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Investigation of DED generated MHD islands in the TEXTOR plasma with 10 kHz Thomson scattering system

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1. Introduction

The electron temperature (T_e) and density (n_e) profiles inside m=2 magnetic islands in TEXTOR plasmas (R/a = 1.75/0.46 m, B_T < 2.9 T, I_P < 800 kA) were measured in the past with a high-resolution double-pulse Thomson scattering system [1]. The large-sized islands showed up as flat regions in T_e-profiles and peaked regions in n_e profiles, respectively. The presence of the islands influences the plasma transport due to an increased heat transport across the islands and moreover, plasma disruptions may occur when the islands grow too large [2].

Recently, a novel multi-pulse TV Thomson scattering (MPTS) system, capable of measuring four times 40 profiles at a repetition rate of 10 kHz has been installed at TEXTOR. The new MPTS diagnostics has been applied to investigate magnetic islands during experiments with the Dynamic Ergodic Divertor (DED) [3], in its 3/1 mode of operation, at TEXTOR. The DED can produce a moving (AC) or a stationary (DC) ergodization of the magnetic field at the plasma boundary. Resonances are made typically at the q=3 surface, generating m=3, n=1 magnetic islands in the plasma. Also an m=2, n=1 sideband is present in the magnetic perturbations inducing m=2, n=1 magnetic islands [4].

An introduction of the new MPTS system will be given, concentrating mainly on the operational characteristics of the diagnostic and new features in the MPTS data analysis. Finally some first results of T_e profiles inside large DED generated islands are shown.

2. Multi pulse Thomson scattering at TEXTOR

In the new MPTS system [5] at TEXTOR, the conventional ruby laser is replaced by a 10 kHz intra-cavity ruby laser, and an ultra-fast, multi-frame detector with CMOS cameras is utilized. The viewing optics samples either the full plasma diameter of 900 mm at 120 spatial points of 7.5 mm each, or a 160 mm edge chord with 98 spatial points of 1.7 mm each. A detailed description of the system will be given in a paper to be published by Barth et al. [6].

The TEXTOR plasma is included in the 18 m long laser cavity (see Fig. 1). A spherical mirror below the tokamak reflects the beam back into the plasma, making double utilization of the probing energy. During a TEXTOR discharge up to four bursts of ~ 40 laser pulses of 10-15 J each can be fired at a rate of up to 10 kHz. The bursts can be triggered with a minimum separation time of ~0.1 s. The width of the laser pulses is typically 1-2 μs (FWHM). The divergence of the beam is <0.7 mrad (defined for 90 % of the energy) resulting in a beam waist of 3 mm in the plasma centre.

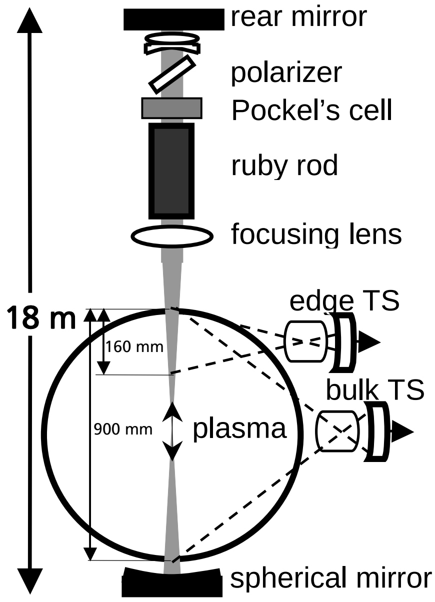

Fig 1. Schematic of the intra-cavity ruby laser at TEXTOR. The viewing lenses for bulk and edge measuring chords are also shown.

The scattered light is collected by multi-element lenses, relayed over a distance of 28 m using two fibre bundles (one for the bulk and other for the edge chord) and finally spectrally analysed by a Littrow spectrometer. A cascade of image intensifiers consisting of one Gen-III (P46, η=50% over 585-800 nm) and three Gen-I intensifiers is employed to intensify the spectrally resolved light to an appropriate intensity (photon gain ~ 4×10^4) before it is imaged onto the cameras. Two CMOS cameras (Phantom V7.0) with an image format of 512×384 pixels (each of 22 μm^2), an inverse sensitivity of 50 photons/count and an effective dynamic range of 10 bits are utilized to record the spectrally resolved light. With the present system the electron temperature (50 eV – 5 keV) and density profiles along the full vertical chord can be measured with an observational error of typically < 8% in T_e and < 4% in n_e (at a density of $n_e \sim 2.5\times10^{19}$ m^{-3} using a laser pulse energy of 15 J).

A double Mattioli function comprising two relativistic spectral distributions corresponding to forward and backward Thomson scattering is fitted to the experimental data in order to derive T_e and n_e profiles. The fit function is convolved with the 1-D instrument function of the system in order to correct the data for the imperfection caused by the 2-D instrument function, since direct 2-D deconvolution is not possible due to lost information from the boundaries of the spectra [7]. The contribution of the plasma light to the spectra is measured between consecutive laser pulses and is subtracted from the spectra before applying the fit procedures.

3. Experimental results and discussion

The first measurements with MPTS at TEXTOR were focussed on measuring the T_e profiles inside m=2 magnetic islands during DC and AC operation of the DED in the 3/1 mode. In the present experiments the length of the pulse train was limited due to thermal lensing effects in the ruby rod. A single burst of 14 pulses at a rate of 5 kHz and energy between 5-15 J is used. The thermal lensing effects will be reduced in the near future by using a ruby rod with an optimized Cr doping.

The temperature profiles through different positions of a large island measured in two different DC-DED shots are shown in fig.2 (a & b). The experiments were performed at B_T=2.25 T, I_P= 300 kA, $n_e(0)$= 2.0×10^{19} m^{-3} and varied only by the relative currents in the external DED coils, leading to different stationary positions of the island positions, about 90° apart. The error bars of only a few percent are achieved by binning over nine consecutive spectra. The m=2 island positioned around ±30 cm has a size of ~8 cm and is clearly seen in both shots. The profile perturbation by the island is observed to be asymmetric. This can be attributed to the fact that measurements are performed along a chord that is shifted by 9 cm towards the low field side. The right wing of the profile in fig. 2 (a) seems to be through the

X-point whereas the left wing is showing the O-point region. In fig. 2(b) it is the other way around. The position of the islands observed with Thomson scattering is consistent with the settings of currents through the DED coils. On both profiles, the temperature is rather flat in the regions of the O-point, which has been also previously observed for 'natural' m=2 islands in TEXTOR [2].

Similar measurements for the DED plasmas operating in AC-mode at 1 kHz are shown in fig. 3(a). In this case electron cyclotron current drive in the co–current direction (co-ECCD) is applied in the plasma core ($\rho<\rho_{mode}$), leading to an enlargement of the island. A sequence of six temperature profiles with a time resolution of 200 µs is plotted above each other. Because the repetition rate of MPTS was set exactly at 5 times the DED frequency, the statistics in fig. 3 was improved by adding the 1st and 6th, the 2nd and 7th, etc. profiles. In addition a four times larger binning in the z-direction was performed compared to fig. 2. Indications of the rotating islands are observed which repeats after one cycle. However, it might be obvious that a better statistics is required to be able to perform a detailed study of this dynamic behaviour. The profiles shown in fig 3(b) are measured when co-ECCD inside the island is applied in order to suppress the DED generated m=2 islands [8]. For this case no flat regions in the sequence of the MPTS temperature profile are observed, indicating indeed the suppression of the islands.

4. Conclusions and Outlook

The first results of MPTS obtained in DC-DED plasmas at TEXTOR have demonstrated the potential of the system in diagnosing the profiles inside large islands. The fact that stationary islands in DC-DED are not detectable by other diagnostics like ECE, Mirnov coils etc., makes MPTS an essential diagnostic for the study of these island structures.

Although for the AC case indications for the dynamics of the rotating islands are observed, better statistics is required for a detailed study of these islands. Multi-burst operation with longer and constant energy pulse trains will be soon possible by employing a low Cr-doped ruby rod. The detailed topology of islands can then be studied by operating the MPTS system in synchronization with the DED.

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5. References

[1] S.K. Varshney et al., Proc. 11th Int. Symp. on Laser-Aided Plasma Diagnostics, Les Houches, France (2003), P18
[2] P.C. de Vries et al., Plasma Phys. Control. Fusion, **39** (1997), 439-451
[3] K.H. Finken et. al., Proc. 30th EPS Conf., St. Petersburg, Europhys. Conf. Abstr. (2003) Vol. **27A**, paper number O-4.4Apd
[4] H.R. Koslowski et. al., this conference, P1-124
[5] H. J. van der Meiden et. al., accepted for publication in to Rev. Sci. Instrum., **74** (2004)
[6] C.J. Barth et al., to be published in Rev. Sci. Instrum., 2004
[7] I. Classen et al., Proc. 30th EPS Conf., St. Petersburg (2003), Europhys. Conf. Abstr. (2003) Vol. **27A**, P2.132
[8] E. Farshi et al., this conference, P1-122

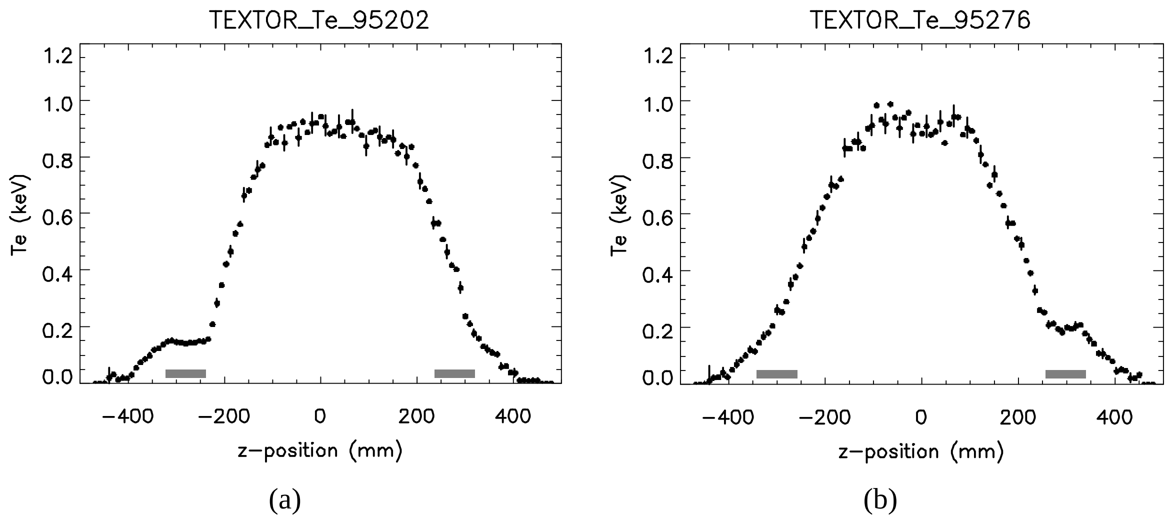

Fig 2. (a, b) Temperature profiles through different positions of a large island, measured in two different DC-DED shots. The m=2 island structures positioned around ±30 cm having size of ~8 cm (depicted by grey areas) are clearly seen in both shots. The profile perturbation by the islands is asymmetric and is consistent with the DED coil settings.

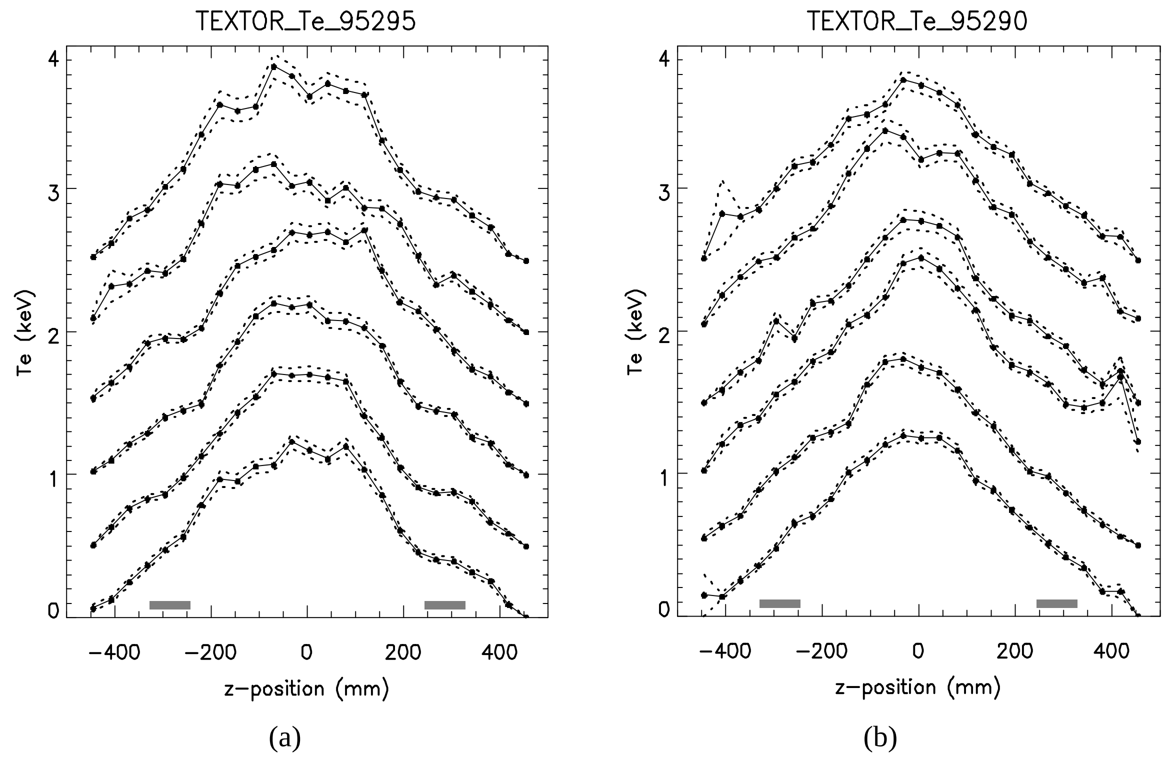

Fig 3. (a) Six T_e profiles recorded every 200 µs in AC DED operation. Error in the T_e measurements is plotted with dashed lines for each curve. The energy in the pulse train varied from 15 to 4 J. T_e profiles are plotted with an offset of 0.5 keV. In this case co-ECCD is applied in the plasma core ($\rho<\rho_{mode}$), leading to an enlargement of the island. The dynamic behaviour in the evolution of profile with islands is visible which repeats after one cycle of the islands rotation (b) Similar measurements at the time of co-ECCD injection inside the island to suppress the rotating islands, indicating the suppression of the islands.