Computational Study of Magnetic Islands in the W7-X and NCSX Stellarators

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The magnetic fields of stellarators and, in general, all not strictly axisymmetric toroidal fusion devices exhibit magnetic islands. They strongly influence the confinement properties of a fusion plasma and are exploited in divertor design. So, the existence and the structure of the magnetic islands are an important issue in configuration design. Codes that determine finite-plasma-β stellarator equilibria while fully accounting for their island structures exist (HINT [1], PIES [2]) and have been applied to the NCSX [3] and W7-X [4] stellarators. In the NCSX standard high-β scenario low-order rotational-transform values exist inside the plasma [5]. Figure 1 shows a poloidal cut of an NCSX case at $\langle\beta\rangle = 4\%$ with $0 < \theta < \pi$ and the normalized radius $r < 1$ of the PIES background coordinates. Several $3/m$ and $6/m$ islands can be seen, e.g. $3/5$ at $r \approx 0.75$ and $3/6$ at $r \approx 0.6$ in the 3-periodic device.

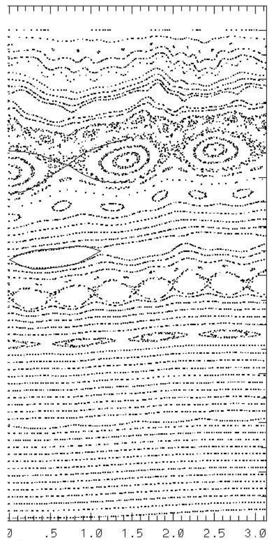

Figure 1: PIES: NCSX at $\langle\beta\rangle \approx 4\%$.

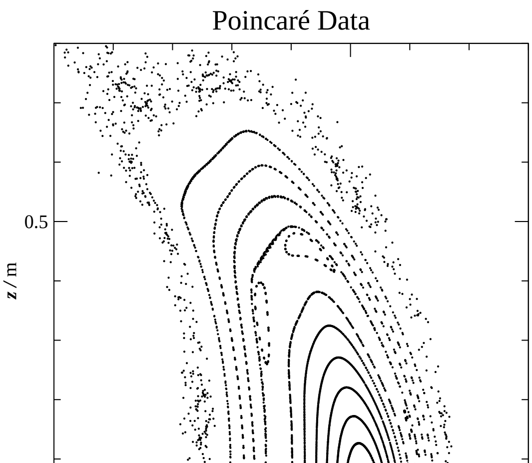

Figure 2: PIES for W7-X at $\langle\beta\rangle \approx 5\%$.

For the W7-X stellarator the situation is different: In the standard high-β case no low-order rationals exist inside the plasma [6]. However, in the W7-X configuration space a case exists with rotational transform $\iota = 5/6$ inside the plasma at high plasma-β, as has been computationally demonstrated (see Fig. 2). The PIES code has been used to compute a free boundary equilibrium at $\langle\beta\rangle = 5\%$. In MFBE calculations preceding the PIES computation, a configuration of coil currents similar to one previously successful at $\beta = 4\%$ [6] was selected. This configuration employs the auxiliary coils, energised so as to maximise the plasma volume by shifting the magnetic axis inward and adjusting the ι profile. The equilibrium found in the subsequent PIES analysis exhibits a low order resonance (5/6) inside the confinement region (see Fig. 2). The plasma volume is reduced to $\sim 15\text{m}^3$ at this β. The rotational transform ranges between $5/6$ and $5/5$ in the vacuum field, it decreases with increasing plasma-β.

An alternative approach to the assessment of magnetic islands in finite-β stellarator equilibria has been developed with the method of perturbed equilibria [7]. Since a perturbed equilibrium represents a small deviation from an equilibrium ideal MHD stability theory and, hence, ideal MHD stability codes, e.g. the CAS3D code [8], can be used to determine a perturbed equilibrium. Discontinuities of the normal displacement at rational surfaces indicate surface currents which are used to model islands. The strength of such a surface current can be used to estimate the corresponding island width. The augmented CAS3D code was applied to equilibria neighbouring the cases of Figs. 1 and 2. A first result for W7-X is shown in Fig. 3 for a case with the rational rotational transform, $\iota = 5/6$, at approximately half of the total enclosed toroidal flux. The CAS3D analysis predicts an island width of ≈ 0.034m which is comparable to the PIES code finding.

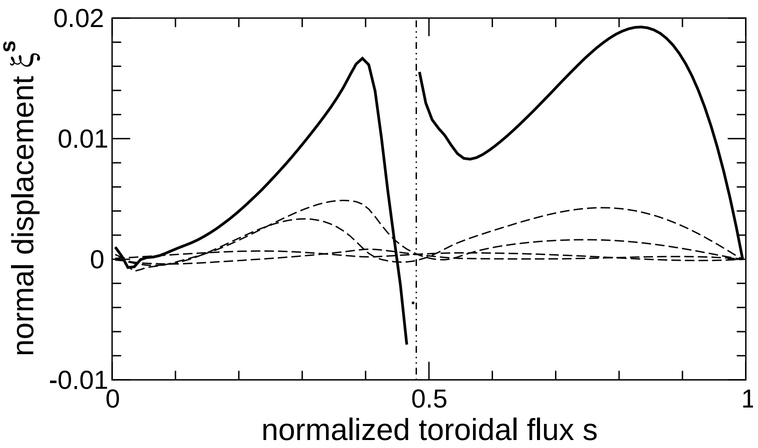

Figure 3: CAS3D results for a W7-X case at $\langle\beta\rangle = 5\%$.

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