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# Transport analysis of first TJ-II plasmas.

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## INTRODUCTION

TJ-II is a four period flexible heliac that has started operation at the end of 1997 in Madrid, and has the following charactersitics: $R_0$=1.5 m, 0.10 < a <0.22 m, and $B_0$ < 1 T. First TJ-II[1] physical results have been recently presented and enough information to perform transport analysis can be obtained from several diagnostics: electron density and temperature profiles are routinely given by Thomson Scattering in a single time in the shot; evolution of electron line density is obtained using an interferometer during the discharge; edge plasma density is measured by Langmuir probes; and radiated power is obtained from bolometers array. The approximate ion temperature is measured using a 5 channels CX system and the energy content of plasmas is measured using a diamagnetic loop.

Transport properties of TJ-II have been investigated and confinement studies under different magnetic configurations have been performed. Hydrogen plasmas are produced and heated **w**ith $P_{ECRH} \leq 300$ kW at 53.2 GHz in 2nd harmonic X-mode, with pulses up to 300 ms. Two experimental campaigns can be distinguished: the first one when the microwave beam waist was about 10 cm at magnetic axis, therefore with a broad power deposition profile and a low power density; while in the second one the waist was about 2 cm near magnetic axis. The second ECH line, that produces a more focalised beam, has also the capability of modifying injection angle by a movable mirror sited inside the vacuum chamber. Generally speaking, plasma performance has been better in the second campaign, due to the more focalised microwaves beam and due to the fact that the chamber wall was baked in order to eliminate light impurities from the plasma.

## ENERGY PLASMA CONTENT

During the last experimental campaign, about 15 magnetic configurations have been explored with line averaged density of the order of $n_e \approx 0.5 - 1.2 \times 10^{19}$ m$^{-3}$ and peek central electron temperatures (measured using ECE) in the range of $T_e \approx 0.4 - 1$ keV. For the configuration with the largest volume (V = 1.2 m$^3$), the measured plasma stored energy is

[1] C. Alejaldre et al. Plasma Physics and Controlled Fusion (1999) In press.

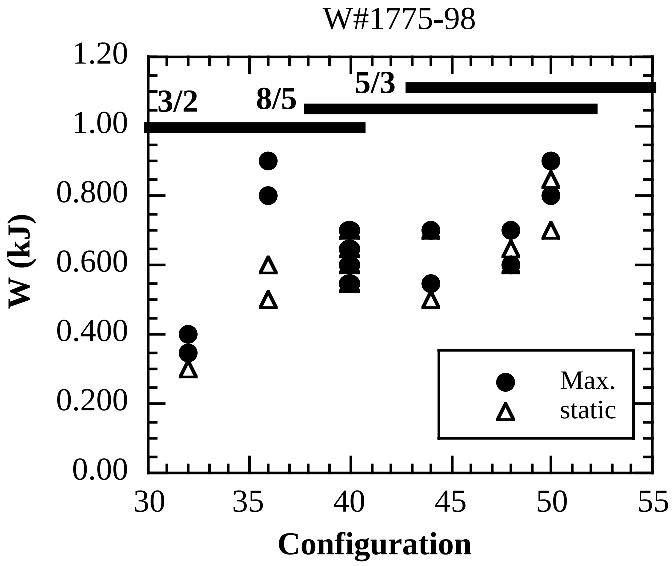


Figure 1. Energy content in TJ-II Configurations

$W_{dia}$ = 1 kJ, which is the maximum value obtained so far in TJ-II[1]. The global $\tau_E$ , the energy confinement time, is about 4 - 5 ms. The dependence of $\tau_E$ on plasma global parameters, such as size, electron density, absorbed power and magnetic field, is close to the present scaling law for stellarators.

Using the ECE measurements and the line density measured by interferometer, the evolution of the electron kinetic energy along the discharge is calculated. Density profile shape is assumed constant and obtained fitting Thomson Scattering measure-ments. A reasonable agreement is got when comparing these results with those obtained from loop diamagnetic measurements.

## TRANSPORT ANALYSIS

The 1,5D predictive transport code Proctr[2], that is a common tool to study properties of stellarator plasmas[3] has been used to simulate TJ-II discharges. Electron heat conductivity is assumed to depend on electron density and temperature as in LHD scaling law. Ion transport is simulated by neo-classical theory and impurity transport is also considered, being C and O the main plasma impurities with concentrations of several percents. Electron density is obtained from the densities of all the ions assuming plasma neutrality, and particle transport parameters are chosen to obtain a density profile similar to the experimental one. The 1-D power balance equation solved by the code is:

$$\frac{3}{2}\frac{\partial}{\partial t}(n_e T_e) = q_{ECRH}(\rho) + q_{rad}(\rho) + q_{ion}(\rho) - 3\frac{m_e}{m_i}\frac{n_e}{\tau_e}[Z](T_e - T_i) - \frac{1}{V'_\rho}\frac{\partial}{\partial \rho}(V'_\rho q_e)$$

Where the heat flux given by

$$q_e = -\left\langle (\nabla\rho)^2 \right\rangle n_e \chi_e \frac{\partial T_e}{\partial \rho} + q_e^{na}(\rho) + \frac{3}{2}\Gamma_e T_e$$

[2] H. C. Howe. "Physics models in the toroidal transport code Proctr" Re. ORNL/TM-11521, Oak Ridge nt. Lab., TN (1990)
[3]M. Ochando et al. Nuclear Fusion **37** (1997) 225

The stellarator geometry is considered averaging the metric tensor on every magnetic surface. Similar equations can be written for ions.

Single pass absorbed power and power deposition profile are obtained using ray tracing techniques[4]. For the temperatures and densities of the first campaign plasmas, single pass absorption is about 60 %, and 20 % more is assumed to be deposited following a parabolic profile. The radiated power was unknown in these plasmas; therefore the analysis has been performed considering different levels of radiation, varying this from 60 to 85 %.

The single pass absorption reaches about 100 % for on-axis heating in the second campaign. Radiation is now measured and reaches values of about 15-20 % of absorbed power. Therefore the densities and temperatures are higher than before.

## RESULTS OF TRANSPORT ANALYSIS

The analysis of three discharges is discussed in this work, the numbers 1787 and 1798 in the second campaign and in the magnetic configuration 100_40_63, and the number 1281 that belongs to the first campaign in the configuration 100_32_60.

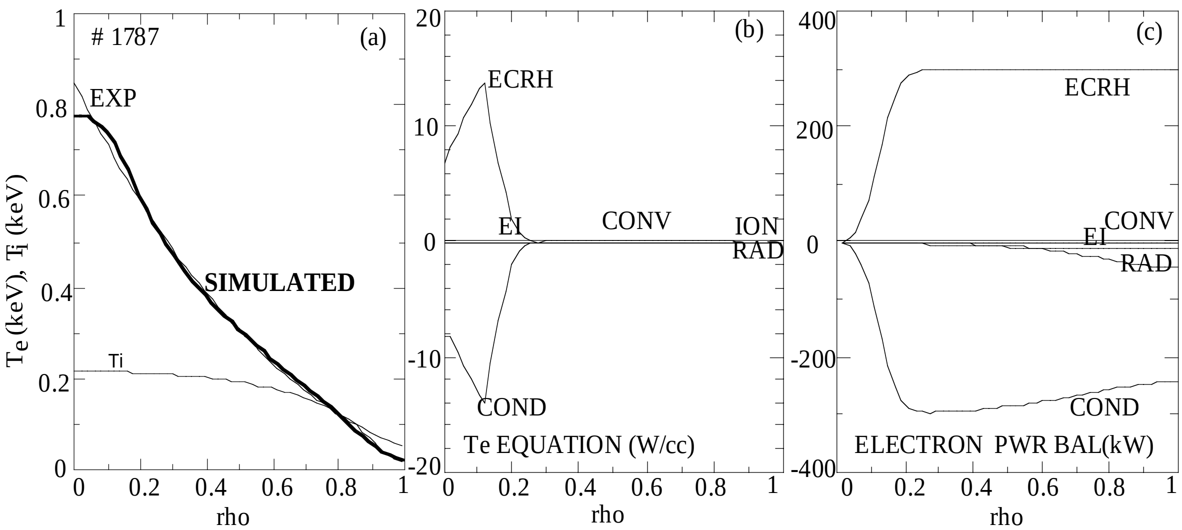


Fig. 2:: Temperature profiles and power balance terms for shot #1787.

In figure 2(a), the temperature profile of plasmas of discharge 1787 is presented. A good agreement is obtained between experimental profile and the simulated one. Electron heat conductivity is shown in figure 3(c). $\tau_E$ of this discharge is estimated from the profiles and gives about 5 ms. $\tau_p$, the particle confinement time, is about 20 ms, this one being less accurate. $\tau_E$ is about a factor 0.5 of neo-classical value, obtained using Monte Carlo code[5]. The contribution of the different terms to the power balance, including power deposition

[4] V. Tribaldos et al. Plasma Physics and Controlled fusion **40** (1998) 2113
[5] V. Tribaldos et al. Poster at this conference.

profile is shown in figure 2(b) y 2(c). The value of $\beta$ is about 0.16 %, in agreement with the value obtained from diamagnetic loop of 0.14 %. Discharge 1798 has lower density than the former, and transport analysis gives the following values: $\tau_E$=3.5 ms, $\tau_p$=16 ms and $\beta$= 0.1 %. $\tau_E$ is again roughly a factor 0.5 of neo-classical values.

In figure 3(a), the temperature profile of plasmas of discharge 1281 is presented. A good agreement is obtained between experimental profile and the simulated one, in spite of the fact that radiated power is unknown. Several values are assumed for this quantity to study the modification on transport coefficients. Electron heat conductivity is shown in figure 3(c). $\tau_E$ of this discharge is about 1.3 ms. The contribution of the different terms to the power balance, including power deposition profile is shown in figure 3(b). And, finally, $\beta$ =0.05 %.

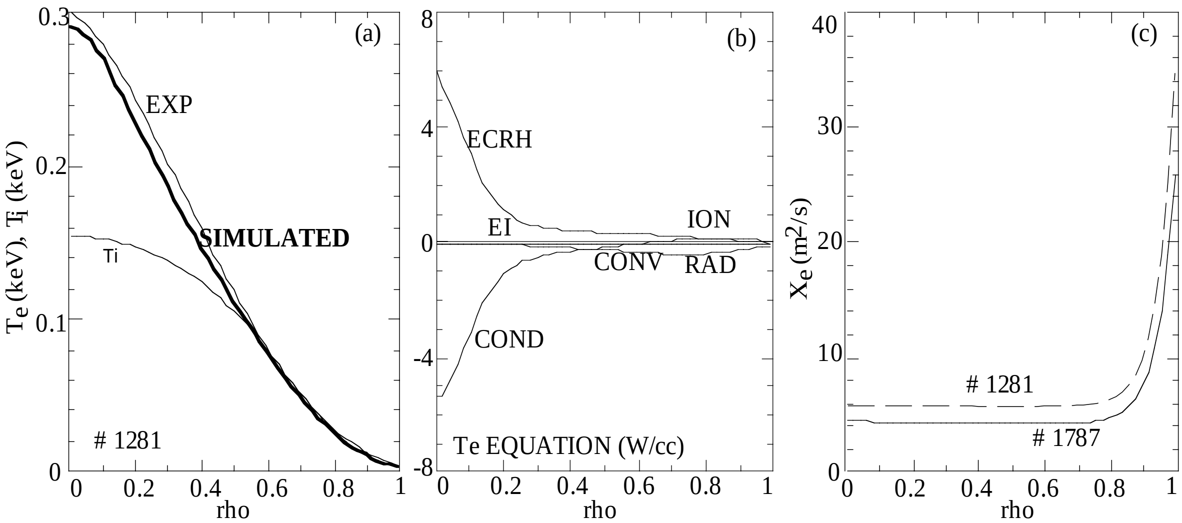


Fig. 3: Temperature profiles and power balance terms for shot #1281. $\chi_e$ for shots #1281,1787.

## CONCLUSIONS

The main result of the simulations is that two radial regions with different confinement properties seem to exist in TJ-II. This result is common for plasmas that present low and high radiated powers, therefore it cannot be attributed to this loss channel.

Two factors seem to affect confinement, neutral density and magnetic structure. The first one is high well inside TJ-II plasmas, since the vacuum chamber groove is near magnetic axis. The magnetic structure shows a strong increasing of magnetic ripple as we approaches the plasma edge. $\chi_e$, the heat conductivity, ranges from a internal value of about 5 and 10 $m^2/s$ and the external one of the order of 20 $m^2/s$. This transport characteristic could be attributed to the fact that magnetic field ripple increases strongly along plasma minor radius. This could cause an enhancement of convection losses at plasma edge, even no conclusive experimental proof is available for the moment. The values obtained for $\chi_e$ are compatible with the results obtained using a Monte Carlo code to study neo-classical transport in TJ-II[6].