FAST DETERMINATION OF FLUX SURFACE STRUCTURE IN ASDEX AND ASDEX UPGRADE USING FUNCTION PARAMETERISATION

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1. INTRODUCTION

The method of Function Parameterisation (FP), whereby the dependence of a simulated data base of desired physical parameters on a corresponding set of raw measurements is determined in a statistically robust manner, is now established as a routine and rapid means of magnetic diagnostic data analysis on the ASDEX experiment /1/, /2/. In contrast to the adequacy of the nested circles model in describing the poloidal cross-section of ASDEX MHD equilibria, ASDEX Upgrade field line geometry will be more general and non-circular flux surfaces with triangularity will be the norm. The conventional method of determining the flux surface structure (FSS) from magnetic diagnostics, i.e. the iterative use of an MHD equilibrium solver to arrive at a best fit to the raw measurements, typically requires several seconds of CPU time per fitted equilibrium. Only a limited number of time points may then be analysed under the constraints of between-shot analysis. Knowledge of the FSS will be, however, a prerequisite for the evaluation of many ASDEX Upgrade diagnostic data with spatially varying profile information. Hence it would be very desirable to have a means of recovering the FSS sufficiently fast to yield, on a between-shot time scale, a comprehensive time history of the latest discharge. An FP solution to this problem is proposed in the following sections. Some tabulated results are presented in Section 4 and some qualifying remarks are noted in the final Section.

2. THE DATABASE

The Garching Equilibrium Code /3/ was used to generate some 5000 limiter and divertor equilibria using the ASDEX Upgrade configuration of poloidal field coils together with the proposed positions of in-vessel magnetic probes and flux loops which were used to generate corresponding raw measurements. Fig. 1 shows the not necessarily final layout for 40 probes and 30 flux loops inside of the ASDEX Upgrade vacuum vessel. Eight degrees of freedom, corresponding to six independently varying poloidal field coil currents and two current profile parameters (the plasma current itself is normalised to 1 MA), characterise the MHD equilibrium in the present instance. As initial conditions, we choose to specify two relations between the six external currents, the R and Z coordinates of the magnetic axis, the R and Z coordinates of one saddle point and the two current profile parameters which are roughly related to the poloidal beta and internal inductance of the equilibrium. Each initial condition is chosen randomly from an appropriate distribution function. After solving the Grad-Shafranov equation on a 64 x 128 grid, a data set of some 500 words is stored on disk for each equilibrium. It consists of the simulated raw measurements, a variety of equilibrium parameters and a set of approximately 250 coefficients of a bi-cubic spline fit to the solution flux function over a fixed subset of the grid large enough to enclose all possible plasma boundaries.

3. RECOVERY OF ARBITRARY CLOSED FLUX CONTOURS

We propose, using an FP approach, a straightforward method of recovering the contour of a given flux value or circular equivalent radius with the sole restriction that it be a single-valued function of polar coordinates with origin at the magnetic axis. The latter quantity will be accurately recoverable (see following section) and so the relative nature of the contour determination does not pose a problem. We parameterise the contour by finding the distance from the origin to its point of intersection with a number of radial chords spaced at fixed angular intervals (see Fig. 1) using the bi-cubic spline fit to the poloidal flux in conjunction with a routine to search along the chord in question for the appropriate flux value. The intersection distances are now stored as additional "plasma parameters" and the normal FP regression against linear and quadratic combinations of a limited number of principal components /1/, /2/ is performed.

4. RESULTS

The sample results depicted in Table 1 arise from a regression of each of the listed parameters on the ten most significant principal components (and their quadratic combinations) of 41 magnetic probe and 37 flux loop measurements. The regression was performed on a subset of the data base consisting solely of lower null divertor equilibria. Dimensioned quantities are in metres.

The first seven parameters and the last two are self explanatory. The intervening names are of the form D:CONTOUR TYPE:ANGLE where ANGLE is the angle (in degrees) made by the intersecting chord (see Fig. 1), D is a normalised distance-like label for the chosen contour (D = 100 for the separatrix) and CONTOUR TYPE indicates either a contour with a particular flux value (PSI) or a particular circular equivalent radius (RHO). Thus 66 RHO 55 is a parameter which takes the value of the distance (m) from the magnetic axis along a chord inclined at 55 degrees to the horizontal to the flux surface enclosing 4/9 of the plasma area (we can also use enclosed volume to label the flux surfaces). Similarly 33 PSI 45 is the distance (m) from the magentic axis along a 45 degree chord to the surface whose flux difference relative to the magnetic axis flux is 1/3 of the axis-separatrix flux difference. For each parameter, the uncertainty in recovery is quoted for noiseless and noisy raw measurements. The significance of the STANDARD DEVIATION and ERROR columns and the choice of error magnitude follows references /1/ and /2/.

5. DISCUSSION

The tabulated results indicate that we can recover individual points on a contour of a specified normalised flux difference or circular equivalent radius with a standard error of about 5 mm, rising to 10 mm in the neighbourhood of stagnation points. If N points on each of K contours are deemed sufficient to define the FSS of the equilibrium, then the real-time computation using the 65 regression coefficients obtained for each parameter in the present study requires about NK/4 msec for 1 megaflop/sec computing power. Thus 20 contours each consisting of one point every 15 degrees of poloidal arc would require 0.12 sec calculation time. It should be noted in regard to the present results that

(a) The selection of lower null point divertor equilibria (or any specific equilibrium category) assumes that it will be possible in real time to adequately discriminate between categories and hence to select the correct set of FP regression coefficients - one set covering all possible equilibria is not adequate (see Ref./1/).

(b) As part of its vertical stabilisation system, ASDEX Upgrade has a number of passive conductors located inside the vacuum vessel. The effects of transient currents on magnetic measurements made near these conductors has not been included, but once accounted for is not expected to be a problem.

(c) The recovery of moments of the flux surfaces rather than individual points is potentially more time efficient, though this approach has not yet been fully investigated.

(d) Finally, the encouraging accuracy of the contour recovery suggests that it may be possible to infer information about the current distribution in ASDEX Upgrade from the currently proposed magnetic measurements. This is consistent with previous reports linking determination of the current distribution in elongated plasmas to knowledge of flux surface geometry (/4/, Chapter 3 and /5/).

REFERENCES:

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PARAMETER	MIN	MAX	RANGE	STANDARD DEVIATION	ERROR NOISE=0	ERR/S.D. NOISE=0	ERROR NOISE= .1xS.D.	ERR/S.D. NOISE= .1xS.D.
RAXIS	1.49	1.81	.32	.074	.001	1.4%	.003	4.5%
ZAXIS	- .15	.30	.45	.106	.003	2.8%	.006	5.4%
RGEO	1.42	1.74	.32	.063	.002	3.6%	.004	6.2%
ZGEO	- .22	.26	.48	.106	.003	2.9%	.005	5.2%
A MINOR	.30	.55	.25	.056	.003	5.7%	.006	11.0%
B MINOR	.44	1.02	.58	.100	.007	6.9%	.010	9.6%
KAPPA	1.03	2.80	1.77	.286	.022	7.6%	.042	14.7%
33 PSI 0	.13	.27	.14	.024	.003	11.5%	.004	15.7%
66 PSI 0	.20	.39	.19	.036	.003	9.3%	.004	10.1%
100 PSI 0	.24	.51	.27	.049	.003	7.0%	.005	9.7%
33 RHO 0	.10	.19	.09	.019	.001	7.1%	.003	13.3%
66 RHO 0	.18	.36	.18	.036	.002	6.0%	.004	11.3%
100 RHO 0	.24	.51	.27	.049	.003	7.0%	.005	9.8%
33 PSI 45	.15	.31	.16	.028	.003	11.8%	.004	13.6%
66 PSI 45	.23	.44	.21	.039	.003	8.9%	.004	9.9%
100 PSI 45	.32	.59	.27	.050	.003	6.0%	.004	8.2%
33 RHO 45	.12	.22	.10	.018	.002	10.7%	.003	13.2%
66 RHO 45	.23	.42	.19	.035	.002	6.3%	.004	9.7%
100 RHO 45	.32	.59	.27	.050	.003	6.0%	.004	8.3%
33 PSI 50	.16	.32	.16	.030	.003	11.4%	.005	14.4%
66 RHO 55	.25	.44	.19	.037	.002	6.7%	.004	9.7%
100 PSI 60	.37	.67	.30	.057	.004	7.3%	.005	9.1%
33 RHO 65	.14	.25	.11	.021	.002	9.4%	.002	10.8%
66 PSI 70	.28	.60	.32	.056	.004	7.8%	.007	11.6%
100 RHO 75	.37	.84	.47	.080	.006	7.4%	.009	10.4%
RLOW SADDLE	1.35	1.62	.27	.071	.008	11.7%	.010	13.9%
ZLOW SADDLE	-1.00	- .70	.30	.074	.007	9.5%	.009	12.8%

TABLE 1.

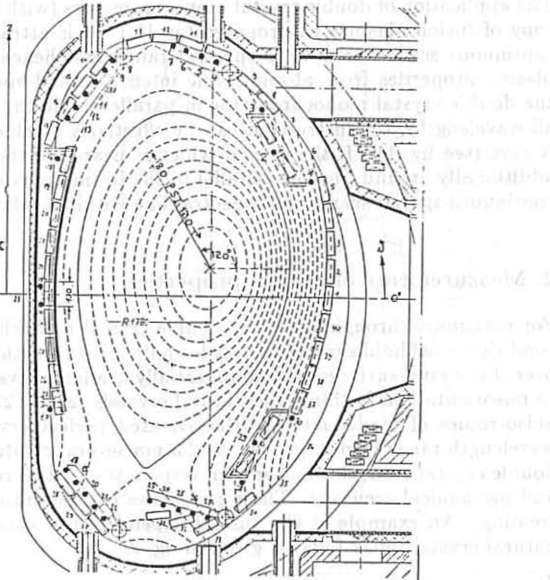

FIG. 1.

Poloidal cross-section of the ASDEX Upgrade vacuum vessel showing in-vessel flux coils (black dots) and magnetic probes (open boxes).