SOME EFFECTS OF FINITE PLASMA PRESSURE IN THE ADVANCED STELLARATOR WENDELSTEIN VII-AS

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ABSTRACT: Modifications of the W VII-AS vacuum fields by a finite plasma pressure are studied numerically. For the parameter range investigated critical or deleterious effects are absent.

INTRODUCTION .

Experiments in the forthcoming "Advanced Stellarator" WENDELSTEIN VII-AS aim at attaining the long mean-free-path regime at substantial densities. Among the essential properties of W VII-AS are the reduction of the PFIRSCH-SCHLÜTER currents and of the collisional diffusion. Therefore the question arises whether these properties are maintained also in the finite -β-equilibrium.In this paper we study modifications of the magnetic topology of W VII-AS by a finite plasma pressure, as well as associated effects on its confinement. This is done using three numerical codes:

- the CHODURA-SCHLÜTER code /1/ which calculates magnetic field and pressure distributions in a fixed spatial grid,
- the GOURDON field tracing code /2/, yielding also essential magnetic field properties,
- the LOTZ code /3/, from which a particle diffusion coefficient is obtained by MONTE-CARLO technique.

SHAFRANOV SHIFT .

The SHAFRANOV shift is evaluated for the standard configuration /4/ of W VII-AS, and for a superimposed vertical field. In the CHODURA-SCHLÜTER code a radial pressure distribution $p(x) \sim \beta(o) \cdot f(x)$ is used, with peak value $\beta(o)$, and an initial radial profile $f(x)$ being characterized by an integer NEXP = 4 or 2 (steep or flat profile, resp.). The fixed spatial grid is centered at R = 206 cm, the average major radius of the W VII-AS vacuum magnetic axis. The grid is of rectangular cross section and comprises 22 or 36 points in each of the three dimensions, (toroidal = one field period). The coarse grid (22) allows a useful aspect ratio of $A \approx 16$. The initial vacuum field is from the actual W VII-AS coil geometry. The accuracy of this grid is sufficient to study the shift Δ of the magnetic axis, see Fig. 1, left part, normalized by the minor plasma radius a = 0.2 m. At $\beta(o)$ = 5.3 %, Δ/a = 0.36 and 0.23 are obtained at the toroidal positions 0 and 1/2 field periods (▷ and 0 ,resp.). A flat pressure distribution yields a slightly lower shift. A superimposed vertical field B_z/B_t = 1 % introduces an inward (negative) shift of the vacuum configuration. This shift is balanced by $\beta(o)$ = 3.3 %, (lower curve); at $\beta(o)$ = 9 % the average shift $\Delta/a \approx 0.2$. At elevated β-values both curves tend towards a saturation. The SHAFRANOV shift in W VII-AS is reduced by a factor of $\approx$ two compared with a conventional $\ell = 2$ stellarator.

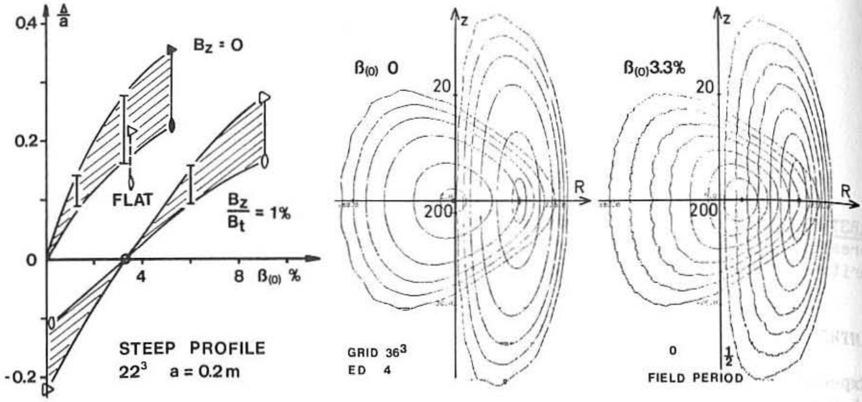

Fig.1 SHAFRANOV shift in W VII-AS for the "standard configuration" as well as for $B_z / B_t = 1$ % (grid 22), and magnetic surfaces at β (o) = 0 and 3.3 % (grid 36) .

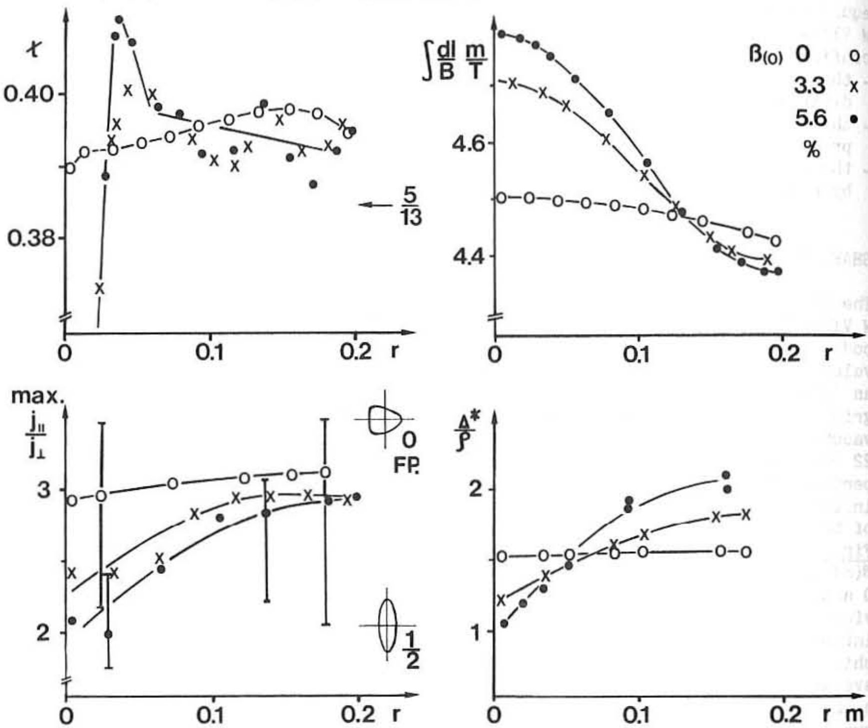

Fig.2 Radial profiles for various properties of the W VII-AS topology, at β(o) = 0 , 3.3 , and 5.6 % .

MAGNETIC SURFACES AND THEIR PROPERTIES .

Magnetic surfaces (Fig.1, right part) and their properties are obtained at a fine grid with 36 points. The full aspect ratio $A \approx 10$ of W VII-AS is attained by first computing a set of DOMMASCHK-potentials /5/ using an appropriate magnetic surface of the original W VII-AS configuration. Thus the influence of large fields close to the W VII-AS coils is avoided, by virtue of the smoother behaviour of the DOMMASCHK fields. At $\beta(o) = 3.3$ % the SHAFRANOV shift thus obtained is ≈ 15 % less than the value of Fig.1, and the magnetic surfaces are "reasonably" smooth.

For $\beta(o) = 0$, 3.3 and 5.6 %, Fig.2 shows properties of the magnetic surfaces as radial profiles. Increasingly with $\beta(o)$, and close to the magnetic axis, the rotational transform ("twist") ι is found to be reduced, as compared to the vacuum field. This drop appears to be compensated by an associated outer overshoot. At $r > 0.1$ m the values agree within 2 % of ι. The rational 5/13 is avoided at the edge. The influence of the grid structure on the scatter of the curves is unknown. The profiles of $\int dl/B$ are smooth and show a substantial deepening of the magnetic well, for $r < 0.1$ m. Within this range some reduction is seen, of the maximum values of $j_{\parallel} / j_{\perp}$ (parallel and perpendicular diamagnetic current density, resp.), as well as of Δ^* / ρ (Δ^*= average offset of drift surfaces for passing particles with LARMOR-radius ρ).

DIFFUSION COEFFICIENT .

Fig.3 shows the particle diffusion coefficient obtained by the LOTZ code in the absence of an electric field. The guiding center motion of 64 particles, starting at random from the magnetic surface with aspect ratio $A = 50$, is followed numerically. The energy is constant. For $0.3 < \lambda \iota / R < 300$ small-angle collisions are simulated by random changes of the velocity direction. At constant collision length λ , the diffusion coefficient DIF1 $\sim \langle x^2 \rangle / T$ is evaluated from the average offset $\sqrt{\langle x^2 \rangle}$ of the particles, attained after the total time T of the chosen number of collisions. For $\beta(o) = 0$ and 5.5 % the results coincide for $\lambda \iota / R < 30$. The values are reduced by identical factors in comparison to D_{P1} and D_{PS} , the plateau and PFIRSCH-SCHLÜTER coefficients, see also /6/, for vacuum fields. A diffusion coefficient at finite $\beta(o)$ and a low aspect ratio remains to be evaluated.

SUMMARY AND CONCLUSION .

As expected, a finite plasma pressure with a steep profile at $\beta(o) \lesssim 5$ % modifies the vacuum magnetic fields of W VII-AS only in the vicinity of the magnetic axis. There the magnetic well is deepened, and the maxima of $j_{\parallel} / j_{\perp}$ are favourably reduced. On the other hand, the particle diffusion coefficient appears to be less influenced. So far, it remains open, whether its slight increase at large values of $\lambda \iota / R$ is due to some numerical effects or is caused by the plasma pressure. For $\beta(o) \approx 3$ %, as expected in the experiments in W VII-AS, no essential change of the optimized properties due to a finite plasma pressure is found in the present study.

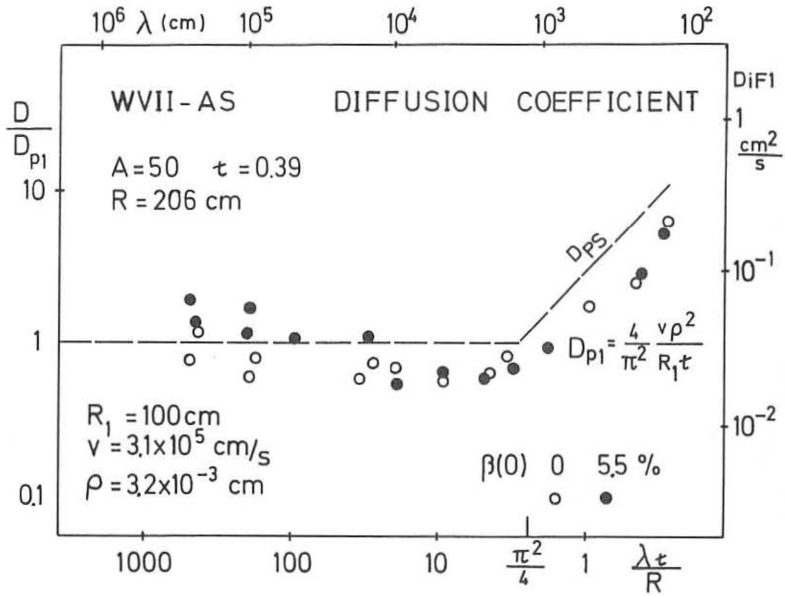

Fig.3 Diffusion coefficient normalized to the plateau value for β (o) = 0 and 5.5 % , at an aspect ratio of A = 50 in W VII-AS .

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