First Observations of Collective Thomson Scattering from JET Plasmas

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1. Introduction

The main aim of the JET fast ion and alpha particle diagnostic is to measure the velocity distribution of the fast alpha particles in JET during the DT phase from collective scattering of high power 140 GHz radiation [1]-[3]. Successful experiments at similar frequencies have recently been reported on the Wendelstein W7-AS stellarator [4]. We report the first observations of collective scattering from JET plasmas. They indicate that the diagnostic will give the predicted performance for observations of alpha particles in JET.

2. The diagnostic system

The gyrotron source can generate 500 kW RF at 140 GHz for 0.5 s, with > 90 % in a Gaussian beam. For these first measurements up to 15 pulses of 1 to 5 ms duration were used. Access to the central plasma is possible at high magnetic fields (B $>$ 3 T). The steerable injected and received beams are focused to waists of 30 mm radius near the plasma centre.

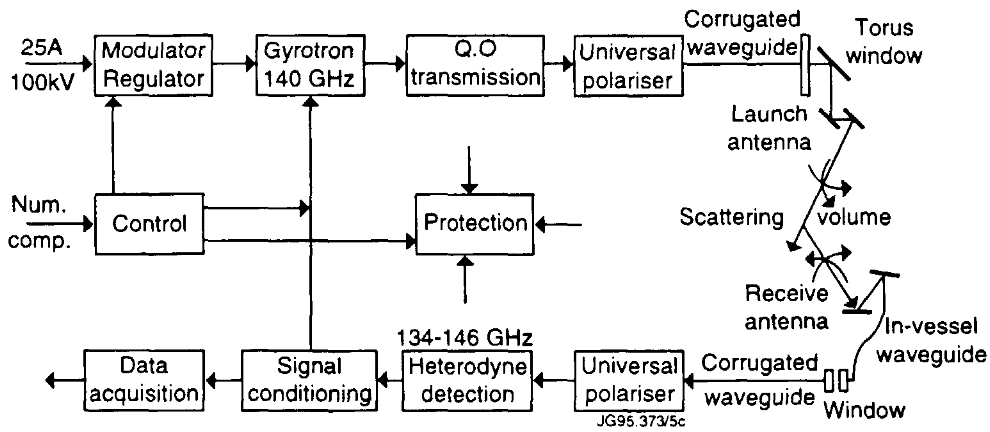

Fig. 1: Schematic overview of the KE4 diagnostic

The gyrotron was operated at ~ 90 % of maximum power to give a stable, spectrally clean output. After filtering and polarization the power was 370 kW, of which almost 100 % reached the torus via ~ 60 m of 88.9 mm ID corrugated waveguide. During transmission the 190 mm diameter water-free fused silica torus window was heated at 100° C/s in the centre. The beam profile at the torus, determined from the pattern on thermosensitive paper, appeared to be closely Gaussian. The effective reflectivity of the vessel was low: even with no plasma the power injected into the torus caused no damage to any of the diagnostic detectors sensitive to this frequency.

On the receiver side, stray gyrotron radiation reaching the receiver antenna (~ 10 mW) was removed by two notch filters in series, with at least 80 dB attenuation and a full width of 200 MHz at -3 dB. Frequencies outside the notch filter, generated briefly during switch-on and switch-off of the gyrotron, caused temporary saturation of the receiver and negative spikes in the raw data. The receiver bandwidth (134 to 146 GHz) is divided into 32 channels, 21 in the lower sideband and 10 in the upper, and one monitoring stray 140 GHz.

3. Results

O to O mode scattering was selected to minimise the effects of refraction. Intersection was required at R = 3.0 m, 20 cm above the torus centre, with $|\mathbf{k}| = |\mathbf{k}^s - \mathbf{k}^i| = 1520 \text{ m}^{-1}$. To set up the system the incident and scattered rays satisfying the required scattering geometry were found for an actual plasma similar to those expected, with $B_0 = 3.4$ T, $n_{e0} = 3.4 \times 10^{19} \text{ m}^{-3}$. From this the necessary settings of the antenna mirrors and of the universal polarizers were computed. The resulting angle between B and k was 122° and the scattering angle 32°. In operation, one beam was adjusted slightly to optimise the overlap.

Clear scattering signals were seen from plasmas with $B_0 > 3$ T. Fig. 2[a] is a sample of the raw data. At lower fields (between ~ 2 and ~ 3 T) absorption of a pulse by EC resonances causes local heating and increased ECE around a flux surface. This is seen in Fig. 2[b]. The linear rise during the pulse and subsequent cooling time constant of a few ms clearly identifies the heating signal. No significant local heating was seen for $B_0 > 3$ T.

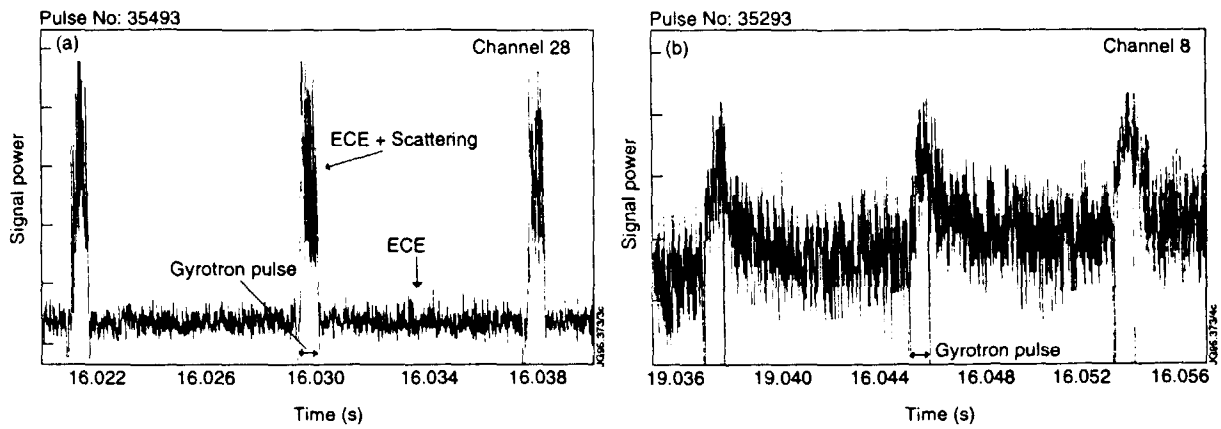

Fig. 2: Raw data from plasmas with [a] B = 3.1 T and [b] B = 2.9 T

In the absence of plasma virtually no signals were observed except in the channel at the gyrotron frequency. Relative calibration was obtained from detected ECE, assumed to be constant over the ranges of interest, and taking into account the measured transmission of the notch filters. System nonliniarity varying between channels was compensated for by using differences between two ECE levels near those observed. Calibration and system nonlinearity are the most important sources of uncertainty in present spectra. In particular the channel at -100 MHz (see Fig. 3a) is unreliable. A rough absolute calibration was obtained by comparing the detected ECE level with that measured by a calibrated ECE diagnostic with a different viewing direction.

Clear scattered signals were obtained for shots with moderate ICRH power coupling to 2nd harmonic of the bulk deuterium. Significant amounts of nitrogen were present (injected for divertor studies). The spectra obtained for these plasmas were all qualitatively similar to Fig. 3a. Spectra were also obtained for a wide variety of other plasma conditions, but the overlap of the injected and detected beams was not always optimised.

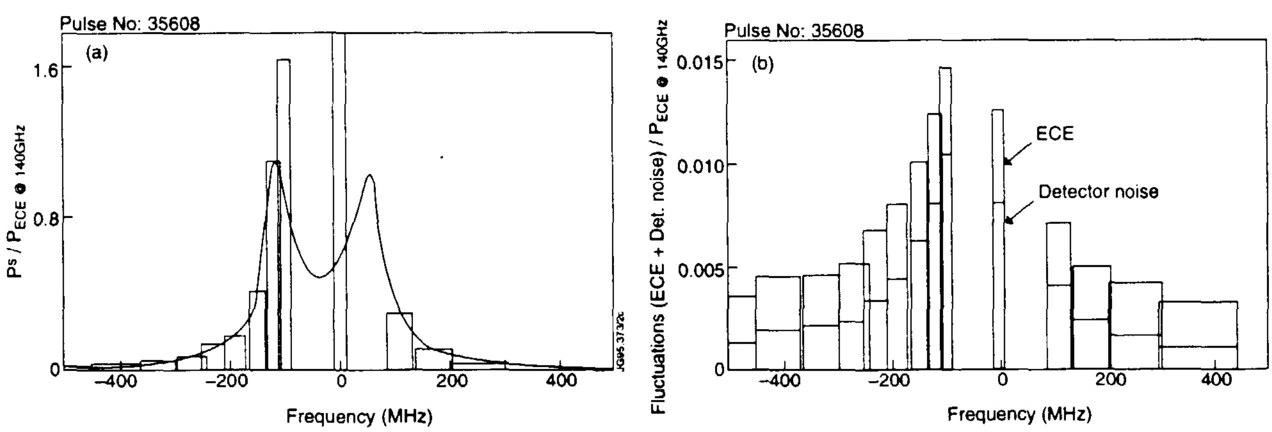

Fig. 3: Shot no. 35608 at 57.5 sec.: 5 MW ICRH, T_{ECE} at 140 GHz = 325 eV.
[a] Spectral intensity of scattered light normalized to spectral intensity of ECE at 140 GHz.
***Histogram**: . Measured scattered signal integrated over 2 gyrotron pulses (1.6 ms).*
***Curve**: theoretical fit. Given: $B = 3.1$ T, $n_e = 4.1 \times 10^{19}$ m^{-3}, $T_e = 3.0$ keV, angle $(k_i, k_s) = 32°$, angle$(k,B) = 122°$. Fitted: $n_{D1} = 1.2 \times 10^{19}$ m^{-3}, $T_{D1} = 3$ keV, $n_{D2} = 0.8 \times 10^{19}$ m^{-3}, $T_{D2} = 20$ keV, $n_N = 0.3 \times 10^{19}$ m^{-3}, $T_N = 3$ keV.*
[b] Spectral intensity of fluctuations in ECE and detector noise normalized to spectral intensity of ECE at 140 GHz. Integration time: 1.6 ms.

The histogram represents the measured spectral intensity in each channel normalized to that of ECE at 140 GHz. The curve is theoretical (Bindslev [3]) based on B, n_e and T_e obtained from other diagnostics: the ion parameters were fitted. The fit is only illustrative. It assumes that scattering in the wings is due mainly to a hot D ion population while the sharp central peak is due to N. The shift of ~ 30 MHz suggests a toroidal drift velocity of $\sim 1.6 \times 10^5$ m/s. The absolute level of the measured spectral intensity is ~ 70 % of that predicted by theory for perfect beam overlap. The discrepancies are well within the uncertainties of the data.

From Fig.3 (a) and (b) the post-detection S/N, *i.e.*

Scattered signal / Fluctuations on integrated (signal + ECE + detector noise),

is in the range from 10 to 100. Similar values are found for other spectra.

4. Conclusions

The diagnostic behaved as expected, and the observed signal-to-noise ratios were in satisfactory agreement with theory. When the full pulse length of the gyrotron can be used with fast modulation, the diagnostic should give the expected performance for observations of fast ions and alpha particles.

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