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Power balance and transport studies using PRETOR code in TJ-II shots

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INTRODUCTION

At the end of 1997 the Asociación EURATOM-CIEMAT started the operation of the flexible heliac TJ-II which has the following characteristics: a major radius of 1.5 m, a small radius between 0.1 and 0.22 m and a magnetic field about 1T. Plasmas confined in TJ-II are heated with two gyrotrons of 300 kW at the second harmonic of the electron-cyclotron resonance frequency (53.2 GHz in X-mode). With this heating power, in first experimental campaign plasmas have reached a highest electron temperature of 1 keV and an averaged electron density of 1.2 10^{19} m^{-3} in shots up to 300 ms [1]. Nowadays, temperatures of up to 2 keV have been reached and the electron density is increased up to the cut-off. The maximum plasma stored energy is about 1.5 kJ.

The power balance is of great importance in the study of plasma transport properties. The main plasma parameters as temperature or confinement time depend strongly on the several loss channels in the plasma by the different radiation processes, namely, Bremsstrahlung radiation and line emission.

The PRETOR code [2], initially developed to simulate shots in big tokamaks, has been modified in the UPC (Universitat Politècnica de Catalunya) in order to simulate stellarator shots [3]. Now the PRETOR-Stellarator version is used to analyse transport in TJ-II, thus several discharges with different configurations are simulated. Radiated power is calculated and the results are compared with those calculated with PROCTR code, commonly used to simulate stellarator transport [4].

TRANSPORT ANALYSIS

Transport properties of TJ-II shots are analysed using the 1.5D PRETOR code. PRETOR solves the power balance equation to determine the electron temperature profile

$$\frac{\partial}{\partial t}\left(\frac{3}{2}n_e T_e\right)=-\frac{1}{V'}\frac{\partial}{\partial\rho}\left(V'\phi_e\right)-3\frac{m_e n_e}{m_p \tau_e}\left(T_e-T_i\right)+q_{add}+q_{\Omega}+q_{fus}-q_{rad}-q_{ion}$$

where the electron flux , ϕ_e, is

$$\phi_e = -<(\nabla\rho)^2>_{\psi}\, n_e \chi_e \frac{\partial T_e}{\partial\rho}+\frac{3}{2}T_e\Gamma_e$$

Similar equations must be solved for ion and impurity transport. Electron heat conductivity is assumed to have the shape given by an empirical model without density dependence calculated by the following expression

$$\chi_e = C_1 + C_2\,\exp\left(-\frac{1-\rho}{0.05}\right)$$

The parameters of this model are chosen to reproduce temperature profiles similar to experimental profiles, that are given in a single time in the shot by Thomson Scattering.

Physical magnitudes are averaged over a magnetic surface and the stellarator geometry is taken into account by the average value of the metric tensor, $\langle (\nabla\rho)^2 \rangle_\psi$, on each magnetic surface [5].

A previous transport analysis were performed on shot #955 of TJ-II [3]. This shot belongs to the first experimental campaign. Present analysis is done considering recent shots #3088 and #3158.

The temperatures achieved in recent shots are higher than in the previous ones. Shot #3088, with a heating power of 500 kW, has a central electron temperature of 1.0 keV, and shot #3158 reaches 0.7 keV with only 300 kW of ECRH power, whereas shot #955 has a maximum temperature of 0.5 keV with 250 kW ECRH heating.

POWER BALANCE

Several sources of power can heat plasmas in a fusion device: fusion power, ohmic power, and external heating. But in a stellarator device as TJ-II, where no fusion reactions are produced and the plasma current is very small, the only heating source is ECRH (Electron Cyclotron Resonance Heating). Even in the future 2 MW of NBI (Neutral Beam Injection) will be available.

Plasma energy can be lost by different radiation processes. PRETOR code distinguishes between different contributions to the radiated power: the electrons can emit Bremsstrahlung radiation when they are accelerated by an ion field. Neutrals can radiate energy by many excitation and de-excitation transitions before they get completely ionised. Finally neutral can also lose their energy when an electron decay from one energy level to other level with less energy.

Deposition profiles in first campaign plasmas are assumed to be about 60 % by single pass and 20 % more is assumed to have in a broad parabolic deposition profile. For current plasmas single pass absorption reaches about 100 % for on axis heating.

Radiation power measured in shots #3088 and #3158 reaches values between 10 and 20 % of additional power whereas first campaign plasmas radiation power was unknown and calculations indicate than radiation reached values about 75 % of absorbed power.

SIMULATION RESULTS

The analysis of two discharges are presented and the outcomes are compared with those obtained previously in shot #955 belonging to the first experimental campaign. All these shots have the same magnetic configuration 100_40_63 so that comparison is not affected by the geometry of magnetic surfaces. Main plasma parameters describing these shots are shown in table 1.

Parameter	***#3088***	***#3158***	***#955***
Averaged small radius	19 cm	19 cm	19 cm
ECRH heat power	500 kW	300 kW	250 kW
Central electron temperature	1.0 keV	0.7 keV	0.5 keV
Central electron density	0.9×10^{19} m^{-3}	1.0×10^{19} m^{-3}	0.5×10^{19} m^{-3}
Radiated power	57 kW	64 kW	~ 200 kW

Table 1. *Main experimental parameters of TJ-II shot #3088, #3158 and #955.*

In figure 1 are plotted the simulated temperature profiles for shots #3088, #3158 and #955. It is shown that a good agreement is obtained between experimental profile and that simulated with PRETOR and PROCTR. Differences in ion temperature are due to the different conductivity models used, as experimental data are not available a comparison is not of interest.

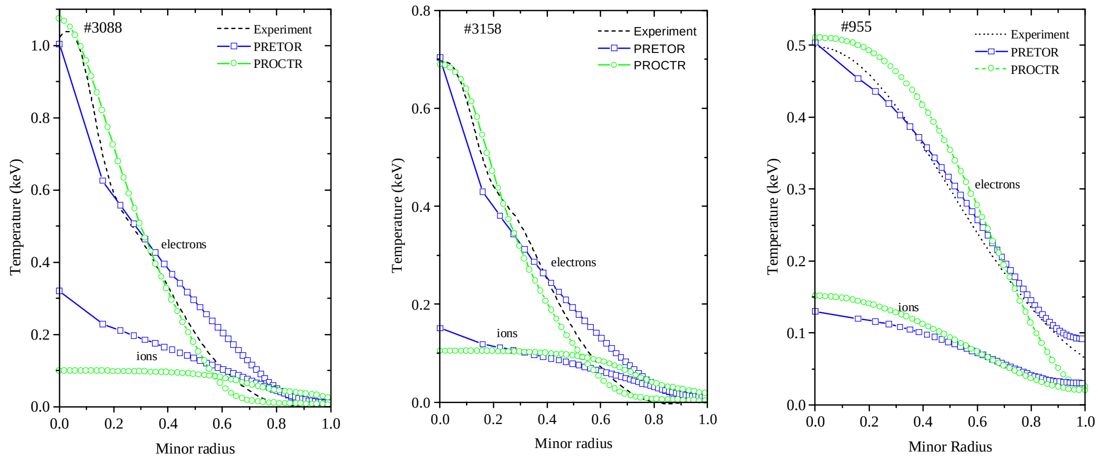

***Figure 1**. Temperature profiles for TJ-II shots #3088, #3158 and #955. Simulated results obtained using PRETOR are compared with the experimental profiles.*

The conductivity profiles used to simulate temperature are plotted in figure 2. Central values for electron conductivity are similar in both codes but as it goes near the edge the difference become higher.

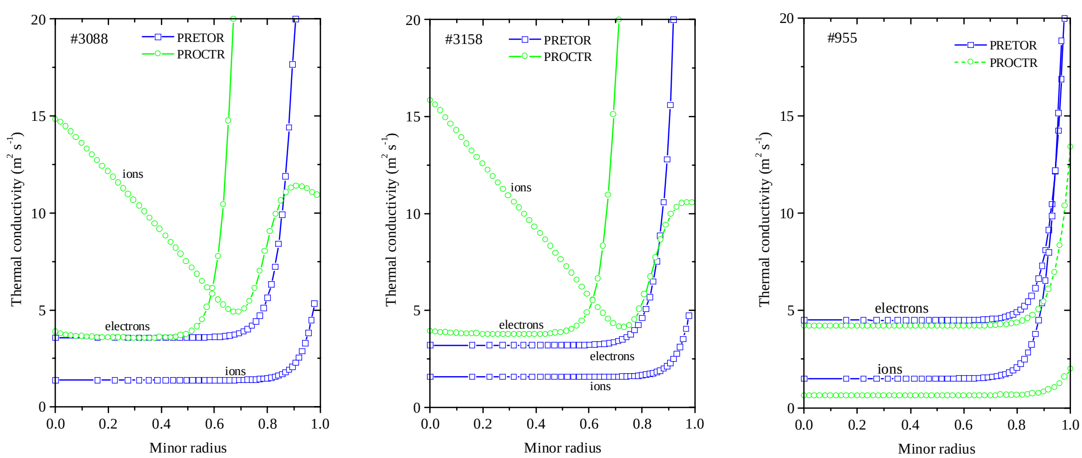

***Figure 2**. Thermal conductivity profiles for TJ-II shots #3088, #3158 and #955.*

Power balance of the three shots considered is summarised in table 2. It stands out that in shots #3088 and #3158 radiated power is less than in case #955 so the confinement is improved.

Power	***#3088***	***#3158***	***#955***
Additional power	500 kW	300 kW	250 kW
Radiated losses	64 kW (*57 kW*)	61 kW (*64 kW*)	200 kW
Conductive losses	360 kW	190 kW	30 kW

***Table 2**. Total power input and losses for shots #3088, #3158 and #955 of TJ-II. In brackets are the experimental values of radiation power.*

Values of important physical magnitudes as plasma energy stored and confinement time are also compared with experimental values, and it is show that these values are reproduced less accurately.

The calculated plasma stored energy is well bellow its experimental value, in #3088 shot the experimental value is between 1 and 1.2 kJ while that calculated with PRETOR-Stellarator is only 0.30 kJ and the calculated from the experimental profiles, including the ions, is about 0.7 kJ. The same happens with the #3158 shot, where the experimental value is 0.9 kJ (the simulated value is 0.21 kJ) and the calculated from the profiles is about 0.65 kJ.

It also occurs for the confinement time, the calculated confinement time is quite lower than the experimental one. In #3088 shot these values are: 0.6 ms for the calculated by PRETOR-Stellarator, and 2.4 ms is the experimental value. In #3158 shot the difference is similar: 2.6 ms is the experimental value and 0.7 ms is that calculated with the code.

CONCLUSIONS

With the help of PRETOR-Stellarator code it can be verified that in nowadays TJ-II plasmas the confinement is improved. The radiated power is between 10 and 20% of additional heating, whereas in first campaign it was about 75%.

Temperature and conductivity profiles are compatible with experimental data and with those calculated using PROCTR code. These two codes can be used to study transport properties in stellarators devices.

Radiated power simulated values agree with experimental data, but the stored energy in the plasma and the confinement time have no such a good agreement. Thus further improvements are needed in order to achieve better results.

The plasma edge parameters are more difficult to reproduce because of especial transport conditions and that the empirical models implemented are not very realistic in this region.

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