MHD equilibria with magnetic islands in TJ-II using SIESTA

B. Centurión[1], J. J. Martinell[1], A. López-Fraguas[2], J.M. Reynolds[3] and D. López-Bruna[2]

[1]*Instituto de Ciencias Nucleares, UNAM, A. Postal 70-543, México D.F., Mexico*

[2] *Laboratorio Nacional de Fusión, As.EURATOM-CIEMAT, 28040 Madrid, Spain*

[3] *Universidad Carlos III, Leganes 28021, Spain*

I. Introduction. Experiments in the TJ-II heliac show a correlation between the position of magnetic rational surfaces and a modification of the electron temperature profile [1], in low density Electron Cyclotron Resonance heated discharges. On Neutral Beam Injection discharges, different rational surfaces can be swept along the minor radius by varying the helical current and it was found that the transport was reduced at the position of the rational surfaces [2]. Bolometry studies have also shown a correlation between transport barriers appearing on rational surfaces and MHD activity [3]. This may also lead to transitions of the L-H type. Since magnetic islands are likely to form at rational surfaces because the magnetic perturbations are resonant there, investigation of the presence of magnetic islands is quite interesting in the context of confinement improvement.

Using SIESTA code we calculated MHD equilibria with magnetic islands in TJ-II to determine the properties of the islands. The starting equilibrium state is the one obtained by the VMEC code with nested magnetic surfaces. Standard computations use the heliac's toroidal periodicity of 4 periods to reduce the code runtime, but this, when used in SIESTA, limits the toroidal periodicity of the islands to multiples of 4. To solve this limitation we tailored the input parameters to run VMEC without 4-period symmetry. In this way, running SIESTA with those equilibria, magnetic islands of any periodicity are obtained, including those resonant at $\iota = 3/2$ whose magnetic islands were previously absent from the simulations. The results also show 2D pressure profiles that match the location of the magnetic islands observed in the Poincaré plots of the field lines.

II. VMEC equilibrium with no periodicity We used the VMEC code to calculate the starting MHD equilibrium state without magnetic islands. Then using SIESTA code we added small perturbations at rational surfaces, where the magnetic islands develop due to the resonance of the perturbations, finding a new equilibrium state. Field lines a re followed with Poincaré plots, while isocontours of pressure display the island flattening.

Previous simulations used the heliac's symmetry of 4 toroidal field periods (NFP = 4) to reduce the code runtime, but this, when used in SIESTA, limits the toroidal periodicity of the islands to multiples of 4. We tailored the input parameters of VMEC to run the code without the 4 period symmetry (NFP = 1). Figure 4 shows the shape of the plasma after running a simulation with NFP = 1 , thus showing that the toroidal periodicity of the machine was kept the same. We worked with three TJ-II configurations used at CIEMAT: configuration 100_44_64 will be referred to as Case A, configuration 100_36_62 as Case B, and its high magnetic shear counterpart produced by Ohmic heating, as Case C.

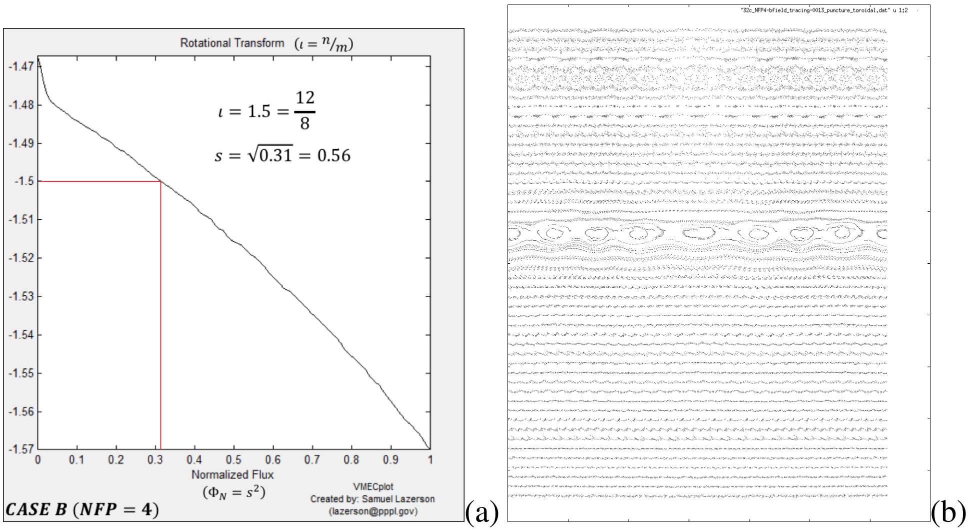

Figure 1: Case B: iota profile and Poincaré plot when field-period=4.

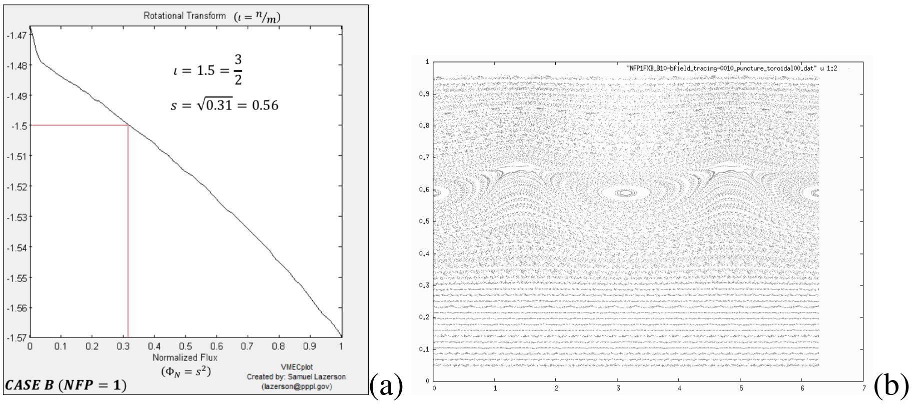

Figure 2: Case B: iota profile and Poincaré plot when field-period=1.

To validate that the code was actually simulating the whole machine without symmetry, we ran Case B, which has a rational surface at $\iota = 3/2$. Figure 1 shows the results before the fix, the perturbated surface had to be $\iota = 12/8$, to make n multiple of 4. Figure 2 was done with NFP = 1, so there was no restriction on the periodicity of the islands in the toroidal direction, and the island chain with $m = 2$ that was previously unable to grow can now be seen.

III. Island formation for arbitrary ***n*****.** With the toroidal periodicity issue solved, we proceeded to look for island formation in the pressure domain. Figure 4 shows $\iota(s)$ for a high magnetic shear configuration (Case C) that covers several rational surfaces, including $\iota = 3/2$ and $\iota = 4/3$, while Fig. 4 is the equilibrium where chains of magnetic islands can be observed around the normalized coordinate $s = 0.66$ and $s = 0.30$ respectively. The islands shown in the pressure profile only develop in equilibria with very small residual forces, and are a sign of a good convergence (Fig.5). The pressure at the rational surface $\iota = 3/2$ did not form pressure islands, most likely because the residual force of the equilibrium is still not low enough. However, other studies have shown that the periodicity of this surface might not be $m = 2$ and could be higher [4], belonging to a multiple of $\iota = 3/2$, such as $\iota = 6/4, \iota = 9/6$ or $\iota = 12/8$ (See Figure 6).

All of those modes were tried without reaching an equilibrium good enough to show pressure islands at that surface. This rotational transform profile also covers other rational surfaces near the magnetic axis ($s = 0$) that resonate with the same poloidal frequency, as seen in Figure 6.

The pressure profiles show a bulging of the pressure in the location of rational surfaces, similar to the bulging of the experimental electron pressure observed in other cases of resonant surfaces in TJ-II. It has been found that at the resonant surface $\iota = 8/5$, the heat diffusivity is reduced, which acts as an internal transport barrier, improving the plasma confinement [2].

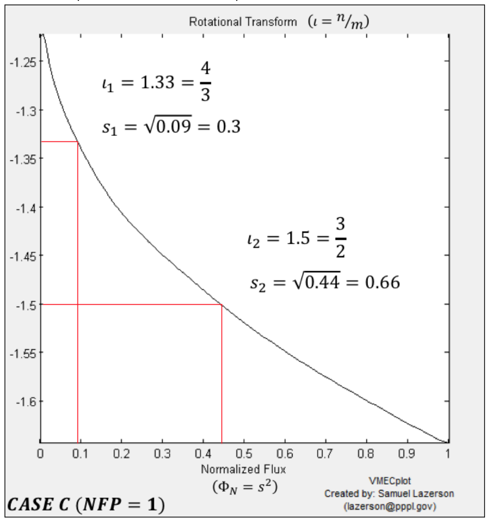

Figure 3: High shear iota profile allowing for $m/n = 3/2, 4/3$ perturbations.

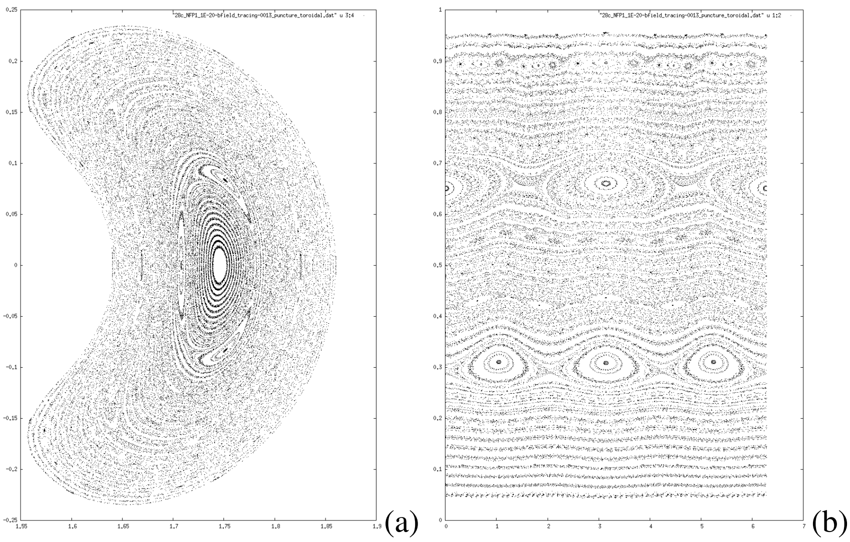

Figure 4: Poincaré plots for high shear case.

IV. Unperturbed island formation. When Siesta is started with no initial perturbations an equilibrium with small magnetic islands is reached, which indicates the equilibrium state from VMEC is not stable to resistive modes for the high shear case. See Figure 7.

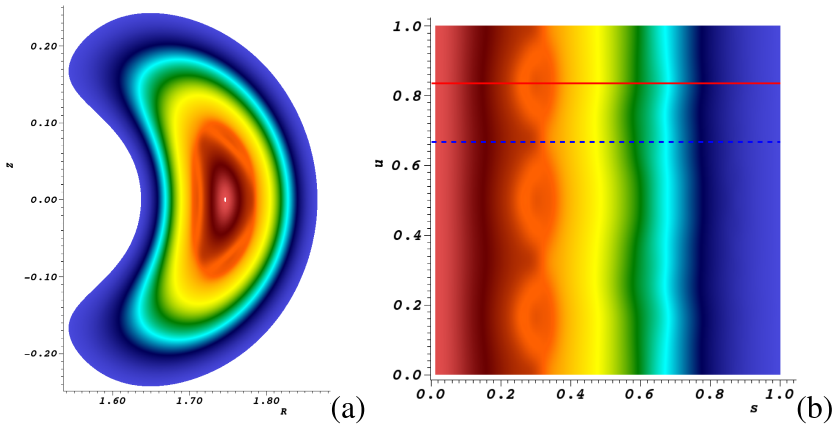

Figure 5: Pressure plots for high shear case; (a) cross ection, (b) $s-\theta$ plane.

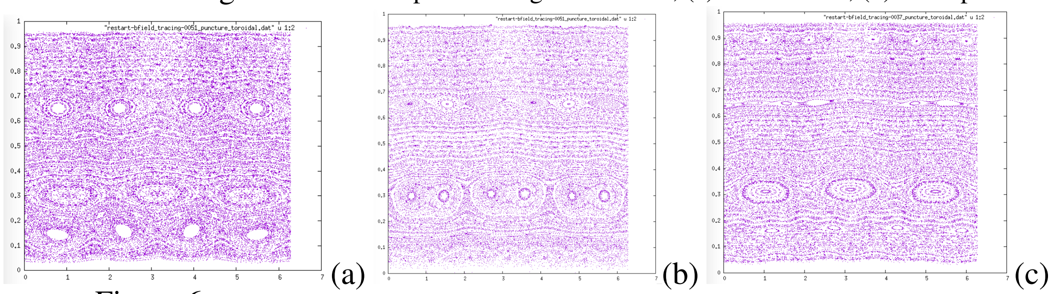

Figure 6: Magnetic surfaces for a second perturbation with $m=4$ (a), $m=6$ (b) and $m=8$ (c).

V. Conclusions. A method was developed to produce magnetic islands with any toroidal periodicity in SIESTA by modifying the equilibria in VMEC. Further work is required to identify which poloidal periodicity is developing at the surface $\iota = 3/2$, and also finding the correct simulation parameters to achieve a convergence with pressure islands on that surface. The results obtained with the simulations of VMEC and SIESTA are very interesting because they can be related to experimental results. Finding the correct number and positioning of magnetic islands could be the key to achieving better magnetic confinements needed for future fusion reactors.

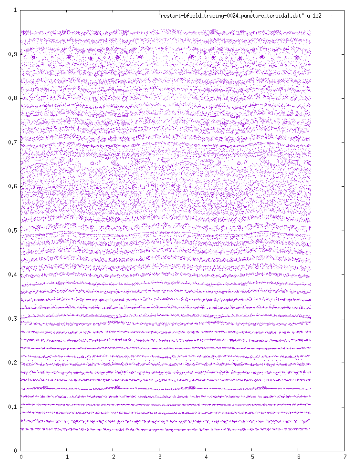

Figure 7: Equilibrium with no initial perturbations for high shear. Islands with m=8 at r=0.66 and m=3 at r=0.3 are seen.

Acknowledgements. This work was partially supported by project DGAPA-UNAM IN112118 and by supercomputo project LANCAD-UNAM-DGTIC-104

References

[1] D. López-Bruna el al., Plasma Phys. Control. Fusion 53, 124022 (2011).

[2] D. López-Bruna el al., J. Physics: Conf. Ser. 591 012013 (2015).

[3] D. López-Bruna el al., Nuclear Fusion 53, 073051 (2013).

[4] M.A. Ochando et al. 19th ISHW - 16th IEA-RFP workshop (2013).