Influence of superimposed shear on the confinement properties of the Wendelstein $\ell = 2$ Stellarator (WII a)

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Abstract: The effect of shear on the confinement properties of the Wendelstein Stellarator was studied and a strong influence observed.

The WII a stellarator is equipped with $\ell = 2$ helical windings producing a large rotational transform, ι, ($\iota = 1$ corresponds to 360°) on the magnetic axis and very low shear. For MHD stability the magnetic field has a mean magnetic well, typically of a few per cent. Minima of the confinement time had been observed whenever the rotational transform was a rational fraction of not too high an order /1/.+) Whatever their cause, they are related to rational surfaces, being established over a large part of the plasma cross section simultaneously. Introducing some shear affects this state and might cause these minima to disappear.

Equally directed currents in three additional coils, as sketched in Fig. 1 enable us to vary the shear over a limited range. These coils are arranged coaxially with the device; their magnetic field, B_s, vanishes on the magnetic axis /3/. Calculations of the corresponding combined magnetic field configuration have shown that the mean-minimum-B properties are only slightly affected by varying the shear in this way, but that too large values of B_s lead to destruction of the magnetic surfaces.

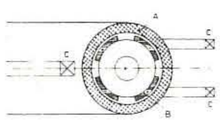

Fig. 1: arrangements for the coils
A: main magnetic field
B: Helical windings, $\ell = 2$
C: additional coils producing B_s

+) Similar results were observed in the L - 1 stellarator at the LEBEDEV-INSTITUTE /2/, but there the minima in confinement time were obviously connected with destruction of the magnetic surfaces.

The major and minor radii of the WIIa stellarator are 50 cm and 5 cm respectively. The toroidal magnetic field B_o of 4.5 kG was maintained throughout the whole experiment. A barium plasma was generated by contact ionization on a tungsten sphere. The ion-density and its radial profile were measured by resonance fluorescence /1/.

In Fig. 2 the dependence of the steady state density on iota for $B_s = 0$ and for $B_s > o$ is shown, with the input ion flux, ϕ, and the superimposed meridional field B_s kept constant. In both cases the magnitude of the shear ($\frac{\Delta\iota}{\iota}$) is a function of iota as shown on the top curves of Fig 2, with

$$\frac{\Delta\iota}{\iota} = \frac{\iota\,(r=4\,\text{cm}) - \iota\,(r=o)}{\iota\,(r=o)}.$$

In those regions where the shear is noticeably increased over the value for $B_s = 0$ the confinement time (which is proportional to the steady state density) is considerably reduced. For iota less than 0.14 extremely poor confinement is achieved; we are inclined to attribute this particular fact there to the break up of the magnetic surfaces as indicated by computations. However, it should be noted that our present knowledge of the magnetic field structure for $B_s \neq 0$ is based on calculations only. There is therefore still a slight possibility that the observed reduction of confinement time beyond iota = 0.14 might also be caused by the above mentioned destruction of the magnetic surfaces rather than by the effect of shear.

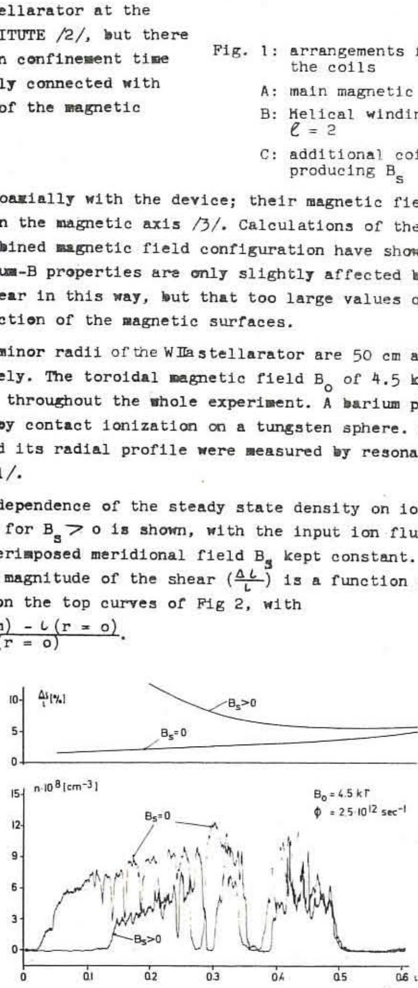

Fig. 2: top curves: $\frac{\Delta\iota}{\iota}$ vs. ι for two cases, $B_s = o$ and $B_s > o$
bottom curves: n vs. ι for the two cases shown in the top curves.

Consequently, another experiment was conducted where the direction of the additional field B_s was reversed so that the weak shear originally inherent in the $\ell = 2$-field could be compensated in the average. The corresponding results are shown in Fig. 3 . In this case one observes an improvement in the confinement time for any applied average shear, which is smaller than the value for $B_s = 0$. This improvement approaches an optimum for $\frac{\Delta\iota}{\iota} \approx 0$. Here again, however, the magnetic surfaces seem to break up when the value of iota crosses a lower limit, i.e. for $\iota < 0.1$.

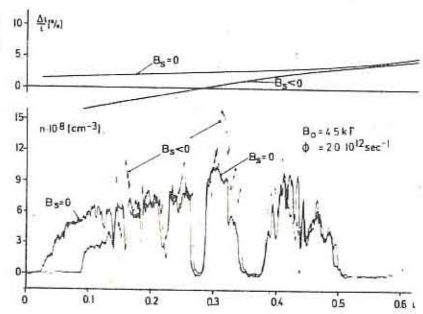

Fig. 3: top curves: $\frac{\Delta\iota}{\iota}$ for two cases, $B_s = o$ and $B_s < o$
bottom curves: n vs ι for the two cases shown in the top curves

It should be noted at this point that the superposition of B_s also leads to a small change of iota. Since the iota scale presented on the curves in Figs. 2 and 3 is obtained by means of an on-line anologue computer which accounts only for the main and the helical field currents, it is slightly incorrect for $B_s \neq 0$. However, the true iota scale can easily be obtained by following the displacement of the individual maxima and minima.

Summarizing one may conclude that already for rather moderate values of additional shear the amplitude between the minima and maxima is reduced, but so is the confinement time itself. By analysing these data one can find a gross relation as plotted in Fig. 4, where the relative dependence of the maximum confinement time (steady state density) on $\frac{\Delta\iota}{\iota}$ is plotted. This figure shows a reduction of the confinement time with increasing shear, provided that a destruction of the magnetic surfaces can be excluded. Our results do not rule out, however, that higher values of shear eventually will improve the confinement properties.

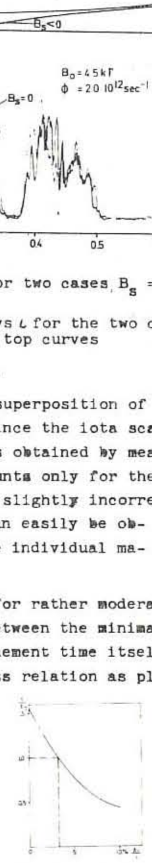

Fig. 4: Relative variation of the confinement time τ vs. shear being represented by $\frac{\Delta\iota}{\iota}$

Such experiments will become possible with our next stellarator, WII c, which will be equipped with two sets of helical windings, $\ell = 2$ and $\ell = 3$, so that iota and $\frac{\Delta\iota}{\iota}$ can be varied independently of each other.

/1/ E. Berkl, D. Eckhartt, et.al. Proc.3rd.Int.Conf.on Plasma Phys. and Contr.Nucl.Fusion Res. Novosibirsk (1969) Bd. I, S. 513

/2/ M.C. Berecheski, et.al. Proc.3rd.Int.Conf.on Plasma Phys. and Contr.Nucl.Fusion Res. Novosibirsk (1969) Bd. I, S. 529

/3/ This arrangement is very similar to the one used by Hartman; private communication

Work performed on association with Euratom.