SENSITIVITY OF A TOKAMAK PLASMA SIMULATION TO SOME MODEL UNCERTAINTIES

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The aim of the work is to present the results of some computer simulations of the ASDEX-Upgrade shot #942 obtained with a free boundary MHD equilibrium code The computed magnetic flux and poloidal field are compared to the measured values. Furthermore the sensitivity of these results to the variations of some physical and modeling parameters is studied.

1. INTRODUCTION

MHD free boundary codes are widely used to analyse plasma equilibrium configurations (static codes) as well as electromagnetic transient phenomena in plasma, caused by current changes in the P.F. coils and/or by variation of the plasma parameters (evolutive codes).

Although the MHD self-consistent treatment of the plasma evolution has reached in the past years a good level of development, the heavy mathematical problems implied make them rather cumbersome for extensive use; in addition, they are quite extravagant from the engineering point of view, since most of the physical assumptions needed for the plasma local behavior have a very little impact on the magnetic field distribution outside the plasma region.

For this reason we have adopted an engineering approach where the time evolution is governed by the eddy currents, whereas the evolution of some global physical plasma parameters is given in input; the resulting code is quite agile and, when satisfactorily validated, can then be used quite extensively.

The aim of the present paper is then twofold:

- validate the code against an experimental situation of relevance for ITER-like studies;
- show the sensitivity of the expected plasma performance to some physical and modeling parameters.

The experimental data were taken from ASDEX-Upgrade, since this machine, which has started its operation in 1990 at the Max Planck IPP, is particularly well suited to study some ITER-relevant electromagnetic operating conditions (e.g. plasma edge conditions, vertical instabilities, disruptions). The data base used in this study is relative to the shot #942. This shot is a normal operation He discharge with a single null configuration during the plasma current flat top.

2. MODELING

2.1 Code description

The code used for the analysis is a MHD free boundary code [1] made evolutive thanks to the coupling with an eddy current code.

Given the applied poloidal field coils currents or voltages, the toroidal plasma current profile and total current at each equilibrium step the code solves the Grad-Shafranov (GS) equation in 2D axisymmetric geometry coupled with the diffusion equation of the poloidal field in the metallic structures. Furthermore the mesh currents of a general LR network (including non-axisymmetric branches of current) are computed for voltage or current driven circuits.

The GS equation is solved by means of a finite elements formulation of the equilibrium problem and a fully implicit scheme is used for the time integration.

It must be noted that to simulate the unstable system made of the plasma, poloidal field coils and passive structures on a time scale long (1 s) respect to the growth time of the instability (100 ms), a feedback control on the plasma vertical motion must be introduced. Alternatively, the time constant of the passive structure can artificially be expanded (e.g. by reducing the ohmic resistances).

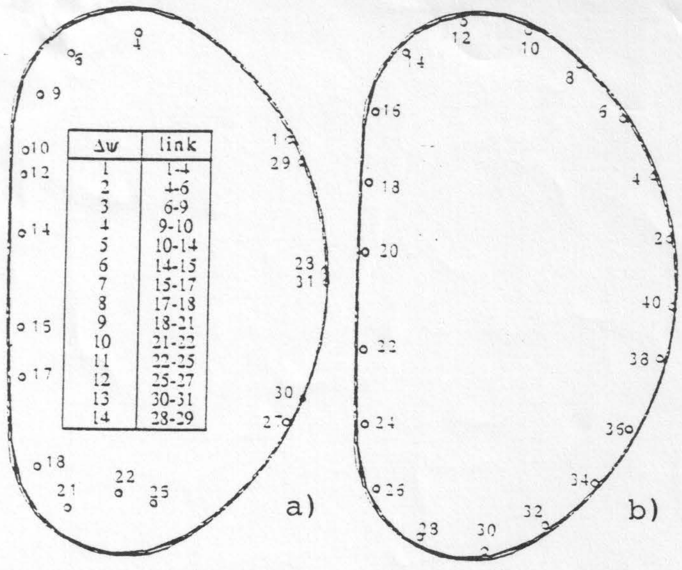
2.2 Experimental database

Table I summarizes the main features of the shot selected for the simulation.

The measured values and P.F. coil currents are given as functions of the time with 1 ms sampling.

Five types of measurements have been considered:

- poloidal flux differences: by means of 14 saddle coils (Fig.1a) placed around the poloidal perimeter of the vacuum vessel, one measures the difference of poloidal flux existing between the two toroidal branches of the saddle coil; this measurement is proportional to the average component of the poloidal field, normal to the vessel surface;
- magnetic field: by means of 20 field sensors (Fig.1b) placed on the inner surface of the vessel, one measures the poloidal distribution of the component of the magnetic field tangential to the vessel surface;
- Vacuum Vessel (VV) current: this is actually an indirect



Δψ	link
1	1-4
2	4-6
3	6-9
4	9-10
5	10-14
6	14-15
7	15-17
8	17-18
9	18-21
10	21-22
11	22-25
12	25-27
13	30-31
14	28-29

Fig. 1 Location of the magnetic flux (a) and field sensors (b).

measurement, since it is obtained by making the difference between the line integral of the above measurements and the measurement given by a Rogowski coil wound outside VV;

- Passive Stabilizer (PS) current: this is measured by means of a Rogowski coil wound around PS;
- loop voltage: this is obtained by measuring the time derivative of the poloidal flux linked with the flux sensor No. 12 ($R=0.99\div1.01$ m , $Z=0.23$ m);
- plasma data: plasma current, beta poloidal β_p, internal inductance l_i and safety factor $q(95\%)/q_{axis}$, geometric parameters (e.g. major and minor radius, elongation, X-point location, etc.); these data are either directly measured or reconstructed by means of a principal component analysis (PCA) [2].

2.3 Main assumptions and input data for the simulation

The current density in the plasma has been assumed to belong to the class of profiles described in [3] where the four parameters specifying each individual profile can be put in correspondence with the physically more meaningful parameters β_p, l_i and q_{axis} .

The four profile parameters have been computed in a number of different times of the discharge, in such a way as to match the poloidal beta and internal inductance provided by the database; a linear interpolation is used in the generic time instant of the simulation.

The experimental currents flowing in the PF circuits have also been assumed as input data.

Table I - Main data characterizing flat top of shot No. 942

Plasma current (kA)	346
Major radius (m)	1.62
Minor radius (m)	0.56
Toroidal field (T) at R=1.65 m	2.00
R-coord. of null point (m)	1.54
Z-coord. of null point (m)	-0.90
Poloidal beta	0.38
Internal inductance	1.50
$q(95\%)/q_{axis}$	6.90

3. STATIC AND QUASI STATIC ANALYSIS

In this first part of the study, we have assigned the poloidal field coil currents at 640 ms together with the plasma current, the poloidal beta and the plasma internal inductance. As far as the currents in the passive stabilizer (PS) and the vacuum vessel (VV) are concerned, we study separately the cases where the eddy currents (1) are zero, (2) attain their experimental values, (3) are given by an eddy current analysis of the first 640 ms of the discharge assuming a filamentary plasma current model. Case 1 can be regarded as a purely static analysis while cases 2 and 3 involve some eddy current computation as pre-processing and we then regard them as quasi-static (in case 2 we use the eddy current distribution of case 3, rescaled is such a way as to match the experimental values of the total PS and VV currents).

Cases 4 to 6 are equal to case 3 as far as the induced currents are concerned, but β is decreased by 20% in case 4 and l_i is decreased by 10% in case 5. In case 6 the plasma current is given by the sum (reliably measured) of vessel plus plasma current, minus the computed vessel current. Computed and measured fluxes and fields at sensors are given in figures 2 to 5. The MHD equilibrium configuration (case 2) is shown in fig. 6.

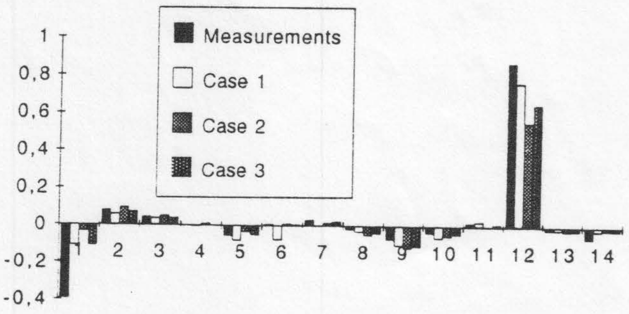


Fig. 2 Measured and computed fluxes for cases 1 to 3.

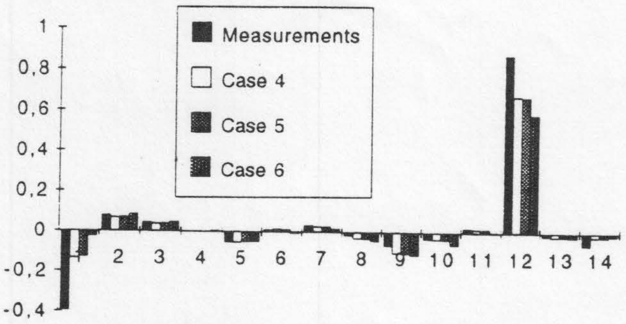


Fig. 3 Measured and computed fluxes for cases 4 to 6.

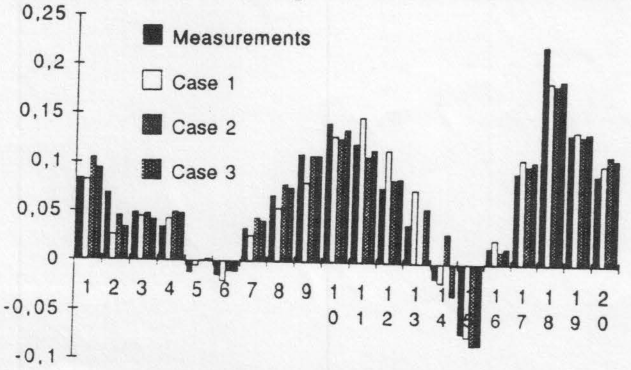


Fig. 4 Measured and computed fields for cases 1 to 3.

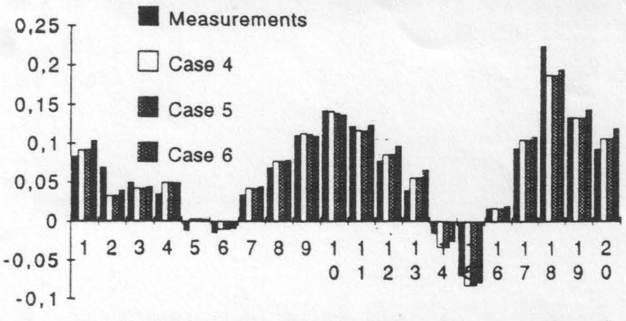


Fig. 5 Measured (and computed fields for cases 4 to 6.

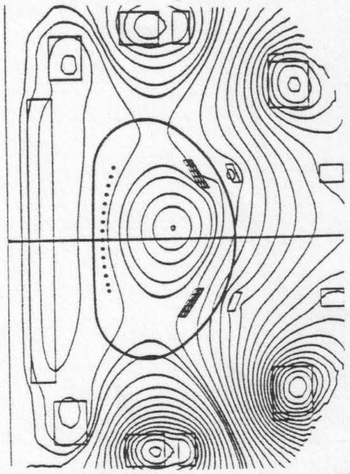


Fig. 6 Plasma equilibrium at 640 ms (flat top); eddy currents as obtained from measurements (case 2).

4. DYNAMIC ANALYSIS: ELECTROMAGNETIC MODEL

In this part of the analysis we compute the eddy currents induced in the vacuum vessel and in the passive stabilizer by the external coils and plasma current changes. The plasma is approximated as a rigid filament positioned in the (identified) plasma current centre. Plasma current and loop voltage waveforms are shown in figures 7 and 8, respectively. The computed and measured currents,fluxes and fields are given in figures 9 to 11. The magnetic flux map at 640 ms (flat top) is given in fig. 12.

The nearly rigid shift between experimental and computed values can be explained by the presence of an initial off-set (which is taken into account in ASDEX-U, but is not reported in the diagrams). In fact, as shown in Fig. 13, a better agreement is obtained comparing the experimental data at 640 ms to the difference between the computed values of case 3 and the values at time=0 as computed using the electromagnetic model.

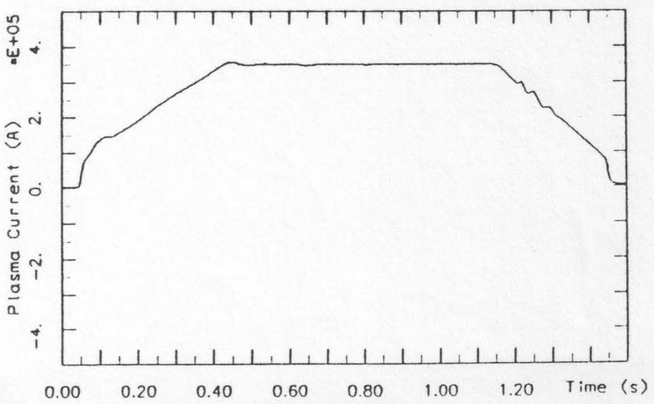


Fig. 7 Plasma current waveform.

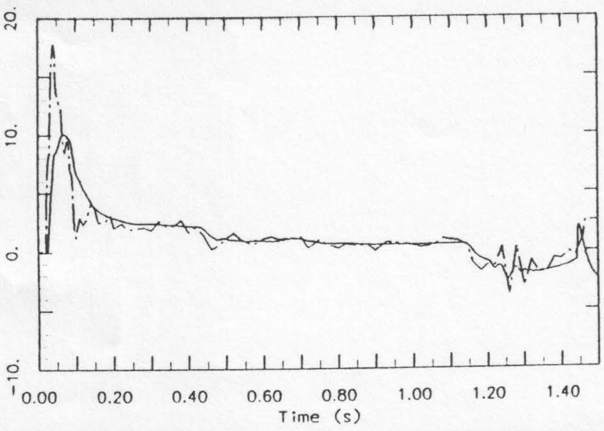


Fig. 8 Measured (solid) and computed (broken) loop voltage at sensor 12; electromagnetic model.

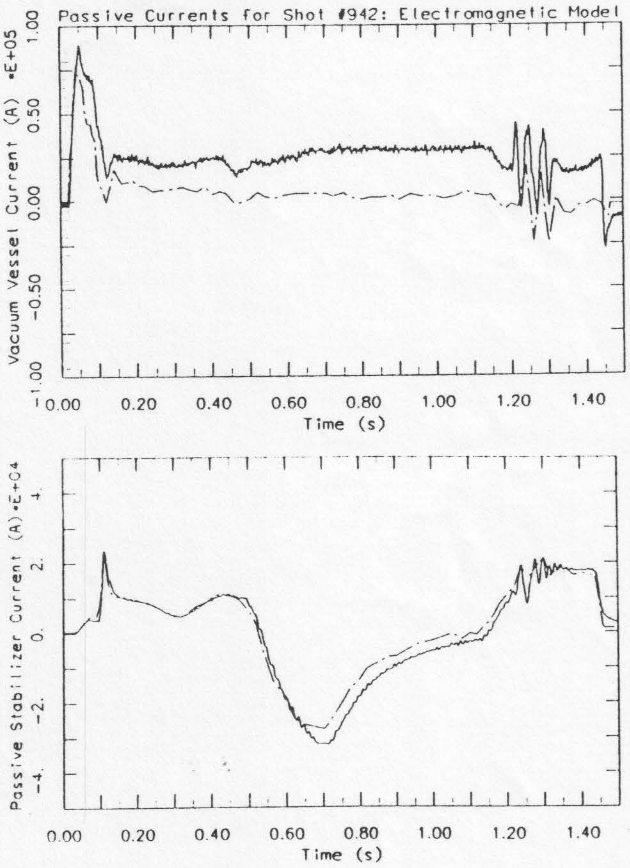


Fig. 9 Measured (solid) and computed (broken) currents .

5. DYNAMIC ANALYSIS: MHD MODEL

The complete scenario of shot #942 is simulated assuming that the plasma is in MHD equilibrium during the whole discharge. The plasma parameters (current, poloidal beta and internal inductance) are those obtained in ASDEX-Up by measurements or a PCA of the shot data.

Computed plasma equilibrium data (X-point position, minor and major radii) are given in fig. 14 and compared with the PCA performed by ASDEX. The computed eddy currents and fields, compared with the measured values, are given in fig. 15 and 16, respectively. Fig. 17 shows the MHD equilibrium at 640 ms, consistent with the computed eddy currents in the passive structures.

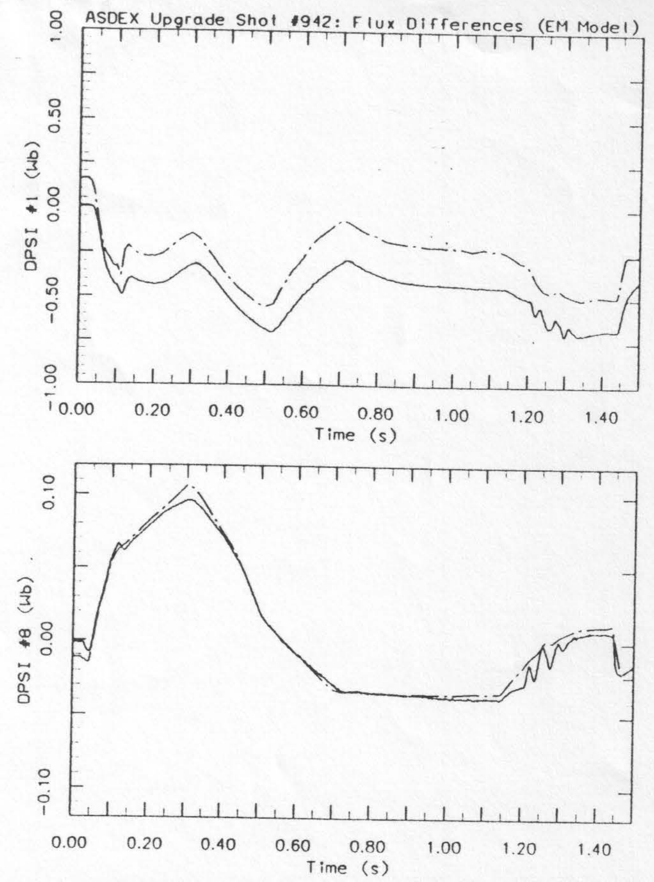


Fig. 10 Measured (solid) and computed (broken) fluxes; electromagnetic model.

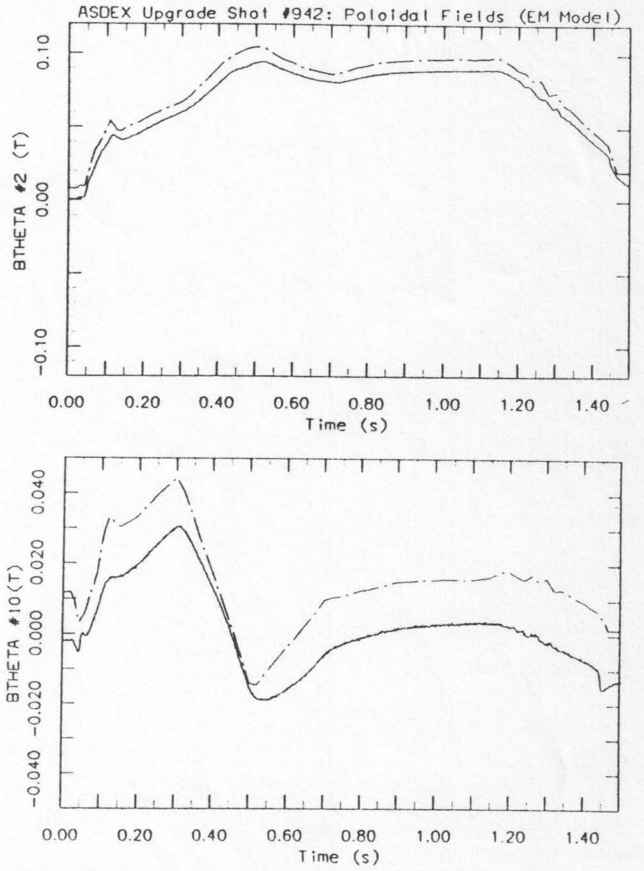


Fig. 11 Measured (solid) and computed (broken) fields; electromagnetic model.

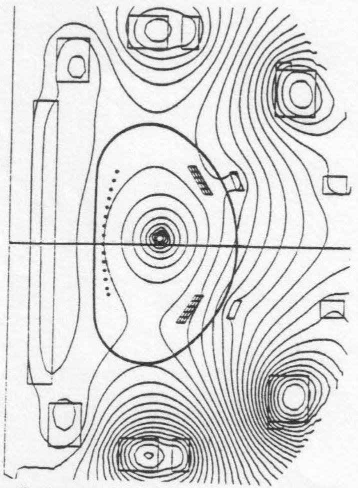


Fig. 12 Map of the poloidal flux at 640 ms (flat top); filamentary plasma approximation.

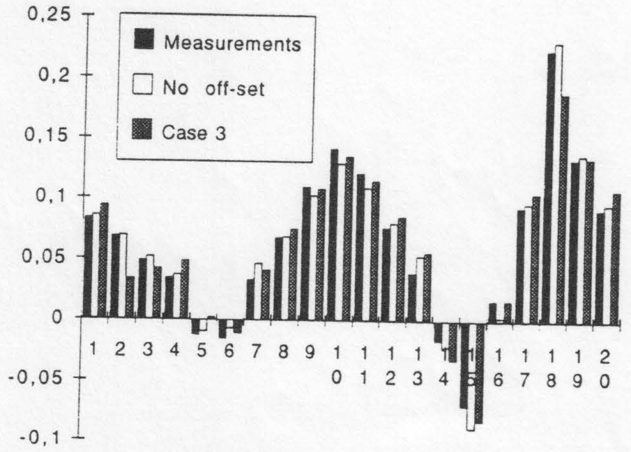


Fig. 13 Influence of the initial offset. Fields at 640 ms: (a) experimental; (b) computed (case 3); (c) computed from case 3 removing the initial offset.

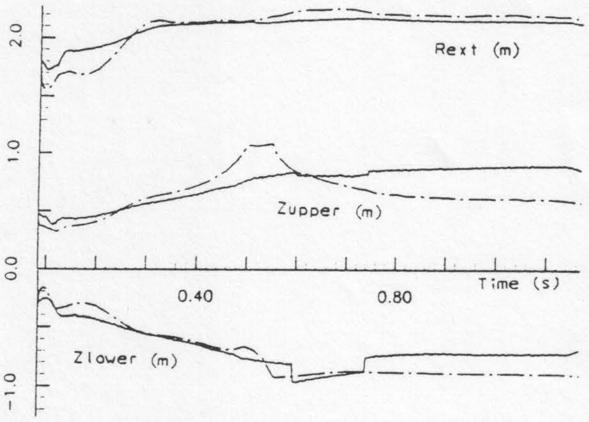


Fig. 14 Reconstructed (solid) and computed (broken) geometric parameters; MHD model.

To avoid plasma vertical instability in the simulation we have artificially brought the PS time constant to infinity by zeroing its ohmic resistance. Of course, this introduces not completely negligible approximations. Better results will certainly be achieved by properly introducing the feedback control system.

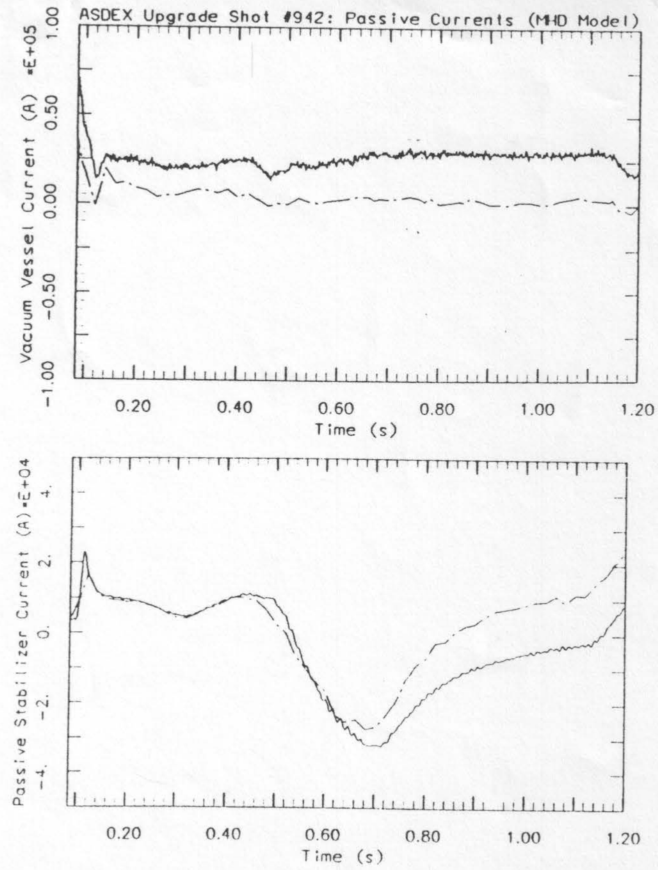


Fig. 15 Measured (solid) and computed (broken) currents in VV and PS; MHD model.

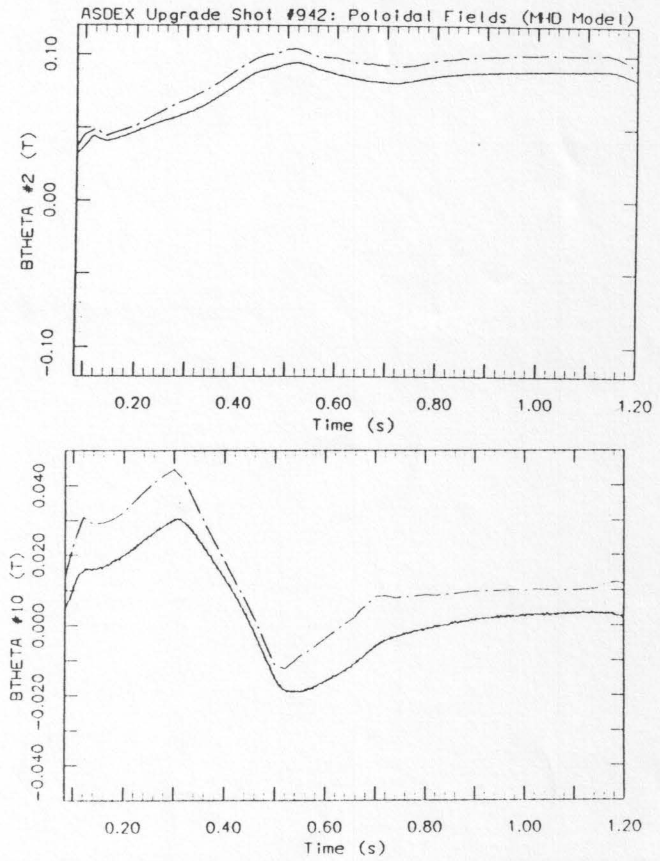


Fig. 16 Measured (solid) and computed (broken) fields; MHD model.

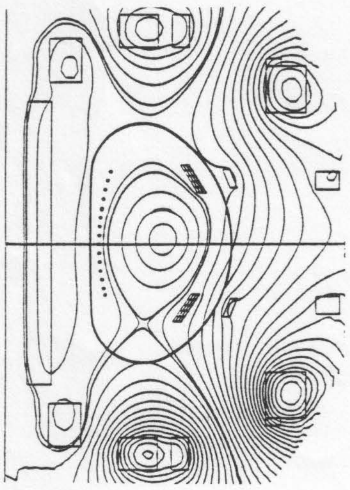


Fig. 17 Map of the poloidal flux at 640 ms (flat top); MHD model.

6. CONCLUSIONS

On the basis of the analysis performed in the paper, the following conclusions can be drawn:

- the most important parameters affecting the electromagnetic field distribution outside the plasma are plasma current and position of its centroid; other parameters, like beta poloidal and internal inductance, have a smaller impact; this is shown by the good results achieved using the filamentary approximation for the plasma current;
- in general, good agreement is found between experimental and computed values, in both static and dynamic analyses;
- there is a discrepancy between experimental and computed vacuum vessel current; this can be explained by a considerable drift of the integrator and by the fact that it is given by the difference of two large signals close to each other;
- as expected, the MHD dynamic simulation fails in the absence of feedback control, since the plasma is vertically lost with a time constant closely related to that of the passive stabilizer; to overcome this problem, one can either artificially expand the PS time constant beyond the discharge duration (e.g. by reducing the ohmic resistance) or properly introduce the feedback controller.

As a general conclusion of the exercise, we have found that a reliable simulation code that accounts for the effects of the eddy currents in the passive structures is not only an essential tool for the design and interpretation of the experimental data, but also an efficient means for detecting possible failures, inaccuracies or lack of reliability of the individual sensors.

REFERENCES

[1] NET Final Report Contract No. F/N/90-259.
[2] P.J. Mc Carthy et al., 19th EPS Conference, Innsbruck, 1992, Eur. Conf. Abstracts, Vol. 16C, Pt. I, 459-462.
[3] J.L. Luxon, B.B. Brown, Nucl. Fus., 22 (1982) 813-821