PERTURBATIVE TRANSPORT EXPERIMENTS ON TJ-II FLEXIBLE HELIAC

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Transport properties of TJ-II are explored performing perturbative experiments and taking advantage of TJ-II flexibility. Rotational transform can be varied in a wide range, which allows one to introduce low order rationals and to study their effect on transport. On the other hand, confinement properties can be studied at very different rotational transform values and for different values of magnetic shear: Experiments on influence of the magnetic shear on confinement are reported. In these cases a Ohmic current has been induced in TJ-II plasma to modify magnetic shear and to evaluate itsd effect on confinement, showing that negative shear improves the confinement. Heat transport is also reduced by locating a low order rational near the power deposition profile. Plasma potential profiles have been recently measured in some configurations up to the plasma core with the Heavy Ion Beam Probe (HIBP) diagnostic and the electric field values measured in low-density plasmas are consistent with neoclassical calculations near the plasma core. Plasma edge turbulent transport has been studied in configurations that are marginally stable due to decreased magnetic well. Results show a dynamical coupling between gradients and turbulent transport. Finally, cold pulse propagation has been studied showing ballistic non diffusive propagation.

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1. INTRODUCTION

In this work transport properties are explored using perturbative techniques on TJ-II Flexible Heliac, a medium size (R=1.5 m, a<0.22 m, l=1, M=4) helical axis stellarator[1], which main characteristic is its flexibility. A wide range of rotational transform, ι, values can be achieved ($0.9 \leq \iota(0)/2\pi \leq 2.2$), that permits to study the dependence of confinement on *ι* and to study the effect of low order rational values on transport. Moreover, the rotational transform profile can be varied inducing moderate OH current in the plasma, that has the effect that magnetic shear can be varied from the shearless vacuum value to positive and negative values. This capability has been used to explore the effect of magnetic shear on confinement.

The magnetic well, which is the main stabilizing mechanism in TJ-II, can also be varied keeping almost constant the rotational transform profile. The magnetic well can vary form values of 6% at the edge to be almost suppressed. This flexibility is used in this work to destabilize the plasma and study the transport in these conditions.

TJ-II is now equipped with a Heavy Ion Beam Probe (HIBP) diagnostic that can measure plasma potential profiles in all the TJ-II configurations. It is admitted that electric field plays a key role on transport and confinement, therefore, such a diagnostic together with the commented flexibility mechanisms allows us to perform clarifying experiments on TJ-II stellarator plasmas. This paper is organized as follows: Sect. 2 is devoted to the effect of low order rationals on electric field and transport. The influence of magnetic shear on confinement is shown in Sect. 3 and the results of magnetic well scan are shown in Sect. 4. Cold pulse propagation is shown in Sect. 5and the conclusions are shown in Sect. 6.

2. EECTRIC FIELD, LOW ORDER RATIONALS AND TRANSPORT

HIBP Results. Comparison with Neoclassical Predictions

Two detectors for the secondary ions are used simultaneously in the HIBP system of TJ-II: a 30º Proca-Green electrostatic energy analyzer and a multiple cell array detector (MCAD)[2]. During operation with electrostatic energy analyzer the sample (ionization) volume position is controlled by changing the entrance angle of the primary beam to the plasma, using electrostatic sweep plates. The operation with two detectors allows enlarging the number of the sample volumes inside the plasma to obtain plasma profiles and their fluctuations. A series of plasma potential radial profiles is shown in Figure 1 (top panel) for several plasma densities. It has been found that bulk plasma potential decreases as plasma density increases.

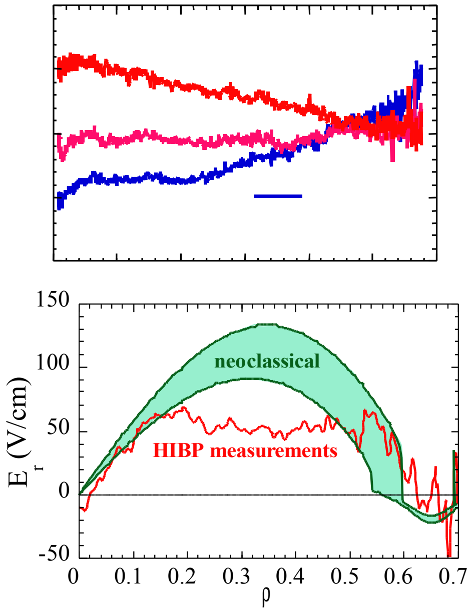


Fig. 1. Top panel: Measured plasma potential profiles for several plasma densities. Bottom panel: Measured electric field for the low density case, compared with neoclassical estimations.

The positive values of radial electric field measured in low-density plasmas agree qualitatively with neoclassical estimations[3] in the plasma center, as shown in Figure 1 (bottom).

The level of fluctuations in the plasma potential profile increases towards the plasma boundary region. However, in some cases, localized turbulent bursts showing a quasi-coherent mode (30-40 kHz) have been observed in the plasma core region. This turbulence might be related to existence of rational surfaces as suggested by the correlation that has been found between the HIBP and the Mirnov coil signals. Moreover, the root mean square (r.m.s.) value of fluctuations in the secondary ion current increases in the vicinity of the radial location where the maximum correlation Φ_{HIBP}-V_{Mirnov} is found.

Influence of Low Order Rationals on Heat Transport in TJ-II Central Plasma

Electron Cyclotron Resonance Heating, ECRH, in low-density plasmas gives rise to a set of characteristic features commonly observed in several stellarators[4,5,6]. Perpendicular ECRH produces an enhanced outward flux of the ripple trapped electrons that are pushed into the loss cone and, as a consequence, a positive radial electric field builds up to reduce the outward electron flux and maintain ambipolarity. This radial electric field may be perturbed by the existence of rational surfaces in the plasma region [6,7] and, because of this fact, the plasma transport properties will change. The steep pressure gradient observed in the Enhanced Confinement Regime (EHC) regime previously observed in TJ-II can be even increased by positioning a low order resonance near the plasma center.

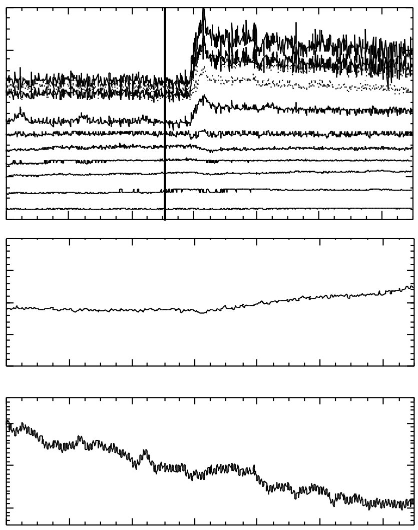


Fig. 2. From top to bottom: time evolution of ECE signals, showing a clear transition, line density, and plasma current.

This point has been investigated by inducing a current using the OH transformer. In this way, the rational surface 3/2, that is absent in the vacuum configuration, has been positioned overlapping with the power deposition area. This hypothesis has been confirmed by VMEC calculations.

Figure 2 shows temporal traces of ECE channels, line density and plasma current. It is observed that for a given value of plasma current (about -1.5 kA) an improvement of heat confinement occurs. This transition to enhanced heat confinement can be observed in the clear rise of the central ECE channels. Figure 3 shows the vacuum ι profile and the electron temperature profiles before and after the transition. It can be seen a clear increase of the temperature gradient in the core.

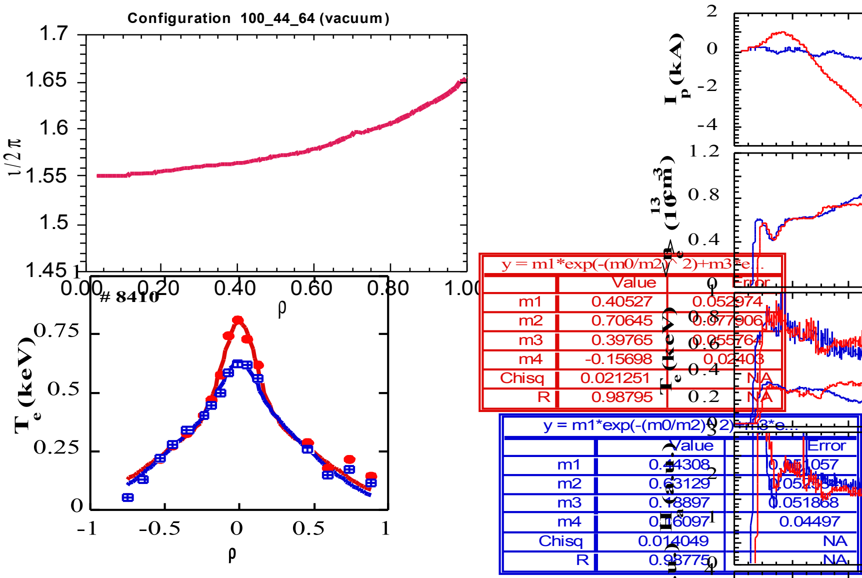


Fig. 3. From top to bottom: time evolution of ECE signals, showing a clear transition, line density, and plasma current. Right panel: From top to bottom: Vacuum rotational transform profile for this TJ-II configuration and electron temperature profile before (squares) and after (circles) the transition.

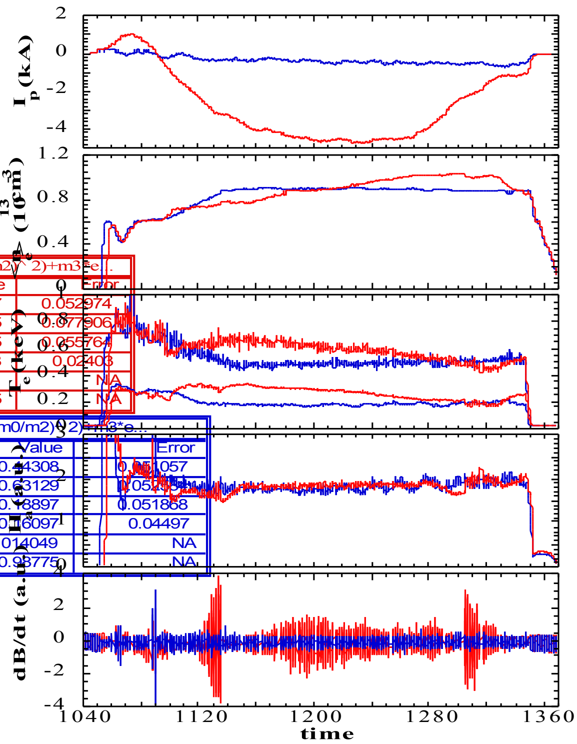


Figure 4. From top to bottom: time evolution of plasma current, line density, two ECE channels, Hα signal and Mirnov coil signals, showing an improvement of confinement in the discharge with negative OH current.

3. INFLUENCE OF MAGNETIC SHEAR ON CONFINEMENT

It has been observed in W7-AS stellarator[8], that a moderate shear imposed by induced toroidal current produce a confinement improvement, independent of the sign of the magnetic shear. In order to investigate this issue in TJ-II a series of experiments has been performed in which profiles are swept with the aid of the transformer at lower rate than the plasma particle (~10 ms) and energy confinement time (~3 ms)[9]. Figure 4 shows temporal traces of two discharges with the same magnetic configuration $\iota/2\pi(a) = 1.68$. One is a reference discharge, with no additional OH current. In the second one, a negative plasma current up to about - 5 kA is induced. The discharge with OH-induced plasma current shows a clear increase in electron temperature (as can be seen in the ECE channels). The symmetric features observed in the magnetic fluctuations temporal trace of the OH-discharge can be interpreted as the two intersections (first “downwards” and then “upwards”) of the rotational transform profile with the 3/2 resonant surface, as the magnetic configuration is swept by the plasma current.

A remarkable broadening of the pressure profile can be observed in the case of negative plasma current, as can be seen in Figure 5, where pressure profiles measured at the plasma flat-top (1200 ms) are shown in for both discharges. The plasma energy is increased in about a 50 % in discharges with strong negative current. A positive current has been also induced and the results indicate that there is not comparable confinement improvement in this case, showing that anomalous transport is reduced only by negative shear in TJ-II in this range of plasma pressure.

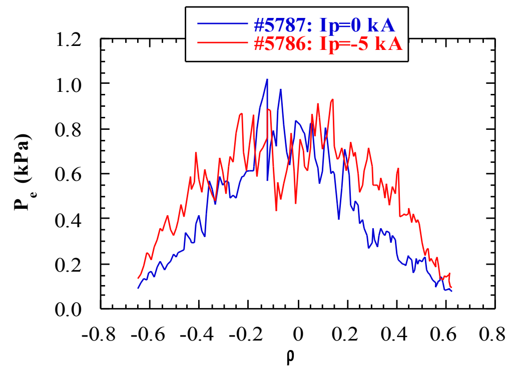


Fig. 5. Pressure profiles for the same both discharges as before, showing a clear improvement of confinement in the discharge with negative current.

Several explanations for this phenomenon are being investigated. We are considering mainly two possibilities: I) Magnetic shear stabilizes trapped electron modes[10] which could easily appear in TJ-II, since its electron temperature is much higher than ion one, we are dealing with low collisionality plasmas and the fraction of trapped particles is as high as 35 %. II) The particle orbits could suffer strong changes due to the modification of the magnetic topology[11], which could cause a modification of transport properties and confinement.

4. MAGNETIC WELL SCAN

Three magnetic configurations with very similar ι profiles and different magnetic well values (2.4, 0.6 and 0.2%) have been investigated. TJ-II is stabilized by magnetic well, therefore, when well disappears plasma will become more unstable. This is observed in the time traces of turbulent fluxes measured by Langmuir probes. The case without well is the most unstable and transport is of a bursty nature. The degree of intermittency of transport show a significant increase when magnetic well is reduced in TJ-II[12]. Results also prove that the turbulent E×B particle flux decreases as the well is increased. A significant fraction of the total E×B turbulent flux can be assigned to large and sporadic transport bursts whose amplitude increase as well depth is decreased.

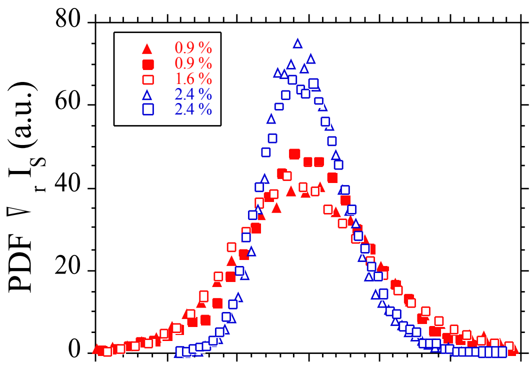


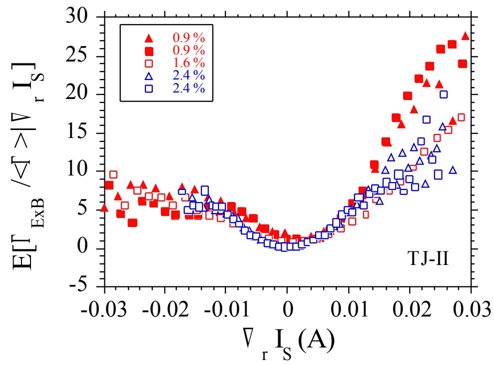
Fig. 6. Probability distribution function of the occurrence of a gradient.

This bursty behavior of turbulent transport is strongly coupled with fluctuations in density gradients. Figure shows the PDF of the occurrence of a gradient for discharges with different magnetic wells. As the well decreases, the non-Maxwellian character of distribution function increases. As the density gradient increases above the most probable value, the E×B turbulent driven transport increases until the system relaxes back to the initial marginally stable situation, as shown in figure 7, where the most probable turbulent flux for a given gradient is plotted again for different magnetic wells. As the gradient separates from the minimum the most probable turbulent flux increases in the positive direction. This beahviour is more pronounced for the cases with low values of magnetic well.

5. COLD PULSE PROPAGATION STUDIES

Nitrogen puffing has performed in TJ-II to perform the study of cold pulse propagation. Nitrogen has been chosen because the recycling of this gas is very low and the atoms hardly penetrate into the plasma. In this way almost all the particles are ionized at the edge and a sudden localized cooling happens. This cooling propagates inwards and its impact on electron temperature is registered by 8 ECE channels.

Fig. 7. The most probable flux associated to a given gradient.



The cold pulse propagation is clearly shown as a sharp change in the signal of the corresponding ECE channels, which remains unperturbed until it is reached by the front. Figure 8 shows the time traces of the 8 ECE channels in which the effect of the cold pulse can be clearly seen. The time when the cold front arrives is registered and fixed by a fitting function. Analysing the times in which ECE signals change it is clearly seen that the propagation is not at all diffusive, being of a ballistic character, since the propagation of the front should be proportional to the square root of time.

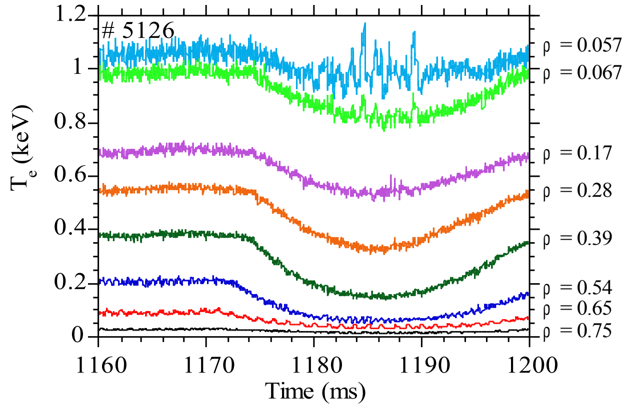


Fig. 8. Time traces evolution of the 8 ECE channels in a

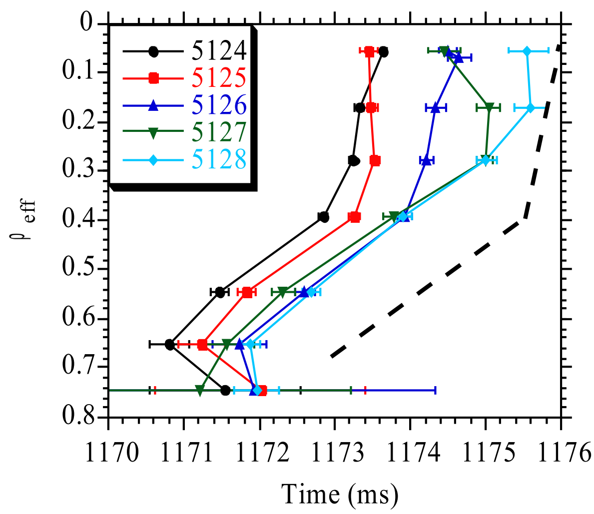


Fig. 9. Time traces evolution of the 8 ECE channels in a discharge with a cold pulse. The arriving of the cold front can be seen as a sharp change of the signals.

Figure 9 shows the propagation velocity of the cold pulse for 5 discharges with different puffing of hydrogen. It is observed that the propagation velocity rises with the amount of puffed nytrogen. Moreover, it is seen that the propagation velocity for single discharges rises as the pulse goes into the plasma. The velocities for 0.7<r/a<.0.4 are about 10-20 m/s and for the inner positions the velocities are about 40-80 m/s. The cold pulse has been, hence accelerated.

The suggested explanation for this phenomenon is that the cold pulse provokes the destabilization of different instabilities as popagates inwards. Therefore, the velocity of the pulse is given at every radial position as v=Dg, i. E., the product of the withd of tyhe instability times the growth rate.

6.CONCLUSIONS

Transport properties of Flexible Heliac TJ-II have studied using perturbative techniques. TJ-II flexibility together with he possibility of modifying inducing OH current are exploited to investigate the effect of low order rationals and magnetic shear on confinement. It is seen that heat confinement is improved when a rational is located near the plasma core, overlapping with the ECH power deposition area. Negative current, that causes negative magnetic shear (estimated like in a tokamak), improves confinement in about 50%.

The modification of magnetic well allows us to change the turbulent transport properties in the plasma edge, showing that the transport becomes bursty for discharges without well. Cold pulses are also used to investigate the transport properties, showing a ballistic propagation, which velocity rises with the amount of gas puffing and is increased in the plasma centre. This property is attributed to the fact that the cold pulse cause the apparition of instabilities as it propagates inwards.

The first measurement of electric field has been presented using the new HIBP, installed in TJ-II and has been compared with neoclassical calculations, showing an agreement in the plasma centre. The fluctuations that have been observed in the HIBP signal are correlated with the apparition of an MHD mode, which means that the electric field is affected by magnetic topology.

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