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# HOMOGENEITY AND LONG PULSE OPERATION OF THE IPP RF SOURCE FOR THE ITER NBI SYSTEM

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The Max-Planck-Institut für Plasmaphysik (IPP) is developing a RF ion source for the neutral beam heating system for ITER. High current densities of negative hydrogen ions (330 A/m$^2$ and 230 A/m$^2$, $H^-$ and $D^-$, respectively) are achieved for a small extraction area ($7.0\times10^{-3}$ m$^2$) and for short pulses (4 s). The development concentrates now on extending the pulse length to up to 1 hour and extending the size of the source (80x80 cm$^2$). Key issues are the homogeneity and the long pulse stability of a RF plasma.

## 1. Introduction

ITER [1] requires for its heating and current drive neutral beam injection (NBI) systems based on negative hydrogen ion sources. The ion source must deliver 40 A of $D^-$ ions for up to one hour with an accelerated current density of 200 A/m$^2$ at a source pressure of 0.3 Pa and an extracted electron/ion ratio of less than unity. The extraction area is 0.2 m$^2$ for a source dimension of $1.5\times0.6$ m$^2$. The source development was initially concentrated on filamented arc sources, that are operational at the Japanese fusion facilities [2,3]. Filamented sources, however, suffer from the requirement of regular maintenance due to the limited lifetime of the high current tungsten filaments. In the case of ITER, this requires a remotely handled replacement of the filaments a few times a year.

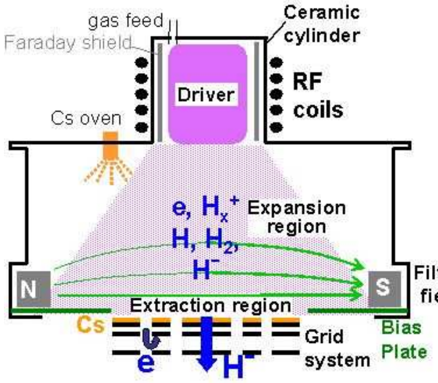

*Figure 1: Schematic drawing of the standard size IPP RF source with a cylindrical driver (∅ = 24 cm, l = 20 cm) and a rectangular body ($32\times59$ cm$^2$).*

As a promising alternative, a high power RF driven negative ion source was successfully developed at the Max-Planck-Institut für Plasmaphysik (IPP) [4,5] and is now the reference source for the ITER NBI system. RF sources offer substantial advantages: they are cheaper to build as they have fewer parts, requiring just a source body, an RF coil, and a matching circuit and they are basically maintenance-free in operation. The IPP RF source has already demonstrated current densities in excess of the ITER requirements at the specified pressure and electron/ion ratio, but only for a small extraction area and limited pulse length.

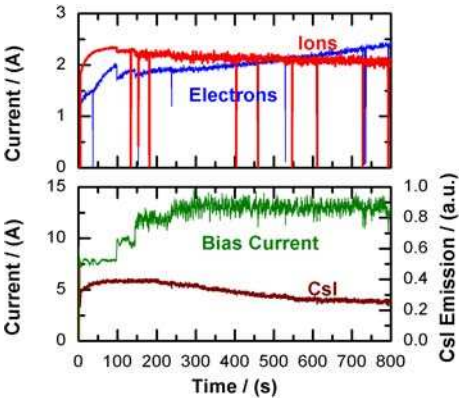

*Figure 2: Time traces of the long pulse experiment. The intensity of the Cs line at 852 nm is measured at 2 cm distance to the grid.*

The standard IPP RF source (f = 1 MHz, $P_{max}$ = 150 kW) consists of three regions (figure 1): the so-called driver, where the RF is coupled to the plasma by a water-cooled RF coil, the actual source body into which the plasma expands, and the extraction region. The latter two are separated by a magnetic filter field (~10 mT). The driver is mounted on the back of the source body and consists of an alumina cylinder and a water-cooled copper Faraday screen protecting the alumina cylinder from the plasma. An additional plate, the so-called bias plate, surrounds the plasma grid, and sits at source potential; it was beneficial in the short pulse experiments especially for the suppression of electrons in deuterium operation.

For optimum performance, i.e. high negative ion current density and low electron current, Cs evaporation into the source is mandatory. The $H^-$ production process is the “surface process”, i.e. the interaction of atoms or ions with materials of low work function. A further reduction of the amount of co-extracted electrons is achieved by biasing the plasma grid with 10 – 20 V against the source body together with a sufficient filter field across the plasma grid.

The further development at IPP Garching concentrates now on extending the pulse length to up to 1 hour and on source size extension. The key issue for the long pulse stability and the homogeneity of a large RF plasma is the spatial and temporal control of the Cs distribution. Furthermore, the homogeneity of large negative ion sources is mainly determined by plasma drifts in the horizontal filter field; large filamented sources suffer from the inhomogeneous flow of the arc currents of the order of 1 kA in the filter field [2,3].

The homogeneity of a RF source, however, is caused by ExB drifts and depends therefore on the potential distribution in the source [5,6]. This potential distribution can be adjusted by Cs seeding, i.e. by changing the sheath potential in front of the plasma grid due to the production of negative ions, and by changing the bias voltage. High performance and homogeneous plasma operation was demonstrated for the small IPP RF source by adjusting the bias voltage just above the floating potential of the plasma grid [6]. The spatially resolved beam homogeneity measurement at the long pulse test facility gives the unique possibility to study the correlation of the plasma homogeneity — which may depend on the distance to the plasma grid — with the beam homogeneity.

## 2. Long Pulse Stability

Up to the end of 2006, the plasma grid (PG) of the long pulse test facility was covered with a grid mask in order to limit the extraction area to ~200 cm$^2$. This grid mask, however, had only a weak thermal contact to the PG. It was therefore not possible, to achieve stable pulses for several hundreds of seconds (see figure 2): in order to keep the electron current low, the bias current had to be adjusted accordingly. The effect of this cover plate can also be seen in the large time constants of the CsI emission during the pulse.

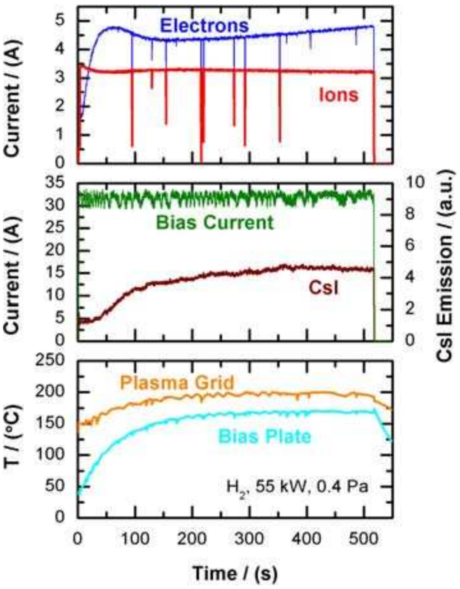

*Figure 3: Time traces of the long pulse experiment with an actively cooled bias plate.*

This PG was then replaced in January 2007 by a new PG having only the apertures being drilled for an extraction area of 200 cm$^2$; hence, the PG cover is no longer necessary. Additionally, an actively cooled bias plate was installed. Figure 3 demonstrates as a first example — the source was not at optimum performance — the effect of the change of the setup: after about 200 seconds, the temperatures of all source components are constant, and consequently, constant electron and ion currents can be achieved. No adjustment of the bias current was necessary. Also the CsI emission follows the temperature of the bias plate with the same time constant, being stable after 200 seconds.

## 3. Plasma and Beam Homogeneity

The long pulse test facility is equipped with a spatially resolved beam emission spectroscopy system [7] for measurements of the beam homogeneity (figure 4). The homogeneity of the accelerated ion beam is obtained by the distribution of the half widths of the Doppler shifted H$_\alpha$ line, being proportional to the local divergence of the beam. As the spectrum is line-averaged over many beamlets, many of them contribute to the width of the Doppler-shifted peak. Especially for a very divergent beam, the peak width might be increased by the wide angle components of beamlets far away from the line-of-sight. This influ-

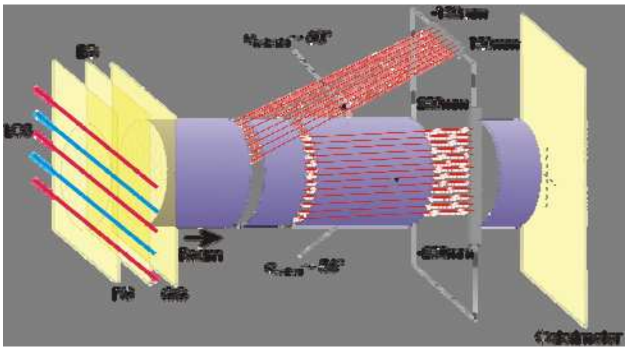

*Figure 4: Spatially resolved H$_a$ Doppler shift beam spectroscopy system at the long pulse test facility.*

ence can be neglected, however, as can be seen in figure 5: for constant beamlet divergence the width of the Doppler line-of-sight profile of the beam is more or less constant across the beam.

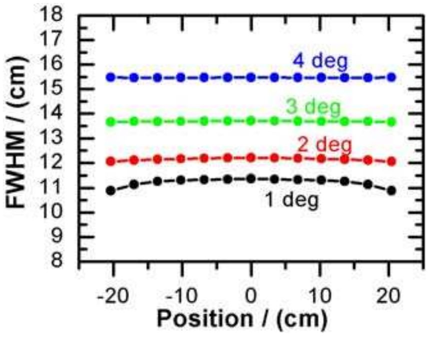

*Figure 5: Calculated width of the local beam power profile along the Doppler line-of-sights for different divergence. All beamlets have the same divergence.*

For the actual operation scenario, an under-perveant beam, the divergence is decreasing with increasing perveance. Thus, for a constant voltage across the grid, the width of the $H_\alpha$ line is indirectly proportional to the local current density of the beam and hence to the local density of negative ion in front of the plasma grid. The corresponding profile of negative ions in front of the plasma grid is measured by the novel technique via the $H_\alpha/H_\beta$ line ratio [8].

Figure 6 shows a first example of a comparison between the negative ion density profile in the source and the measured profile of the beam divergence. The negative ion density decreases from top to the bottom due to ExB drifts of the plasma in the horizontal filter field. This correlates clearly with the lower beam divergence of the upper part of the beam. Furthermore, the negative ion density increases with decreasing distance from the PG, as it is expected for negative ions being produced at the plasma grid surface.

## 4. Conclusion

Long pulse stability of the IPP RF source was achieved for several hundred of seconds by controlling the temperatures of all source components. Pulses of up to 3600 s are now no longer limited by technical constraints. A first measurement shows that the beam homogeneity, measured by a spatially resolved $H_\alpha$ Doppler shift system, correlates with the plasma homogeneity.

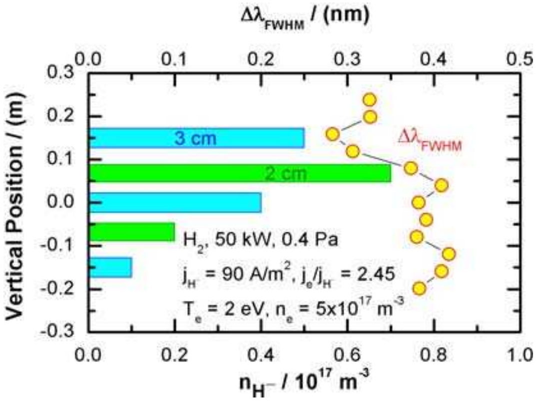

*Figure 6: Beam homogeneity (via $\Delta\lambda_{FWHM}$ of the Doppler-shifted peak) vs. the profile of negative ions in front of the plasma grid (in a distance of 2 and 3 cm, respectively).*

## 5. References

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