*29th EPS Conference on Plasma Phys. and Contr. Fusion Montreux, 17-21 June 2002 ECA Vol. **26B**, P-2.090 (2002)*

Application of Three-Dimensional Codes to Tokamaks

E. Strumberger, S. Günter, P. Merkel, E. Schwarz,

C. Tichmann, H.P. Zehrfeld and the ASDEX Upgrade Team

Max-Planck-Institut für Plasmaphysik, EURATOM Association,
D-85748 Garching

Introduction

For tokamak experiments the stabilization of magnetohydrodynamic (MHD) modes is an important task. For this purpose, promising concepts like additional helical fields [1,2], wall-stabilization [3] and active feedback coil stabilization [4] are investigated which require three-dimensional tools for quantitative numerical equilibrium and stability computations.

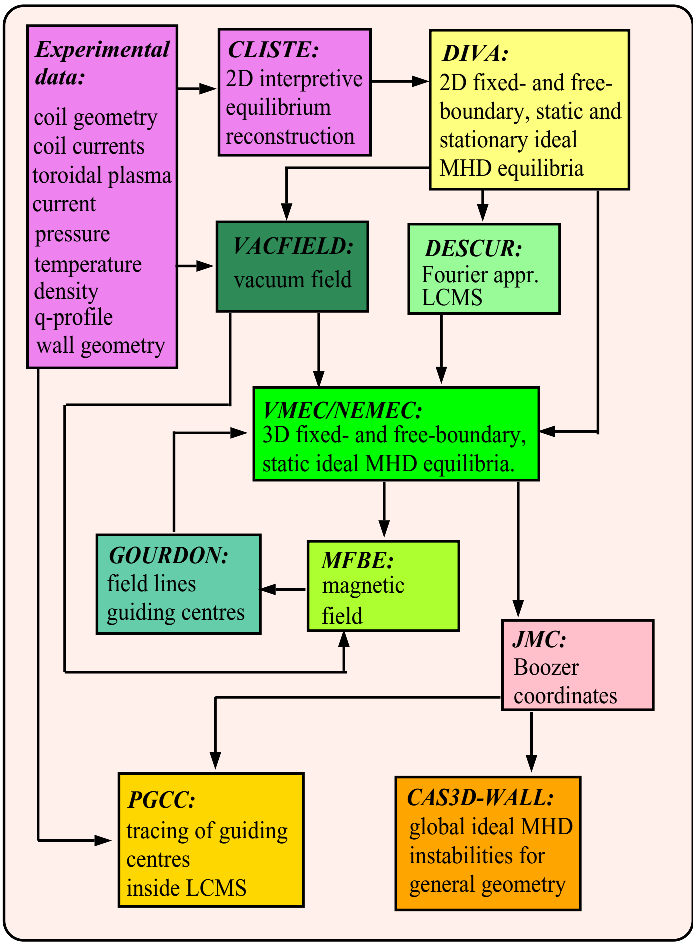

Fig. 1: *Overview of the code system*

Fig. 1 gives an overview of a code system which will be applied to these stabilization concepts. It contains three-dimensional codes which originally have been developed for stellarators. Some of these codes make use of the stellarator symmetry, which is not fulfilled in case of not up-down symmetric tokamak configurations. For this reason, these codes need to be extended to asymmetric configurations. This generalization has already been done for the DESCUR code [5] and the fixed and free-boundary equilibrium VMEC/NEMEC code [6] (S.P. Hirshman), the global MHD stability CAS3D code [7] (C. Nührenberg) and the MFBE code [8], while work is in progress for the JMC code [9], which transforms the flux coordinates used in VMEC/NEMEC into Boozer coordinates. The VACFIELD code, which computes the magnetic field of external coils, and the field line and guiding centre tracing GOURDON code do not depend on the stellarator symmetry. In the following first applications of theses codes to two and three-dimensional tokamak configurations are described.

Two-dimensional tokamak equilibria

We consider two ASDEX Upgrade type equilibria, namely an up-down symmetric equilibrium and the equilibrium of shot 12224 (t=0.72s). Both equilibria are limiter-defined and computed with the two-dimensional DIVA code [10] by solving the Grad-Shafranov equation. In order to reproduce these equilibria with the three-dimensional codes, the DIVA results are used as input. The profiles of pressure and rotational transform or pressure and toroidal current, as well as the Fourier representation of the plasma boundary (DESCUR) serve as input to the fixed-boundary VMEC code. The VACFIELD code provides the magnetic field of the external coils, which is needed by the MFBE code. For these axisymmetric equilibria the toroidal field is approximated by the simple relation $B_{\mathrm{t}} = (\mu_0 J_{\mathrm{b}})/(2\pi R)$ with J_{b} being the poloidal current at the plasma boundary. Then the MFBE_2001 code [11] computes the magnetic field of the VMEC equilibria in a form suitable for tracing field lines and guiding centres. MFBE_2001 - a modified version of MFBE - uses the 'virtual casing' principle [12]. It computes the magnetic field of equilibria with and without net-toroidal current, and it has been extended to asymmetric configurations. The magnetic field serves as input to the GOURDON code which yields the field topology by tracing field lines.

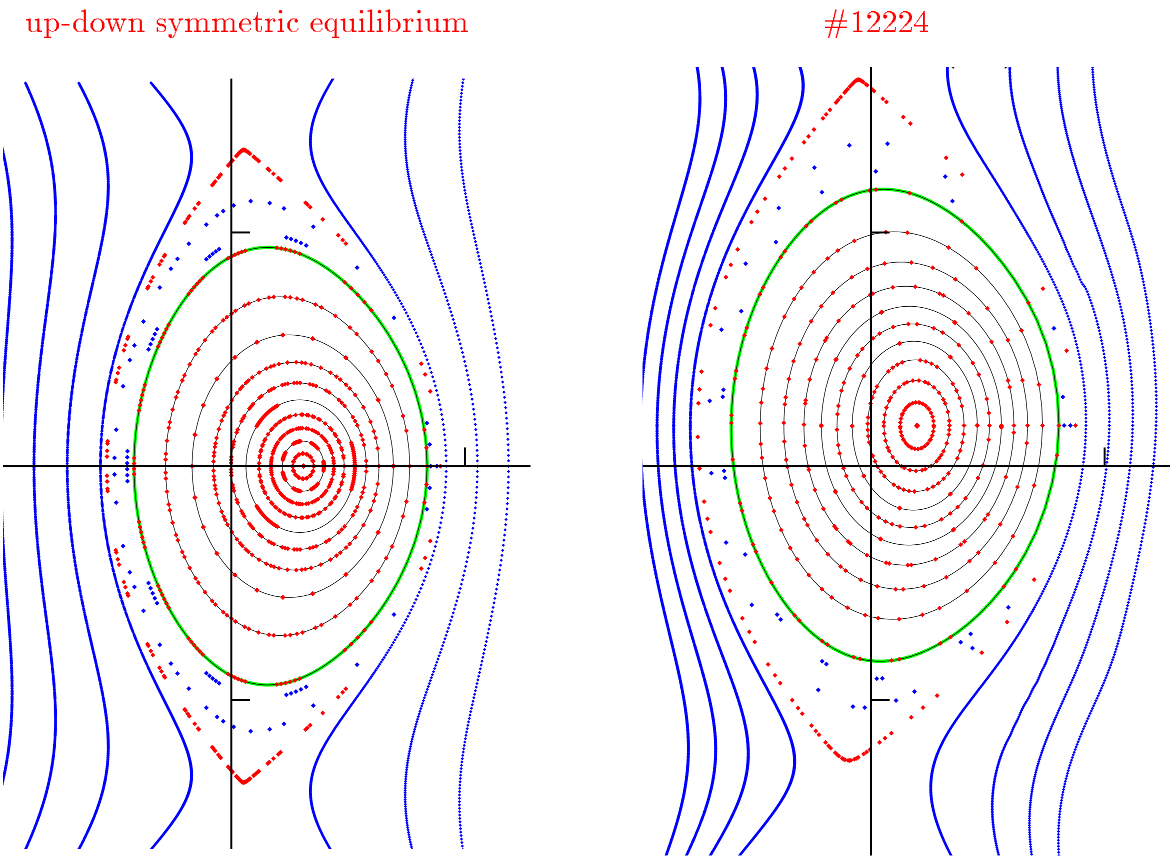

Fig. 2: *Flux surfaces of the axisymmetric equilibria computed with DIVA (black lines) and the three-dimensional code system (red and blue dots). The green line indicates the plasma boundary.*

The high numerical accuracy of magnetic fields computed with VMEC+MFBE_2001+ GOURDON is demonstrated in Fig. 2. There the flux surfaces obtained with DIVA are compared with the corresponding surfaces of the magnetic field computed with the three-dimensional codes. The surfaces coincide very well.

Three-dimensional tokamak equilibria

Theory [1] and experiments at DIII-D [2] show that non-resonant helical fields are able to damp or even stabilize neoclassical tearing modes. Here the influence of such an additional field on the magnetic field topology of the up-down symmetric equilibrium shown in Fig. 2 (left) is investigated. Furthermore, the toroidal field ripple produced by the 16 toroidal field coils of ASDEX Upgrade is taken into account. Using a helical coil geometry similar to DIII-D and a coil current of 20 kA, a three-periodic helical field is added to the 16-periodic toroidal field. On the plasma boundary the maximum field strength of the helical field (≈0.008 T) is comparable to the strength of the ripple field (≈0.009 T). The resulting vacuum field corresponds to a one-periodic stellarator-symmetric configuration. Computing the equilibrium with the free-boundary NEMEC code, the magnetic field with the MFBE_2001 code and tracing field lines with the GOURDON code yield the Poincaré plot shown in Fig. 3.

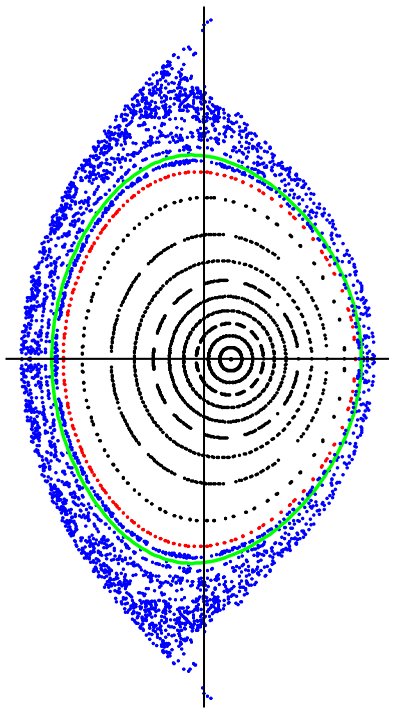

Fig. 3: *Poincaré plot of the 3D magnetic field at the toroidal cross-section $\varphi = 0$. The green line indicates the NEMEC plasma boundary.*

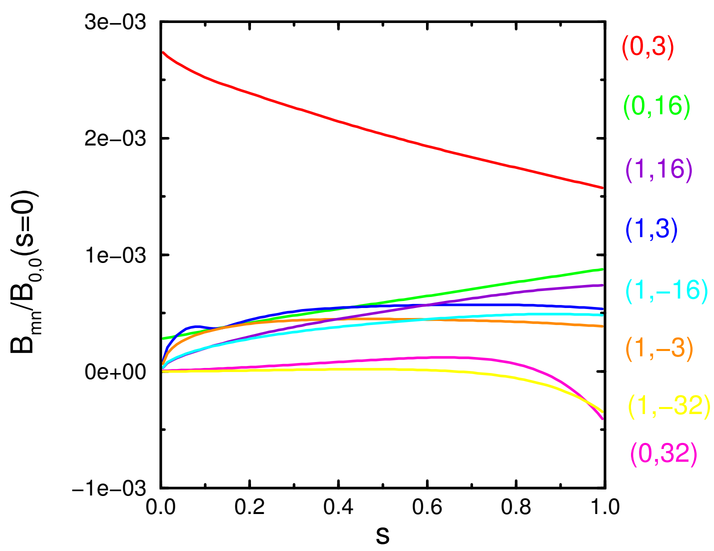

Fig. 4: *Normalized Fourier coefficients of the magnetic field strength $B_{\mathrm{m,n}}$ as function of the normalized toroidal flux s. Here, only the most important helical (n=3) and toroidal ripple components (n=16 and 32) of the equilibrium field are plotted.*

A comparison of this plot with the up-down symmetric field given in Fig. 2 shows that the helical field leads to an ergodization of the edge region (it has been verified that the toroidal ripple field does not ergodize the edge region). This ergodization may be the reason for the experimentally observed, slight confinement deterioration.

The JMC code [9] yields the Fourier coefficentes of the magnetic field strength in Boozer coordinates. In Fig. 4 these coefficentes are plotted for the helical and the toroidal ripple components of the equilibrium field. There, the Fourier coefficent $B_{0,3}$ and $B_{0,16}$ correspond to mirror fields of approximately 0.2% and 0.05%.

Summary and outlook

A link between experimental data, the two-dimensional DIVA code and the three-dimensional codes has been established. The 3D codes VMEC/NEMEC, MFBE_2001, GOURDON and JMC have been applied to two and three-dimensional tokamak configurations, and effects of an additional helical field have been studied for an up-down symmetric equilibrium. While VMEC/NEMEC and MFBE_2001 are already extended to not up-down symmetric configurations, this work is in progress for JMC and also for PGCC. The Parallel Guiding Centre Code (PGCC) [13] traces guiding centres by using the guiding centre equations in Boozer coordinate representation and computes particle losses. These three-dimensional codes, extended to asymmetric configurations, will provide a numerical tool for detailed studies of the influence of an additional helical field on i.) the magnetic field structure, ii.) the number of reflected particles and iii.) the particle confinement.

The VMEC/NEMEC code and the JMC code are also needed for providing the equilibrium input for the CAS3D-WALL code (C. Nührenberg, P. Merkel) which is a generalization of the 3D CAS3D MHD stability code [7] taking into account the effect of a conducting wall around the plasma. The CAS3D-WALL code allows to study wall stabilization by arbitrarily shaped conducting structures including holes, poloidal and toroidal gaps.

References

[1] Q. Yu et al., Nuclear Fusion **40** (2000) 2031.
[2] R.J. La Haye et al., Phys. Plasmas **9** (2002) 2051.
[3] A. Bondeson et al., Phys. Plasmas **6** (1999) 637.
[4] R. Fitzpatrick, Phys. Plasmas **8** (2001) 871.
[5] S.P. Hirshman et al., Phys. Fluids **28** (1985) 1387.
[6] S.P. Hirshman et al., Comput. Phys. Commun. **43** (1986) 143.
[7] C. Nührenberg, Phys. Fluids **B5** (1993) 3195.
[8] E. Strumberger, Nuclear Fusion **37** (1997) 19.
[9] J. Nührenberg et al., in Theory of Fusion Plasma, Varenna 1987, Eds. A. Bondeson, E. Sindoni, F. Troyon, 1988, EUR 11336 EN, 3-23.
[10] H.P. Zehrfeld, 26th EPS Conf. on Control. Fusion and Plasma Phys., Maastricht 1999, ECA 23J. Europ. Phys. Soc., Geneva 1999, 1421.
[11] E. Strumberger et al., Report IPP 5/100, Garching (2002).
[12] V.D. Shafranov et al., Nuclear Fusion **12** (1972) 599.
[13] E. Strumberger, Nuclear Fusion **40** (2000) 1697.