Latest experimental results of TJ-II Flexible Heliac

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Introduction. TJ-II is a four period low magnetic shear stellarator, designed with a high degree of experimental flexibility, which is operating in Madrid since 1998 (R = 1.5 m, a < 0.22 m, $B_0 \leq 1.2$ T, $P_{ECRH} \leq 600$ kW, $P_{NBI} \leq 3$ MW under installation) [1]. In the last experimental campaign, coupling of the full ECH power to the plasma has been possible, using two ECRH transmission lines with different power densities (1 vs. 15 W/cm^3) and steering launching capabilities (fix vs. poloidal and toroidal variation)**.** Both helium and hydrogen fuelled plasmas have been investigated

Particle control and wall conditioning. In order to get reproducible and controlled discharges under full ECH power injection, new gas control and wall conditioning techniques have been implemented. That has implied the sequential application of He (overnight) and Ar (<30 minutes) glow discharge to the metallic vessel and the development of a gas injection monitoring system for very low gas flows (<0.05 Pa.m^3.s-^{1}) [2]. Low Z effective values and low radiated powers (<20%) are typically achieved under all heating schemes applied. These facts are consistent with the spectroscopic observations (small amount of metallic species) and low values of desorbed Ar [3, 4]. A wall desorption rate proportional to total injected power has been observed, that has limited the operation in He at P< 600 kW. This outgassing rate could not be associated to the change of edge characteristics in the density and power scans (see below), and suggest the presence of direct particle losses to the vessel walls

Configurational effects. Magnetic configuration (iota ≈ 1.28 – 2.24) and plasma volume (0.6 – 1.1 m^3) scans have been investigated. Plasma stored energies (W) up to 1.5 kJ have been measured for electron densities and temperatures up to 1.2 x 10^{19} m^{-3} and 2.0 keV respectively with $P_{ECRH} \leq 600$ kW. The dependence of diamagnetic energy of helium plasmas as a function of rotational transform shows, roughly, two regions, as shown in figure 1 (left). In the low iota range, up to iota(0) ≈ 1.6 energy content increases. For higher iota values, energy content shows a decreasing trend, partly due to the confinement deterioration associated with iota=2 and also associated to the decreasing tendency of the plasma volume in the higher iota region. In hydrogen plasmas only the higher iota region has been studied so far. It shows no clear dependence of the rotational transform, as seen in figure 1 (right). The obvious influence of the plasma volume in the energy content for a given magnetic configuration can be subtracted, in first approximation, by normalising to the calculated configuration volume. The result, shown in figure 2, indicates an increasing dependence for helium with iota and a smaller but also positive slope for hydrogen plasmas. [5]. Several data points in the iota range 1.8-2.0 are missing in figure 2. The reason is that no accurate volume values have been calculated due to code convergence problems in the proximity of iota=2.

High spatial resolution Thomson scattering measurements have revealed the presence of a fine structure in both density and temperature profiles in all magnetic configurations [6]. The investigation of impurity radiation profiles has also shown the presence of topological structures, using an automated pattern recognition procedure [7]. Their possible link to the iota profile (i.e. rationals) and the influence of plasma parameters (collisionality, instabilities) is under investigation.

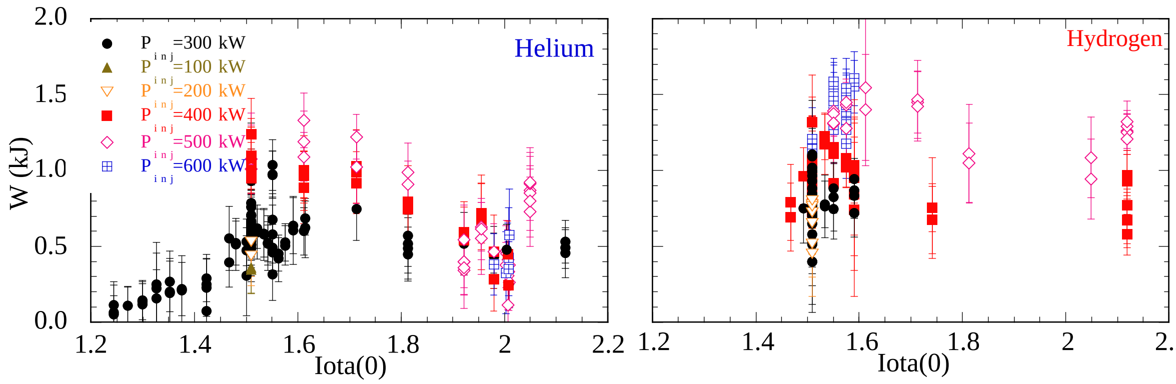

Figure 1: Evolution of diamagnetic energy content as a function of rotational transform for helium and hydrogen plasmas and several values of heating power.

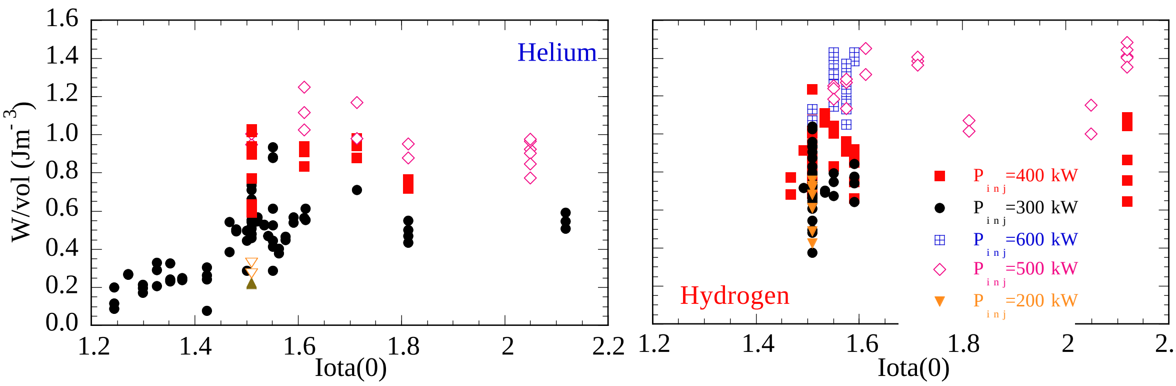

Figure 2: Evolution of diamagnetic energy content normalised to the calculated configuration volume as a function of rotational transform for helium and hydrogen plasmas and several values of heating power.

Transport studies. Electron heat diffusivities have been investigated by ECRH power modulation experiments and power balance analysis. The heat conductivity is about 4 m^2/s in the plasma core region and increases when approaching the plasma boundary region.
Measurements of electron temperature profiles using electron cyclotron emission (ECE) and Thomson scattering diagnostics have shown evidence of internal heat transport barriers in the TJ-II stellarator (Fig. 3). Transport analysis shows a reduction in transport coefficients to a transport rate consistent with neoclassical predictions based on Monte Carlo simulations [8]. Ripple trapped electrons pumped out by ECRH and ExB decorrelation effects are candidates to explain the experimental results. Indeed, non-Maxwellian features have been observed in electron distribution functions over the 1 - 5 keV energy range, which could be related to an ECRH induced deformation of the distribution function.
MHD (ELM-like) events have been measured in plasmas with stored energies of about 1 kJ. The plasma develops bursts of magnetic activity (observed in the Mirnov coils), followed by

a large spike in the Hα signal [9]. The electron temperature measured by the ECE system shows a pivot point at the plasma radius $\rho_{eff} \approx 0.6$ (where the temperature is in the range of (100-200) eV). As a consequence, the electron temperature profile flattens at this plasma position . This flattening is explained in terms of an electron heat conductivity enhancement by a factor of two. These events are localised at the pressure gradient region suggesting the possible role of resistive ballooning instabilities.
Edge parameters (electron density and temperature) have been investigated for a fixed magnetic configuration in both, H and He plasmas by means of He and Li atomic beams and Langmuir probes [10]. Density and power scans have been carried out. No significant differences between both species have been detected. A high insensitivity of edge characteristics to the operational parameters has been found, such as constant edge density for central density scan and constant edge temperatures for the power scan. However, a systematic broadening of edge profiles with P/n_e was seen. SOL particle e-folding lengths were also recorded, allowing the evaluation of diffusion coefficients and global particle confinement times under the assumption of no strong asymmetries. D values of the order of D_{Bohm} and τ_p values ranging from 14 to 3 ms were obtained. A clear degradation of particle confinement with injected power was found, together with indication of confinement enhancement with density. Again, no significant difference between H and He plasmas was found.

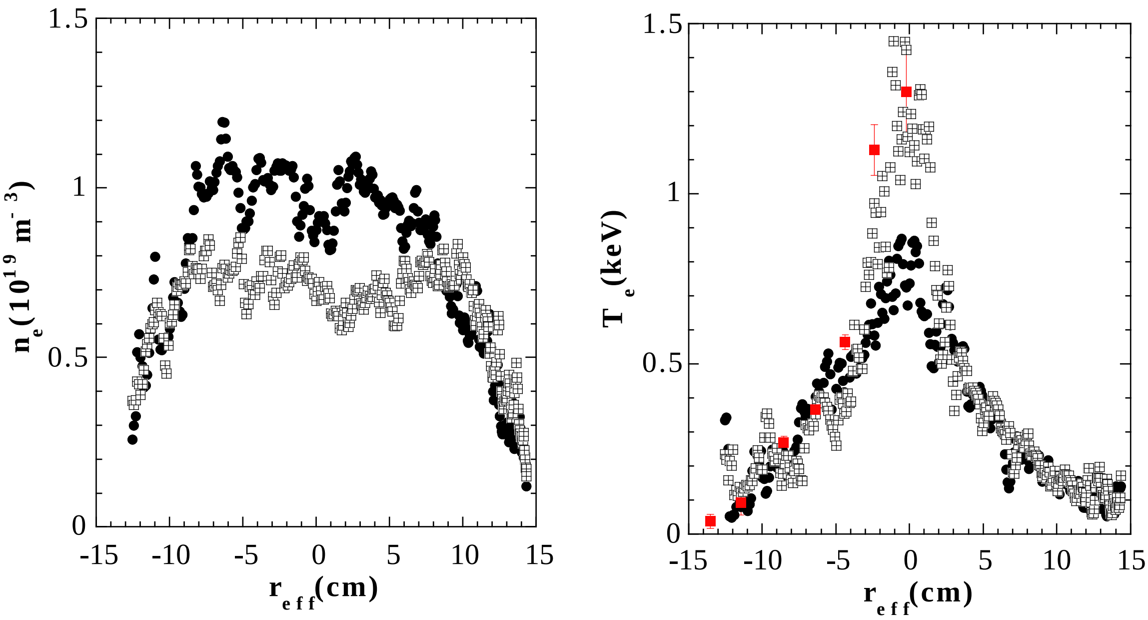

Figure 3: Thomson scattering profiles of helium plasmas with injected power of 300 kW, rotational transform iota(0)=1.51 and different electron density. ECE temperature profile is displayed for the low density case in which the ITB appears.

Turbulence studies. ExB sheared flows have been observed in the proximity of rational surfaces (8/5 and 4/2) in the plasma boundary region for different magnetic configurations [11,12]. Frequency spectra are dominated by frequencies below 200 kHz with density fluctuation levels in the range (10 – 40) %. A modification in the root mean squared (rms) of floating potential fluctuations and in the poloidal phase velocity of fluctuations has been observed near the 4/2 rational surface. The measured correlation time of fluctuations (10 ms) turns out to be comparable to the inverse of the ExB decorrelation rate, suggesting the possible role of rational surfaces to access high confinement regimes. The role of turbulence (via Reynolds stress), breakdown of ambipolarity and the presence of non-thermal electrons are candidates to explain the generation of ExB flows near resonant surfaces.

Measurement of the wave number spectra in fusion devices is difficult due to the fact that spatially resolved information is required. A comparative study of the wave number spectra obtained using both a high-resolution Thomson scattering system (core plasma region) and Langmuir probes (edge region) is under way. The (radial) wave number spectra show a remarkable similarity in shape, which does not appear to depend significantly on either measuring technique, plasma region or plasma conditions. Specifically, the wave number spectra obtained from Thomson scattering are similar to wave number spectra obtained in various devices using different techniques, indicating that the detailed structure observed in the density and temperature Thomson profiles may show the footprint of "common" turbulence as well as the influence of magnetic topology [6,13].

The flexibility of TJ-II allows the magnetic well depth to be modified over a broad range of values (0 – 6 %). The high degree of flexibility in the TJ-II device makes it attractive for investigating transport characteristics close to instability thresholds. The radial profile of ion saturation current and floating potential and their fluctuations has been measured in magnetic configurations with the same rotational transform (iota (a) ≈ 1.8), but with the magnetic well varied from 0.2 % to 2 %. The level of fluctuations increases in the plasma configuration with magnetic hill in the plasma edge. The increase in the fluctuation level is due to fluctuations in the frequency range (1-30 kHz). Interestingly, the breaking point in the frequency spectra (i.e. 1/f region) is directly related with the level of fluctuations. These experimental results show the important role of magnetic well to stabilize pressure gradient instabilities in the TJ-II stellarators and open the possibility to investigate the properties of turbulent transport in the proximity of instability thresholds [14].

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