STABILITY OF LOCAL MODES IN TJ-II

J. NÜHRENBERG, R. ZILLE
Max-Planck-Institut für Plasmaphysik
IPP-EURATOM Association
D-8046 Garching bei München
and
S.P. HIRSHMAN
Oak Ridge National Laboratory
Oak Ridge, TN 37831/USA

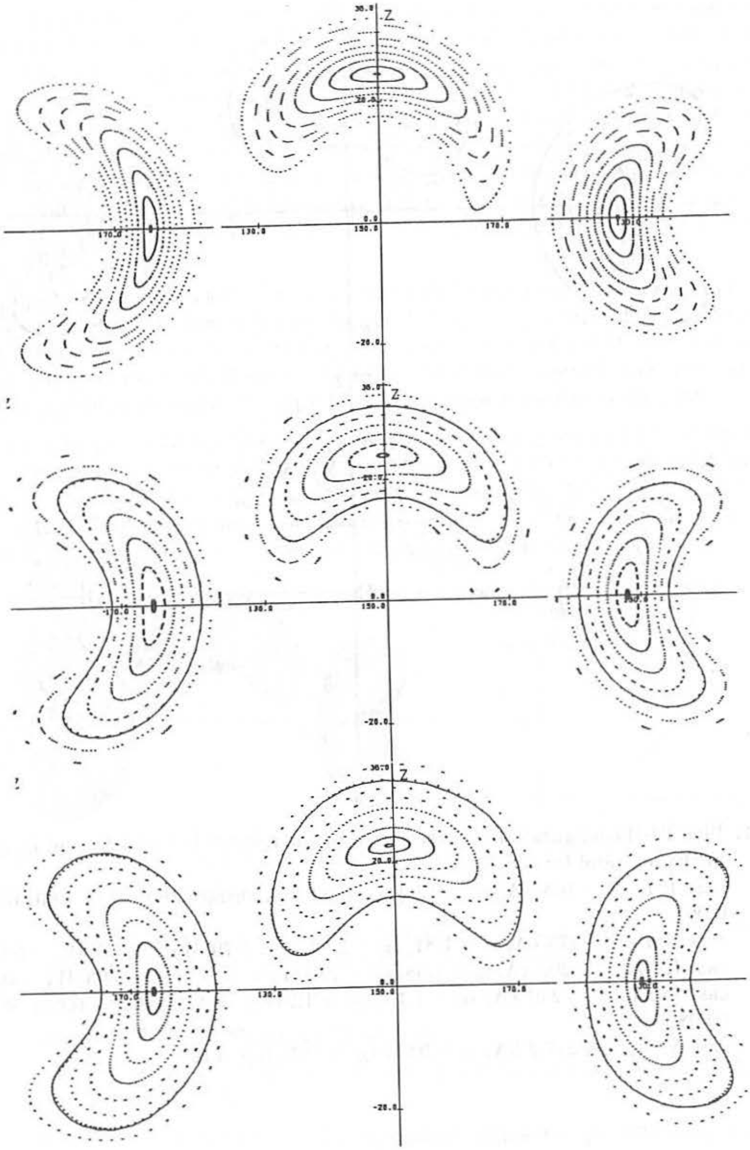
The TJ-II four-period heliac [1] derives its flexibility largely from the replacement of an axisymmetric toroidal heliac current [2] by a combination of this current with a helix-like one twisted around it [3]. Two key parameters, the rotational transform and the magnetic well, can be controlled in this way. In this paper, various TJ-II configurations are analyzed with respect to their local mode stability properties [4], only resistive interchange stability results being described because they are very close to Mercier stability results for heliacs.

Vacuum field calculations approximating TJ-II configurations are performed with fixed TF coil line currents, fixed VF coil line currents, and various circular-coil (cc) as well as helical-coil (hc) line currents. A selection of configurations from the TJ-II operational space is obtained with the following prescription for the cc and hc currents:

$$I_{hc}\ [\mathrm{kA}] = -2.1(I_{cc}\ [\mathrm{kA}] + 257.2).$$

Figure 1 shows configurations of this type; the rotational transform per period ι_p is in the range $\frac{1}{4} \lesssim \iota_p \lesssim \frac{1}{2}$; the magnetic well W is given by $0 \lesssim W \lesssim 0.06$; deep wells and large rotational transform occur simultaneously. For these configurations, magnetic surfaces inside but close to the boundary of the confinement region are selected as plasma boundary for the VMEC fixed-boundary 3D code [5]. Such a surface is Fourier analyzed in a form suitable as input for VMEC. Figure 1 shows these boundaries which approximate the original magnetic surfaces sufficiently well. Improvement of the representation is still necessary for the very indented case.

Case III is described in some detail. The currents $(I_{cc}, I_{hc}) = -(200, 120)$ kA result in ι_0 (at the magnetic axis) $= 1.58$, ι_1 (at the boundary) $= 1.592$. The boundary is chosen such that $V'' \approx 0$, and the overall magnetic well is $W \approx 0.03$. This boundary lies just inside the $\iota_p = \frac{2}{5}$ resonance. Use of the VMEC code with approximately 10^2 Fourier amplitudes and 25 radial grid points yields $\iota_0 \approx 1.63$, $\iota_{min} \approx 1.58$, $\iota_1 \approx 1.598$, and $W \approx 0.038$ for the $\beta = 0$ case. While these values are fairly accurate, the fictitious increase in twist near the magnetic axis artificially introduces the $\frac{2}{5}$ resonance. Calculation of a finite β equilibrium with a bell-shaped pressure profile, which is close to the optimum (for stability) because of $V'' = 0$ at the boundary,


30.0
Z
20.0
170.0
130.0
0.0
150.0
170.0
170.0
-20.0
30.0
Z
20.0
170.0
130.0
0.0
150.0
170.0
170.0
-20.0
30.0
Z
20.0
170.0
130.0
0.0
150.0
170.0
170.0
-20.0

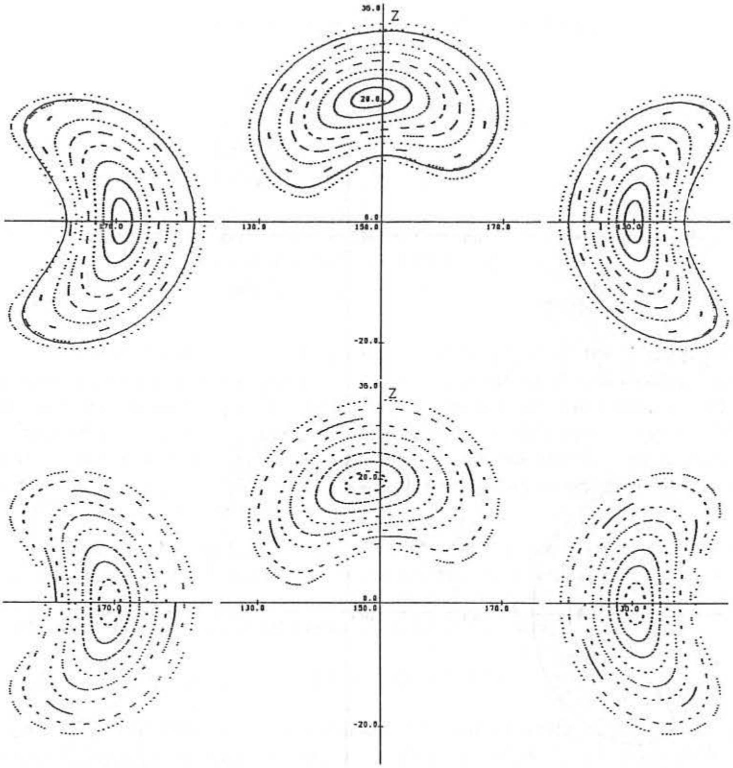
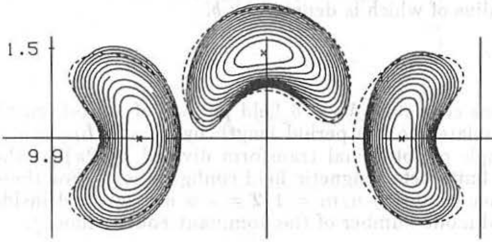


Fig.1: Five TJ-II configurations characterized by the relation between I_{hc} and I_{cc} given in the text and for
case I: $I_{cc} = -163$ kA, $\iota_0 = 1.90$, ι_E (last flux surface shown) $= 1.90$, $W_E = 0.064$,
case II: $I_{cc} = -175$ kA, $\iota_0 = 1.81$, $\iota_E = 1.82$, $\iota_1 = 1.79$, $W_E = 0.05$, $W_1 = 0.036$,
case III: $I_{cc} = -200$ kA, $\iota_0 = 1.58$, $\iota_E = 1.61$, $\iota_1 = 1.59$, $W_E = 0.03$, $W_1 = 0.03$,
case IV: $I_{cc} = -240$ kA, $\iota_0 = 1.15$, $\iota_E = 1.24$, $\iota_1 = 1.22$, $W_E = 0.006$, $W_1 = 0.008$,
case V: $I_{cc} = -257.2$ kA, $\iota_0 = 0.92$, $\iota_E = 1.05$, $W_E \approx 0$.

yields a stable equilibrium at $\langle\beta\rangle = 0.01$. At this value of β the change in rotational transform is negligible; $\langle j_\parallel^2 / j_\perp^2 \rangle \approx 2$ at $\iota_p = \iota_{min}$, where the $\frac{2}{5}$ resonance is not important, and becomes large at the boundary owing to this resonance. At $\langle\beta\rangle = 0.015$ the stability condition becomes approximately marginal; at $\langle\beta\rangle = 0.02$ the equilibrium is unstable over most of the plasma cross-section. If the resonant contribution to the parallel current density is neglected, i.e. only the non-resonant part of the parallel current density drives the interchange instability, the equilibrium is stable. It has been verified that this behaviour leads indeed to stability at $\langle\beta\rangle \approx 0.02$, with resonances up to order 10 being taken into account, if the configuration is carefully adjusted between $\iota_p = \frac{3}{8}$ and $\iota_p = \frac{2}{5}$.

The results for the other cases shown in Fig. 1 exhibit the same basic features. Case IV, for example, avoids low-order resonances, but $\iota_p = \frac{3}{10}$ occurs. Without taking this resonance into account, the stability boundary is $\langle\beta\rangle \approx 0.01$, with this resonance slightly lower. As expected, these results verify that deeper magnetic wells and larger transforms yield larger stable β values if low-order resonances can be avoided.

A sequence of TJ-II-like equilibria is defined as follows. Suppression of small Fourier amplitudes of the boundary and symmetrization of those which are non-vanishing in helical symmetry yields a neighbouring boundary (see Fig.2). With the aspect ratio of the period fixed, the number of periods N can be used to obtain the limit of helical symmetry by taking $N \rightarrow \infty$. Figure 3 shows β-values obtained in this way.



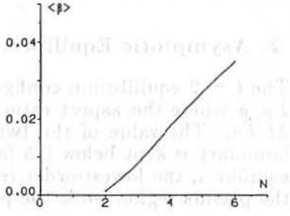


Fig.2: Flux surfaces of a TJ-II and a symmetrized TJ-II configuration.

Fig.3: β limit as a function of the number of periods.

[1] A. Perea, J.L. Alvarez Rivas et al., 12th Eur. Conf. on Contr. Fusion and Pl. Phys., Budapest 1985, ECA Vol. 9F, Part I, 433.

[2] S. Yoshikawa, Nucl. Fusion **23** (1983) 667.

[3] J.H. Harris et al., Nucl. Fusion **25** (1985) 623.

[4] J. Nührenberg, R. Zille, 5th Int. Workshop on Stellarators, Ringberg 1984, EUR9618 EN, Vol. I, 339.

[5] S.P. Hirshman, W.I. van Rij, P. Merkel, Comput. Phys. Comm. **43** (1986) 143.