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Transport, Radiation and Rotation Properties of Carbon on TEXTOR under the Influence of the Dynamic Ergodic Divertor - Physical Issues and Design of a New Diagnostic

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1. Introduction

On TEXTOR the feasibility of an efficient power exhaust through enhanced edge radiation induced by intrinsic and injected impurities has already been demonstrated. However, the requirement of low central plasma impurity contamination for a burning thermonuclear plasma, also due to the production of α-particles, strongly limits the level of impurity seeding [1]. Theory [2] and experiments [3,4] have shown that, for a given and tolerable impurity concentration in the plasma core, the level of radiation emitted by the impurity ions at the edge can be substantially enhanced by increasing the particle transport at the plasma periphery. This can be achieved by perturbing the equilibrium field of the closed magnetic flux surfaces at the plasma periphery by external coils. The resulting reconnection of the magnetic field lines at the plasma edge (which does not affect the central plasma) is expected to be beneficial for the power and particle exhaust through enhanced recycling, particle transport at the edge, impurity screening and enhanced radiation. For that purpose the Dynamic Ergodic Divertor (DED) has been designed and is presently under construction on TEXTOR.

2. The Dynamic Ergodic Divertor in TEXTOR – experimental set-up and different operational regimes

The DED in TEXTOR consists of sixteen toroidal perturbation coils (four quadruples), installed in the vessel at the high field side and aligned parallel to the q=3 surface. Graphite tiles, which protect the DED coils, form the target plates. The amplitude of the maximum perturbation current in each coil is 15 kA. By changing the phasing between the currents in the different coils the generated perturbation field can rotate poloidally at different frequencies, from DC up to 10 kHz. The base mode has poloidal number m = 12 and toroidal number n = 4. A mixture of this base mode and of modes with lower m and n (e.g. m/n = 6/2)

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will be used. The high mode numbers are chosen to create chains with many small islands, minimizing the disturbance of the magnetic structure in the core. At the same time, due to the components with longer wavelengths, the decay of the amplitude of the perturbation field is decreased, extending the width of the disturbed zone. On top of that the structure and dimensions of the new magnetic configuration is also influenced by the plasma current, through the position of the q = 3 surface.

3. Motivation and design of a new diagnostic for the study of the behaviour of carbon ions

The magnetic perturbation will influence the sources, recycling and radiation efficiency of impurities. A new diagnostic is designed for the measurement of the carbon fluxes and of the brilliances of spectral lines from C^{2+} and C^{4+} ions. The light from nine chords, directed towards the high field side of the tokamak, where the coils of the DED are located, is focused on nine optical fibres (fig. 1). On fig. 2 the lines of sight are shown on a Poincaré plot of the edge magnetic field, typical locations for the carbon ions are indicated. A first monochromator, in the visible, will detect the fluxes, related to the sources of carbon and thus mainly to the strike points of the magnetic field lines on the divertor plates. Another set of nine fibres is connected to the entrance slit of a high resolution spectrometer (UV in air) to measure CIII and CV lines in the spectral range of 230 nm. This spectrometer has two orthogonal exit slits at which the two spectral lines appear at about 6 mm distance. The two exit slits of the monochromator will be equipped with two different detection systems:

- One system consists of two series of nine photomultipliers in order to observe both spectral lines for each of the nine chords at the same time. This allows a time resolution of the order of 1 ms, but it does not resolve the spectrum. On fig. 3 some lines of sight of the new diagnostic are plotted on a simulation of the power load density to the wall of TEXTOR during static operation of the ED [5]. However, during low frequency operation (50Hz) the strike points on the divertor plates are expected to rotate at the same frequency, decreasing the level of hot spots - as seen on Tore Supra - and spreading the heat load over a wider area. This relatively fast detection system, in combination with the measurement of the carbon fluxes, allows following in time the effect of the rotation of the magnetic structure and of the changing position of the strike points on the carbon production and radiation. On the other hand, a time of 1 ms is also comparable to the lifetime of carbon ions at low ionisation level and it is therefore convenient to detect transient phenomena at the plasma edge.

- The other detection system consists of a CCD camera equipped with image intensifier. The camera is intended to detect the spectra of the three channels that are most tangential to the magnetic flux surfaces (the outermost three on the left side of the figure), the choice of these three channels being determined by the necessity of maximizing the projection of the poloidal velocity along the line of sight. Indeed, for collective and non-transient phenomena, as in the case of plasma rotation induced by the high frequency operation of the DED [6], the poloidal velocity of carbon ions can be determined from the Doppler shift of the spectral lines. Although uncertainties in the theory persist (possible contribution by electric fields), the expected poloidal velocities are of the order of a few 10^4 m/s, which correspond to a shift of the spectral lines of a few tenths of Ångström for the considered wavelengths. Taking into account the dispersion of the UV-spectrometer (0.4 nm/mm), this shift corresponds to a few tens of µm at the exit slits. Considering moreover the estimated photon flux and the performances of the detection system, the spectra from the three channels should be measured simultaneously with a time resolution of the order of 10 ms, which is a fraction of the total particle and energy confinement time.

As an example of the signals we expect from this diagnostic, fig. 4 gives the time evolution of CIII and CV lines during CO injection at TEXTOR where the strong increase of the intensity of the CIII line during the injection is not accompanied by a similar increase of the CV line. Although these signals have been acquired before the installation of the DED, the same spectral lines will be used in the new diagnostic to derive the change in transport properties in the new magnetic configuration.

References

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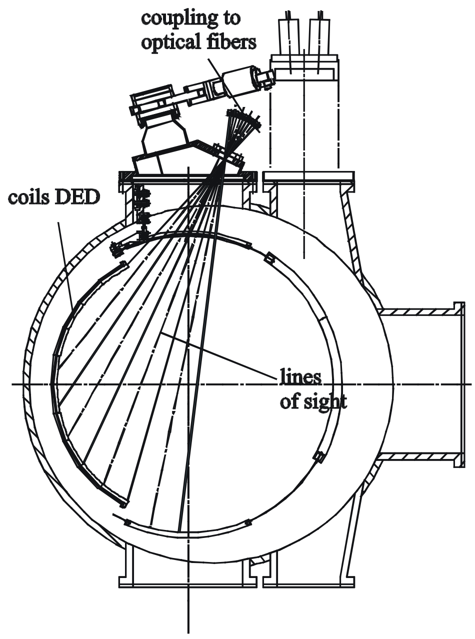

Figure 1 : A poloidal cross-section of TEXTOR with the nine lines of sight of the new diagnostic and the location of the DED coils at the HFS.

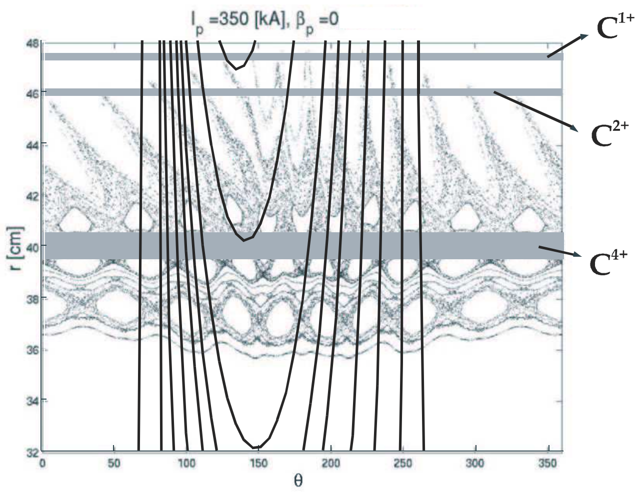

Figure 2 : The lines of sight of the new diagnostic on a Poincaré plot of the edge magnetic field lines for plasma current I_p = 350 kA and β_{pol} = 0 (X axis poloidal angle, Y axis minor radius). Typical locations of C^{1+}, C^{2+} and C^{4+} ions are indicated.

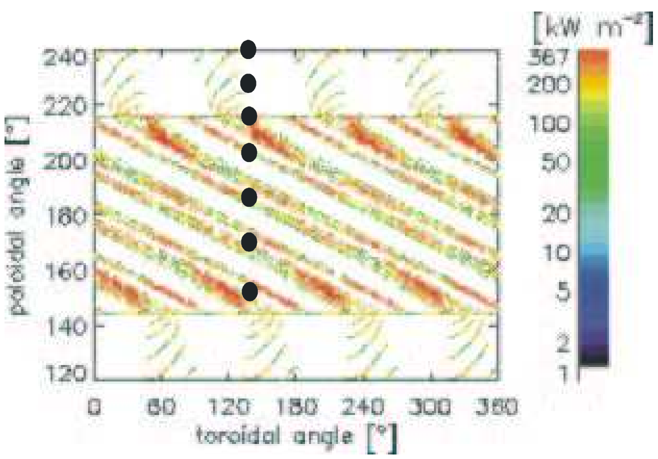

Figure 3 : Calculated power load density to the wall of TEXTOR during static ED operation [6]. Rotation of the perturbing field will smear out the divertor strike zones over the whole surface of the divertor target plates. The black spots are the fixed lines of sight of the new diagnostic. With a sufficiently high time resolution (at least 1 ms for low frequency (50 Hz) operation) the rotation of the strike points and the changing location of the carbon sources can be followed through the variation in time of the carbon signals.

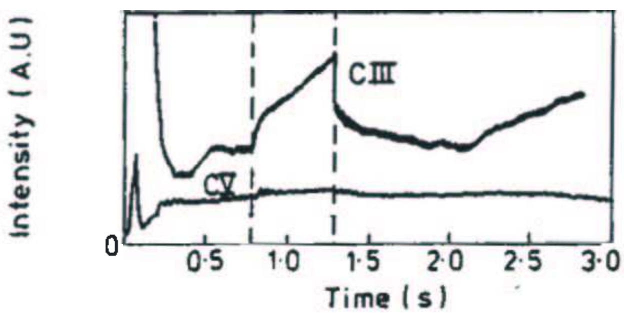

Figure 4 : An example of the time evolution of the two carbon lines CIII and CV along one chord, during CO injection at TEXTOR (gas puff between t = 0.75 and t = 1.25). These signals have been acquired with a similar diagnostic before the installation of the DED.