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Received by OSTI

SEP 28 1988

Panel on High Beta and/or High Field Tokamaks and Stellarators*

CONF-880967--1

DE88 017367

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Presentation to Fusion Power Associates Meeting
Santa Fe, New Mexico, September 1988

For many years it was believed that conventional stellarators, with a circular axis, were inherently low beta devices. The reasoning behind this conclusion was simple. The equilibrium beta limit is small at low plasma aspect ratio, and increases with increasing aspect ratio, see figure 1. As the beta is raised, the increasing plasma pressure gradients drive currents which modify the magnetic field in a deleterious or inadequate way to handle the increased pressure, ultimately inducing instability. Perversely, the stability limit increases with decreasing aspect ratio, because of a deepening of the magnetic well. Thus it was concluded that the maximum beta would be at some intermediate aspect ratio, generally large, at which equilibrium and stability gave the same limit. This result was in large measure due to the use of models which studied the equilibrium and stability by expansion of the magneto-hydrodynamic (MHD) equations in a large aspect ratio approximation. Within the framework of modern economic studies [1], such a large aspect ratio device, R/a ~ 20 and beta of 3-4%, would not be economic unless very high magnetic fields were used. This realization prompted a re-evaluation of the stellarator using less constrained MHD equations, and less conventional configurations, which would have simpler coils (see Figure 2). Two basic approaches to obtaining reactor relevant configurations emerged:

* It was found that, through careful design of the coils, a torsatron could have a high equilibrium beta at moderate aspect ratio R/a ~ 4-10. A torsatron [2] or heliotron [3] is a device in which two helical coils, carrying current in the same direction, enclose the plasma, while poloidal coils are used to adjust the equilibrium, see Figure 3. At the same time the profile of rotational transform (the ratio of poloidal to toroidal field) could be shaped to put the major rational surfaces in regions of either a deep well or strong magnetic shear. In a rational surface the field lines close after traversing the torus an integer number of times, e.g., twice toroidally, and once poloidally. Such regions are susceptible to the growth of perturbations having the same structure. A magnetic well and a strongly changing twist of the field lines with changing radius - shear - act to inhibit such growth. In these modern torsatrons, the plasma pressure induced currents, they act to deepen the magnetic well rapidly enough to handle the increasing beta, thereby offering access to a higher beta in the second stable region [4], see Figure 1b. The ATF device at ORNL [5] is the first torsatron built to study second stability. It is designed to extend the work of the earlier Heliotron-E, which has already achieved 2% volume average beta, into the 5-8% beta region.

* An alternative approach makes use of what is in effect a single helical coil. The helical axis of such devices leads to a low or zero toroidal shift when the pressure is raised, negligible plasma driven currents, and low or zero shear in the magnetic field. The magnetic geometry

*Research sponsored by the Office of Fusion Energy, U.S. Department of Energy, under Contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

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does not change much with increasing pressure. In many ways such devices look like a straight system, but they have a magnetic well due to the helical effect.. Examples are the heliac (6) and the helias (7). New experiments to test these principles include the Sheila, and H-1 flexible heliacs at Canberra University in Australia, and the Wendelstein VII-AX, helias, being studied at Garching in West Germany.

In the next few years the stellarator program is looking forward, to substantial advances in the understanding of MHD phenomena, and to raising beta into the reactor range.

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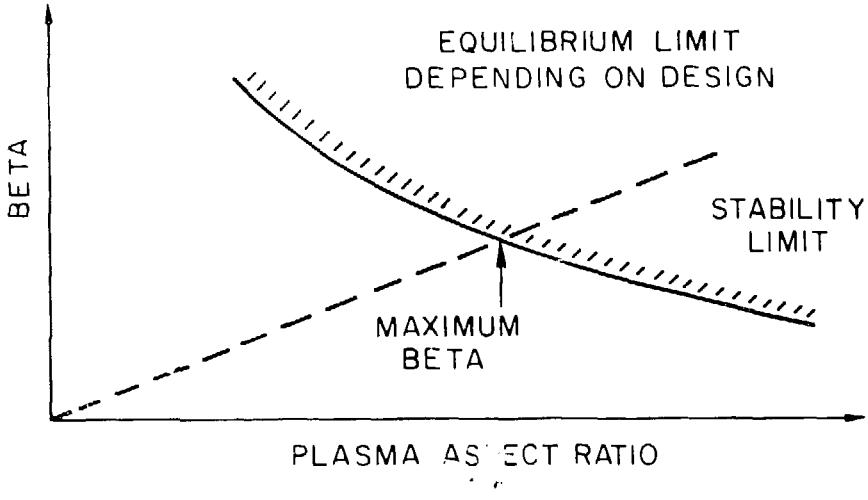
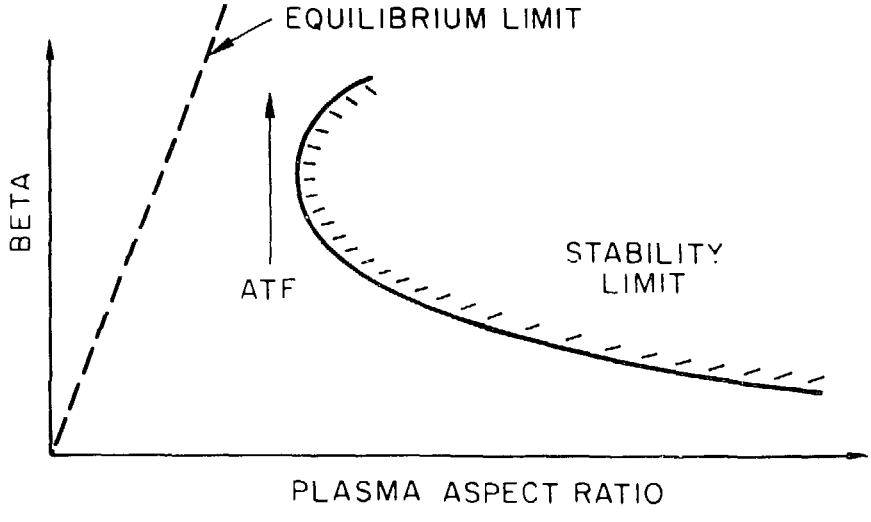
STELLARATOR BETA LIMITS – REVISITED

"TRADITIONAL"

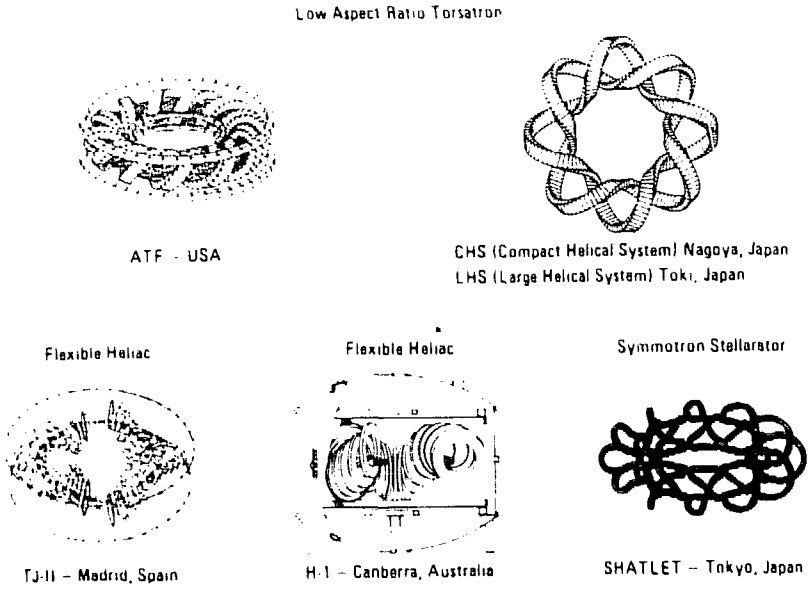


1a. Conventional view of equlibrium and stability limits to beta in a stellarator.

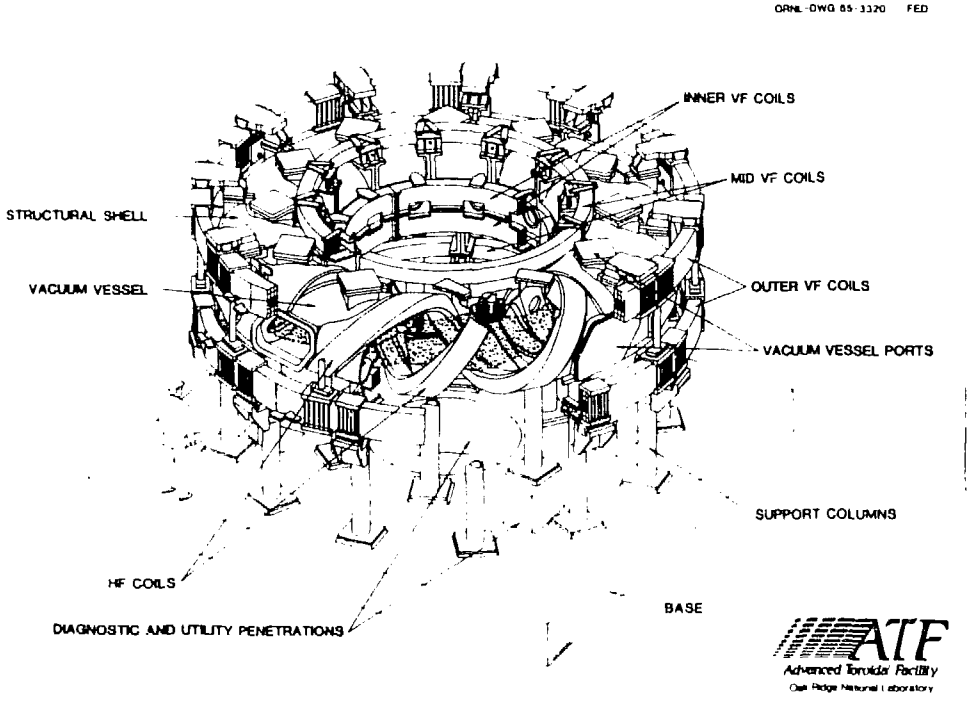
"OPTIMISED"
SHAFRANOV (KURCHATOV)



1b. Access to second stable beta region in a low-aspect-ratio torsatron.



2. Some of the stellarator concepts being studied in the world fusion program.



3. The Advanced Toroidal Facility at ORNL.