On Conventional and Modular Heliacs

E. Harmeyer, J. Kisslinger, F. Rau, H. Wobig

Max-Planck-Institut für Plasmaphysik, EURATOM-Association
D-8046 Garching

Abstract

For conventional and modular Heliacs with 4...8 field periods vacuum field properties, guiding center trajectories, and (for specific cases) 3D-Monte-Carlo computations of a particle diffusion coefficient are evaluated numerically. Although less flexible in their parameter range, modular Heliacs avoid an interlinked coil system, and thus are more reactor relevant than conventional systems.

Heliac Configurations

Among Stellarators, the Heliacs are characterized by a helically shaped magnetic axis, by a specific indentation of the outer flux surfaces, and by a reasonably low aspect ratio. The Heliac offers prospects for stable plasmas at comparatively large values of ß, due to its large rotational transform and magnetic well /1/.

Magnetic fields of conventional Heliacs are produced /1/ by a system of planar toroidal field coils arranged helically around a center current ring, and using an appropriate vertical field. Their rotational transform increases with the number of field periods and with the ratio of the helical to the major radius of the coil arrangement. A magnetic well can be obtained. The parameter range can be extended e.g. by a further helical conductor close to the center current ring /2/.

Heliac configurations can also be realized by modular coil systems. They avoid the interlinked arrangement of the conventional Heliac coils. As compared to planar noncircular coils /3/, nonplanar (twisted) coils are preferred since they allow a larger distance between the coils and the last magnetic surface, and also provide for a deeper magnetic well /4/. An analytic winding law for twisted coils is described in /5/.

In Heliacs with equally spaced toroidal field coils a comparatively large modulation of the magnetic field strength along the magnetic axis arises. It can be reduced considerably by different coil currents, or by proper arrangement of the coils in the toroidal direction. By the latter method, simultaneously, at outer flux surfaces broad minima of mod B can extend helically along the field period /4/.

Reference Cases

The present paper is concerned with a study of conventional and modular systems of m = 4...8 field periods. The magnetic properties of vacuum fields are obtained by numerical computations. Typical values of the rotational transform per field period are ι_m = 0.3...0.4; the shear is small, but a magnetic well can be ensured in many cases.

As examples for the various configurations studied, Fig. 1 and 2 show in the left part the coil arrangements and in the right half flux surfaces of the vacuum magnetic field, for a conventional Heliac with 4 field periods, and a reactor-sized modular system with 5 field periods, respectively. Some characteristic data are listed in the inserts. For the conventional Heliac the plane circular TF coils are tilted and placed at different toroidal distances. The vertical field coils are not shown. Note the close distance between the center ring and the last magnetic surface. In the reactor sized modular configuration, a distance D = 1.8 m is chosen between the last magnetic surface of Fig. 2 and the coils, such as to allow sufficient space for blanket and shield.

Magnetic field properties of conventional and modular Heliacs of 4 and 8 field periods are listed in Table I. For the cases with 8 field periods the major radii and the coil aspect ratios are twice those of the systems with m = 4.

Table I: Heliac Reference Configurations

		Conventional		Modular		
field periods	m	4	8	4	8	
av. major radius	R_o	1	2	2	4	m
av. minor radius	r	13.5	15.1	28.7	27.3	cm
rotational transform						
axis		1.18	2.78	1.63	3.32	
edge		1.29	3.03	1.53	3.24	
magnetic well	V"	-2.0	-0.8	0.9	-0.7	%

As a figure of merit for comparison of the different configurations we use the quantity

$$J^* = \langle \frac{B_o{}^2}{B^2} \cdot (1 + \frac{j_\parallel^2}{j_\perp^2}) \rangle$$

where B_o is a reference field and $\langle \dots \rangle$ denotes the average on a magnetic surface. J* is a measure for the Pfirsch-Schlüter-currents, and also enters the stability criterion of resistive interchange modes /7/. Small J* is favourable for interchange stability. This number is about 11 for a standard ℓ = 2 Stellarator like WENDELSTEIN VII-A and can decrease to J* $\approx$ 2 in the 8-period Heliac.

Low Pfirsch-Schlüter currents lead to a small Shafranov shift and high values of the equilibrium ß. Using the BETA-code /8/, a finite-ß equilibrium in a 5-period modular Heliac was calculated. At $\langle \beta \rangle$ = 5.3 % a small Shafranov shift of 10 - 20 % of the plasma radius occurred /9/.

Fig. 1: CONVENTIONAL HELIAC

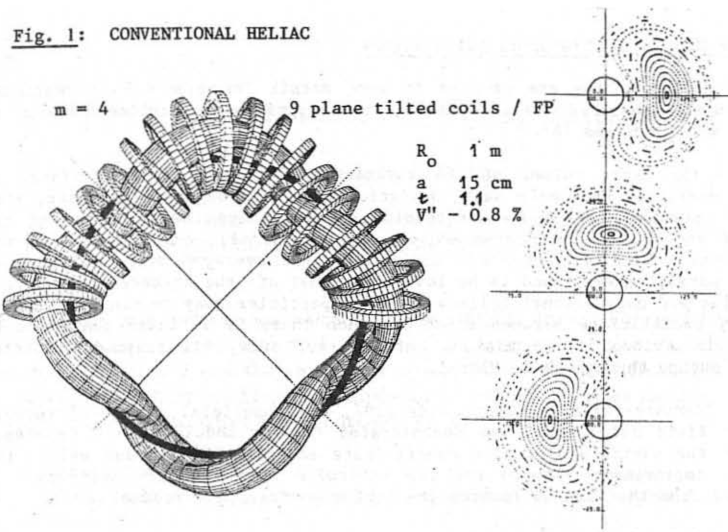
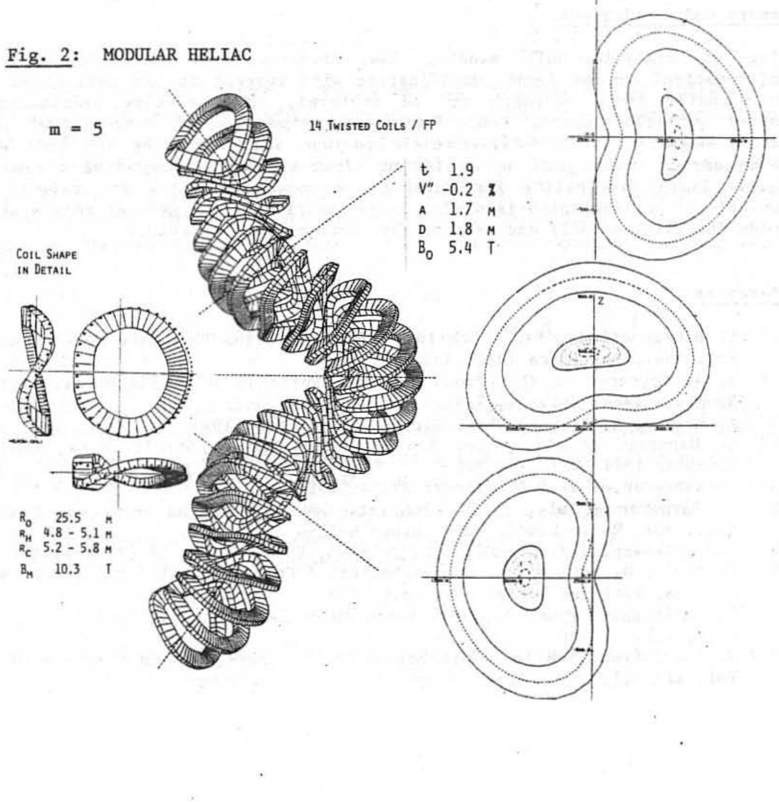


Fig. 2: MODULAR HELIAC



Particle Orbits and Transport Calculations

Guiding center orbits are studied in more detail for a m = 8 conventional Heliac with reduced field modulation, in comparison to earlier results of modular m = 5 systems /6/.

Due to the large values of the rotational transform, drift surfaces of passing particles show only small deviations from the magnetic surfaces, with maximum (minimum) offset in the toroidal planes where the direction of the toroidal and helical curvatures are opposite (parallel), respectively. In the configuration with reduced field modulation, the averaged drift velocity of trapped particles was found to be lower than that of the standard case. Both, in modular and conventional Heliacs, trapped particles stay on confined orbits for many oscillations between mirrors. Since there is a finite chance to be trapped in a local field minimum between two coils, all trapped particles finally escape through this channel.

Using a 3D-Monte-Carlo transport code /10/, the beneficial effect of reduced magnetic field modulation was demonstrated /6/ for modular m = 5 systems. Although the particle diffusion coefficients exceeded the plateau value, the relative improvement between the two otherwise nearly equal configurations increased from the plateau towards the long mean-free-path regime.

Summary and Conclusions

Using an analytic coil winding law, modular coil sets for Heliac configurations can be found. Optimization with respect to the modulation of the magnetic field strength can be achieved, thus reducing neoclassical trapped particle losses. Comparing field properties of conventional and modular Heliacs with m = 4...8 field periods and increasing the coil and plasma aspect ratios with m, so far no clear preference regarding m can be stated. Large flexibility for varying the parameter range is present in conventional heliacs which is useful in an experiment. The modular coil system avoids interlinked coils and thus appears more reactor relevant.

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