stellarator news

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Editor: James A. Rome Issue 140 April 2013
E-Mail: jamesrome@gmail.com Phone (865) 482-5643

Plasmas of an arbitrary degree of neutrality confined in a stellarator

Non-neutral plasmas have been traditionally confined in Penning-Malmberg and purely toroidal traps. However, stellarators can also confine non-neutral plasmas, and the confinement of pure electron plasmas has been extensively studied using the Columbia Non-neutral Torus (CNT) stellarator since 2004 [1]. Indeed, stellarators present some advantages and flexibility for the study of non-neutral plasmas. A stellarator can confine plasma even in the absence of significant space charge (in contrast to purely toroidal traps), can confine both signs of charge simultaneously (unlike Penning traps), and does not require large internal currents for confinement (in contrast to tokamaks). Thus, plasmas of an arbitrary degree of neutralization (ranging from pure electron to quasi-neutral) can be confined in a stellarator. A recent paper [2] shows that it is experimentally possible to create, sustain, and study plasmas at any degree of neutralization in a stellarator. This represents a first step in the characterization of plasmas of arbitrary degree of neutrality.

Steady-state plasmas are created in CNT by thermionic emission. In non-neutral plasmas, confinement is limited by a rather low density limit [3, 4]. In CNT, a typical pure electron plasma created using a filament biased at $\phi_e = -200$ V held on the magnetic axis is characterized by $n_e \approx 3 \times 10^{12}$ m^{-3}, and T_e ranging between 2 eV and 7 eV. This implies that many Debye lengths of pure-electron plasma are confined in CNT.

The emitter filament creating the plasma and the probes for diagnostics are mounted on alumina rods held inside the plasma. These ceramic rods charge negatively with respect to the plasma and act as steady-state sinks for ions [5]. Thus, the degree of neutralization of the plasma in CNT can be varied continuously between pure electron and quasi-neutral by adjusting the neutral pressure in the chamber, which determines the steady-state balance between volumetric ionization of neutrals and recombination on the rods.

The physics of the detected fluctuations at the two extremes of the neutralization scale is completely different. Quasi-neutral plasmas in CNT develop spontaneous oscillations driven by density gradients (drift waves). The observed global mode presents an approximately offset linear relationship with E/B, and a small local phase shift between density and potential oscillations. Measurements with a set of capacitive probes and a high-speed camera show that these oscillations are almost perfectly aligned

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with the magnetic field lines and present a resonant m=3 poloidal structure.

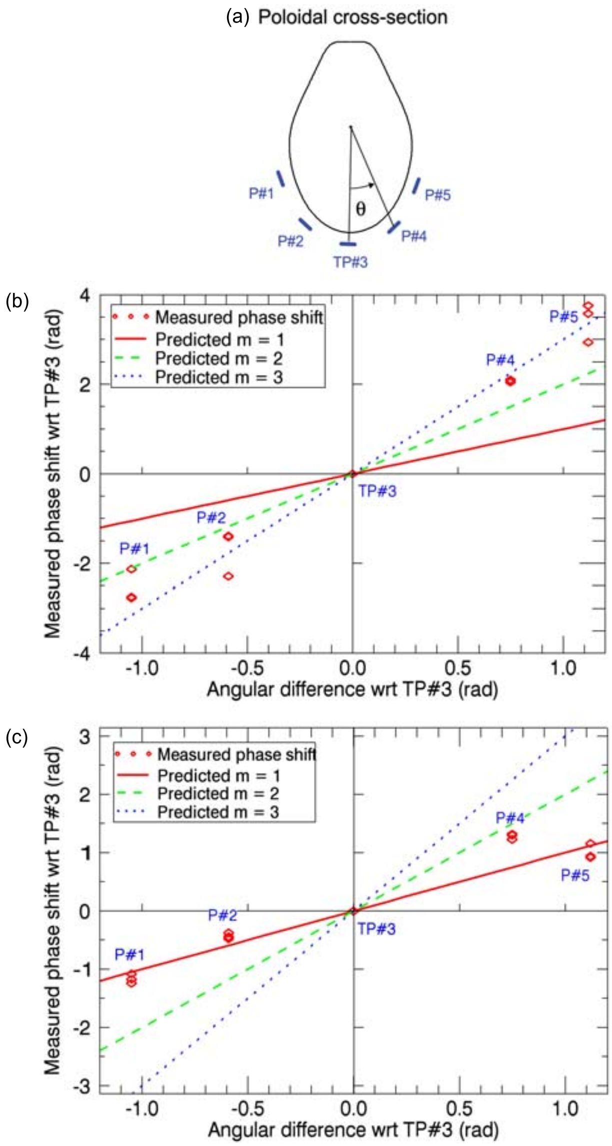

Fig. 1. (a) Layout of the array of capacitive probes around the poloidal cross section of the plasma. (b) and (c) show respectively the measured phase shift of the oscillations detected in quasi-neutral and electron-rich plasmas using these probes. TP #3 is used as the phase reference.

At the other extreme of the neutralization scale, the physics of the unstable fluctuations in electron-rich plasmas with a small but non-negligible amount of ions is dominated by electrostatics. The observed mode presents a non-resonant m=1, n=0 spatial structure under exactly the same magnetic configuration (as the quasi-neutral case), which has an almost flat ι profile, $\iota \approx 1/3$. First observations of these oscillations were reported by Marksteiner in Ref. [6]. The behavior of this mode is identical to the ion-driven instability detected in Penning traps [7] and purely toroidal traps [8]. However, such a spatial structure in a stellarator implies that the instability breaks the parallel force balance (even in the presence of low order rational magnetic surfaces), and the poloidal magnetic flux is not conserved. Figure 1 compares measurements of the poloidal structure of the mode observed in CNT's quasi-neutral plasmas (b) with the mode detected in electron-rich non-neutral plasmas (c). Partially neutralized plasmas lying between these two extremes of the neutralization scale present broadband behavior.

X. Sarasola and T. Sunn Pedersen
Max Planck Institute for Plasma Physics
EURATOM Association,
Wendelsteinstr. 1, 17491 Greifswald, Germany

Deptment of Applied Physics and Applied Mathematics, Columbia University, New York, NY 10027, USA

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Wendelstein 7-X news

Continuous heat flows are a challenge for the in-vessel components of the Wendelstein 7-X (W7-X) stellarator, which is under construction in Greifswald, Germany. For experiments with 30 min duration, as planned for W7-X, a discharge corresponds to 200–2000 conventional pulses. Therefore the relevant W7-X components must be continuously water-cooled. Eighty ports (one third of the ports on W7-X) are used to feed water pipes into the plasma vessel. Inside the plasma vessel, 4 km of piping will be installed. Accurate predictions for the expected thermal load are critical for the design of these components, in particular for the divertor. The 10 divertor modules are designed for a continuous heat load of 10 MW/m^2 occurring in footprints of the plasma with a poloidal width of about 10 cm (half width around 5cm) and 150 cm in toroidal length. This load is about 20 times higher than usual in heat exchangers used for conventional power plant technology. It is also higher than the load placed on the edges of the wings of the space shuttle when it re-enters the atmosphere—6 MW/m^2 for "only" several hundred seconds. Figure 1 shows the geometry of these W7-X components. Figures 2 and 3 are photos of some of the actual components.

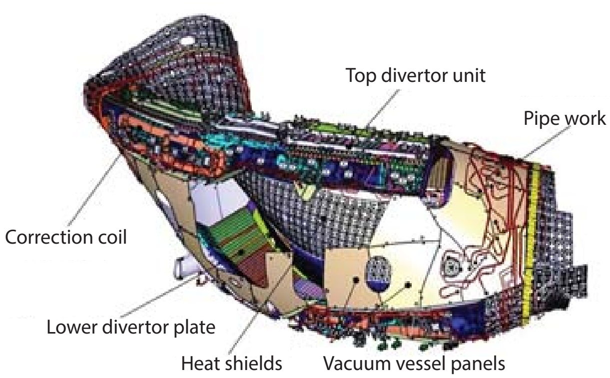

Fig. 1. In-vessel components for one of five modules: top and bottom divertor modules, baffle modules, heat shields, and stainless steel wall panels, the latter for the lower loaded areas of the wall. Protection structures for the ports will be installed in the plasma vessel also but are not shown for clarity. A complex system of cooling water supply lines for these elements uses 80 of the ports. Additionally, control coils and cryopumps and diagnostics are integrated in the divertor as well as in and behind the first wall elements; altogether, the 2500 in-vessel components comprise about 710,000 parts. Graphic: IPP, Jean Boscary

As a result of these cooling issues, Wendelstein 7-X will go through two different operating phases. For the first phase with short pulses of 5 to 10 s, a temporary test divertor unit (TDU) with inertially cooled copper plates coated with graphite tiles will be installed. This TDU allows precise measurements of the local thermal loads for all important operating scenarios. These measurements form the basis for optimization of the water-cooled target modules of the high-performance heat exchanger. After about 2 years of operation, the test divertor will be replaced by the actual high-heat-flux (HHF) divertor, this shutdown being scheduled to last another 2 years. The HHF divertor consists of 890 elements with tiles made of 8 mm thick carbon-fibre-reinforced carbon which are connected to water-cooled metal blocks by means of a patented process. Serial production of these elements is going on and their installation is scheduled for 2017.

Fig. 2. Heat shields at higher loaded parts of the wall (local design heat load 500 kW/m^2, average load 250 kW/m^2) during installation in the plasma vessel of W7-X. The water-cooled CuCrZr heat sinks of the shown heat shield segment are not yet covered by their graphite tiles. Photo: IPP, Torsten Bräuer

Fig. 3. Wall protection prepared for a port to be used for neutral particle heating. Photo: IPP, Robert Haas

Status of Wendelstein 7-X:

In-vessel components: Most of the in-vessel components have already been delivered to Greifswald, and in-vessel assembly including also diagnostic components and cable routing has started. To attach the different components, 1200 bolts and brackets are being welded to the vessel wall in each module using a positioning robot. First experience with assembly of the in-vessel components themselves shows that the detailed adaptation to the vessel shape is rather time consuming.

Vacuum vessel: The assembly of the plasma vessel modules has been completed, and the connection of the modules with each other is proceeding as scheduled. The ports of the modules are completely assembled and welded to the vessels. For three of the five module separation planes, the ports in the transition zone between two neighboring modules are welded as well. The welding of the ports at the fourth and fifth module separation planes will be finished during the first and second quarter, respectively.

Trim coils: The four trim coils of type A manufactured in cooperation with Princeton Plasma Physics Laboratories and Everson Tesla have been delivered to IPP on schedule. Manufacturing of the type B coil is still proceeding.

Fig. 4. Current leads for the superconducting coils.
Photo: IPP, Beate Kemnitz

Current leads: The serial production of the current leads at the Karlsruhe Institute for Technology has been completed and the first pair has been installed on Wendelstein 7-X, as shown in Fig. 4.

from Wendelstein 7-X Newsletter
contact: Prof. Dr. Robert Wolf (robert.wolf@ipp.mpg.de)

Meetings

Next Stellarator-Heliotron Workshop

The next International Stellarator-Heliotron Workshop, will be combined with the RFP workshop and held in Padua, Italy, in September 2013. See the Web page for more information:

http://www.igi.cnr.it/ish_rfp_ws2013/

The range of topics covered this year is even broader than previously, and thus will accommodate talks on 3D configurations generally (tokamaks, stellarators, RFPs, and anything else toroidal with bumpy fields).

Although the deadline for invited papers has passed, abstracts for contributed papers may be submitted through the Web site between 30 April and 15 May.

Dr. Jeffrey Harris
Fusion Energy Division
Oak Ridge National Laboratory
P.O. Box 2008
Oak Ridge, TN 37831-6169

Telephone: +1 865 241 6546
Fax: +1 530 420 4650
Mobile: +1 865 274 8631
Skype: jhh112
E-mail: harrisjh@ornl.gov