Influence of magnetic well on electromagnetic turbulence in the TJ-II stellarator

F. Castejón, A. M. Aguilera, E. Ascasíbar, T. Estrada, C. Hidalgo, A. López-Fraguas, M. A. Ochando, S. Yamamoto[a], A.V. Melnikov[b,c], L.G. Eliseev[b], S.V. Perfilov[b], and the TJ-II Team

Laboratorio Nacional de fusión. CIEMAT. Av Complutense 22. 28040 Madrid. Spain

[a]Institute of Advanced Energy, Kyoto University, Uji, Japan

[b]National Research Centre, NRC 'Kurchatov Institute', 123182, Moscow, Russia

[c]National Research Nuclear University MEPhI, Moscow, Russia

1.- Introduction.

Stellarator optimization takes into account several criteria, including neoclassical transport and stability (see e. g. [1]). Mercier criterion provides stability against interchange modes and is usually considered among the optimization criteria[2]. The magnetic well, related to the plasma shape, is a key stabilizing ingredient and, hence, the optimized configurations are usually complex and must be created by complicated coils, difficult to build and to maintain, which is especially relevant for a stellarator-based reactor, where the operations of maintenance must be performed using remote handling techniques. Therefore the relaxing of such a criterion can help to design simpler and cheaper stellarators.

The flexible heliac TJ-II allows one to vary the magnetic well, keeping constant the rotational transform profile, although the volume values of the magnetic configurations are reduced as the magnetic well decreases. Figure 1 shows the magnetic well and the rotational transform profiles and the volume values for the family of configurations used for these experiments.

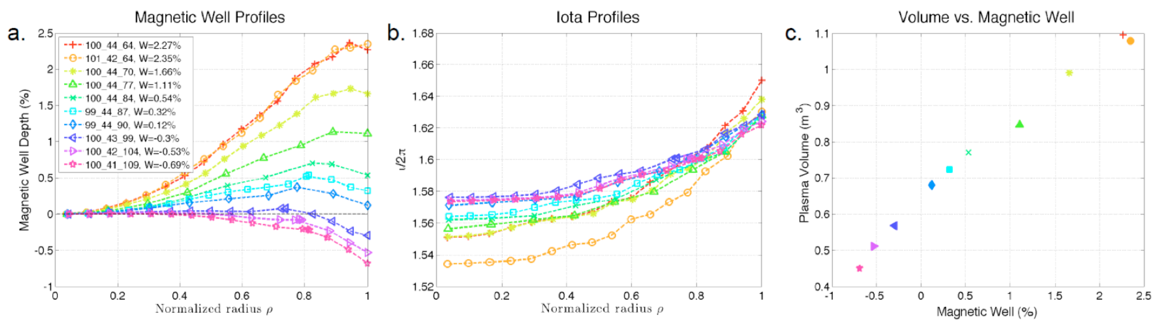

Figure 1: a) Profiles of magnetic well of the family of TJ-II configurations used for these experiments; b) rotational transform profiles and c) volumes of these configurations.

The previous magnetic well scan experiments on TJ-II have shown the existence of stable plasmas in Mercier-unstable magnetic configurations[3]. The position of LCFS is the same as the predicted by the theory and the confinement time presents a weak degradation for configurations with magnetic hill, as well as the electrostatic turbulence shows a moderate increase for those configurations[4]. In this work, we explore the electromagnetic properties of the turbulence during the magnetic well scan.

2.- General Experimental Results

The experimental set-up consists of Langmuir Probes, Mirnov coils, HIBP, arrays of bolometers and a Doppler reflectometer. In the configuration scan, Mirnov coils detect three groups of modes of different nature. First of all, it is detected a family of high frequency (above 100 kHz) modes together with others with middle frequencies (tens of kHz), depending on the NBI co- or counter-injection and the magnetic field structure of the configuration. The population of high frequency modes, being of Alfvénic nature, is much richer for counter injection. Regarding the intermediate frequencies, in some cases, a coherent mode appears with decreasing frequency as the magnetic well decreases. Finally, the family of configurations in this magnetic well scan is characterised for having the resonant value 8/5 of the rotational transform at $\rho \approx 0.8$ in vacuum. The onset of an oscillation at $f \approx 10$ - 20 KHz happens in several cases, showing a destabilization of the mode in configurations with low magnetic well or magnetic hill, although this behavior is not systematic.

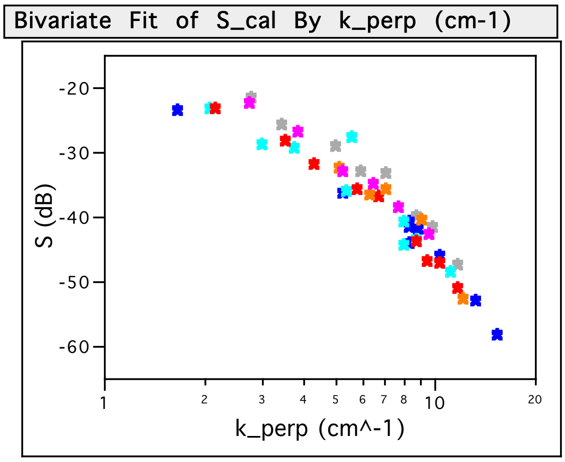

Figure 2. Wave vector spectrum of the explored family of configurations. The colours correspond to the different configurations (see figure 3).

The broadband turbulence is measured by Doppler reflectometer on this configuration scan. For the positions detected by the reflectometer (0.7 < ρ < 0.9), it can be seen that the wave number spectrum is the same, for the same values of densities, in all the cases, as

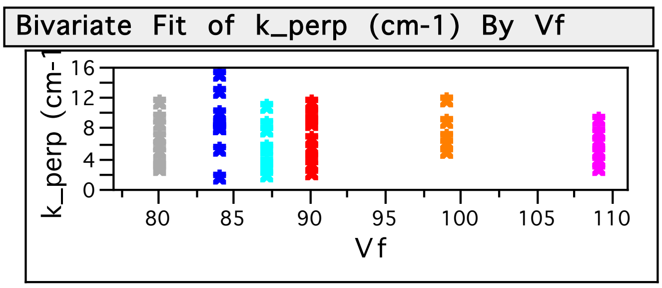

Figure 3. Explored values of the wave vector for the different configurations (Vf is the value of the current of the vertical field coil, the last number of the configuration name in Fig. 1).

can be seen in Figure 2. This fact shows that even in the configurations with magnetic hill, the structure of the turbulence is similar. The values of the wave vector explored with the reflectometer can be seen in Figure 3, showing that similar values of this vector are explored in all the cases.

3.- Low Frequencies

The family of configurations in this magnetic well scan is characterised for having the resonance 8/5 at $\rho \approx 0.8$ in vacuum. The onset of an oscillation at $f \approx 10$ - 20 KHz happens in several cases, showing that the mode creates a rotating island mainly in configurations with low magnetic well or magnetic hill, although this behaviour is not systematic. The behaviour of the island depends strongly on plasma current, which is able to move the resonance outwards in the plasma, when it takes negative values, or to inner positions for Ip>0. The onset of the island could have influence on the Alfvénic spectrum[5], since the structure of magnetic field is modified.

4.- High and intermediate frequencies

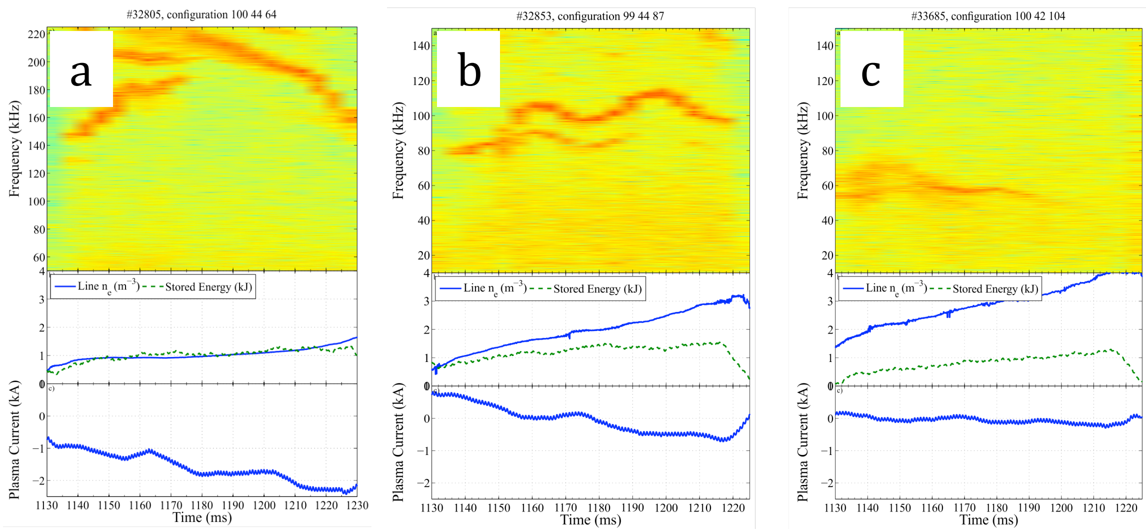

Figure 4. Spectrum of the turbulence measured by Langmuir probes, together with the evolution of plasma current, density and storage energy, in three configurations: a) 100_44_64 (W=2.27); b) 99_44_87 (W=0.32%); c) 100_42_104 (W=-0.69%).

Despite of the fact that the vacuum rotational transform is very similar in all the cases, the mode structure changes drastically when decreasing the magnetic well, showing a non-monotonic behaviour of the amplitude, and a decrease of the typical frequencies. Figure 4 a,b,c) shows the onset of the Alfvén mode for three configurations with co-NBI, the first one with deep magnetic well, the second with an intermediate value and the third one presenting magnetic hill. The mode is of Alfvénic nature in the three cases (The mode of spectrum 4a that appears between 1135 and 1170 ms at freq. between 145 and 180 is an artefact due to aliasing), since the frequency variation due to the changes in the density and the plasma current is given by[6]:

$$2\pi f = k_{\parallel} v_A \propto \frac{1}{\sqrt{n}}\left|m\iota - n\right| \approx \frac{1}{\sqrt{n}}\left|m(C(\rho)I_p + \iota_{vac}) - n\right| \sim \pm\frac{\left|I_p\right|}{\sqrt{n}}$$

Where Ip is the plasma current and C is a function with weak dependence of ρ, extracted from the experimental results. The changes observed from one configuration to another one must be attributed to the changes in the magnetic configuration, as it is shown by calculations performed with the code STELLGAP[7], which can justify the strong frequency variation from one configuration to another one, as well as the spatial location. Regarding the intermediate frequencies, a coherent mode appears for the cases with intermediate magnetic well with non-monotonic frequency evolution and mode location as the magnetic well decreases. The role of plasma current on this behaviour is under study. This mode has been observed previously and identified possibly as a GAM, which is driven by fast particle driven Alfvén modes[8].

5.- Discussion and Conclusions

The former studies of the effect of reducing magnetic well have shown a modest influence, if any, of magnetic well on global confinement. An increase of the level of electrostatic turbulence, detected by the Langmuir probes, happens for decreasing magnetic well. The level of fluctuations detected by Langmuir probes strongly depends on the magnetic configuration. The spectrum of wav e vector does not depend on magnetic well, showing the same rtole of the scales in the magnetic well scan. The typical frequencies of the Alfvén modes that appear in the co-NBI heating tend to decrease with the magnetic well, as does their radial postion. These findings show that the effect of magnetic well is very limited in the general confinement properties, although the changes in magnetic turbulence could affect the fast ion transport.

Acknowledgements

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

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