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NCSX review success

The National Compact Stellarator Experiment (NCSX) passed a crucial milestone in May 2002, with the completion of a successful Conceptual Design Review. The review was conducted by a panel of distinguished experts from the fusion community and the U.S. Department of Energy (DOE): David Anderson (U. Wisconsin), Paul Anderson (General Atomics), James Carney (DOE), Martin Fallier (Brookhaven National Laboratory), Jöst-Henrich Feist (IPP-Greifswald), Jeffrey Harris (Australian National U.), Clarence Hickey (DOE), Jeffrey Hoy (DOE), Joseph Minervini (Massachusetts Institute of Technology), Ronald Parker (Massachusetts Institute of Technology), Peter Politzer (General Atomics), Ray Schwartz (DOE), and Harold Weitzner (New York U.).

The panel examined all aspects of the NCSX project—physics; engineering; cost; schedule; environment, safety, and health; and management. In their closeout briefing, the panel members reported that they were very impressed with the quality of the work that had been done, the close integration of physics and engineering, and the close integration of the Princeton Plasma Physics Laboratory (PPPL) and Oak Ridge National Laboratory (ORNL) team. They found that the project has made excellent progress in resolving comments from the 2001 physics validation review pertaining to design and fabrication. They found the engineering design and the cost and schedule estimates to be well developed for the current stage of the process, and made valuable suggestions aimed at streamlining the fabrication process. They concluded with a recommendation that the NCSX go forward to the next DOE decision point, CD-1, which will permit project funds to be expended on NCSX, starting this October.

The NCSX, a national project managed by a partnership between PPPL and ORNL is the lead element in a U.S. program to develop the knowledge base for compact stellarators. Its mission is to acquire the physics knowledge needed to evaluate the compact stellarator as a fusion concept and to advance the understanding of three-dimensional plasma physics for fusion and basic science. In 2001, the NCSX passed a DOE physics validation review and was endorsed by the U.S. Fusion Energy Sciences Advisory Committee (FESAC) as a proof-of-principle experiment. In its Congressional budget submission for FY 2003, DOE has requested $12M for the first year of project funding. The fabrication project is planned to start in October 2002 and finish in June 2007 at a cost of $73.5M. The facility will be sited at PPPL.

Details of the NCSX Conceptual Design Review can be found at

http://www.pppl.gov/ncsx/Meetings/CDR/NCSX_CDR_index.HTML

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In this issue . . .

Configuration scans and magnetic fluctuation studies in the H-1NF heliac

Introduction

The goal of experiments with the heliac configuration is to study plasma confinement phenomena at rotational transform (denoted by ι without the historical bar) $\iota > 1$ with an average magnetic well. The flexible heliac [1] was designed to permit fine control of the rotational transform profile by incorporating a helical control winding. In the case of H-1NF ($R = 1$ m, $\langle r \rangle \sim 0.2$ m, $B_0 \sim 1$ T, $N = 3$), optimum magnetic surfaces can be produced in the range $1 < \iota < 2$ by varying the ratio of the helical winding current to the circular coil current (κ_h) while keeping the other currents fixed. Variation of the vertical field coil current relative to the circular coil current (κ_v) changes magnetic well, and also changes the transform profile, but over a much smaller range of ι, as shown in Fig. 1. The profiles in Fig. 1 were computed using the HELIAC code [2, 3].

A newly installed computer-controlled magnet power supply permits precise control of the coil currents to within better than 1 part in ~10,000. With this system, we are able to control the ratio of the coil currents (e.g., κ_h) to within 0.1%, thus allowing us to explore the role of resonances in the rotational transform. In the present experiments, the heliac plasmas were produced using 50–60 kW of 7-MHz ion cyclotron resonant heating (ICRF) in a 3:2 H:He mixture at $B_0 = 0.5$ T. The ICRF antennas are conformal helical picture-frame coils located 3–4 cm outside the last closed flux surface [4].

Magnetic probes in H-1NF

Several sets of magnetic coils have been used in H-1NF. The coils have a diameter of 6 mm and either 50 or 100 turns. The results presented here were obtained using a radially scanning probe. This probe has 2 degrees of freedom (radial translation and rotation about the probe axis), and has coils oriented radially and tangentially to the flux surfaces. The coils are mounted inside a 1-cm-diam. glass tube that is inserted through a gate valve into the vacuum vessel.

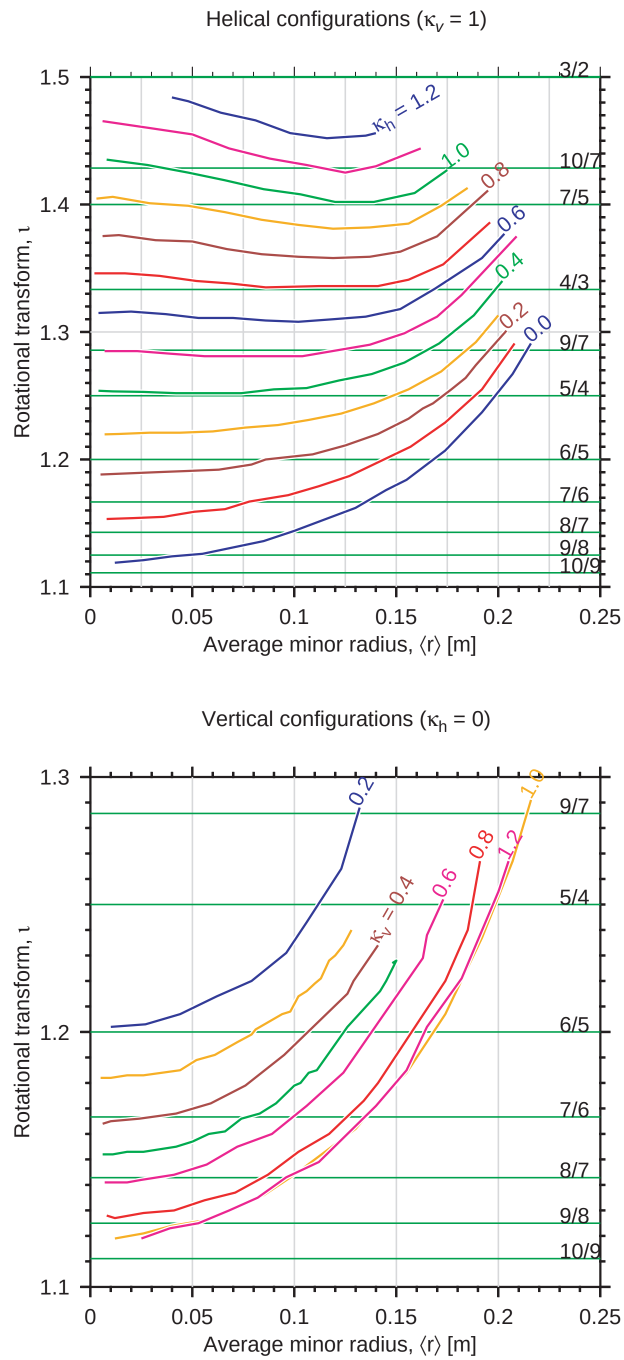

Fig. 1. Variation of ι profiles with configuration.

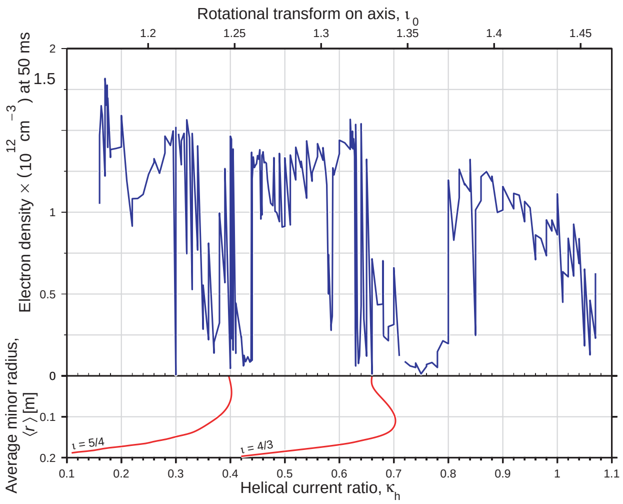

Fig. 2. Configurational dependence of electron density, showing locations of low-order rational surfaces.

Results of configuration scans

Behavior of plasma density and magnetic fluctuations in κ_h scans

Experimental scans of rotational transform were performed by varying κ_h over the range 0.1 to 1.1, which varies the rotational transform on axis from about 1.1 to just under 1.5, as shown in Fig. 1. The toroidal magnetic field, ICRF heating power, and gas fill were held constant for these experiments. Note that the plasma size remains nearly constant over the range $1.15 < \iota < 1.4$; thus, the separation of the plasma and the ICRF antennas also remains nearly constant.

Line-averaged plasma densities were measured using a 2-mm microwave interferometer. Detailed temperature measurements are not available for this sequence of discharges, but spot measurements using Langmuir probes and spectroscopy indicate that both the electron and ion temperatures are in the range of 10–40 eV.

To compare confinement at different values of κ_h, the line-average density at a reference time of 50 ms is plotted as a function of κ_h in Fig. 2. Since the pressure in these discharges is quite low ($\beta < 0.1\%$), finite-pressure effects on ι profiles (Fig. 1) are assumed to be negligible, and vacuum rotational transform profiles are used for reference.

The data show a series of peaks and valleys at particular values of κ_h In the figure, the largest gaps correlate approximately with the low-order resonant values of rotational transform $\iota = 5/4$ and 4/3. Here central values of ι are used for simplicity because of the low shear of the configuration. It is tempting to identify other valleys with higher order resonances. Results at various magnetic fields (±10%) confirmed that the features are related to κ_h values rather than to $|B|$. We interpret this as an indication that particle confinement effects were more important here than plasma generation effects.

Magnetic fluctuation data were also taken during the configuration scan. Cross-power spectral techniques [5] were used to measure spectra and relative phases. Fluctuations measured by external probes had magnetic components of order 100 mG, which corresponds to $\sim 2 \times 10^{-4}\ B_0$. In most of the configurations studied, the magnetic fluctuations show transitions in spectral characteristics which are correlated with small changes in density. The fluctuation spectra exhibit coexisting modes, coherent harmonics, and periodic variations in frequency outside the resonant dips, and have only low-frequency ($f < 20$ kHz) broadband signals within the resonant regions.

Radial scans of magnetic fluctuations

The scannable magnetic probe system was used to measure magnetic fluctuations inside the plasma. For these experiments, a scan of vertical magnetic field ($0.6 < \kappa_v < 1.2$) was used. Measurements of density and magnetic signals from a *fixed*, *external* probe were used to show how insertion of the scannable probe affects the plasma. When the probe tip is inserted to $\langle r \rangle_{probe} < 0.1$ m, the density drops significantly (10% or more) for all configurations in the scan, and the magnetic fluctuations measured by the external probe steadily increase with insertion depth. Thus, we conclude that only the data for $\langle r \rangle_{probe} > 0.1$ m can be considered to be minimally perturbed by the probe.

The radially oriented probe signals show a peak in fluctuation amplitude at $\langle r \rangle_{probe} = 0.11$m for $\kappa_v = 0.6$, which shifts outward as κ_v increases. This is consistent with the predicted movement of the transform profile, in particular, of the $\iota = 7/6$ rational surface. This conclusion must be treated with caution, because the shift is small and there is a possibility of probe perturbations. The profile of the poloidal component of fluctuations shows no clear trend with κ_v.

Figure 3 shows a typical density profile for the "standard" configuration ($\kappa_h = 0$, $\kappa_v = 1$) measured with the multichord far infrared (FIR) interferometer [6–8] plotted with the radial component of magnetic fluctuations (arbitrary magnitude scaling) measured with the scannable probe. At present, the density profile measurements do not quite extend to the location of the peak in magnetic fluctuations, but it is evident that there is a significant density (and presumably pressure) gradient in the region of the fluctuation peak.

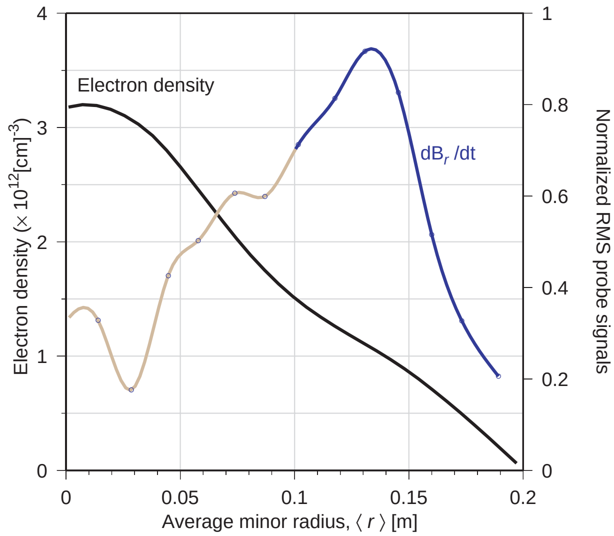

Fig. 3. Electron density and dB_r/dt vs radius for the standard configuration ($\kappa_h = 0$, $\kappa_v = 1$). The brown line denotes the region where the probe significantly perturbs the plasma ($\langle r \rangle_{probe} < 0.1$m).

Summary and discussion

The experimental results can be briefly summarized.

- The effectiveness of particle confinement is a strong function of rotational transform, with evidence of resonant structures near rational values. This behavior is quite similar to that seen in the Wendelstein series of low-shear stellarators with $\iota < 1$ [9]. There are also some broad similarities with experiments in the tabletop SHEILA heliac [10], which showed the effects of very low order resonances (e.g., $\iota = 3/2$) but not higher order resonances, probably because of finite Larmor radius effects.
- The magnetic fluctuation spectra change qualitatively and dramatically as the transform is varied. This is also suggestive of resonances.
- Radial scans show that the magnetic fluctuation amplitudes that peak inside the plasma are near two-thirds of the minor radius, i.e., in the gradient region, and/or nearby the 7/6 resonance.

These observations complement the results from the TJ-II heliac [11] (which is about 1.5 times larger than H-1NF and operates at higher magnetic field and heating power), where bursts of magnetic fluctuations (thought to be $m = 3$, $n = 2$) are observed on external Mirnov coils prior to edge-localized mode (ELM) events that change the transport properties and pressure profile in the outer region of the plasma.

Future experiments to repeat these studies at higher power operation with 200 kW of ICRF and 200 kW of 28-GHz second harmonic electron cyclotron heating are now beginning. More extensive magnetic probe arrays are now being installed on H-1NF; these will permit detailed measurements of mode numbers and amplitudes. Systematic studies of density and temperature profile behavior in configuration scans (including profiles in the outer part of the plasma) are now beginning with the aim of determining the source of the observed fluctuations.

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