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MAGNETIC CONFIGURATION DEPENDENCE OF THE PLASMA ENERGY CONTENT IN TJ-II STELLARATOR

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Introduction

Several energy confinement scaling laws predict a dependence on the rotational transform [1]. TJ-II stellarator (R=1.5 m, <a> $\leq$ 0.2 m, B_0=1T) is, in principle, a suitable installation to attempt this type of studies since its high flexibility allows to obtain plasmas in a very broad range of magnetic configurations [2]. This paper presents experimental results of energy content measured in TJ-II helium and hydrogen plasmas, for different values of rotational transform, plasma volume and injected power. However, it must be noticed that the explored configuration range is only a small fraction of the complete TJ-II flexibility diagram.
Magnetic configuration fine tuning is provided in TJ-II by the independent control of the currents flowing through the four main coil systems, toroidal, vertical, helical and circular coils. These two last coil systems are located very close to the plasma and produce most of the poloidal magnetic field component that determines iota-value. Two mobile poloidal limiters are used to define the last closed magnetic surface (LCMS) and change the plasma volume. In the current phase, TJ-II plasmas are produced and heated by means of two gyrotrons, 0.3 MW each. The achieved plasma density tends to be coupled to the heating power but still, with adequate external gas puffing, it is possible, to certain extent, to keep density constant while scanning the injected power to the plasma.

Experimental

Most of the plasma discharges summarised here have been obtained with the same wall conditioning technique: He glow discharge cleaning (GDC) overnight followed by a short period (typically, 30 min) of Ar GDC just before starting the experiment [3]. The total number of analysed shots is about three hundred.
Rotational transform at the magnetic axis has been changed between 1.24 and 2.13. ECH power injected in the plasma can be varied from 100 to 600 kW in 100 kW steps. In this study perpendicular injection has been used with pulse duration up to 280 ms [4], Most of the plasma shots have an average electron density in the range 0.4 to 1.1 x 10^{19} m^{-3}, and central electron temperatures up to 1.5 keV.
Plasma volume for each configuration is calculated with VMEC code [5]. It depends on the configuration as shown in fig. 1. TJ-II magnetic surfaces have bean shaped cross section. Since it depends strongly on the toroidal coordinate, the usual approach of defining an effective radius as a label for every flux surface is used. It allows to compare results from different diagnostics located anywhere on the machine. When movable poloidal limiters (two are available, located 180 toroidal deg.apart) are not inserted the LCMS is defined by the protruding region (“groove”) of the vacuum vessel. It acts as a toroidal (helical, one could say) limiter over the

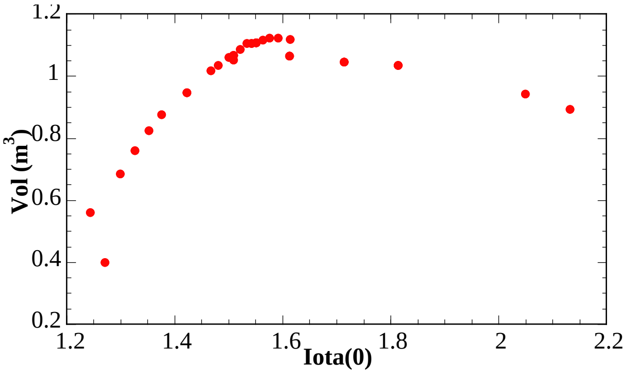

Fig. 1: Calculated plasma volume as a function of central rotational transform.

lower part (up to 1.6) of the studied iota range [6]. For higher iota configurations, plasma touches the inner wall in different regions, so that, they are not toroidal limited configurations anymore. Energy content is measured by two diamagnetic loops located 90 deg. apart, inside the vacuum vessel [7]. The core of experimental results presented in this paper is based on the plasma energy content measured in this way. Extremely accurate vacuum field compensation, essential for the correct measurement of the diamagnetic energy, is difficult to get along all the plasma discharge, mainly due to the presence of low frequency harmonics (≈ 30 Hz) in the coil currents. So, the energy data are taken always during the last 30 ms of every shot, when the measured magnetic flux base line is reliable enough.

Electron density data are taken from the temporal traces measured by the microwave interferometer. In several shots, the kinetic energy has been calculated from the density and temperature profiles measured by Thomson Scattering diagnostic [8], in the core plasma, and by Li and He beams in the plasma edge [9].

Results

Iota dependence of the energy content.

For helium plasmas, the behaviour of diamagnetic energy of as a function of rotational transform shows, roughly, two regions, as shown in figure 2.

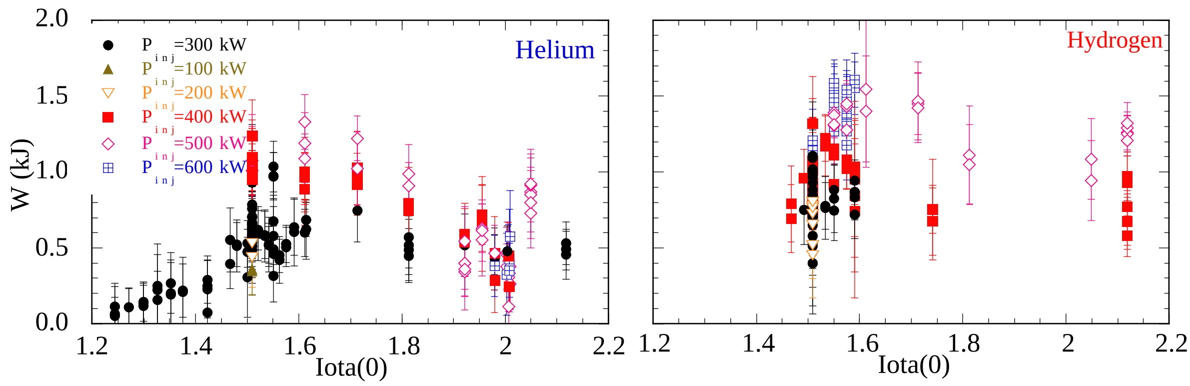

Fig. 2: Diamagnetic energy as a function of rotational transform for helium and hydrogen plasmas.

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 explained by 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: see figure 2. The 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 3, indicates an positive dependence for helium and a smaller but also positive slope for hydrogen plasmas.

The smooth plasma volume increase in the lower iota range will decrease the penetration of neutrals to the plasma core and can explain the observed confinement improvement shown by helium data. This interpretation remains to be confirmed by hydrogen data. Several data points in the iota range 1.8-2.0 are missing in the W/vol. vs., iota plot. The reason is that no accurate volume values have been calculated so far due to code convergence problems in the proximity of iota =2.

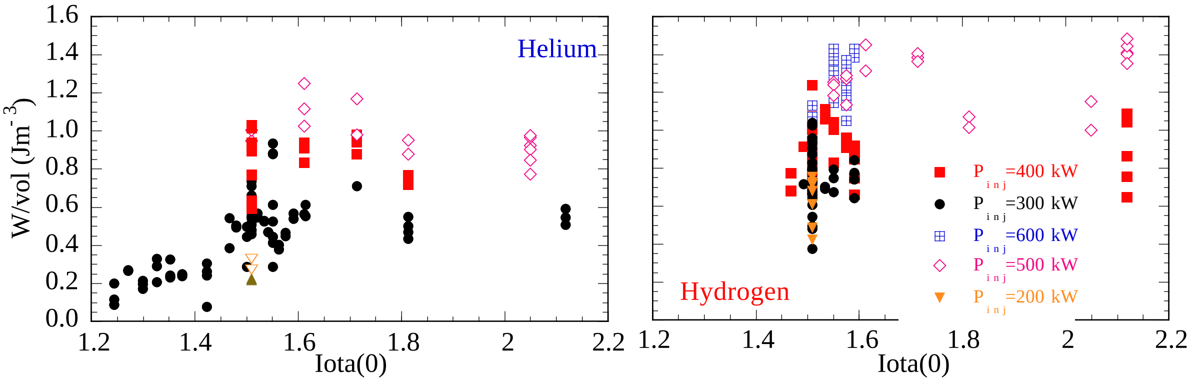

Fig. 3: Diamagnetic energy normalised to the calculated plasma volume as a function of rotational transform for helium and hydrogen plasmas.

Still a density dependence can be hidden in the normalised W/vol. data. Fig. 4 shows the line average electron density corresponding to the energy points plotted in figs. 2 and 3. It can be observed that, in general, density is higher for hydrogen plasmas than for helium ones because when operating the device, density control at high density values with external puffing has been easier in hydrogen due to its lower recycling coefficient [10]. Fig. 5 shows the diamagnetic energy for helium and hydrogen normalised to the plasma volume and to the measured electron density. It is remarkable that a roughly linear increasing shows up both in the helium and hydrogen data, being higher the slope in the helium case. This fact could be an indication of a positive iota-dependence of the confinement in TJ-II plasmas. It is obvious that much more shots in the high iota region are needed in order to extract quantitative information.

It can be observed in fig. 2 that many shots have been done in helium plasmas in the iota-region close to iota = 2, Plasmas in this region are very unstable and confinement is very poor. This is the reason why plasma densities are very low in this iota range.

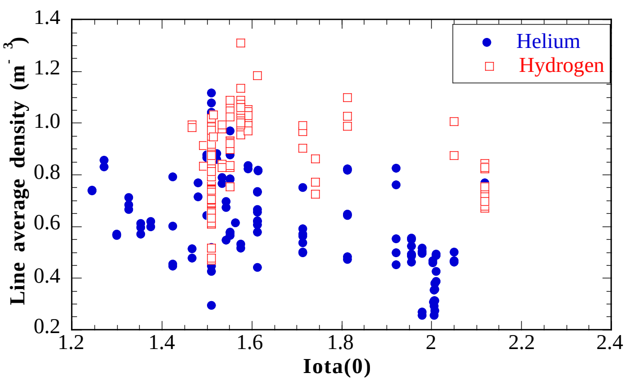

Fig. 4: Line average electron density as a function of rotational transform for the selected set of shots

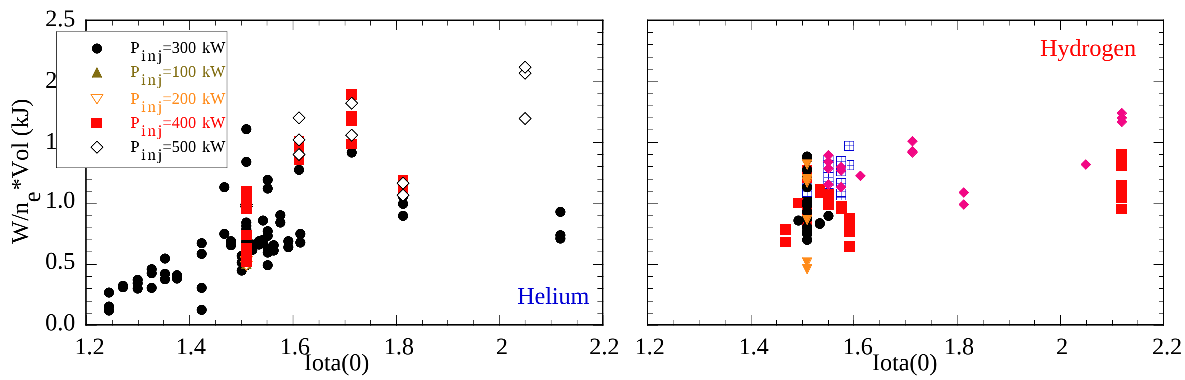

Fig. 5: Diamagnetic energy normalised to the calculated plasma volume and to the measured line average electron density as a function of rotational transform for helium and hydrogen plasmas.

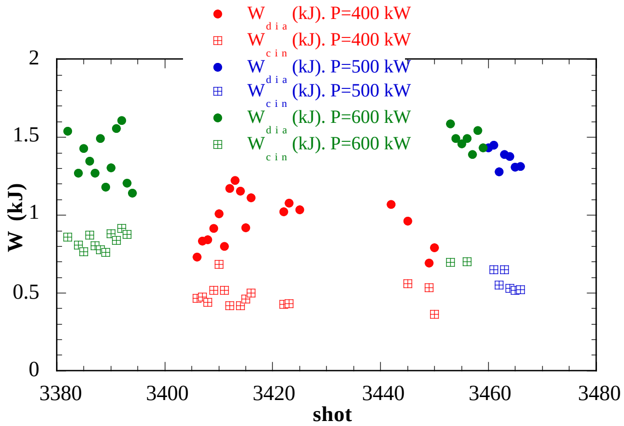

Fig. 6: Diamagnetic and kinetic energy for a series of shots with different iota and heating power

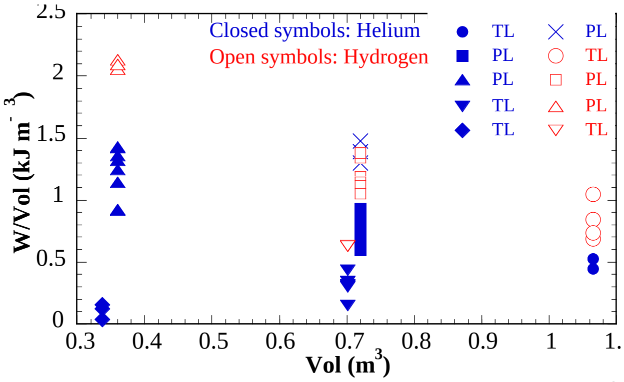

Fig. 7: Volume normalised diamagnetic energy for different configurations having the same iota and plasma volume but different limiter.TL and PL stand for toroidal and poloidal limiter, respectively.

Comparison between diamagnetic and kinetic energies.

Fig. 6 shows, as an example, the diamagnetic (closed circles) and kinetic (open crossed squares) energy measured for a series of shots with different injected power and different configurations. The measured diamagnetic energy is always higher than the kinetic one obtained from the electron density and temperature profiles. This discrepancy is about a factor 2, roughly independent of the total heating power and the magnetic configuration. Its origin is still under investigation. In the calculation of the kinetic energy the ion temperature profile is assumed to be as the electron density one (quite flat) with central ion temperatures in the region 90-120 eV (obtained from CX diagnostic).

Confinement with toroidal and poloidal limiters

The experiment consists in producing helium and hydrogen plasmas in selected configurations with equal volume and rotational transform but either limited by the movable poloidal limiter (PL) or simply the vacuum vessel groove acting as a toroidal limiter (TL). Heating power is 300 kW in all cases except for the crosses which correspond to 500 kW.

Fig 7 shows the diamagnetic energy normalised to each corresponding configuration volume in order to compare their confinement. It can be seen that for a given plasma volume hydrogen plasmas are more energetic. Confinement improves as the poloidal limiter is inserted. The poorer confinement exhibited by TL configurations has been interpreted in terms of the higher transparency to neutrals associated to the colder and less dense S.O.L. of the TL plasmas [6].

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