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Confinement and stability on the TJ-II stellarator

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Abstract

This paper describes a series of experiments performed in TJ-II stellarator with the aim of studying the influence of magnetic configuration on stability and transport properties of TJ-II plasmas. Plasma potential profiles have been measured in several configurations up to the plasma core with the heavy ion beam probe diagnostic. Low-order rational surfaces have been positioned at different plasma radii observing the effect on transport features. 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. Experiments on the influence of magnetic shear on confinement are reported. Global confinement issues as well as enhanced confinement regimes found in TJ-II are discussed as well.

1. Introduction

Electron cyclotron resonance heating (ECRH), in low-density plasmas gives rise to a set of characteristic features commonly observed in several stellarators [1–3]. 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, that can be fairly large in the plasma central region, builds up to reduce the outward electron flux and maintain ambipolarity. This radial electric field may be modified by the existence of rational surfaces in the plasma region and, as a consequence, the plasma transport properties will be altered [4].

Magnetic and, especially, $E \times B$ shear are known to reduce anomalous transport via radial decorrelation of turbulent structures [5–7]. It has been observed in W7-AS that the application of magnetic shear (either positive or negative) via inductively driven toroidal plasma current improves the confinement previously degraded by high-order rationals in the plasma edge [8, 9]. The results found in TJ-II so far indicate that magnetic shear improves confinement only when its sign is negative, following the tokamak approach.

As stellarators are inherently flexible devices they are very well suited for the investigation of the complex phenomenology that interrelates electric field, instabilities, magnetic configuration and transport. Among them, TJ-II heliac presents some peculiarities that place it as a very suitable tool for this type of studies [10].

- (a) It has a very wide range of achievable magnetic configurations ($0.9 \leq \iota(0)/2\pi \leq 2.2$).
- (b) Its low magnetic shear allows an accurate control of the low-order rationals present in the $\iota/2\pi$ -profile.
- (c) Magnetic well is the main stabilizing mechanism in TJ-II [11, 12]. The magnetic well depth (up to 6%) can be almost suppressed in the edge region keeping essentially constant the rotational transform profile. This fact allows locating TJ-II plasmas close to instability thresholds and studying the onset of fluctuations and related phenomena.
- (d) TJ-II is equipped with a heavy ion beam probe (HIBP) diagnostic that can measure plasma potential profiles in all the TJ-II configurations.

This paper is organized as follows: section 2 presents a short outline of the device and its experimental set-up. In section 3 recent HIBP results are presented and compared with neoclassical predictions. Then a series of experimental results linking the presence of low-order rationals in the plasma with several transport-related phenomena found in TJ-II are reported. In section 4 some results on fluctuation-induced turbulent transport and its relation with density gradients, electric fields and instability thresholds are discussed. Cold pulse experiments showing non-diffusive features of transport will be also addressed. Section 5 shows experiments and results using induced toroidal current to study the influence of magnetic shear on confinement. Finally, section 6 deals with issues related to the global confinement in TJ-II and its dependence on plasma parameters and wall conditioning. Some improved confinement regimes found in TJ-II are also reviewed there.

2. TJ-II experimental set-up

TJ-II is a four periods stellarator (heliac type, $B(0) \leq 1.2$ T, $R = 1.5$ m, $\langle a \rangle \leq 0.22$ m) that can explore a wide rotational transform range ($0.9 \leq \iota(0)/2\pi \leq 2.2$) in low, negative shear configurations ($\Delta q/q < -6\%$; note that in the following the tokamak approach is used for the definition of magnetic shear as the radial variation of the flux surface-averaged safety factor). So far, TJ-II plasmas have been produced and heated with ECRH (2 gyrotrons, 300 kW each, 53.2 GHz, 2nd harmonic, X-mode polarization). The last mirror of the quasi-optical microwave

transmission line is located inside the vacuum vessel and allows for current drive up to 1 kA. The power density is high, $p \approx 15 \text{ W cm}^{-3}$. In these plasmas the line-averaged density is up to $1.2 \times 10^{19} \text{ m}^{-3}$, the electron temperature at the centre of the plasma is up to 1.5 keV and the ion temperature about 0.1 keV. The thermal energy content is up to 0.6 kJ and the net, bootstrap plasma current (in absolute value) is lower than 1 kA.

The HIBP diagnostic uses Cs^+ ions with beam energy in the range 100–140 keV [13]. The primary beam current ranges from 10–100 μA and the secondary current is up to 200 nA. The time evolution of the electron temperature profile is measured by means of an absolutely calibrated multi-channel ECE radiometer [14]. A Thomson scattering (TS) system is used to determine the radial profiles of the electron temperature and density with a high spatial resolution [15]. Edge electron density profiles are measured with a reflectometer [16]. Atomic beams (thermal lithium and supersonic He) provide information on edge density and temperature radial profiles [17]. A fast reciprocating Langmuir probe has been used to investigate the structure of edge plasma profiles and profile fluctuations.

3. Electric field, low-order rationals and transport in TJ-II

3.1. HIBP results. Neoclassical predictions

The advantage of HIBP system on TJ-II consists of the simultaneous utilization of two detectors for the secondary ions: a 30° Proca-Green electrostatic energy analyser and a multiple cell array detector (MCAD) [18]. During operation with electrostatic energy analyser the sample (ionization) volume position is controlled by changing the entrance angle of the primary beam to the plasma, using electrostatic sweep plates. The MCAD observes a sequence of sample volumes along the trajectory of the primary beam simultaneously. The operation with two detectors allows enlarging the number of sample volumes inside the plasma to obtain plasma profiles and their fluctuations. Recently, first plasma potential profiles reaching the magnetic axis have been obtained [19]. A radial profile is shown in figure 1, lower box, in which

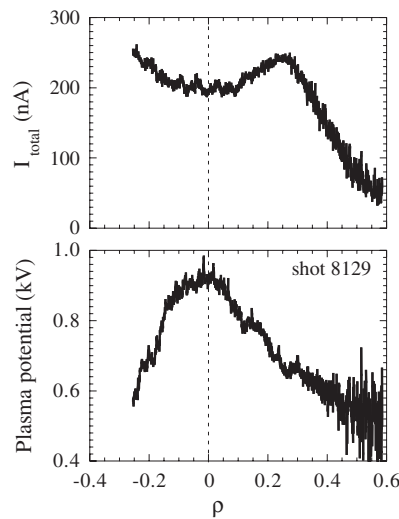


Figure 1. Upper box: the total (secondary) current profile is hollow as expected from its proportionality to plasma density. Lower box: plasma potential increases up to 1 kV near the magnetic axis (i.e. positive radial electric fields) in low-density plasmas.

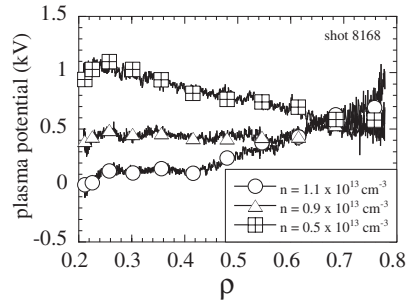


Figure 2. Plasma potential profiles measured with the HIBP diagnostic in a single discharge for three increasing values of line electron density.

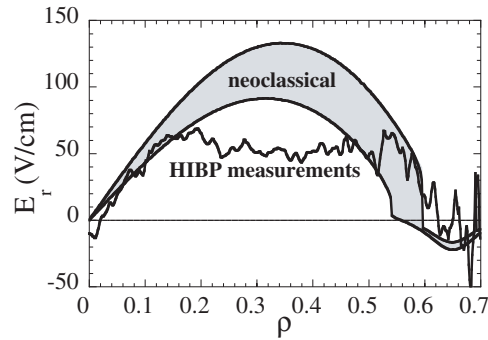


Figure 3. Comparison between the measured plasma potential profile (solid line) and the neoclassical estimation (dashed region).

the plasma potential increases to 1 kV up to the plasma centre (positive radial electric field). Figure 1, upper box, displays the total current profile, proportional to plasma density. It is hollow, in agreement with TS density profiles. It has been found that bulk plasma potential decreases as plasma density increases as shown in figure 2. The positive values of radial electric field (up to 100 V cm^{-1}) measured in low-density plasmas agree qualitatively with neoclassical estimations [20] as shown in figure 3. 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 the magnetic topology (e.g. rational surfaces). In some shots correlation has been found between the HIBP and the Mirnov signals. The root mean square (rms) value of fluctuations in the secondary ion current increases in the vicinity of the radial location where the maximum correlation $\Phi_{\text{HIBP}} - V_{\text{Mirnov}}$ is found. This fact can be explained on the basis of localized perturbations linked to the magnetic topology (e.g. rational surfaces). In particular, it has been recently argued that a possible explanation of the flow structure near the magnetic island [4] is the coupling between the vacuum field island and a plasma instability [21].

3.2. Influence of low-order rationals on heat transport in TJ-II central plasma region

An enhanced heat confinement (EHC) regime can be achieved in TJ-II for high ECH absorbed power density and relative low-density discharges [22]. There are experimental indications

suggesting that the presence of low-order rationals close to the central plasma region might increase even further the pressure gradient in the EHC region. An experiment has been made trying to investigate this point: negative toroidal current has been induced with the TJ-II ohmic transformer in order to lower dynamically the iota profile during the discharge. The central vacuum iota value of the starting configuration is 1.55, just above $3/2$. Figure 4 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 energy confinement occurs. This transition to enhanced energy confinement can be observed in the clear rise of the central ECE channels. Figure 5 shows the ECE profiles before and after the transition. A clear increase of the temperature gradient close to the plasma centre can be seen. The small modification of the superthermal electron population indicates that the enhancement of central ECE signal must be attributed to bulk electrons. We interpret this effect as due to the $3/2$ resonance travelling across the plasma central region. VMEC calculations confirm this hypothesis.

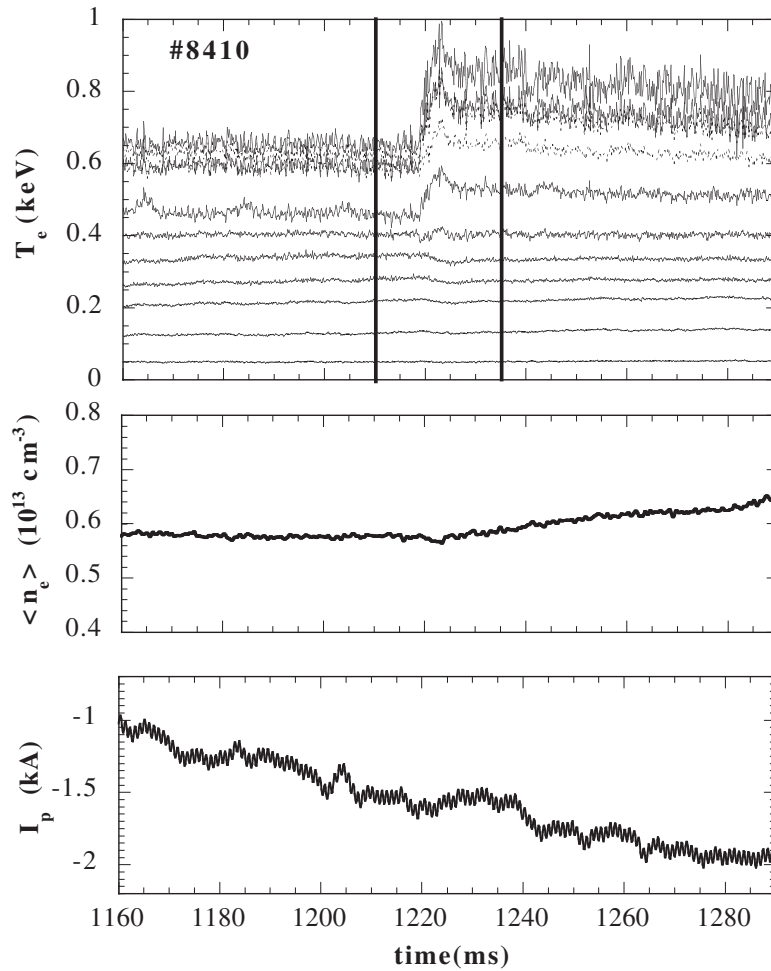


Figure 4. Temporal traces of ECE channels (upper box), line average plasma density (mid box) and plasma current (lower box) in a discharge in which the magnetic configuration is swept (rotational transform lowered) due to the induction of toroidal plasma current with the OH transformer.

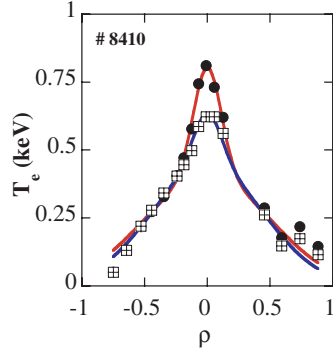


Figure 5. Comparison of the electron temperature profiles measured at the instants marked in the figure 4, i.e. before the transition (1210 ms; open squares) and after the transition (1235 ms; closed circles).

3.3. Transport events and low-order rationals in TJ-II

The presence of low-order rationals in the rotational transform profile of TJ-II plasmas causes transport events with very distinct features. The experimentally measured characteristics of these features depend on the radial position of the resonance. When the low-order rational is located close to the plasma centre, in the region where the ECRH power is deposited, a transient behaviour characterized by fast drops in the electron temperature can be observed [23]. If the low-order rational is moved outwards and reaches the density gradient region, ELM-like events [24] are generated [25]. Both circumstances are illustrated in figure 6. The lower box shows numerical (VMEC) calculations of the TJ-II vacuum (currentless) rotational transform profile and the resulting profiles after being modified by two different values of ECRH-driven current. The upper box shows temporal traces corresponding to a plasma current value oscillating around -0.1 kA (this oscillation is an undesired effect induced by a slight modulation—about 0.2%—of the current in the circular coil). Fast drops in the central electron temperature appear because the current value is such that the $3/2$ -resonance just enters into the $\iota/2\pi$ -profile, according to the calculation shown in the lower box. The external electron temperature channels show no change and the MHD activity measured by a magnetic coil increases slightly. The middle box shows temporal traces corresponding to a plasma current value oscillating around -0.9 kA. In this case, the central electron temperature channel shows no variation, but the footprints of ELM-like events can be recognized in the other temporal traces: coherent MHD activity can be observed in the magnetic coil correlated with local flattenings of the temperature profile at mid-radius, as revealed by opposite changes in the electron temperature measured at two intermediate radii ($\rho = 0.5$ and 0.7). According to the calculations shown in the lower box, these ELM-like events appear when the current value is such that the $3/2$ -resonance is located precisely at mid-radius.

What happens if the low-order rational is moved further out, up to the plasma edge? In this case the presence of natural resonances has been clearly related to flattenings in the edge plasma profiles (floating potential and ion saturation current) of TJ-II [26]. A significant variation of plasma potential just outside the flattening region has been measured and interpreted as an increase of the sheared $E \times B$ flow linked to the radial location of the low-order rational. So, although the connection between rational and transport events described preceding in this section still is not fully understood, it is sensible to consider that the rational surface is affecting the radial electric field in its vicinity. The HIPB diagnostic appears as an essential tool for the experimental effort needed to clarify this link.

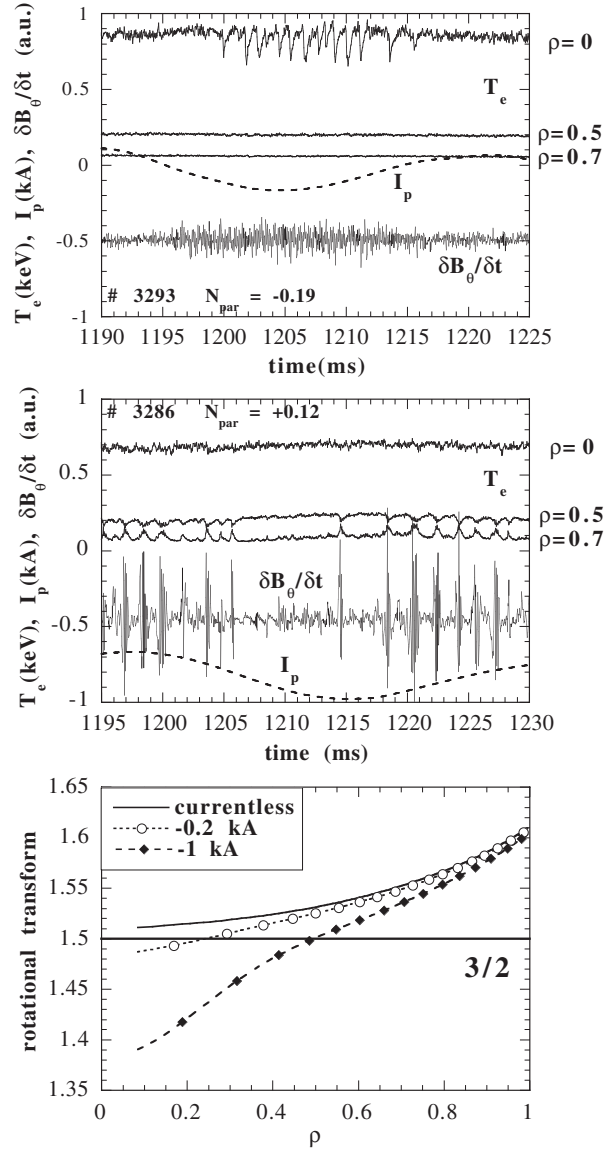


Figure 6. The upper and middle boxes show temporal traces (three electron temperature channels, plasma current and poloidal magnetic field derivative) corresponding to two discharges with the same vacuum magnetic configuration but having two different values of ECH-driven plasma current. The lower box shows the corresponding calculated vacuum rotational transform profile (3/2-rational value close to the plasma centre) and the modified profiles due to the effect of the plasma current for the two values shown above (open symbols: -0.2 kA with rational value at the plasma centre; closed symbols: -1 kA with rational value at mid-radius).

4. Turbulent transport and instability thresholds in the TJ-II boundary region

4.1. Magnetic well scan

Three different magnetic configurations with very similar iota profiles and magnetic well values 2.4%, 0.6% and 0.2 % have been investigated. As expected from a theoretical point of

view, the level of edge fluctuations shows a significant increase when magnetic well depth is reduced [27]. Electron density profiles measured by reflectometry show narrowing of profiles and decrease of the gradient as the magnetic well decreases. Figure 7 shows the probability density function (PDF) for fluctuations in gradients and the expected value of the $E \times B$ flux, for a given density gradient, taking the magnetic well as a parameter. Fluctuations in gradients and $E \times B$ flux are measured with the fast reciprocating Langmuir probe. From the upper graph it can be deduced that the density gradient PDF is rather gaussian around the average gradient. The lower graph shows, in contrast, that turbulent flux is strongly non-gaussian: a significant fraction of the total $E \times B$ turbulent flux can be assigned to large and sporadic transport bursts whose amplitude increase as well depth is decreased [28]. This bursty behaviour of turbulent transport is strongly coupled with fluctuations in density gradients. As the density gradient increases above the most probable value the $E \times B$ turbulent driven transport also increases until the system relaxes back to the initial marginally stable situation. Similar results have been recently observed in the plasma boundary region of the JET tokamak [29].

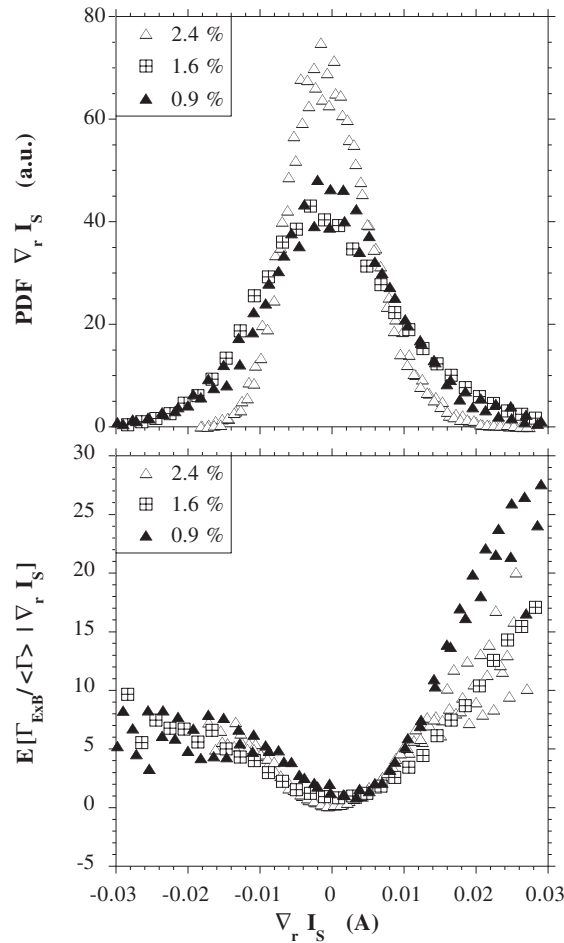


Figure 7. Upper box: PDF of the density gradient for different magnetic well depth values. Lower box: expected turbulent flux at a given density gradient. The most probable value of density gradient minimizes the flux events amplitude.

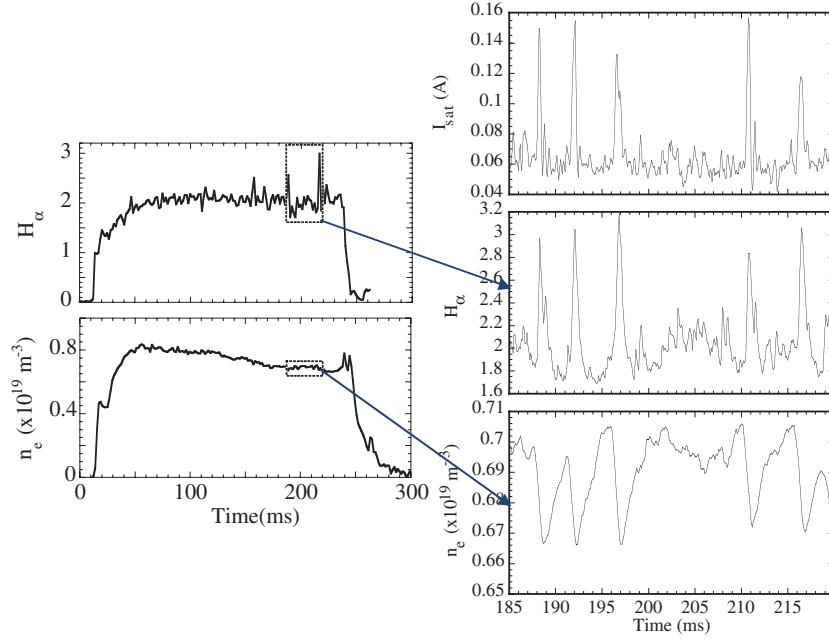


Figure 8. Time traces of plasma parameters in the configuration with minimum value of magnetic well depth. Left column: H_α signal and line-average density showing strong bursts. Right column: magnified graphs of the time-windows selected on the left. Large bursts in H_α and line density are correlated with the ones in ion saturation current signal.

The strong bursts in fluctuations signal observed in the unstable configuration (0.2% magnetic well) and illustrated in figure 8, represent large amplitude transport events that are observed simultaneously in the H_α , ECE and line average density signals. The propagation velocity of these strong transport events has been evaluated from the delay in the ion saturation current measured by two probes radially separated by about 1 cm. The measured time delay implies radial velocities in the range $500\text{--}1000 \text{ m s}^{-1}$ [30], a value comparable to the radial propagation of ELMs in the JET plasma boundary region [31]. These results emphasize the importance of the statistical description of transport processes in fusion plasmas [32] suggesting the existence of different transport mechanisms for small and large transport events (diffusive versus non-diffusive) in the plasma boundary region [33].

4.2. Non-diffusive transport phenomena

Cold pulse propagation has been studied in TJ-II using nitrogen puffing by means of a fast injection system with the goal of elucidating transport mechanisms [34]. Analysis of the pulse propagation, as measured by ECE, shows that the propagation speed is of the order of $v = 10\text{--}20 \text{ m s}^{-1}$ in the outer half of the plasma ($\rho \geq 0.4$), whereas it speeds up to around $v = 50\text{--}80 \text{ m s}^{-1}$ in the central part ($\rho < 0.4$). This behaviour is not at all in accordance with diffusive propagation, which would slow down as it propagates (travelled distance $\propto \sqrt{t}$). Besides, a 40 kHz MHD mode is triggered at the time the cold pulse reaches the plasma region ($\rho \approx 0.3\text{--}0.4$), where the $\iota/2\pi = 3/2$ rational surface is located according to VMEC calculations. Qualitatively, the pulse propagation behaviour is very similar to the pulse propagation seen in a simulation of resistive pressure-gradient driven turbulence in cylindrical

geometry [35], in which the propagation involves the successive destabilization of modes on adjacent rational surfaces. Thus, a possible explanation for the observed propagation of the cold pulse front in TJ-II is the sequential triggering of pressure-gradient driven modes, in an avalanche-like fashion.

5. Effect of transformer induced toroidal current in confinement

It has been observed in W7-AS stellarator, 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 have been performed in which $\iota/2\pi$ -profiles are swept with the aid of the transformer at lower rate than the plasma particle (~ 10 ms) and energy confinement time (~ 3 ms) [36]. Figure 9 shows temporal traces of two discharges with the same magnetic configuration $\iota/2\pi(a) = 1.68$. One is a reference

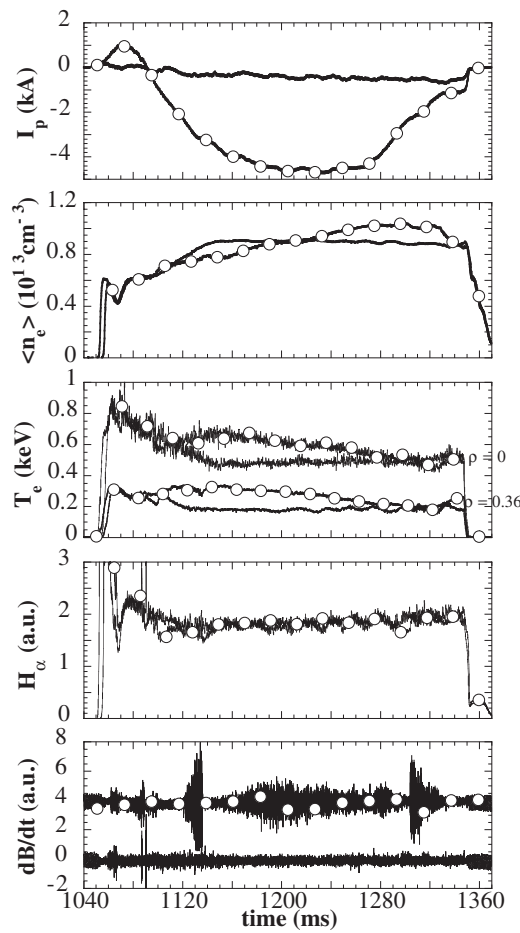


Figure 9. Confinement improvement with negative plasma current. From top to bottom: plasma current, line average density, electron temperature (two channels at $r = 0$ and 0.36), H_α emission and poloidal magnetic field derivative temporal traces for two discharges, one for reference with no OH current (trace with no symbols) and the other with induced current up to about -5 kA (open circles).

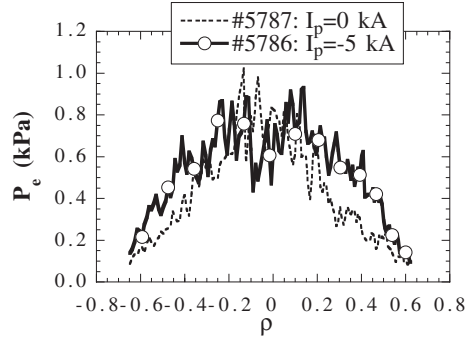


Figure 10. Pressure profiles measured at $t = 1200$ ms for the two discharges shown in figure 9. The one with negative current is clearly broader.

discharge, with no additional OH current. In the second one, negative plasma current up to about -5 kA is induced. The discharge with OH-induced plasma current shows a clear increase in electron temperature (two 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 plasma profile with the $3/2$ resonant surface, as the plasma current sweeps the magnetic configuration. Pressure profiles measured at $t = 1200$ ms for both discharges are shown in figure 10. A remarkable broadening of the pressure profile can be observed in the case of negative plasma current. Recent experimental results indicate that there is no confinement improvement when the induced current has positive sign; instead, indications of confinement degradation are detected. Further experiments and analysis are in progress.

6. Global confinement in TJ-II. Enhanced confinement modes

6.1. Global energy confinement

Figure 11 shows the best fit of a set of measured values of energy confinement time in TJ-II with a model that assumes dependences on the four parameters that have been varied in the device so far: density, heating power, minor radius and rotational transform [37]. Table 1 shows the exponents obtained from the TJ-II data along with the corresponding exponents deduced from the International Stellarator Scaling (ISS95) database [38]. The parameters found in TJ-II are well in line with the ISS95 ones. The TJ-II dataset exhibits a positive $\iota/2\pi$ -dependence of the energy confinement time, with an exponent value of 0.5 ± 0.1 . It is worth mentioning that the rotational transform values in the TJ-II dataset spans from 1.2 to 2.1, whereas the corresponding data range inserted in the ISS95 database, coming from W7-AS is considerably narrower ($0.3 < \iota/2\pi < 0.5$). Therefore, this TJ-II result supports the positive $\iota/2\pi$ -dependence deduced in the ISS95 database (exponent 0.4), in which, with the exception of W7-AS, the rest of devices have a fixed $\iota/2\pi$ -value.

6.2. Boronized versus metallic wall

A strong modification of plasma parameters, such as edge temperature, impurity composition and concentration as well as radiated power, takes place upon boronization of the TJ-II device [39, 40]. Total radiation after wall boronization is a factor of 3–4 lower than before. Radiation profiles are broader and hollow with respect to the non-boronized wall and the soft-x-ray (SXR)

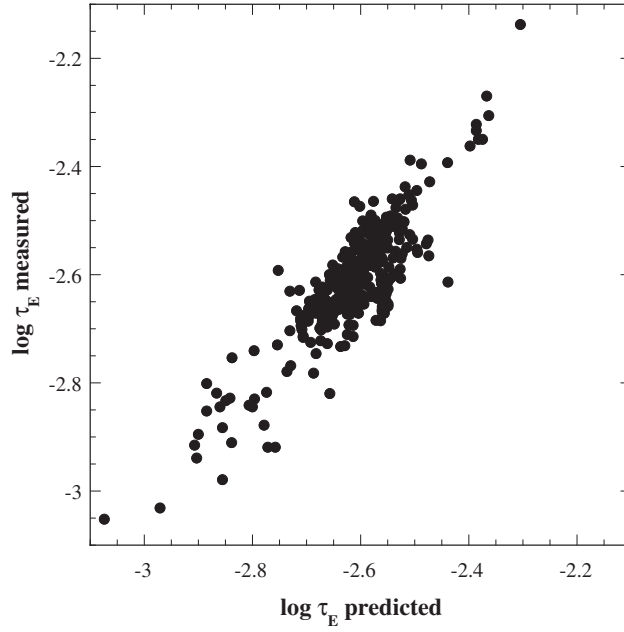


Figure 11. Measured confinement times versus the values predicted by the model which yields the best fit to the TJ-II dataset (see parameters in table 1).

Table 1. Regression results of TJ-II compared to the exponents deduced from the ISS95 database: from left to right exponents of the pre-factor, minor radius, rotational transform, absorbed power and plasma density, respectively.

	α^x	α^a	α^t	α^p	α^n	α^R	α^B
TJ-II	-1.63 ± 0.08	1.93 ± 0.10	0.51 ± 0.10	-0.74 ± 0.03	0.61 ± 0.04		
ISS95	-0.95 ± 0.07	2.24 ± 0.06	0.42 ± 0.05	-0.59 ± 0.02	0.51 ± 0.02	0.65 ± 0.04	0.81 ± 0.02

signal level drops to its minimum detectable level. Edge temperature at the LCFS was measured by a triple Langmuir probe located at the limiter. Figure 12 shows the edge characteristics of similar discharges (using the average density as reference parameter) for both wall scenarios. There is good agreement between different diagnostics. Atomic beams (thermal lithium and supersonic He) provide information on edge density and temperature radial profiles [41]. Reflectometry is used to monitor the density profiles in a range further inwards, but partially overlapping with the Li beam. Langmuir probe data are cross-checked against the beam diagnostics when available. ECE data at the outermost positions are underestimated because plasma is not optically thick for such low values of local density. As seen in figure 12, while electron density profiles do not exhibit any significant difference, higher electron temperatures are systematically measured in the boronized case.

6.3. Improved confinement modes

The enhanced particle confinement (EPC) mode of the TJ-II stellarator [42] can be characterized by a spontaneous enhancement of the ratio between line integrated density and edge density, $\langle n_e \rangle / n_a$. This mode leads to an increase in the global particle confinement time by a factor >3 . The conditions for the achievement of the transition to the mode under metal wall include

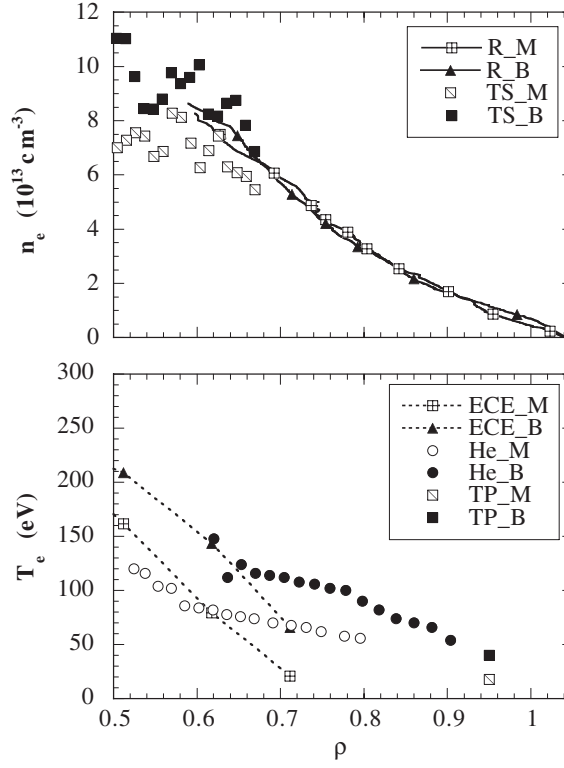


Figure 12. Edge density and temperature profiles for similar discharges, under boronized (B; solid symbols) and non-boronized (M; open symbols) first wall conditions. Line electron density is about $6 \times 10^{18} \text{ m}^{-3}$. ECE (electron temperature), R (reflectometer), He (He beam) and TP (triple probe) data are shown.

a critical trimming of the gas puffing waveform and a critical density, $\langle n_e \rangle_{\text{crit}} \sim 6 \times 10^{18} \text{ m}^{-3}$. For boronized wall the transition is obtained under different recycling/gas puffing conditions. Some of the main features, such as a sudden increase of the effective fuelling rate ($dN_e/dt / Q_{\text{gas}}$) and the constancy or reduction of the H_α signal and saturation current are found in both cases. But edge temperatures do not drop in the boronized case while they decrease in case of a non-boronized wall. An increase in the total energy content, following that of the electron density, takes place in the boronized case. This fact appears as a direct consequence of the constancy in the electron temperature profile during the transition, as opposed to the non-boronized wall scenario. Besides, spontaneous improvements in particle and energy confinement have been observed in a configuration in which the $5/3$ rational value is very close to the plasma centre in the vacuum calculation ($\iota(0)/2\pi = 1.68$) and can enter into the confinement region due to the effect of the negative bootstrap current [43]. Density and temperature profiles broaden giving rise to energy content enhancement up to a factor 1.4. Figure 13 presents temporal traces of global and edge parameters for a discharge showing this enhancement. The spontaneous transition to an improved regime is identified by an increase in the electron temperature (three ECE channels) and the SXR line emission at about 1147 ms (upper box). In the enhanced phase, the electron temperature profile becomes broader, showing the maximum temperature increase about mid-radius. Line average density increases fast after the transition as well as the plasma current (in absolute value) as shown in the second box. Diamagnetic energy

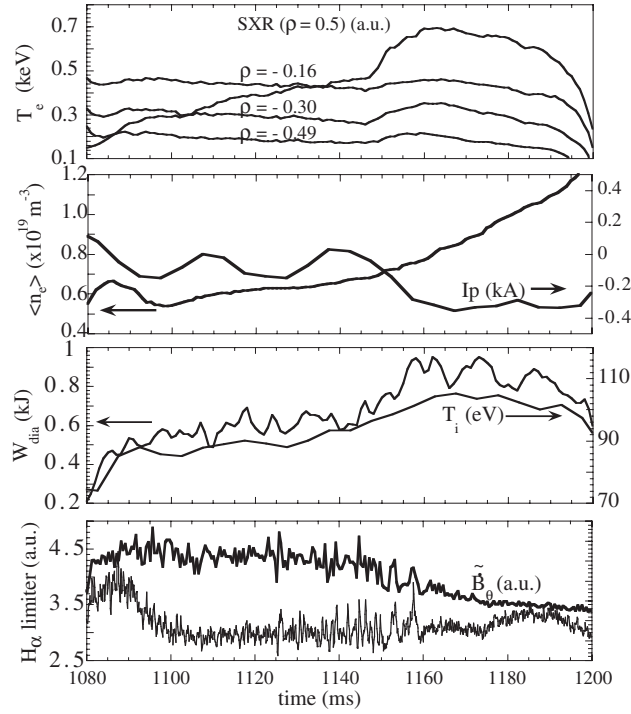


Figure 13. Time evolution of different plasma parameters, across the transition to enhanced confinement mode in the discharge #5196. The transition time is $t = 1147$ ms.

and ion temperature exhibit a clear rise after the transition (see third box). The lower box shows that magnetic activity (present before the transition and attributed to ELM-like events associated with the 5/3 resonance) is reduced after the transition and, simultaneously, there is an enhancement of the particle confinement as indicated by a constant H_α -signal together with the rapid increase of the line averaged density, so that the rate ($H_\alpha / \langle n_e \rangle$) is reduced after the transition. The behaviour of these temporal traces reminds some features of the L–H transitions observed in other devices but in TJ-II there is a clear difference. One of the main characteristics of the L–H transition is the rapid formation of an edge transport barrier whereas the transport analysis of the TJ-II transitions performed with the transport shell ASTRA [44] describes the evolution of the profiles via a sudden reduction ($\sim 50\%$) of the thermal and particle diffusivities in an extended region well inside the main plasma [45]. The position of the rational surface with respect to the maximum pressure gradient region might be related to the transition but further experimental and analytical work is needed to confirm this point.

7. Conclusions

First, plasma potential profiles up to the plasma centre have been measured in TJ-II: in low-density plasmas positive values of radial electric field are measured, in qualitative agreement with neoclassical predictions. Measurements with the HIBP system have shown evidence of plasma fluctuations linked to low-order rational magnetic surfaces in the plasma confinement region.

Low-order resonances provoke changes in the TJ-II pressure profile. Depending on the position of the low-order rational in the rotational transform profile the dominant effect may

differ from enhanced temperature gradients in the central region, resembling a transport barrier, through ELM-like events at mid-radius, to increased $E \times B$ sheared flows in the plasma edge.

Edge transport in TJ-II can be controlled by means of magnetic well. The device flexibility has allowed showing that there is a non-monotonic relation between fluctuations in gradients and turbulent transport and that different transport mechanisms seem to be responsible for the radial propagation of small and large transport events. Cold pulse propagation experiments demonstrate the existence of non-diffusive transport in TJ-II. The radial propagation of the pulse front exhibit features that are consistent with a model based on the sequential triggering of pressure-gradient driven modes.

Several enhanced confinement regimes have been found in TJ-II. Additional experiments and analysis are in progress to identify the key parameters governing the transitions in each case. Negative magnetic shear improves confinement in TJ-II. This is not the case when the sign is positive.

Global energy confinement in TJ-II improves with rotational transform. The parametric dependence agrees with the one obtained in the ISS95 and supports its validity because it has been deduced from a substantially wider $\iota/2\pi$ -range.

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