INTERPRETATION AND CONTROL OF HELICAL PERTURBATIONS IN TOKAMAKS

C.V.Atanasiu, I.G.Miron
National Institute for Lasers, Plasma and Radiation Physics, Bucharest, Romania

During the period January-December 2002, the common research between the **Mathematical Modelling for Fusion Plasmas Group** of **the National Institute for Lasers, Plasma and Radiation Physics (NILPRP),** Magurele - Bucharest, Romania with the **Max-Planck - Institut für Plasmaphysik (IPP)**, Garching, Germany has been focalized, according with the Working Programme 2002 approved at the 3rd Steering Committee on the following objectives:

1 Improvement of equilibrium calculations for stability analysis of modes in the separatrix vicinity in order to determine the influence of the plasma triangularity on the tearing mode stability parameter Δ' for the ASDEX-Upgrade tokamak.

The following **milestones** have been achieved:

1.a Developing of analytical Solov'ev-like equilibrium solutions, able to describe a separatrix;

To check the capability of our new moment method to calculate the metric coefficients given by an equilibrium solver, a comparison of the moment solutions with analytical solutions has been performed for the case of a diverted configuration.

We have extended the analytical Solov'ev solution of the Grad-Shafranov equation by specifying the following functional dependences of the source profiles on the stream function Ψ: $p(\Psi)=a/2/\mu_0\Psi^2+b/\mu_0\ \Psi$ and $F^2(\Psi)=c\Psi^2+\ 2d\Psi+F^2_0$ with a, b, c and d constants. These dependences are evidently more close to the real pressure and poloidal current distributions in a tokamak. In Figure 1a-d and Figure 2a-d the 3D representation of the g_{ik} metric coefficients as functions of the "radial" coordinate $a=(\Psi_{ax}-\Psi)^{1/2}$ and poloidal coordinate θ are given. Both a D-shaped plasma (Figure 1) and a diverted one (Figure 2) have been considered. It is to note that the metric coefficients $g_{ik}(\Psi,\theta)$, unlike the metric coefficients $g_{ik}(a,\theta)$, present a singularity at the magnetic axis. Note the dominant influence of the separatrix on the metric coefficients at and near the separatrix.

1.b Improvement of the calculation of the 1st and 2nd partial derivatives (with respect to both the radial coordinate *a* and the poloidal θ coordinate) of the metric coefficients in the vicinity of the X point;

To improve the calculation of the 1st and 2nd partial derivatives (with respect to both the radial coordinate *a* and the poloidal θ coordinate) of the metric coefficients in the vicinity of the X point we have extended the analytical forms in the vicinity of the separatrix, not only for the separatrix itself as presently. Exponential interpolation functions or Chebyshew interpolating polynomials in place of spline functions (even with smoothing) have been investigated. We have found that not one could be used successfully for all possible plasma discharge scenarios.

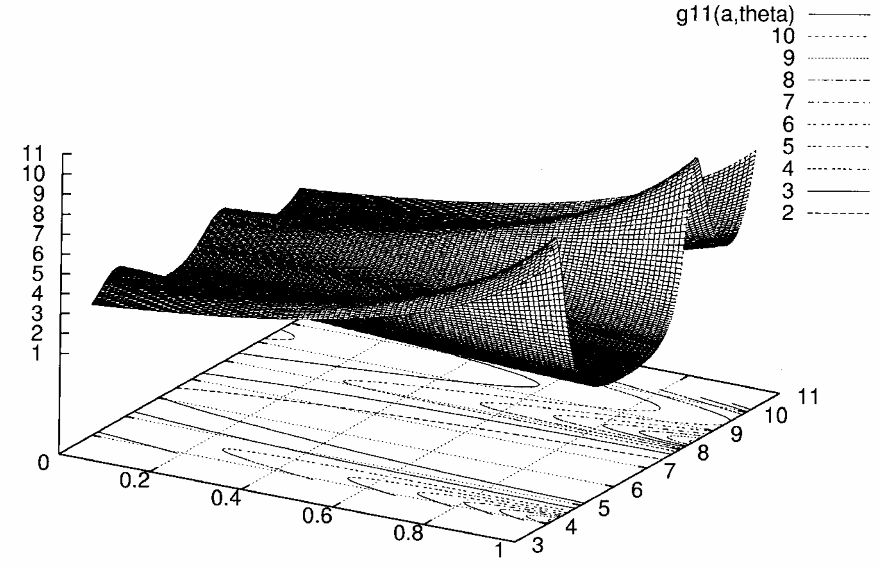


Figure 1.a 3D representation of the $g_{11}(a,\theta)$ *metric coefficient for a D-shaped plasma. The "radial" coordinate a has been normalized to 1, while the poloidal coordinate* θ *has its origin in the* 3^{rd} *quadrant (to have an equivalent poloidal coordinate origin like the X point is for the diverted configuration).*

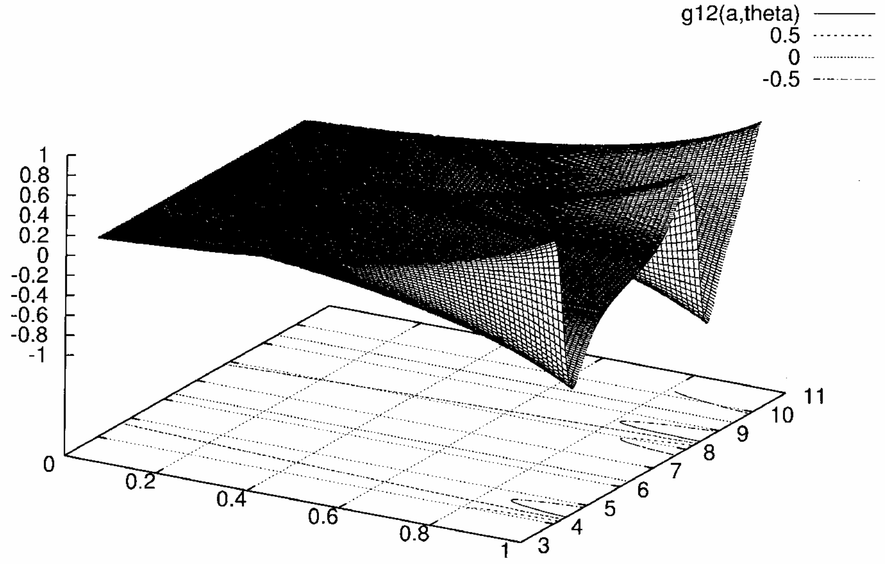


Figure 1.b 3D representation of the $g_{12}(a,\theta)$ *metric coefficient for a D-shaped plasma. The "radial" coordinate a has been normalized to 1, while the poloidal coordinate* θ *has its origin in the* 3^{rd} *quadrant*

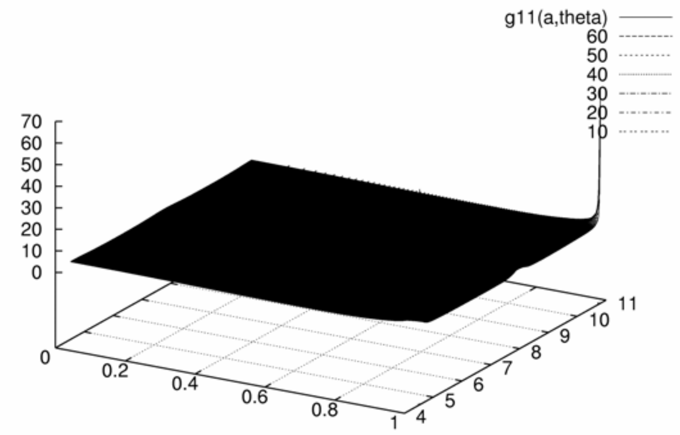


Figure 2.a 3D representation of the $g_{11}(a,\theta)$ metric coefficient for a diverted plasma (shot 5000 at 1.55 sec. of the ASDEX-Upgrade tokamak). The "radial" coordinate a has been normalized to 1, while the poloidal coordinate θ has its origin at the X point, in the 3^{rd} quadrant.

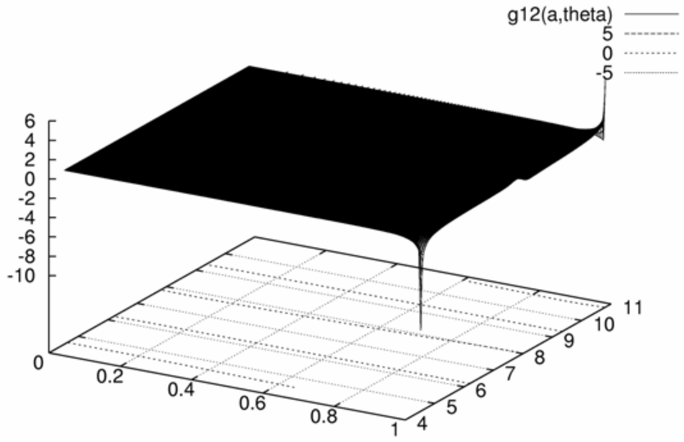
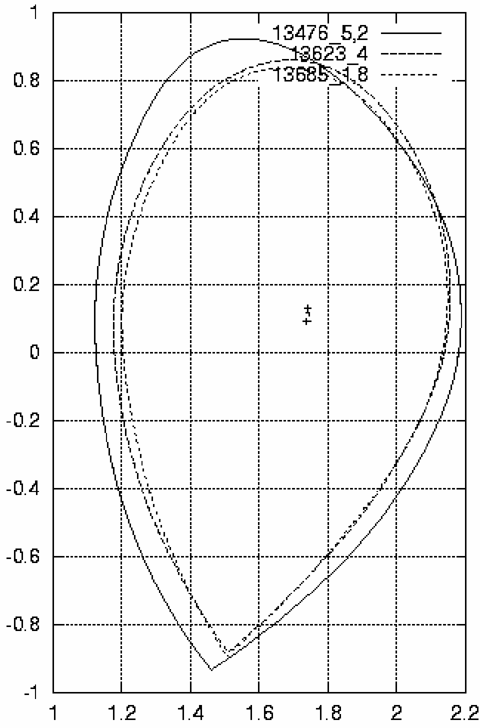


Figure 2.b 3D representation of the $g_{12}(a,\theta)$ metric coefficient for a diverted plasma (shot 5000 at 1.55 sec. of the ASDEX-Upgrade tokamak). The "radial" coordinate a has been normalized to 1, while the poloidal coordinate θ has its origin at the X point, in the 3^{rd} quadrant. One can see the singular behavior of the derivatives with respect to θ.

1.c Interpretation of different experimental discharges of the ASDEX-Upgrade tokamak from the Δ' (the tearing mode stability parameter) point of view;

- We have interpreted different experimental discharges (the shots of the ASDEX Upgrade tokamak: no. 13476 at 5.2 seconds, no. 13623 at 4 seconds and no. 13685 at 1.8 seconds all corresponding to an advanced scenario) from the Δ' (the tearing mode stability parameter) point of view. The results obtained are presented in Figure 3. The increasing of the stability against the m/n=3/2 mode by increasing both the triangularity (characterizing the "deviation" from a pure elliptical cross-section, the triangularity has to be considered in absolute value) and the ellipticity is evident. The stabilizing influence of the stability index Δ' by keeping the ellipticity constant, results more evident from Fig. 4. Classical linear resistive mode theory (Furth, Killeen, and Rosenbluth, Phys. Fluids **6**, (1963)) predicts stability when the linear stability index for the tearing mode Δ', defined as the jump of the logarithmic derivative of the flux function perturbation across the rational surface, is negative for the pressureless limit, or smaller than a positive threshold in the finite pressure case if the resistive interchange index is less then zero (and unstable if this index is positive) For our case, the more the stability index becomes negative the more the considered tokamak system is able to "absorb" the potential energy given by the tearing mode perturbation, i.e. to be stable against these modes. Starting from the configuration corresponding to the shot no. 13476 at 5.2 s of the ASDEX Upgrade tokamak, and using the coordinates transformation $r=a\cos\theta + d\sin^2\theta$; $z=\lambda a\sin\theta$, the numerical results have confirmed the improvement of the stability parameterΔ' by increasing the triangularities *d*. The results are presented in Figure 4.



Shot no.	Time	Upper triangularity d_u	Lower triangularity d_l	Medium triangularity d_m	Ellipticity λ	Delta prime Δ'
13476	5.2 s	-0.173	-0.365	-0.269	1.746	-2.715
13623	4.0 s	0.068	-0.318	-0.125	1.782	-3.305
13685	1.8 s	0.05	-0.355	-0.175	1.828	-6.292

Figure 3 $\Delta'_{3/2}$ *dependence on the triangularities d for three shots of the ASDEX Upgrade tokamak: no. 13476 at 5.2 seconds, no. 13623 at 4 seconds and no. 13685 at 1.8 seconds*

This work has been carried out in close collaboration with our German colleagues from the Tokamak Physics Department of the Max-Planck-Institut für Plasmaphysik, during the mobility 02.08.02 – 30.10.02 and part of the mobility 19.12.02 – 18.03.03 at IPP Garching and at our home institute NILPRP.

In a next step: other plasma discharges of the ASDEX Upgrade tokamak will be investigated from the Δ' point of view.

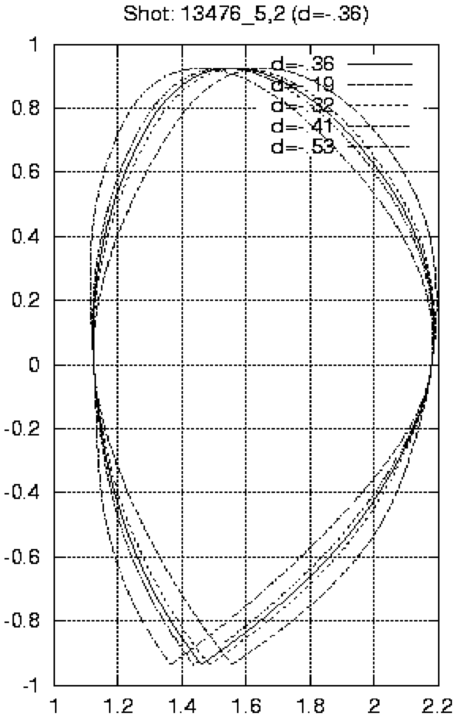
2. Plasma models for feedback control of helical perturbations

The following **milestones** have been achieved:

2.a Determination of the inductance matrix of the wall and coils

2.b Determination of the feedback equation for wall modes.

If for this objective the representation of the plasma by using a surface current model, the determination of the inductances of the plasma, wall and coils, and the determination of the linear response of the plasma to perturbation have been already investigated analytically and partial numerically, we have extended our approach of boundary integral equations to the wall geometry. First we have considered a superconducting wall with an axisymmetric geometry: toroidal shell



Upper triangularity d_u	Lower triangularity d_l	Medium triangularity d_m	Ellipticity λ	Delta prime Δ'
0.004	-0.193	-0.094	1.736	-2.285
-0.128	-0.322	-0.225	1.745	-2.556
-0.173	-0.365	-0.269	1.746	-2.715
-0.218	-0.408	-0.313	1.746	-2.860
-0.345	-0.529	-0.437	1.736	-3.442

Figure 4 $\Delta'_{3/2}$ *dependence on the triangularities d by modifying the plasma boundary corresponding to the ASDEX Upgrade shot no. 13476 at 5.2 s according to the coordinates transformation* $r=a\cos\theta + d\sin^2\theta$; $z=\lambda a\sin\theta$ *(with a the radial coordinate,* θ *the poloidal coordinate, d the triangularity and* λ *the ellipticity of the separatrix.)*

totally enclosing the plasma, spherical shell which does not link the plasma, and toroidal shells only partially enclosing the plasma. We have investigated the influence of the distance between the shell and the plasma on the flux function perturbation at the unperturbed plasma boundary.

We have continued our work by assuming a thin resistive shell and a feedback coil structure accurately modeled in θ and ζ (the poloidal and toroidal angles) albeit with only a single harmonic variation in ζ. Time constants and induced currents in the resistive shell have been calculated.

This work has been carried out in close collaboration with our German colleagues from the Tokamak Physics Department of the Max-Planck-Institut für Plasmaphysik, during part of the mobility 19.12.02 – 18.03.03 at IPP Garching and at our home institute NILPRP.

In a next step:

- we will extend to non-symmetric (with respect to the middle plane, i.e. for diverted plasma configurations) plasma our approach to describe the magnetic properties of a perturbation by giving the normal component of the magnetic perturbation at the unperturbed plasma boundary;
- we will define the inductance of the modes;
- we will draw the feed-back equations of the resistive modes.

Publications:

1. **Gruber O., Arslanbekov R., Atanasiu C.V., et al.**, *"Overview of ASDEX Upgrade results"*, Nuclear Fusion, **41** (2001), 1369.
2. **Sips A.C.C., Arslanbekov R., Atanasiu C.V., et al.**, *"Steady state advanced scenarios at ASDEX Upgrade"*, Plasma Physics and Controlled Fusion, **44** (2002) B69-B83.