EXPERIMENTAL RESULTS OF MAGNETIC SURFACE MAPPING IN THE STELLARATOR W VII-AS

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Before starting plasma experiments in the new modular stellarator W VII-AS the magnetic surfaces have been studied in detail. W VII-AS has small shear, and by means of a superimposed toroidal field the rotational transform ι can be varied between about 0.25 and 0.70. Further details of the different coil systems, the expected shape of the vacuum magnetic surfaces etc. can be found in Ref. [1]. Two different methods have been applied to map the vacuum magnetic surfaces. Both methods use a directed electron beam source that can be positioned on an arbitrary magnetic surface in the poloidal cross section. At magnetic fields $B_o > 0.2$ T and electron energies < 150 eV used in the experiments single electrons emitted parallel to the magnetic field follow almost exactly the magnetic field lines.

The first or standard technique uses a capacitive point probe which is scanned across the poloidal cross section to detect the positions of the electron beam transits [2]. The electron gun is pulsed in this case so that the number of toroidal revolutions can be derived from a time-of-flight measurement. In this way the rotational transform can be calculated from the definition $\iota = (n + \Delta n)/m$ where n and m are the numbers of the poloidal and toroidal transits, respectively. The deviation Δn from a rational value $\iota = n/m$ can be determined rather accurately for $\Delta n \ll 1$ by comparing the measured transit positions with the prediction from a field line tracing code.

Fig. 6 shows an example of a measured $\iota(\bar{r})$ profile. The average radius $\bar{r}$ of the cross section of the magnetic surface is used as a radial magnetic field coordinate. The measured ι-values are compared with values calculated from two versions of the W VII-AS field line tracing code. The first one (Code, old) is the original version of this code used to design the W VII-AS modular field (MF) coils [1]. It predicts ι-values which are typically only 1.5 % smaller than the actual values. By decreasing the MF-coil radius by about 1 mm (compared to an average coil radius of about 50 cm) the agreement can still be improved (Code, new).

A much faster detection of the electron beam is achieved with the second method. It uses a fluorescent rod to record the positions of the electron beam transits and has been applied for the first time at the Stellarator WEGA at IPF, University of Stuttgart [3]. The rod coated with a fluorescent powder (ZnO_2 : Zn) emits light usually at both intersection points with the magnetic surface under consideration when it is struck by a continuous electron beam. To gain a complete surface picture the rod has to be swept over a poloidal cross section. Recording was done with a CCD TV-camera together with an image processing system which adds together at first the individual light points to a complete surface picture and then also several surfaces with different radii $\bar{r}$ of a given magnetic field configuration. With this technique up to a few hundred toroidal transits can be detected with a spatial resolution of a few mm. Therefore, it is suited to investigate magnetic surface structures up to rather tiny details.

Sometimes also toroidal transit numbers can be deduced from the fluorescent rod pictures, especially in cases with small shear and when at least one surface with a rational ι-value happened to be found resulting in a discrete number of light points. Such an example is shown in Fig. 5, and the ι-values calculated from these surface pictures have also been included in Fig. 6.

In addition, the fluorescent rod pictures can be used to compare the measured shape and spatial position of magnetic surfaces to numerical predictions. Examples for a magnetic surface with an extreme triangular and an extreme elliptical shape [1] are given in Figs. 1 to 4. Again, very good agreement is found. Only in the case of Figs. 3 and 4 a systematic radial shift of < 1 cm can be seen which seems to be larger than the experimental error.

Summarizing the results of all the surface mapping experiments we can state that it has been demonstrated in the Stellarator W VII-AS that it is possible to produce excellent magnetic surfaces in good agreement with the numerical predictions by means of modular field coils [1]. Fig. 5 shows an example typical for the situation at low ι-values where closed magnetic surfaces extend even beyond the limiter ($\bar{r} \lesssim 18.5$ cm). At high ι-values the last closed magnetic surface is given by a magnetic separatrix (Fig. 8). This separatrix is usually determined by one of the 5/m resonances which are a consequence of the five toroidal field periods and the pentagonal shape of the magnetic axis [1]. An example of a higher order 5/m resonance with m = 11 is presented in Fig. 7. Imperfections e.g. in the coil shapes and/or alignment which are not included in the code lead to additional perturbation fields. They produce large magnetic islands especially at major resonances like $\iota = 1/2$ and 1/3, but smaller islands have also been found at higher order resonances. An example is shown in Figs. 1 and 3 where close to the boundary the resonance $\iota = 2/5$ results in islands which are not predicted by the field line tracing code (Figs. 2 and 4).

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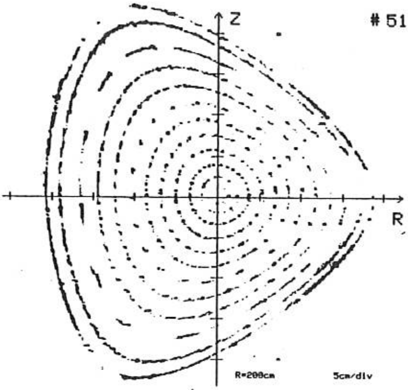


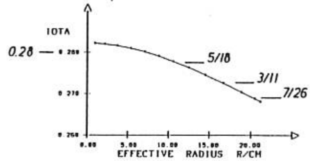


Fig. 5

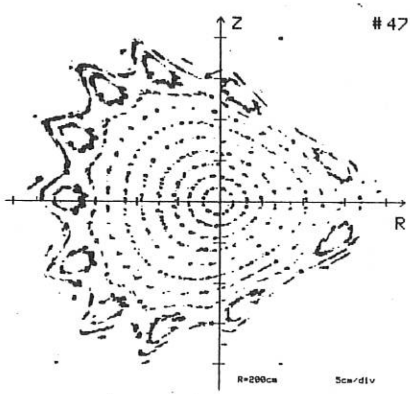
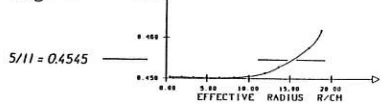


Fig. 7



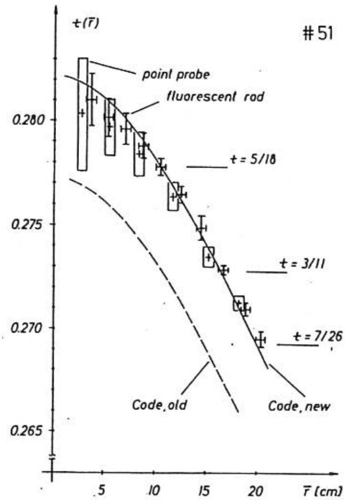
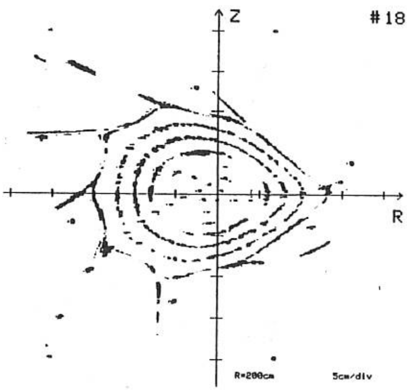


Fig. 6



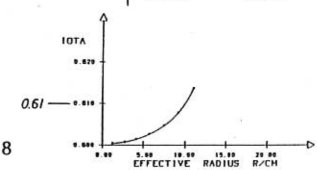


Fig. 8

SOURCES OF TOROIDAL CURRENT IN THE WENDELSTEIN VII-AS STELLARATOR

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INTRODUCTION - The nearly shearless modular stellarator Wendelstein VII-AS (major radius $R = 2\ m$, averaged minor radius $< a > = 0.2\ m$) started plasma operation in October '88. As in W VII-A, also in W VII-AS a strong correlation between the global confinement properties and the value of the rotational transform ι has been observed in "net-current-free" plasmas. Apart from the confinement degradation at values of ι corresponding to low order rational values, already observed in W VII-A, broader intervals of degraded confinement are also found at values of $\iota = \frac{5}{m}$ (m integer) where, due to the five field period structure of the machine, the vacuum field configuration presents natural magnetic islands /1/. In the first months of operation particular attention has been paid to the investigation of 2^{nd} harmonic Electron Cyclotron Resonance Heating (ECRH) in the ι-region $\frac{1}{2} \leq \iota \leq \frac{5}{9}$. The vacuum ι-profile can be affected by toroidal currents. At $B_0 \simeq 1.25\ T$ (2^{nd} harmonic heating) a current I_P causes a change $\Delta\iota_a \simeq 0.014 \cdot I_P(kA)$ at the boundary value ι_a or the rotational transform ($\Delta\iota_a \propto \frac{I_P}{B_0}$). For the ranges of B_0 and ι currently under examination, the maximum tolerable I_P for operation in the good confinement ι-interval is about 1 kA. Within neoclassical theory radial diffusion drives a net current ("bootstrap-current") peaked in the pressure gradient region. The existence of this current component is experimentally supported. Since the magnitude of this current is related to plasma energy, the existence of a critical current I_P can influence the maximum achievable energy. Operation at values of ι corresponding to good confinement properties during the whole duration of the discharge could require an external ι-profile control acting on the current profile itself and not merely obtained by having two channels of current of different sign at different radii. Due to the possibility of controlling the profiles of the absorbed power and of the driven current, electron cyclotron waves are a natural candidate for current profile control. The strong dependence of global confinement properties on the ι-profile puts a particular interest in the investigation of the toroidal current sources. Furthermore, the "net-current-free" regime of operation of most Stellarator-devices gives the opportunity of observing and studying non inductive currents without the presence of an "obscuring" Ohmic current. The results of the analysis of the toroidal current in W VII-A /2/ are reconfirmed.

AUXILIARY HEATING SOURCES - Three different auxiliary heating systems will be used in W VII-AS: Neutral Beams Injection (H^0, 1.5 MW, tangential injection) Electron Cyclotron Resonance Heating (70 GHz, 1.0 MW), and Ion Cyclotron Resonance Heating

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