FIRST SURVEY OF FINITE-β MAGNETIC FIELDS OF W7-X

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The optimized Wendelstein 7-X (W7-X) Helias stellarator is expected to reach volume averaged β-values of up to 5%. Part of the experimental flexibility will be achieved by modifying the rotational transform in the range $5/6 \leq \iota \leq 5/4$. In order to optimize the divertor geometry for various plasma equilibria and to improve SOL studies, a detailed knowledge of the corresponding magnetic field structures is necessary. For this purpose, magnetic fields are calculated for finite-β equilibria up to $\langle\beta\rangle = 5\%$ and rotational transform values of $\iota = 5/5,\ 5/6,\ 5/4$ in the edge region.

For these first computations the following system of numerical codes is used. The GOURDON code calculates the vacuum magnetic field, traces field lines and computes the rotational transform and the magnetic well. Further, the last closed magnetic surface (lcms) is determined. It lies inside the macroscopic islands (5/6, 5/5 or 5/4 islands) because these islands are intersected by divertor plates (see e.g. [1]). The data of the coordinates along the field line forming the lcms are used in the DESCUR code [2] to approximate the lcms by a set of Fourier coefficients, which serve as initial guess of the plasma boundary in the three-dimensional free-boundary equilibrium NEMEC code [3]. The NEMEC code is a synthesis of the VMEC code (**V**ariational **M**oments **E**quilibrium **C**ode) and the NESTOR (**NE**umann **S**olver for **TO**roidal **R**egions) vacuum code. It computes free-boundary finite-β Helias equilibria. Using the results obtained with the NEMEC code the MFBE code (**M**agnetic **F**ield Solver for **F**inite-**B**eta **E**quilibria) [4] calculates the magnetic field of the finite-β equilibrium on a grid inside and outside the plasma boundary. This magnetic field serves as input to the GOURDON code, which is used to determine the lcms of the finite-β equilibrium. If this lcms does not coincide with the plasma boundary obtained by the NEMEC code, the toroidal flux, which is a free parameter in the NEMEC code, is modified, that is, the toroidal flux is determined iteratively [4]. Finally, the JMC code [5] yields the Fourier spectrum of the magnetic field and the stability of the three-dimensional finite-β equilibrium with respect to Mercier [6] and resistive interchange modes [7] is studied.

Figure 1 shows the resulting magnetic fields in their dependence on the volume averaged β-value for the low-iota case (case A: $\iota = 5/6$), the standard case (case B: $\iota = 5/5$) and the high-iota case (case C: $\iota = 5/4$). For case C, which has the largest aspect ratio (see Fig. 3), finite-β equilibria could only be obtained up to $\langle\beta\rangle = 4\%$ in the framework of the used method (NEMEC + MFBE code), but $\langle\beta\rangle = 5\%$ may be reached by a more appropriate choice of the coil currents. The width of the 5/5 islands (case B) increases with increasing β, while the remnants of the 5/4 islands (case C) become

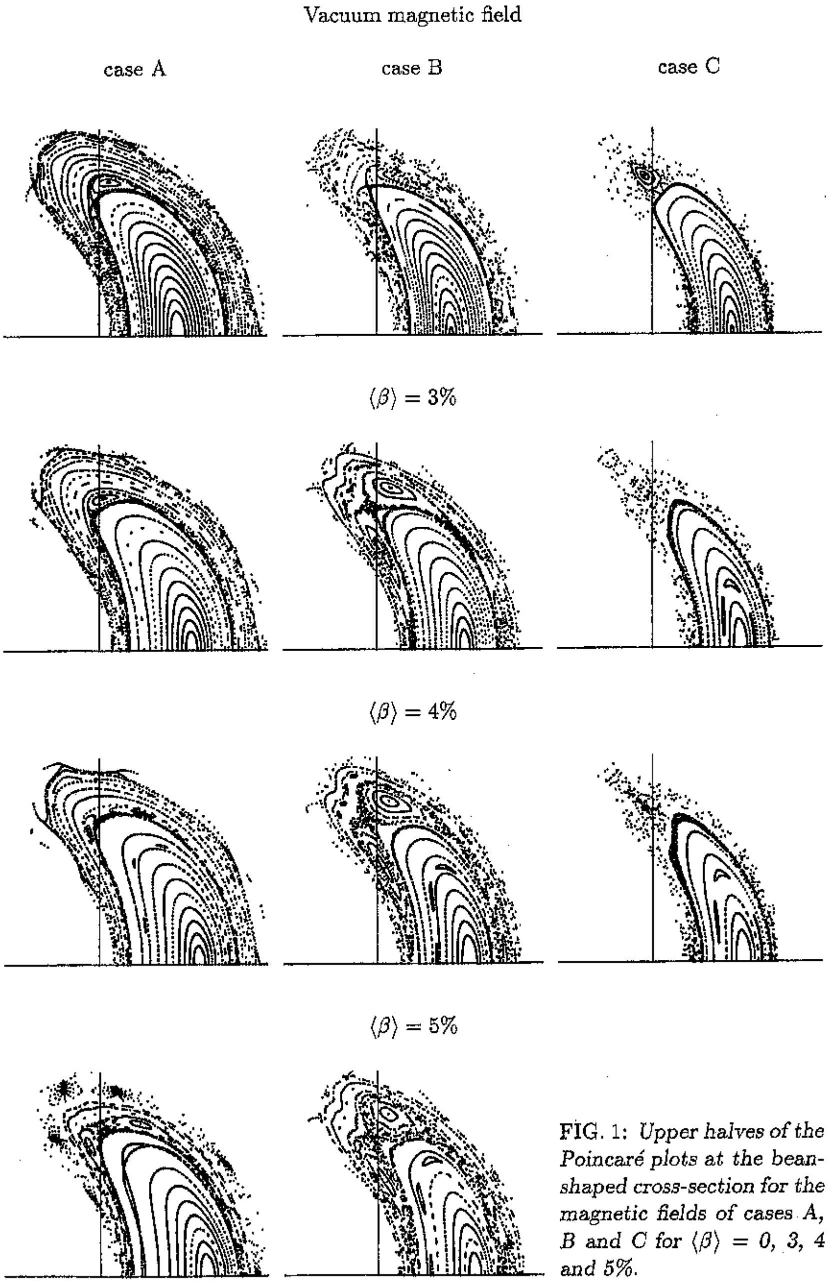

FIG. 1: *Upper halves of the Poincaré plots at the bean-shaped cross-section for the magnetic fields of cases A, B and C for* $\langle\beta\rangle$ *= 0, 3, 4 and 5%.*

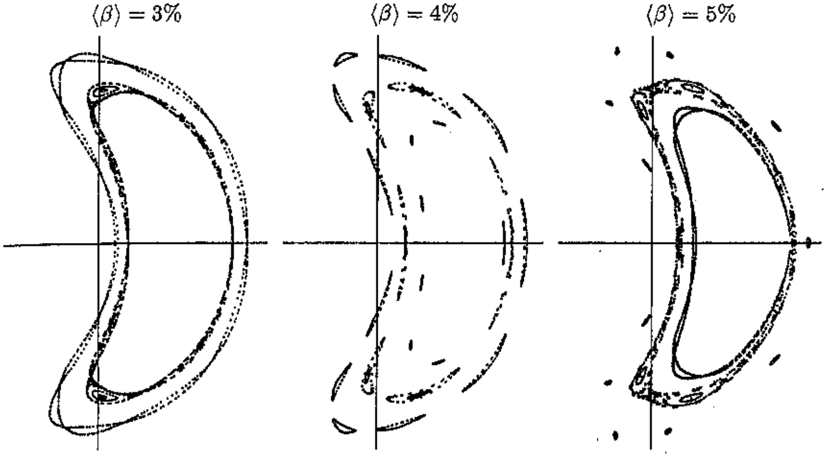

FIG. 2: *Case A: phase shift of the 5/7, 5/6 and 10/11 islands. The islands are plotted for $\langle\beta\rangle$ = 3, 4 and 5%.*

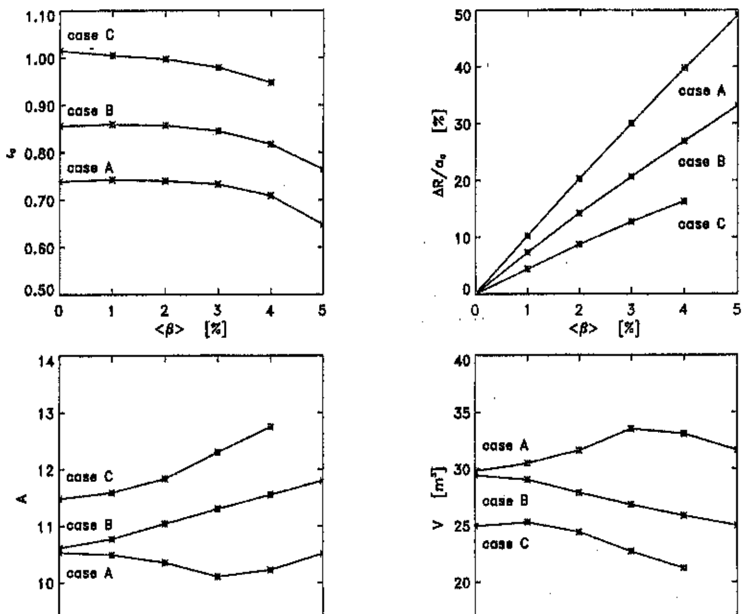

FIG. 3: *Rotational transform ι_0 on the magnetic axis, normalized shift of the magnetic axis $\Delta R/a_0$ (ΔR = mean shift of the magnetic axis, plasma radius: a_0 = 0.55 m), aspect ratio A and volume V enclosed by the lcms versus $\langle\beta\rangle$.*

smaller because of the increasing ergodization of the edge region. The positions of the X- and O-points of these macroscopic islands are almost unchanged. The width of the 5/6 islands (case A) decreases up to $\langle\beta\rangle = 3\%$. For $\langle\beta\rangle \geq 4\%$ phase shifts of these macroscopic islands and also of the 5/7 and 10/11 islands are observed. As shown in Fig. 2, the phase shifts of the 5/6 and 10/11 islands occur between $\langle\beta\rangle = 3$ and 4%, while the phase shift of the 5/7 islands takes place between $\langle\beta\rangle = 4$ and 5%. It will be interesting to compare these results with those obtained by other codes, e.g. the PIES code [8].

The $\langle\beta\rangle$-dependences of the rotational transform ι_0 on the magnetic axis, the normalized shift of the magnetic axis $\Delta R/a_0$ ($\Delta R =$ mean shift of the magnetic axis, plasma radius: $a_0 = 0.55$ m), the aspect ratio A and the volume V enclosed by the lcms are summed up in Fig. 3. For case A the aspect ratio A and the plasma volume V as functions of $\langle\beta\rangle$ show a behaviour different from those of case B and case C because of the phase shift of the macroscopic islands. The mean shifts of the magnetic axes and the rotational transform profiles of cases A, B and C slightly depend on the mass profile used in the NEMEC code as input [9]. Here a mass profile of the form $m(s) \approx 1 - 2s + s^2$ ($s =$ flux lable with $s = 0$ at the magnetic axis and $s = 1$ at the plasma boundary) has been chosen.

Finally, cases A, B and C are stable with respect to the Mercier[6] and resistive interchange [7] criteria up to $\langle\beta\rangle = 3\%$. For higher β-values formal instability prevails around the 5/7, 5/6 and 5/5 resonances. The formation of these resonances may be suppressed by suitably chosen coil currents [10] and also depends on the mass profile.

A more detailed representation of the computations described in this paper will be given in [9].

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