DISCRIMINATION BETWEEN MAGNETIC SHEAR AND TOROIDAL ELECTRIC FIELD EFFECTS IN TJ-II PLASMAS

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The response of TJ-II plasmas to an induced toroidal electric field, E_ϕ, was studied in past experiments with the aid of Ohmic inducted current. It was found that positive induced plasma current, I_p, degrades the confinement while negative I_p improves it. Candidates to provide a physical explanation are E_ϕ itself and the plasma current via magnetic shear modification. A movable mirror in an electron Cyclotron Heating line of TJ-II permits varying the refraction index of the heating wave, $N_{||}$, thus allowing for *non inductive* electron cyclotron current drive (ECCD) up to $I_p \approx \pm 1$ kA. Comparing discharges without and with ECCD (changing shear but not E_ϕ) but sharing the same transformer action (changing both shear and E_ϕ), magnetic shear and electric field effects can be discriminated in time. It has been found that plasma response with ECCD is delayed respect to the transformer switch-on time, clearly pointing to shear effects. Effects related to E_ϕ alone, if they exist, are weaker.

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1. INTRODUCTION

The TJ-II facility[1] is very well suited for investigating confinement properties in different magnetic configurations, as it covers an ample range of rotational transform profiles, ι. In addition to this, a set of coils designed to induce toroidal plasma currents, I_p, can be used to sweep ι profiles during a discharge. This has been used recently to study the confinement in TJ-II under positive and negative induced plasma currents[2]. Since the technique is essentially the induction of a toroidal electric field via transformer action, which gives the ohmic heating (OH) mechanism in tokamaks, we shall refer to it as OH induction. The main result was found that $I_p>0$ causes a degradation of confinement and vice versa in a very reproducible way. Two global magnitudes can change sign under OH induction: the toroidal electric field and, being TJ-II vacuum configurations almost shearless, the magnetic shear defined as $\hat{s} = -(\rho/\iota)(d\iota/d\rho)$, where ρ is a flux surface radial coordinate. The symmetry of the effect on confinement suggests that either magnitude can be explicitly invoked as the main cause of the observations. To discriminate among them, new experiments were designed based on non inductive techniques to drive I_p. It is worth investigating the physics behind these observations because the possibility of improving (degrading) confinement with external means opens a convenient way to control confinement in stellarator plasmas. Moreover, the knowledge of the effect on transport of magnetic shear, current and electric field that can be studied on stellarators maybe extensible to tokamaks and other confinement devices as well.

2. DESCRIPTION OF THE EXPERIMENTS

A movable mirror in the Electron Cyclotron Heating (ECH) line of TJ-II allows varying the refraction index of the heating wave, $N_{||}$, thus forcing currents of either sign without electric field induction. Here we have launched the waves at $N_{||}=0.0$ and $N_{||}=\pm0.2$, i.e., no ECCD and a drive of approximately –1 kA for $N_{||}=0.2$ and 0.3 kA for $N_{||}=-0.2$. A typical discrimination experiment consists of a set of three discharges: a reference one without OH and two more with the same prescription for OH coils but different ECCD level. Fig. 1 shows typical prescriptions for the current in the OH coils.

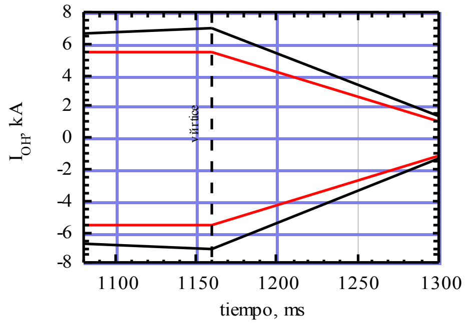

Fig. 1. Typical prescription of the current in the OH coils. The discharges start with null or very low dI_{OH}/dt and, at a prescribed time (vertical line), I_{OH} is ramped up or down to induce a toroidal electric field.

The discharges are taken to equilibrium and then the toroidal electric field is induced.A transition in the line density evolution can be easily identified after the time at which OH starts (vertical dashed line in Fig. 1). Discharges with different ECCD have different I_p, but share the same loop voltage. Therefore, a delay in the transition in line density (or any other reproducible timetraces) is an indicator that I_p, but not the electric field, provokes the plasma response.

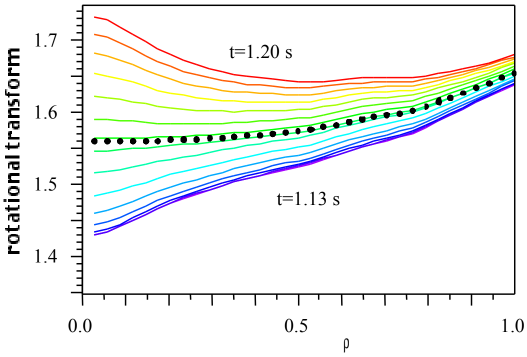

Fig. 2. Simulation of ι evolution from t=1.13 s (Ip=-1.5 kA) to t=1.20 s (Ip=2.3 kA). The vacuum profile is shown with dots.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The induced current in these discharges is enough to cause notable changes in the magnetic shear along the discharges. To ilustrate this, in Fig. 2 we plot the evolution of ι calculated for a ramp up rate dI_{OH}/dt=25 kA/s, starting from negative current, in toroidal geometry and conditions similar to the experiments.

Fig. 3 shows a 200 ms time window for a typical OH experiment with positive induction. From top to bottom and left to right the following raw data from several diagnostics are shown: plasma current, line average density, electron temperature near the plasma center, H_α emission line at the limiter, loop voltage, soft X-ray emission, charge exchange neutral emission and Mirnov coil signals. It can be observed that the levels of I_p are different for the three discharges but the loop voltages are experimentally the same except for the control case (no OH induction). In despite of this, some distinguishable signatures in the time traces for the case with lower I_p are delayed with respect to the case of higher I_p. This is what was expected in the case that the main cause for plasma changes is I_p instead of the toroidal electric field. Note that the larger MHD events (see Mirnov coil signals in Fig. 3) are correlated with brief transients in H_α and other diagnostics (density, electron temperature, soft X-rays) but not with the time at which confinement changes trend.

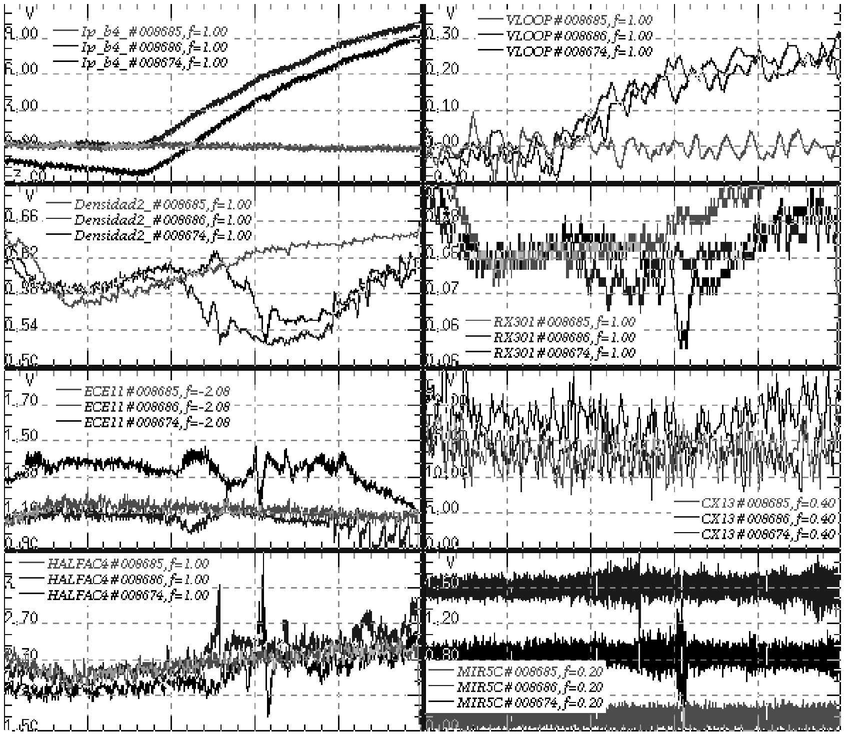

Fig. 3. Time traces of several TJ-II diagnostics in a case of positive OH induction at several levels of plasma current.

As a general rule, the same patterns as in previous experiments have been found: improvement (degradation) of the confinement at negative (positive) plasma current. It is worth noting, however, that when the positive plasma current is high enough the confinement seems to recover.

This fact is illustrated in Fig. 4 where the evolution of line density is plotted versus the plasma current for three discharges with different line densities. The apparent dependence of the density on I_p is stronger at higher density. In the high density case it is clear how the density drops but recovers as of $I_\mathrm{p}\approx 6$ kA. In cases (not shown) of negative plasma current induction, the density increases monotonically with the magnitude of the current up to the values reached of ≈-10 kA.

These experiments show that, for the present plasma conditions (Electron Cyclotron Heating, average density below 10^{19} m^{-3}, peaked electron temperature with $T_\mathrm{e}\approx 1$ keV at the magnetic axes and ≈0.1 keV ions), the plasma current is the main responsible for the changes in confinement. Toroidal electric field effects *per se* are, if any, much weaker. An important result to consider in the passing is that, if the *global* magnetic shear is a true knob in these experiments via plasma current, then not only its magnitude, but also its sign, plays a role in the confinement.

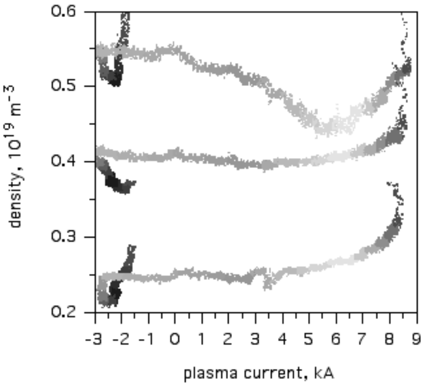

Fig. 4. Relation between line density and plasma current in three discharges with low, middle and moderate density.

Possible explanations, still to be investigated, rely on:

i- Dissipative trapped electron modes. These are expected at $T_e >> T_i$, low collisionality, low or negative density gradient and large fraction of trapped particles. All of these conditions are met in the present plasmas. They are sensitive also to global magnetic shear[3]. A calculation[4] of trapped fraction for TJ-II in the vacuum configuration pertinent to these experiments is ≈35%.

ii-Electron temperature gradient modes. The corresponding growth rates may be affected by both the sign and the magnitude of the magnetic shear.

iii-Modification of particle orbits due to changes in the magnetic topology. This may affect considerably the fraction of direct particle losses in TJ-II. Three-dimensional calculations[5] suggest that these losses can affect very differently to the populations of passing and trapped particles depending on the rotational transform of the configuration.

Numerical calculations of drift wave growth rates in stellarator geometry point to the *local* magnetic shear as an important magnitude to consider[6]. However, the very low values of plasma β in these experiments should exclude any changes in this parameter.

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TEMPERATURE OF IMPURITY IONS IN A RF HEATED PLASMA OF THE U-3M TORSATRON AS MEASURED BY MEANS OF THE DOPPLER SPECTROMETRY

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1. INTRODUCTION

The spectroscopic methods of measurements of ion temperature, T_i, are routinely used in magnetic fusion experiments. However some strong requirements must be satisfied as for the quality of spectroscopic equipment and reproducibility of plasma parameters when spectral line profile is obtained shot by shot. Besides, the radial location of ions of the given ionization state in the plasma volume should be known. The correctness of T_i measurement results has to be controlled by comparing them with temperature T_i of the main plasma ion component (H^+, D^+) by calculation of energy balance for impurity ions. Important is also the requirement to estimate the role of other possible mechanisms of broadening of the impurity ion line profiles.

The goal of this paper is to determine the plasma ion temperature using data on profiles of spectral lines of intrinsic impurity, i.e., carbon ions (lines CV 227.1 nm and CIII 229.6 nm) in the plasma confinement volume of U-3M torsatron and to compare these results with data of T_i measurements based on the energy distribution of charge exchange atoms (CXA) obtained by neutral particle analyzer (NPA).

2. EXPERIMENTAL CONDITIONS AND RESULTS

The experiments were carried out on the fusion device Uragan-3M (U-3M) which is a l=3, 9 magnetic field period torsatron with major radius 100 cm and mean plasma radius 12.5 cm. The hydrogen plasma was produced and maintained during ~50 ms by RF fields in the frequency range $\omega \leq \omega_{ci}$ corresponding to a multimode Alfven resonance regime. The spectroscopical measurements were provided for the following conditions: toroidal magnetic field 0.7T, $P_{RF} \leq 240$kW, mean plasma density $\sim 1 \cdot 10^{18}\, m^{-3}$.