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RI mode in FTU ohmic plasmas by Ne injection.

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Introduction

The RI mode is an improved confinement regime obtained in Tokamak by injecting controlled quantities of gaseous impurities (mainly noble gases such as Ne, Ar and Kr). One of the main advantages of RI mode is that it can be obtained in different magnetic configurations (circular or elongated discharges, with plasma cross section limited by a limiter or a magnetic separatrix), and with different heating systems (NBI, ICRH and Ohmic) [1]. Indeed the IOC regime of Asdex [2] can also be interpreted as an RI mode.

Thus an experimental campaign has begun in FTU to find the signature of a RI mode, starting with ohmic heating only.

The strategy used to achieve this improved regime of confinement is based on the interpretation given by TEXTOR [3]: injection of light impurities increases the value of the average charge Z of the plasma, which triggers a decrease of the growth rate of the Ion Temperature Gradient (ITG) instability. The resulting decrease of the outward particle flux leads to a peaking of the density profile, which further attenuates or even quenches the ITG turbulence. When the latter is the dominant mechanism for heat anomalous transport, an improvement of the energy confinement results, which increases linearly with plasma density (like in the Neo-Alcator scaling law).

FTU has some pecularities with respect to all other Tokamak in which RI mode has been obtained and studied. FTU is a circular cross section high field compact machine, that can operate at high densities (up to 3 10^{20} m^{-3} with gas puffing) and with metallic first walls : TZM (a Mo alloy) for the limiter material and stainless steel for the vacuum chamber.

The Experiment

Based on the experience on other Tokamaks, Ne was chosen as the proper light impurity to be injected into the plasma.

The plasma target itself was chosen with the following parameters: at B_T=6T a plasma current of 0.8-0.9 MA was set up to avoid the onset of marfees; operation was done at an electron density (D_2) larger than 10^{20} m^{-3}, in order to be well in the saturated ohmic confinement (SOC) regime. In FTU the critical density to enter the SOC regime is 0.7-0.8 10^{20} m^{-3}.

The plasma column leans onto the inner toroidal limiter. The external deuterium flow is stopped at the beginning of the current flat-top (0.45 sec) , just before a short Ne puff (10-30 ms duration) is programmed (at 0.5 -0.6 sec).

Experiments are performed both just after boronization of the vacuum chamber (boron coating with glow discharge with a mixture of 90% He and 10% dyborane, B_2H_6) [4], and a few weeks far away, in a well conditioned machine (impurity content dominated by metals). The shots with fresh boronized walls have the advantage of low radiation power fraction (30-40%), compared with the usual (for FTU) ≥ 60%, and thus with a longer Ne gas puff possible, but with the disadvantage of contamination with hydrogen particles released from the Boron film (up to 60% of the total fuel content). The essential phenomenology obtained by Ne injection does not differ appreciably in the two cases.

The Ne concentration into the plasma is monitored by a UV SPRED spectrometer (Ne VII line at ~ 10.6 nm) and the brightness of different Ne lines analysed by a Schwob-Fraenkel grazing incidence spectrometer.
The full set of standard FTU diagnostic has been utilised to obtain temperature and density profiles, neutron yield, radiation losses and their profile, recycling from the limiter and the walls, the value of Zeff, etc.

Experimental results

Fig 1 shows the effect of Ne injection at 0.5 s on line average density, radiated power and neutron yield, compared with a reference discharge, at 6T and 0.9 MA.
The average density of the reference discharge decreases slowly because no D_2 gas puffing is present after 0.45 sec, and the recycling coefficient is less than 1. The density of the discharge with Ne puff increases for the whole duration of the pulse: this increase cannot be attributed to Ne only, since the Ne concentration, estimated by the variation of Zeff (from 1.4 to 2) is not sufficient to account for the density difference.
Radiated power reaches up to 85% of the ohmic power at the end of the pulse. Neutron yield increases by a factor ~4.
Metallic impurities (Mo and Fe) are observed to decrease after Ne injection: indeed the conducted/convected power through the last closed magnetic surface decreases substantially, and therefore we can expect a corresponding decrease of the SOL temperature (in spite of a smaller particle flux) [5] and a smaller sputtering yield for the limiter and wall material.
Fig. 2 shows the density, electron and ion temperature profiles for the two discharges. Density and electron temperature profiles are measured, while the ion temperature profile is deduced by using the 1-D transport code EVITA in the interpretative mode. The transport coefficient χ_i is taken to be $\alpha\chi_{ineocl}$. In order to reproduce the enhancement in the neutron yield for the discharge with Ne puff, the anomaly factor α must be decreased by at least a factor 2. Typically, in ohmic discharges in the SOC regime, α is about 3.
In Fig.3 the total thermal energy and the ohmic power are compared. While the total energy increases substantially as soon as Ne is injected, the input power remain practically the same.
As a consequence the energy confinement time, as shown in Fig.4 , is larger in the Ne puffed discharge. The improvement factor is 1.4 at 1.2 sec, i.e. of the same order as the ratio of the density to the critical density for SOC regime, 1.5.

Discussion and conclusions

From these first results, it appears that the typical signatures of an RI mode have been observed in FTU ohmic plasmas: density profile peaks after Ne injection, and electron and ion temperature increase at the same input power, so that a noticeable improvement in energy confinement is achieved. Ion transport seems to approach the neoclassical level, pointing to a possible attenuation of ITG turbulence. These regimes have not been yet optimised: for instance TEXTOR suggests that the best RI modes are obtained when the plasma is far away from the inner limiter. Neither we can conclude that the Neo-Alcator scaling law is recovered in FTU.
We plan to experiment with plasmas leaning on the outer poloidal limiter and at progressively higher density, trying also to measure the fluctuations density spectrum by reflectometry.
In addition we will also try to obtain RI modes in additionally heated plasma. Up to 3 MW of additional power is available in FTU (2 MW of LHH at 8 GHz and 1 MW of ECRH at 140 GHz). Since these additional heating systems interact only with electrons, it will be interesting to prove the possibility of an RI mode in these

conditions. Indeed so far RI modes have been obtained only with strong ion heating (TEXTOR, DIII-D, AUX, etc.)

References

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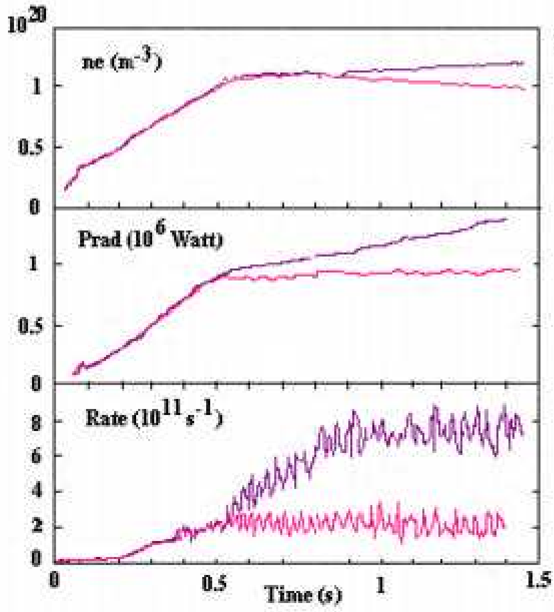

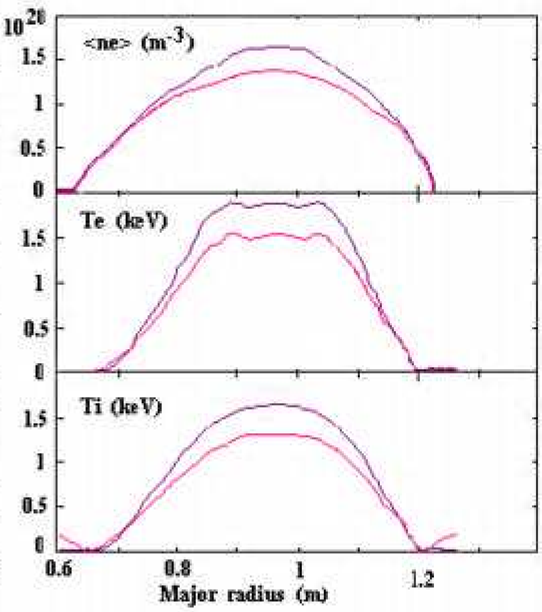

Fig.1 a) Line average density from the DCN interf.; b) Total radiated power from bolom.; c) neutron yield for two shots: (red) w/o Ne and (violet) with Ne.

Fig. 2 a) density profile; b) electron temp. profile from Michels. interfer.; c) ion temp. profile from transp. code simualtion: (red) w/o Ne; (violet) with Ne.

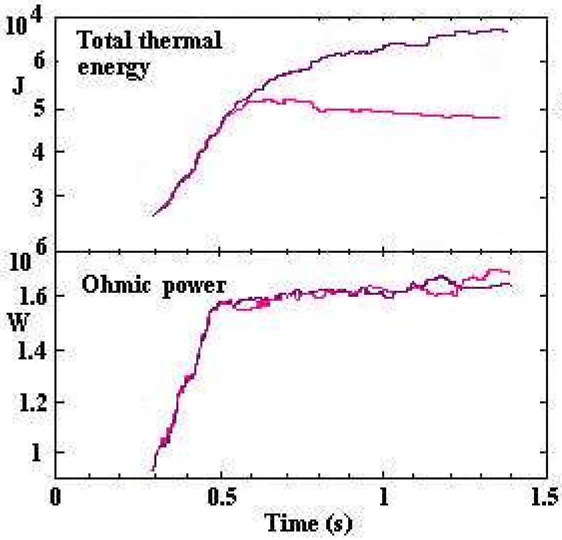

Fig.3 a) Total thermal energy; b) Ohmic power: (red) w/o Ne ans (violet) with Ne puff.

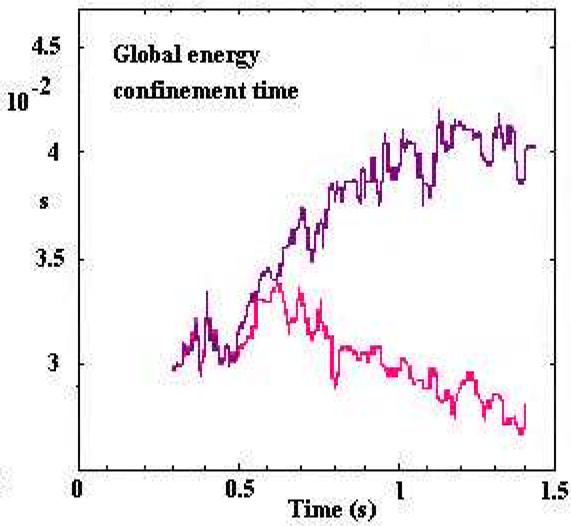

Fig.4 Global energy confinement (red) w/o Ne and (violet) with Ne puff.