

STRUCTURES IN T_e PROFILES: HIGH RESOLUTION THOMSON SCATTERING IN RTP

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1. Introduction

Electron heat transport is the main topic of the RTP (Rijnhuizen Tokamak Project) research program. Especially, the possible role of small scale structures in the magnetic configuration and their influence on electron temperature, density and pressure (T_e , n_e and p_e) is a key issue in the study. For this reason RTP ($R/a = 0.72/0.16$ m, $B_T \leq 2.5$ T, $I_p \leq 150$ kA, $q_a \geq 2$) is equipped with high resolution diagnostics, including a 16 channel electron cyclotron emission imaging system (ECE-I), a 20 channel ECE radiometer, a 19 channel interferometer, and a 80 channel, five camera soft X-ray tomographic system, [1]. However, the size of the smallest structures expected to have influence on macroscopic plasma phenomena is of the order of the ion Larmor radius, which is a few mm in RTP. This level of detail cannot be resolved with any of the above mentioned, time-resolving diagnostics, of which the spatial resolution is 1.5 cm at best, but it can be accessed with the double pulse Thomson scattering (TS) system. This diagnostic takes two snapshots of T_e and n_e along a vertical chord through the plasma, with a spatial resolution of 3 mm and a time separation of 20-800 microseconds. Measurements with this diagnostic reveal small scale structures in practically all plasma conditions, ranging from multiple peaks of high temperature in the central plasma (filaments), small magnetic islands to large $m=2$ modes. The double pulse option serves the following purposes: 1) to test the reliability of the measurement; 2) to obtain some information on the dynamics of the small scale structures, and 3) to perform a crude mode analysis (in the case of rotating islands). In this paper we discuss a few typical examples of profile measurements obtained with the double pulse Thomson scattering diagnostic: an ordinary, central sawtooth collapse, showing the displacement of the hot core; filamentation of the central plasma in a period when the central temperature is rising in response to edge cooling; and a rotating $m=2/1$ mode.

2. Thomson scattering diagnostic

The TS diagnostic, [2, 3], measures T_e , n_e and p_e with a high spatial resolution of 3 mm FWHM along a vertical chord of 300 mm. The relative accuracy of the measurements is 4 % for T_e and 3 % for n_e for $T_e = 1$ keV and $n_e = 5 \times 10^{19} \text{m}^{-3}$. The laser system is a 25 J Ruby laser (694.3 nm) that can be operated in double pulse mode, firing two laser pulses of ≈ 12 J each with 20–800 μs pulse separation. The 300 mm laser chord is imaged, using conventional optics, onto the 200 mm entrance slit of a spectrometer. This Littrow based grating spectrometer produces a two dimensional image with spatial information along the vertical axis and spectral information (in the range 530–850 nm) along the horizontal. The double CCD based detector system contains two Intensified CCD cameras (ICCD's), one gating at the first laser pulse and the other at the second laser pulse. T_e and n_e are obtained by fitting the spectra with a Gaussian-like expression taking into account relativistic effects and assuming an isotropic velocity distribution. The CCD's have 300 pixels in the spatial direction divided over the chord representing 300 mm. Since the resolution is 3 mm, it is oversampled with 3 pixels.

3. Central sawteeth

Fig. 1 shows the central ECE channel of a plasma with $I_p=60$ kA, $q_a=5.8$, and $q_0 < 1$, $n_e(0)=1.5 \times 10^{19} \text{m}^{-3}$. The plasma is centrally heated applying ECH and has strong sawtooth activity. The sawtooth activity is enhanced by launching the EC waves under a small angle of 7° , thus peaking up the current density profile. A current of ≈ 10 kA is driven this way. Three well reproducing discharges are considered, in which the TS laser was fired in three different stages of the sawtooth crash, as indicated in Fig. 1. Fig. 2 shows the three TS profiles belonging to these discharges. Fig. 2(a) shows the T_e -profile just before the crash with a high central $\langle T_e \rangle$ of 2.3 keV because of the central heating. It is a filamented profile with filaments of 5–10 mm wide and 500–700 eV high. Fig. 2(b), measured during the sawtooth crash shows the spectacular displacement of the hot core. The profile of (a) is overplotted for comparison. Fig. 1(c) shows the profile just after the crash. The profiles (a) and (c) are equal outside the inversion region, while the top of (c) is flattened.

4. Filaments in non-locally heated plasmas

Filaments are a common observation in low density ECH heated plasmas, [5], see Fig. 2(a). However, they have also been observed in plasmas which show a transient central temperature rise in response to fast edge cooling [3, 6, 7] In these plasmas a small hydrogen pellet (0.6 mm diameter) is shot in and passes the plasma center at normalized radius $\rho > 0.65$. This 'non-local' central rise of T_e has been observed in plasmas with $2.5 \times 10^{19} \leq n_e(0) \leq 4 \times 10^{19} \text{m}^{-3}$. An example is given with $n_e(0)=2.5 \times 10^{19} \text{m}^{-3}$, $q_a=5$ and $I_p=80$ kA. Fig. 3 shows the central T_e by ECE and the central line-integrated density by interferometry. The pellet is injected at 205 ms and the central T_e goes up to 20% of the level before injection and reaches its maximum at 209 ms. The line integrated n_e increases by a factor of ~ 1.5 . Sawtooth activity is enhanced by the pellet. Fig. 4(a) and (b) shows two TS p_e profiles taken during the same shot, 400 μs separated in time as indicated in Fig. 3. The p_e profiles are presented rather than T_e because the effect to be shown is more obvious on p_e . The first laser pulse is on the $T_e(0)$ maximum just before a major sawtooth crash and shows that the p_e profile is filamented. Fig. 4(b) shows that the p_e profile is flattened due to the sawtooth crash and the filaments have disappeared. As observed before, [3], the sawtooth crash destroys the filaments.

5. Rotating modes

Double pulse TS is applied at a centrally ECH heated plasma with $I_p=60$ kA, $q_a=5.8$, and $n_e(0)=1.5 \times 10^{19} \text{m}^{-3}$. The magnetics show $m=2$ activity with a rotation period of 114 μs , see Fig. 5. The two TS pulses are fired with 400 μs separation. The timing in relation to the rotating mode is indicated in Fig. 5; the pulses are 3.5 periods separated. Fig. 6 (a) and (b) shows the two TS T_e profiles of this discharge. The $m=2$ has rotated from showing its X-point to showing its O-point.

6. Conclusion

In summary, the double pulse Thomson scattering diagnostic at RTP, which presently offers the best resolution and accuracy for measurements of T_e and n_e in tokamak physics, is fully operational. It shows that practically all tokamak discharges in RTP show a fine structure at the scale of 5-10 mm, or 3-6% of the minor radius. In this paper we have given a few examples of the type of phenomena that can be studied with this diagnostic. A similar system has been installed

at TJ-2 and has produced results recently, while a third system is presently being developed for TEXTOR-94.

Acknowledgements

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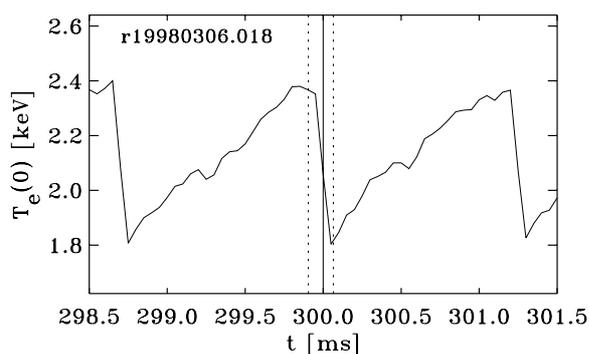


Figure 1. Central ECE channel of a sawtoothing ECH plasma. The vertical lines indicate the firing of the TS laser relative to the crash for the discharges in Fig. 2.

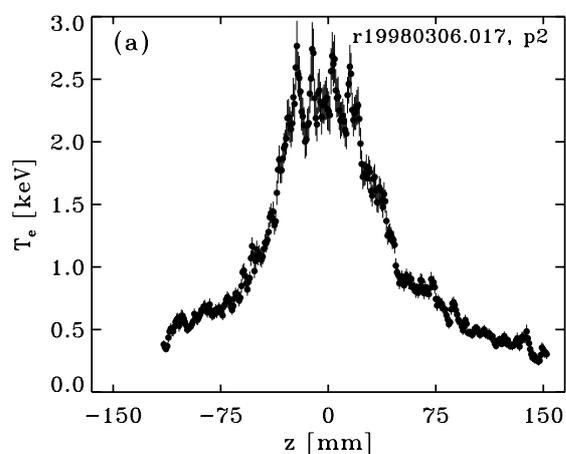


Figure 2 (a). TS profiles just before the sawtooth crash, with high central T_e and a filamented core.

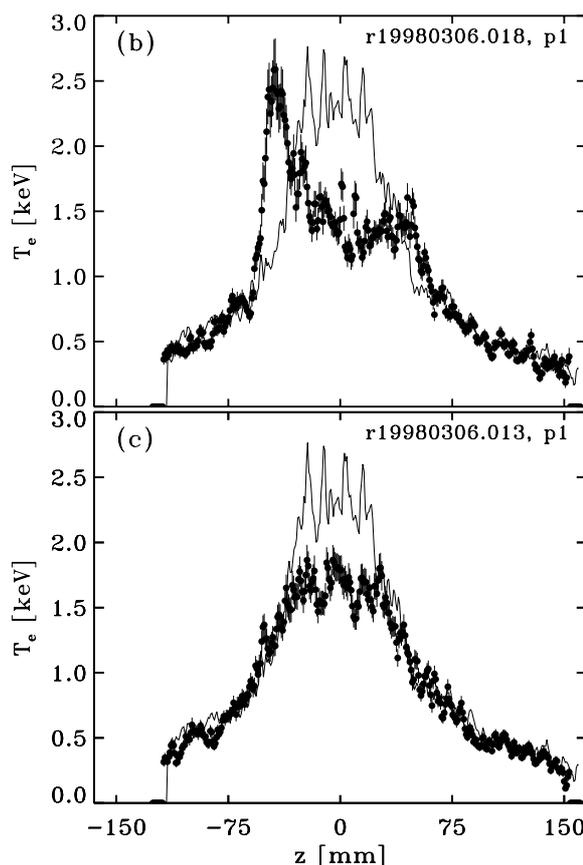


Figure 2 (b) and (c). (b) Profile inside the sawtooth crash, showing the displacement of the hot core. (c) After the sawtooth crash the flattened top of the profile is visible. The profile of (a) is overplotted in (b) and (c). The measurements are taken in three well reproducing discharges.

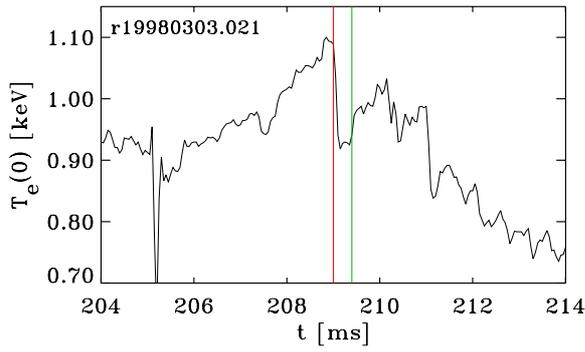


Figure 3. Central T_e by ECE. A pellet is shot in obliquely at 205 ms. A transient $T_e(0)$ rise occurs, and sawtooth activity is enhanced. The timing of the TS pulses, Fig 4 is indicated by the dotted vertical lines.

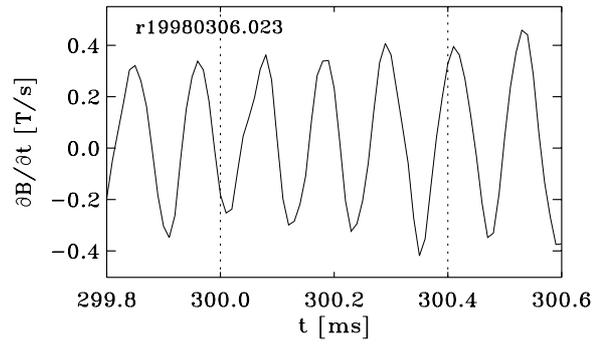


Figure 5. Signal of the magnetics showing a rotating $m=2$ mode. The signals of four Mirnov coils are combined to select this mode. The timing of the TS pulses, Fig 6 is indicated by the dotted vertical lines.

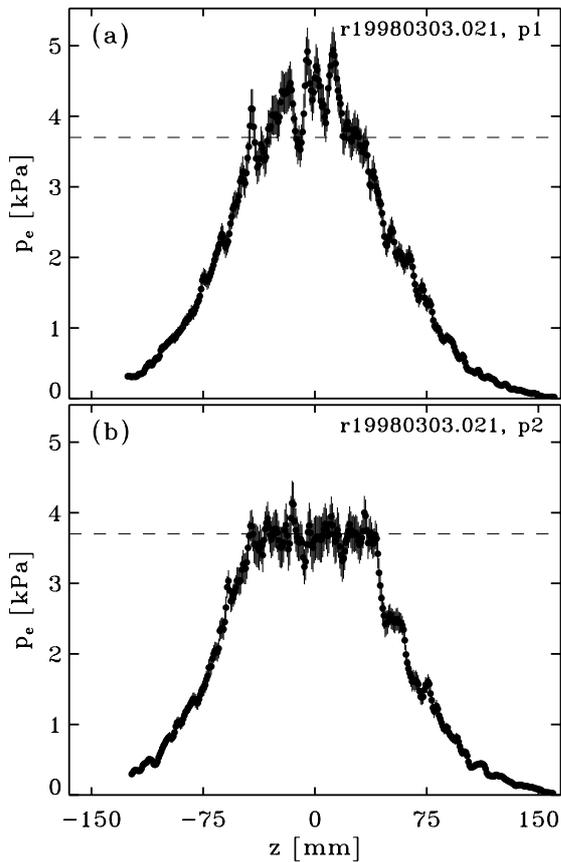


Figure 4. Two TS p_e profiles taken in the same discharge $400 \mu\text{s}$ separated in time. (a) In response to the pellet induced edge cooling, the central temperature rises and filaments form. (b) After a sawtooth crash the center is flattened and the filaments have disappeared.

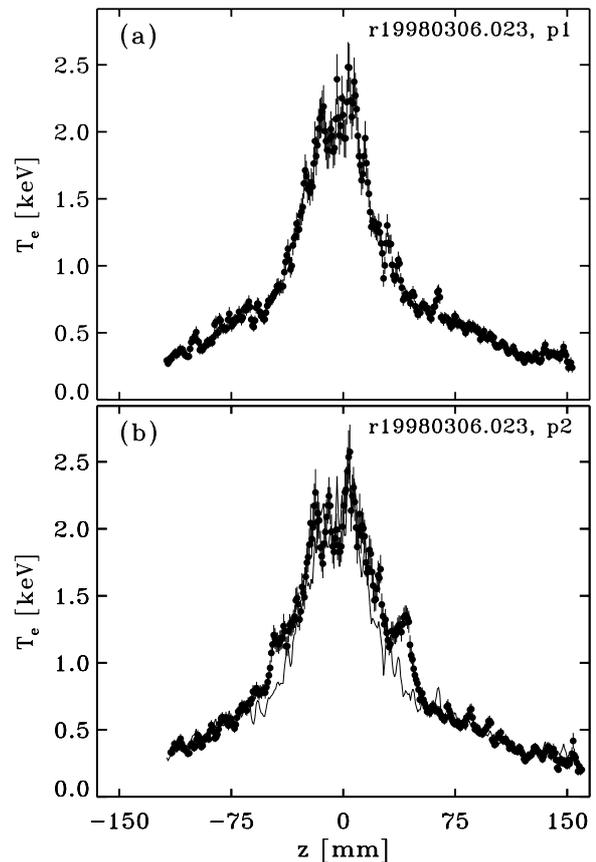


Figure 6. TS profiles $400 \mu\text{s}$ separated in time, i.e. 3.5 periods of the $m=2$ activity (Fig 5). (a) T_e profile showing the X-points of the $m=2$ island. (b) T_e profile showing the O-points of the $m=2$ island. The profile of (a) is overplotted in (b).