# Spatially resolved plasma rotation profiles with ICRF on JET

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# Spatially Resolved Plasma Rotation Profiles with ICRF on JET

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**Abstract.** Detailed measurements of the rotation profile in L-mode plasmas heated by ICRF only (H minority in D), show a distinct off-axis maximum in the co-current direction. There is a slight dependence on the position of the resonance layer: the off-axis maximum in the rotation profile is modestly higher for a high field side position of the resonance layer than for a low field side position. The differences due to the direction of the antenna spectrum (co or counter) are small.

## INTRODUCTION

Even without direct momentum input (which tends to dominate in the case of neutral beam injection) other terms in the toroidal force balance equation can lead to rotation in a magnetized plasma. For ICRF minority heating in particular, the radial transport and the trapping /de-trapping of the fast minority particles can lead to radial currents and thus to a toroidal torque. Several theories treat those terms in various approximations, leading to distinct predictions for the dependence of the toroidal rotation on a number of parameters, such as for example on the location of the resonance layer.

A recent review on the subject is given in [1]. Results of toroidal rotation with ICRF in H-mode on JET were presented in [2]. Latest experiments on Alcator C-mod have addressed the issue of rotation with ICRF only [3]. Whereas rotation profiles have previously been recorded for the combination of NBI and ICRF in TFTR, see [1], no information has been available on detailed toroidal rotation profiles for ICRF only.

On JET a systematic study was made of the toroidal rotation profiles for a large set of parameters (L/H mode, position of resonance layer, antenna spectrum), thus providing for the first time clear experimental data against which theories can be tested. This paper reports specifically on the difference observed in L mode between a high field side and low field side position of the resonance layer, for different phasing of the antennas. Further results will be presented in [4].

## EXPERIMENTS

The experiments were conducted on JET at a plasma current of 2MA, and magnetic fields between 2.3T and 3.2T. Several ICRF frequencies (37, 42, 51 MHz) as well as the variation of the magnetic field were used to position the resonance layer of the H minority ($n_H/ n_D = 0.01$) at various locations in the plasma. The antennas have four strap which can be phased arbitrarily yielding symmetric spectra (phasing used were $0, \pi, \pi, 0$ or $0, 0, \pi, \pi$,) or directed spectra (the wave is directed in the co-current direction with $0, \pi/2, \pi, 3\pi/2$ or counter-current with $0, -\pi/2, -\pi, -3\pi/2$). Typical spectra of the antenna current are shown in Fig.1. Short pulses of D neutral beam injection ($E = 140$ kV, $\Delta t = 200$ ms) were utilized to measure the plasma rotation profile. As will be shown, it was carefully checked that the measurements did indeed measure the undisturbed rotation of the plasma (i.e as it was before the beam was injected) and not the rotation as affected by the beam.

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## ICRF conditions

Fig 2 a,b show the power deposition for the resonance layer positioned at the high field side (B= 2.8T, f= 51MHz) and at the low field side (B= 2.8T, f= 37MHz) respectively, for the dominant $k_{//}$ in the directed spectrum ($n_\phi$=12). In Fig. 3 the electron temperature and density profiles are plotted at the time of the measurement.

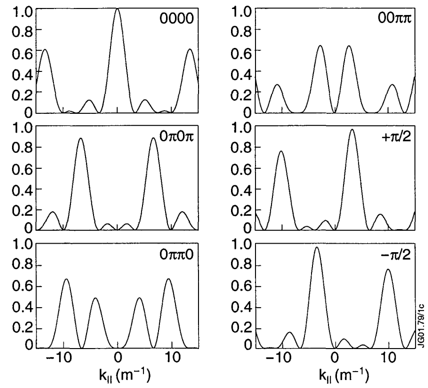


**Figure 1:** Antenna spectra for different phasings

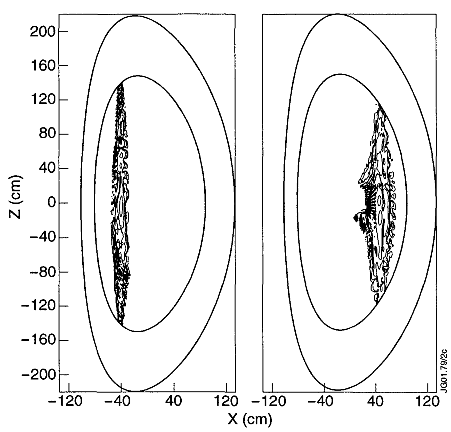


**Figure 2:** Power deposition profile for an off-axis HFS and LFS position of the resonance, calculated with TORIC for $n_\phi$=12 and up/down symmetric magnetic geometry (the real geometry is asymetric, and displaced upward by 35cm)

## Measurement method

The measurement of the rotation was deducted from the Doppler shift of the charge exchange resonance line of C, whereby Be- assumed to be non rotating in the scrape off layer- was used in each shot as a wavelength reference. To measure the Doppler shift, the spectrum of the C was fitted with one Gaussian after deducting a background spectrum without beams.

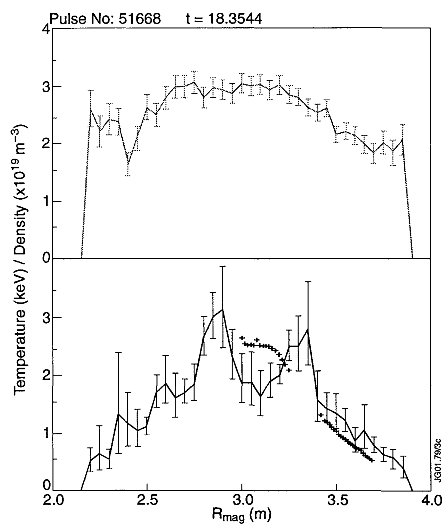


**Figure 3:** $T_e$ and $n_e$ profiles for Pulse no: 51668 (see figure 4) at t = 18.35s

### RESULTS

Fig. 4. shows some typical traces of the experiments. Both during the low ICRF power (2 MW), and during the high ICRF power (8 MW) phase of the discharge (usually in H-mode) there are sequences of 4 beam blips. The first and the third are 140kV beams, used for the CXRS measurement, the second (80 kV) for poloidal rotation measurement, the fourth (80 kV) for MSE. During each beam blip, spectra are gathered every 50 ms, so that during each 200 ms beam blip, 3 to 4 spectra are recorded.

## Measurements check

The evolution of rotation profiles during one beam blip indicates that the rotation is little affected by the first beam blip (as seen in Fig 5).The first rotation profile during the first beam blip can be compared with the first rotation profile in the third blip, in the presence or absence of a second beam blip.

With the second beam blip present, the cumulative effect of the beam induced rotation due to the first and the second beam blips starts to significantly affect the rotation profile at the beginning of the third beam blip (see Fig. 6). Looking now at the four profiles in the first beam blip alone, in Fig. 5 and 6, we do notice a fast evolution of the central rotation.

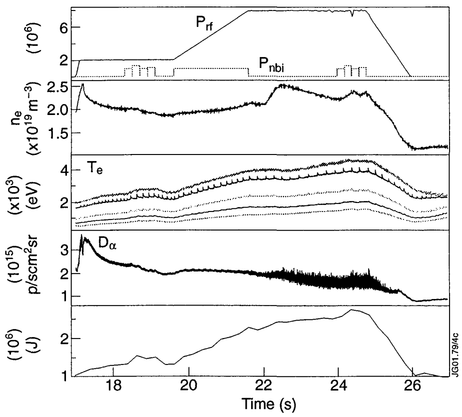


**Figure 4:** Typical time traces for Pulse No: 51668, where two frequencies (52 & 37 MHz) were used simultaneously, to position the resonance layers at the High Field Side (co directed spectrum) and Low field side (counter directed)

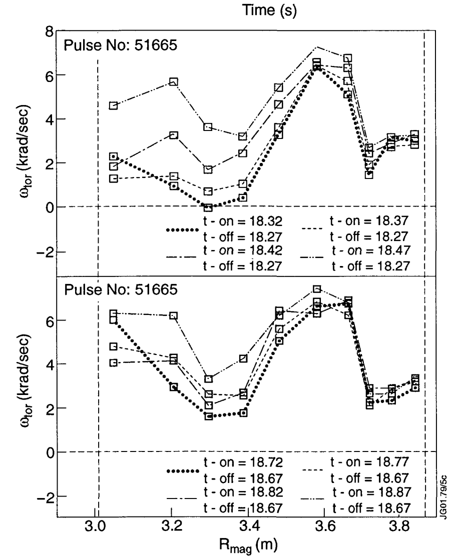


**Figure 5:** Variation of the rotation profile, during the first beam blip (top) and third blip (bottom), in the absence of a second blip.

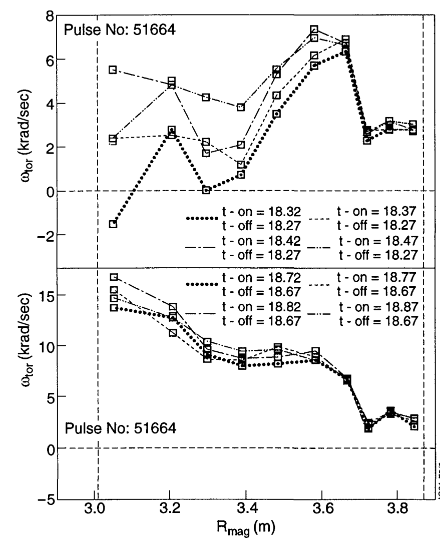


**Figure 6:** Variation of the rotation profile, during the first beam blip (top) and third blip (bottom), in the presence of a second blip.

Experiments where a mild central n=1 mode can be identified, allow to check independently the time scale of the evolution of the central rotation due to the beams. From those we can conclude that indeed, the central rotation is becoming affected already by the end of the first blip, but that the first measurement is still o.k. Those experiments also permit a separate measurement of the value of the central rotation, which is in agreement with those measured by CXRS. A cross check is further provided by discharges that are strongly affected by MHD modes (for example after a big sawtooth crash). In contrast to discharges not affected

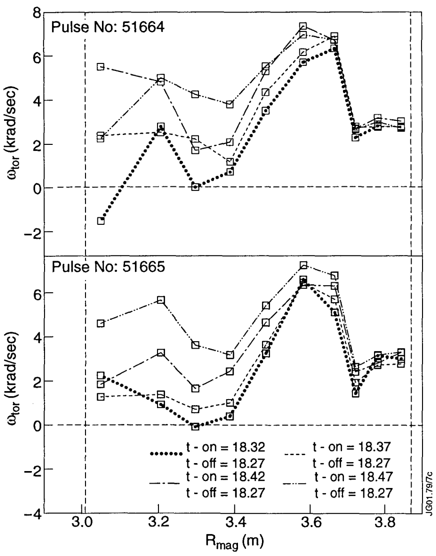


**Figure 7:** Rotation profile, for a HFS position of the resonance layer (51MHz, 2.8T), for a co (top) and counter directed spectrum (bottom).

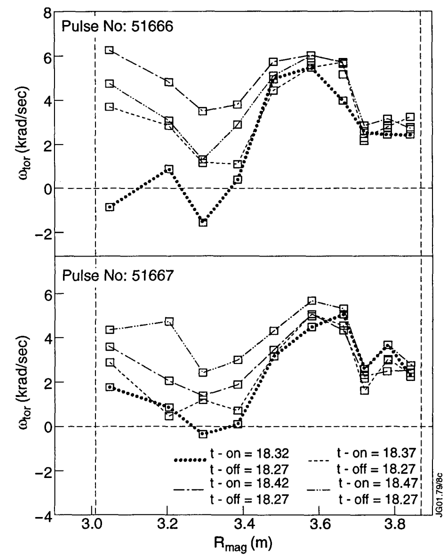


**Figure 8:** Rotation profile, for a LFS position of the resonance layer (37MHz, 2.8T), for a co (top) and counter directed spectrum (bottom)

by the strong MHD modes, the measured rotation profiles are then very flat, the value of the rotation low. This is indicative of a powerful braking effect due to the modes.

## In L mode, with HFS and LFS position of the resonance layer

Fig. 7 shows the rotation profile for a HFS location of the resonance layer, co- and counter directed spectra, and in fig. 8 a LFS location, for both spectra.

The overall rotation in L-mode with only ICRF is smaller than with neutral beam injection. Whereas the profiles with NI are monotonically decreasing from the center to the edge, the profiles with ICRF only, show more distinct structures with both for LFS and HFS position of the resonance layer a clear maximum of co-rotation off-axis. The location of the resonance layer plays a role in that a HFS location of the resonance layer leads to a slightly larger value of this maximum than for a LFS position of the resonance layer. It is on the other hand not clear whether the counter-rotation in the center, observed for both positions of the resonance layer for a co-directed spectrum, as opposed to the co-rotation for a counter directed spectrum is significant or not.

The profiles with ICRF only and in particular the differences seen with the position of the resonance layer provide the first data against which to test the existing theories.

## ACKNOWLEDGEMENT

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