stellarator news

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TJ-II assembly completed

The TJ-II team is very happy to announce to *Stellarator News* that on Friday, 5 October, the last coil of TJ-II was installed, finalizing TJ-II coil assembly. At this point the central coil system (called the hard core), the poloidal field coils, the toroidal field coils, the vacuum vessel, and the general support structure are in their final position.

The intense assembly phase began in the summer of last year with the positioning of the hard core and the four lower octants of the vacuum vessel. From September 1995 until April 1996, the upper octants were assembled and welded together. After the vacuum vessel had passed vacuum tests, the toroidal field coils were assembled in July and August 1996. At the beginning of October, the outer rings of the general support structure, which carry the outer poloidal field coils, were installed.

During the months ahead, the peripheral systems will be installed. The installation of the four vacuum pumping systems will be done in November 1996. Each of the four pumping units consists of a turbopump and a forepump. The vacuum tests of the vacuum vessel done in June 1996 showed very good vacuum properties and a very low leak

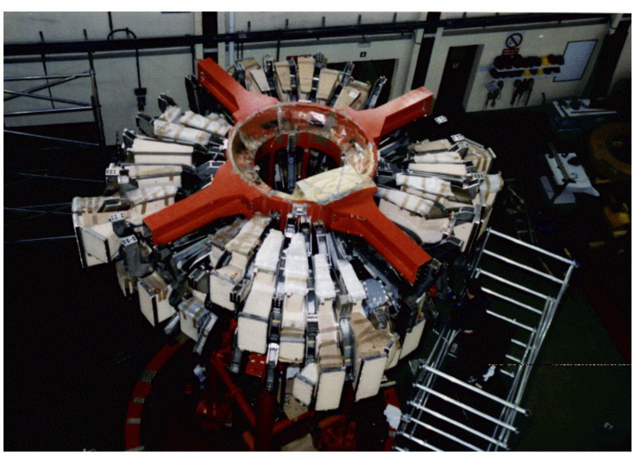

Fig. 1. The helical structure of the TJ-II vacuum chamber can be appreciated in the distribution of the 96 experimental ports

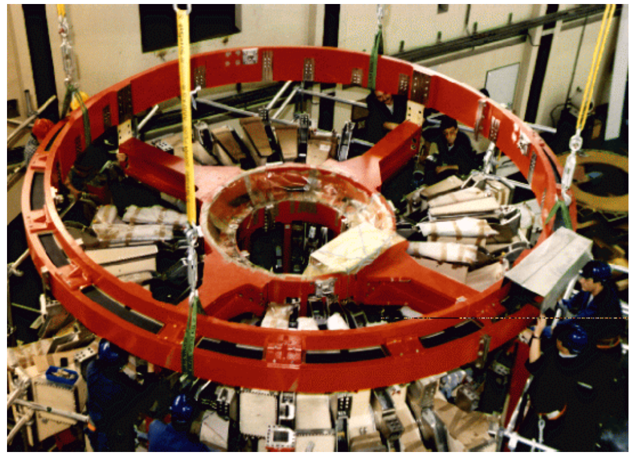

Fig. 2. The picture shows the moment when the outer ring of the support structure holding the vertical field coil was placed in position, completing the coil assembly.

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rate (a global leak rate as low as 1×10^{-9} mbar·L/s was measured with just one pump). The connection of the coil systems to the cooling system will be finished in December 1996. The cooling plant itself was commissioned last year. The assembly of the high-power lines in the torus hall is planned for January and February 1997.

The installation of the power supply system commenced only in August of this year because of the delayed availability of the building for this system. Meanwhile all the thyristor converters and the transformers have been put in their position. The no-load breakers and the high-current cables from the experimental site and the site of the power supply have been mounted. In January 1997, the assembly of all the main components, including the motor generator, will be finished. First tests of the power supply system with a DC dummy load are planned for February 1997.

The magnetic field mapping for TJ-II will be performed in January 1997. As the direct currents required for this measurement are rather low, we will supply the magnetic field coils of TJ-II by DC converters fed directly from the grid. The first half of 1997 will be used for the commissioning of the power supply system and the entire experimental device. The first plasma can be expected in summer 1997.

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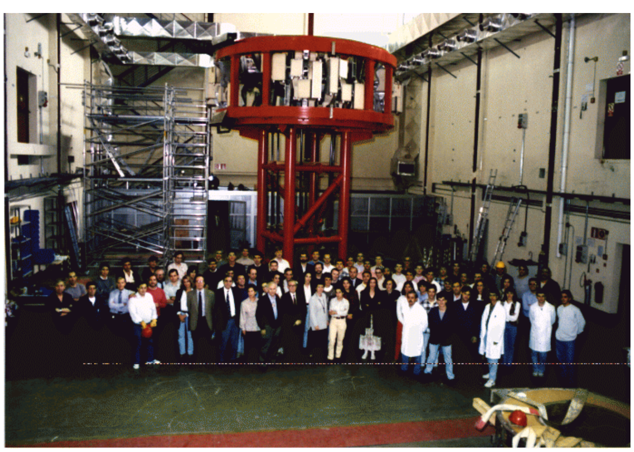

Fig. 3. The TJ-II team standing below TJ-II. An experimental platform beneath TJ-II is presently being installed.

Spherical Stellarator concept

The Spherical Stellarator (SS) concept, proposed in Ref. [1] and further analyzed in Refs. [2–5], represents a novel and promising approach in stellarator research. The three principal characteristics of the SS approach are (a) ultra-low aspect ratio, in the range of $A \sim 1.2$–3.5, (b) relatively simple modular coils, and (c) significant plasma current (i.e., its contribution to the total rotational transform is significant). Our research indicates that the SS concept features many attractive properties of importance to a future fusion reactor. Among these are the following:

- Compact design, making it inexpensive to construct and operate
- Easy access to the plasma
- Simple, toroidally symmetric divertor
- Strong bootstrap current enhancing the vacuum rotational transform
- Good control over the horizontal plasma position and magnetic axis location
- High-beta regimes of operation
- Good particle and energy transport at high beta
- Enough space to install a blanket and to protect the coils (including their central parts) from intense fluxes of particles, heat, and neutrons
- Easy plasma start-up
- No need, in principle, for the ohmic current transformer or for an auxiliary current drive (CD) system

The three principal characteristics of the SS concept are rather unusual for a standard stellarator approach, which normally features a large aspect ratio, $A \sim 10$, complicated three-dimensional (3-D) coils, and an almost currentless plasma.

The SS concept can be viewed as a synthesis of the two leading concepts for magnetic plasma confinement: stellarators and tokamaks. Tokamaks normally feature much lower aspect ratios than stellarators, much simpler planar coils, and a strong plasma current. This is especially true for the relatively recently proposed concept of the Spherical Tokamak (ST), which promises to be more compact, less expensive, less disruptive, capable of achieving higher β, etc., than a standard tokamak. The SS concept appeared partially to overcome some severe problems of ST such as: problems of plasma startup (for an ST-ractor, the central ohmic current transformer cannot be used), problems of long-pulse or steady-state operation, problems of the central post, and danger of a large plasma current.

The plasma current can be supplied in an SS by the bootstrap effect alone [3,4] in a relatively large device with high beta. However, in relatively small initial experiments, the bootstrap current will be small and other

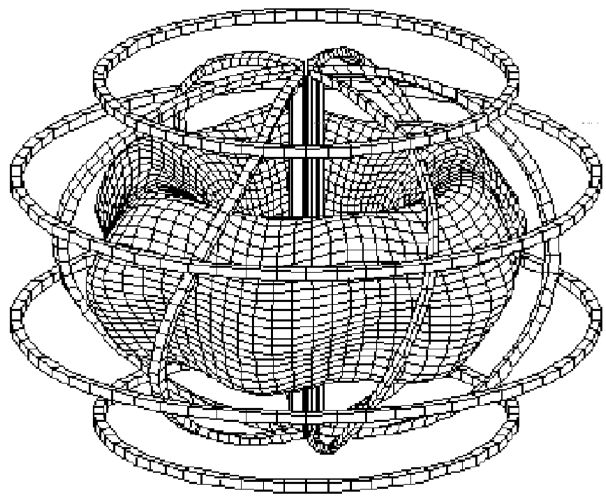

Fig. 1. Configuration of an SS as given in Ref. 1. Shown are the coil system and the last closed vacuum flux surface.

means to excite the plasma current, such as ohmic or auxiliary CD, will be necessary. Such a device will be a stellarator-tokamak hybrid.

Different SS-type devices are under investigation [6] as part of the SMARTH (SMall Aspect Ratio Toroidal Hybrid) project. Present participants are ORNL, the University of Texas at Austin, Auburn University, the University of Tennessee, and the University of Wisconsin. Many scientists from other institutions have been helping us by giving good advice and comments and by supplying their numerical codes or the results of calculations.

This contribution documents the results obtained for the original SS configuration of Ref. 1 (see Fig. 1) with bootstrap current added [3,4]. The size of the device and the plasma parameters are chosen to correspond to the SS2 device of Ref. 4: a_p = 1 m, R_0 = 2 m, B_0 = 1 T, $n_e = 10^{20}$ m^{-3}, T_e = 1 keV, β = 7.5%, I_{bs} = 0.9 MA, P_{heat} = 30 MW. In such a device, according to bootstrap current calculations and to the Large Helical Device (LHD) scaling law, it is possible to reach good plasma parameters without ohmic or auxiliary CD.

Figure 2 shows the radial profile of the vacuum rotational transform (ι) together with its internal (inboard) and external (outbord) components [1] as well as the total rotational transform. One can see that the bootstrap current contribution is significant.

Figure 3 demonstrates the results of Monte Carlo simulations for 640 test protons with energy E = 1 keV in this device. No radial electric field was applied. The simulation time was chosen to be two collision times. The Boozer coordinates are used, so a concentric circle with a normalized radius, ρ, represents a flux surface with the corresponding average normalized minor radius. The density and temperature radial profiles have been chosen to

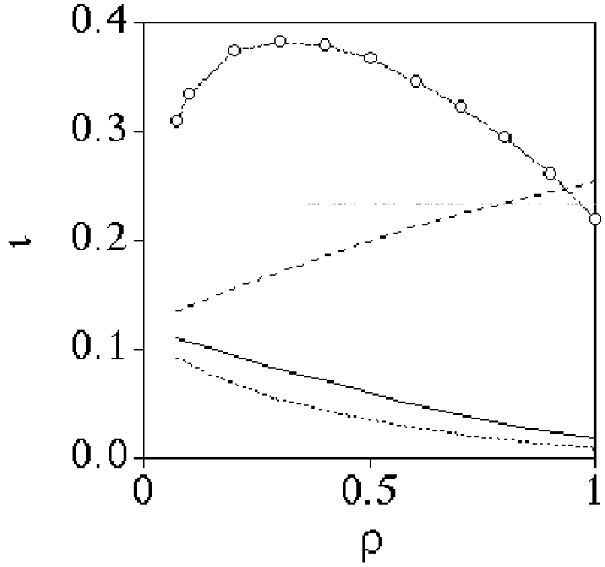

Fig. 2. Radial variation of the vacuum rotational transform (solid curve) and its external (dashed) and internal (dotted) components. The total rotational transform for the case with strong bootstrap current is shown by the curve with circles.

be parabolic. Figure 4 shows the statistics of particle distribution over the flux surfaces for the same case.

Similar calculations were carried out for ions and electrons and for different minor radii. For comparison, calculations have been carried out also for an equivalent tokamak, i.e., for an axisymmetric plasma with the same minor and major radii and the same temperature and density, but with the rotational transform of a typical tokamak: $\iota(\rho) = 1 - 2\rho^2/3$. The results, shown in Fig. 5, indicate that neoclassical diffusion coefficients near the plasma edge in an SS are almost the same as in a

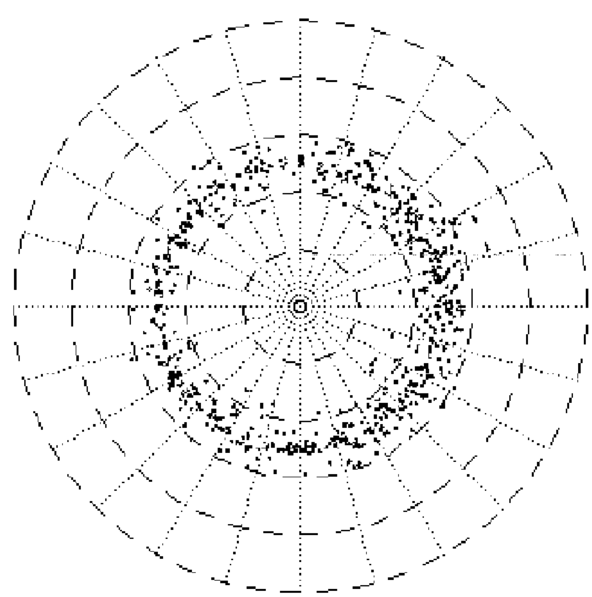

Fig. 3. Final locations of 640 test protons. The starting radius is ρ = 0.5.

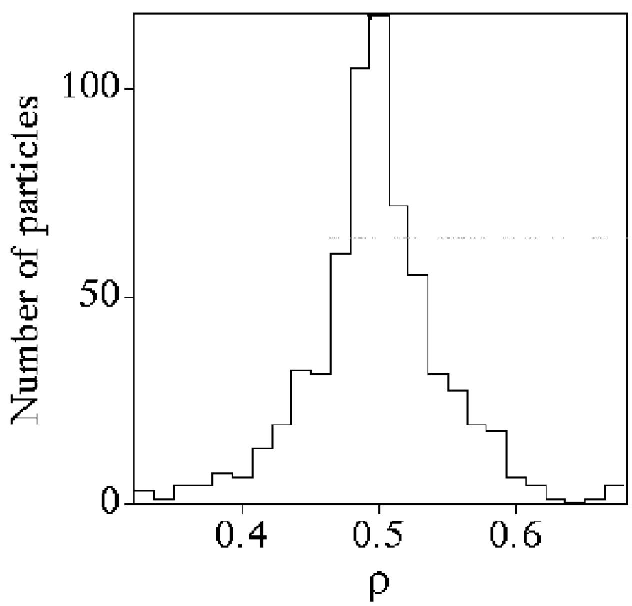

Fig. 4. Distribution of protons over the flux surfaces.

tokamak, while near the magnetic axis diffusion in an SS is somewhat larger. This is a very promising result, showing that transport in SS might be almost as good as in a tokamak and that a transport barrier exists at the plasma edge.

Another important result (the detailed description will be given elsewhere) was obtained at our request by W. A. Cooper running his code TERPSICHORE [7] for ballooning and Mercier stability criteria. His calculations for the SS configuration considered here, for a volume average beta $\langle\beta\rangle = 7.5\%$ and a hollow current profile, show 3-D ideal MHD stability at all radii.

In conclusion, SS research has only recently begun, and the particular SS configuration discussed here is probably far from optimal. Still, it demonstrates several attractive features. We see the SS approach as an unexplored area of magnetic confinement with the potential to develop physics which might provide significant advantages for a future thermonuclear reactor. A broad base of coherent theoretical and experimental research is necessary for advancing this novel concept to its full potential.

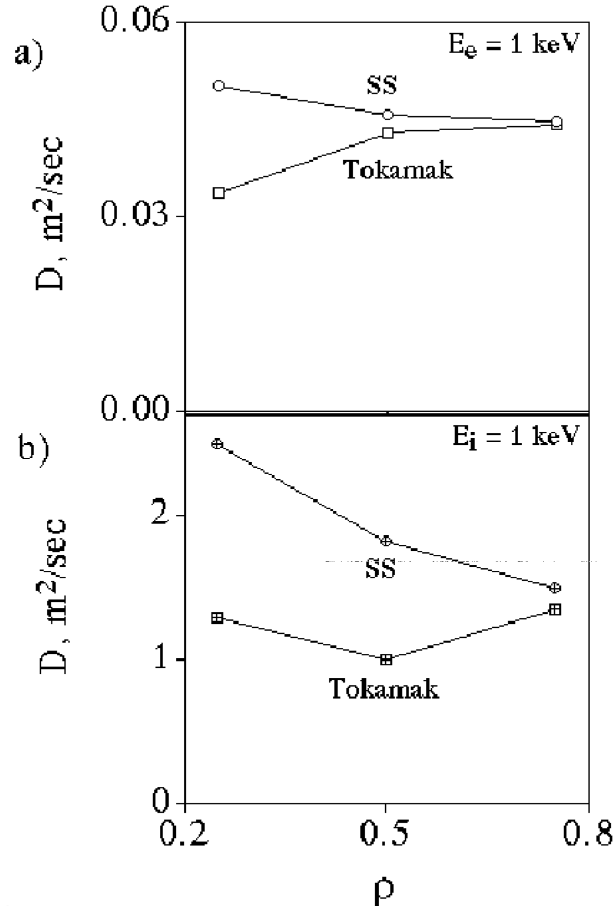

Fig. 5. Comparison of diffusion coefficients for (a) electrons and (b) protons in an SS and in an equivalent tokamak.

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