixed extraction voltage determines the divergence of a beamlet, which was then the input parameter for the code. Table 3 shows the correlation of these two parameters for an applied extraction voltage between plasma grid and extraction grid of U = 5.8 kV.

In total, 36 calculations were performed and the simulated spectra were evaluated with an automatic routine, which is also used for the real measurement. By comparing the ratio of the extracted currents from the upper and lower grid half with the divergence ratio of an upper and lower LOS, one can evaluate the quality of reconstructing the beam homogeneity in future measurements. As LOS the two most outer ones are chosen which are pLOS #5 and pLOS #1. For a comparison, also the ratio of the divergence derived from the actual two LOS #2 and #1 is taken.

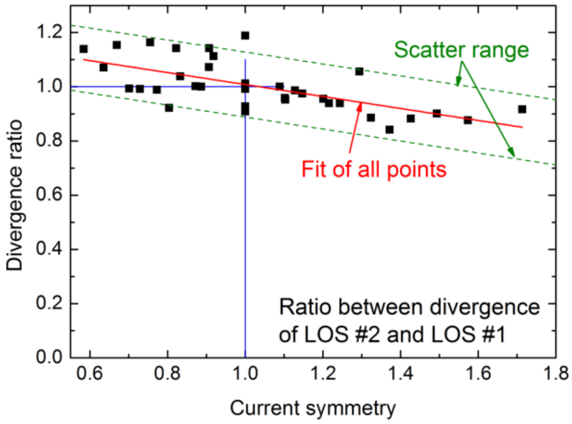

Figure 2: Divergence ratio of LOS #2 and LOS #1 versus current symmetry.

Results

Figure 2 shows the Divergence ratio of LOS #2 to LOS #1 for the various current symmetries which were considered in the calculations. It can be seen that the correlation follows a linear trend with an expected divergence ratio of 1 at a current symmetry of 1. However there is a scatter in divergence ratio for equal current symmetries. This comes from two effects. On the one hand, fitting the Doppler shifted peak with a Gaussian function always has a certain error which is in this case around 2%. On the other hand the beam consists of two sub-beams, each contributing a Gaussian distributed Doppler shifted peak in the spectrum. However, the position of this peak is dependent on the inclination angle of the grid half and the width of the peak is dependent on the divergence. In a sum, the final Doppler shifted peak of the BES spectrum, accumulating from the Doppler shifted peaks of the two sub-beams, is no more Gaussian, but still fitted with a Gaussian function. This leads to an error of around 10% for the averaged divergence obtained by the spectrum, which was not expected so far and can be improved.

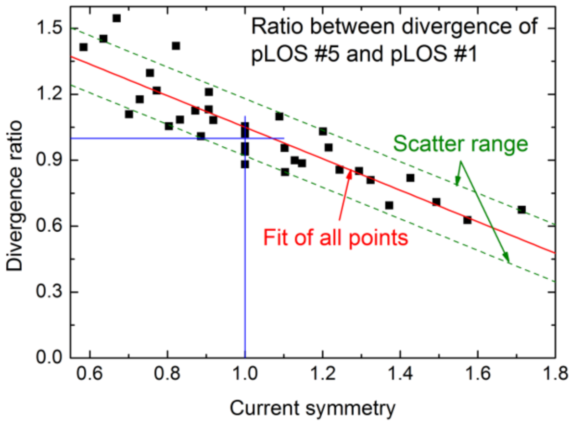

Figure 3: Divergence ratio of pLOS #5 and pLOS #1 versus current symmetry.

Having a closer look on a divergence ratio of 1, one can see that this refers to current symmetries in the range between 0.5 to 1.5, which is an error of 50%. The current experimental setup is therefore not sufficient for studies on beam homogeneity.

Figure 3 shows the same plot as in Figure 2 but with the divergence ratio between pLOS #5 and pLOS #1. The accuracy to assign the beam inhomogeneity is much better, namely below 20%. However a beam inhomogeneity of less than 10% cannot be predicted by this method. Therefore several next steps for the future are planned to obtain this goal.

First, a proper/better definition of beam homogeneity for BES, which takes all LOS into account, will be investigated. Secondly, the automatic data evaluation of the BES spectra will be enhanced, which means the fitting procedure will be adapted considering the fact, that the whole beam consists of two sub-beams. Lastly, in fall 2013 the new experiment setup will be tested in operation and compared with the code results. Transferring the gained experience to ELISE gives the possibility to demonstrate an ITER-relevant beam.

References

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