Equilibrium, Stability and Transport Analysis for Reduced Field Period HELIAS Reactors

T. Andreeva, C.D. Beidler, Yu. Igitkhanov, J. Kisslinger, H. Wobig

Max-Planck-Institut für Plasmaphysik, Greifswald, Germany

The Wendelstein 7-X experiment, which is now under construction in Greifswald (Germany), is the basis for Helias reactor (HSR) studies. A straightforward extrapolation of W 7-X towards a power reactor leads to a 5-period machine with a major radius of 22 m. In order to reduce the size and the cost of the reactor, 4- (HSR4, 18m) and 3-period (HSR3, 15m) options have been investigated. The main optimisation principles of the Helias reactor line remain the reduction of the Pfirsch-Schlüter currents and the Shafranov shift [2], while maintaining an MHD stability limit of $\beta\geq4\%$, and good confinement of trapped $\alpha$-particles.

Equilibrium and stability properties with respect to the Mercier and resistive interchange criteria have been considered for HSR3 and HSR4 devices for different pressure profiles and several $\beta$ values. Simulation has shown that the Shafranov shift is sufficiently small for both, 3- and 4-period, configurations. The maximum $\beta$ limit is around 4%.

Numerical codes system and calculation procedure.

For the computation of the magnetic fields in W7-X, the system of numerical codes, described in details in [3], was used. The vacuum magnetic configuration is taken from the Gourdon code, which allows one to calculate vacuum magnetic fields from the given currents by using Biot-Savart’s law or by the interpolation from grid points, calculated once by Biot-Savart and stored on a grid. The plasma equilibrium and its corresponding magnetic field is computed with the help of NEMEC [4], MFBE [5] and the Gourdon code by an iteration procedure. The NEMEC code requires as an input an initial guess of the plasma boundary, vacuum magnetic configuration and a “mass” profile, which is related to the pressure profile through the adiabatic law [6]. Pressure profiles used are shown in fig.1. The Fourier representation of the magnetic field, flux surfaces and the potential on the LCMS computed by NEMEC are the input parameters.
for the MFBE code, which calculates the magnetic fields outside the LCMS and determines the full magnetic field representation on a grid. This grid is used in the field line tracing computation in the Gourdon code in order to obtain a new shape of the plasma boundary, which should be compared with the input value of the NEMEC code and if necessary the loop of computations is repeated. When the equilibrium calculation is finished, stability properties are investigated by means of the JMC code [7].

**Equilibrium and stability simulation in HSR3.**

In figures 2 and 3 are the simulated rotational transform value and magnetic well profiles versus magnetic surface label shown for different values of $\beta$. At $\beta=3\%$ for the peaked pressure profile 3/5-resonances appear inside the LCMS. With the increase of the plasma pressure the rotational transform at the centre drops significantly and the range of possible rotational transform values becomes larger. These features are more pronounced for the peaked pressure profile than for the parabolic one. The magnetic well deepens with the increase of $\beta$ from 4 to 12,5% at the boundary for the peaked pressure profile and from 3,2 to 10% for the parabolic one.

Figure 4 demonstrates that the Shafranov shift is rather small for this configuration. These are Poincaré plots at the bean-shaped and triangular cross-sections obtained for the peaked pressure profile. For the parabolic pressure profile the numbers for the Shafranov shift are 20% smaller.

Stability analysis has shown that Mercier and resistive-interchange criteria for both pressure profiles are satisfied up to $\beta=3\%$. The maximum $\beta$-limit is around 4%.
Equilibrium properties of HSR4.

Simulation for HSR4, provided for the indicated pressure profiles, also revealed a drop of the $\varphi$ value at the magnetic axis with the increase of the plasma pressure (fig.5), but the range of possible values is not as broad as in the HSR3 case. The magnetic well, shown in fig. 6, changes from 2.8 to 9.2% for peaked and from 2.2 to 7.5% for the parabolic pressure profile. A small Shafranov shift was found for $\beta$ values from 1 till 5% for both parabolic and peaked pressure profiles.

**Fig.4** HSR3, Poincaré plots

**Fig.5** HSR4, Rot. transform

**Fig.6** HSR4, Magnetic well
**Transport studies.**

Neoclassical transport levels have been found to be very small in all cases considered (effective helical ripples of less than 1% at all radii). The confinement of fusion $\alpha$-particles is also satisfactory from the point of view of the power balance, although further optimization is desirable. The bootstrap current is significantly reduced compared to the equivalent axisymmetric device, however it is not yet clear whether the reduction is sufficient to insure a divertor-compatible edge topology, especially for the 3-period case.

**Conclusions.**

It was found that the Shafranov shift is sufficiently small for HSR3 and HSR4 configurations. The range of rotational transform values increases for higher beta, so that low-order resonances appear inside the LCMS. To investigate an equilibrium with islands, other numerical tools are required.

For HSR3, Mercier and resistive-interchange stability criteria for the chosen pressure profiles are satisfied for $\beta=3\%$ and the maximum $\beta$ is around 4%. In future, the CAS3D code [8] will be applied for stability analysis of both configurations. HSR3 needs further optimisation with respect to the bootstrap current, $\alpha$-particle confinement and rotational transform profile. Future plans include self-consistent pressure profiles simulated with the help of transport codes.

**References:**

3. E. Strumberger, Nuclear Fusion, **V. 40**
5. E. Strumberger, Nuclear Fusion, **Vol. 37** (1997)