stellarator news

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First Wendelstein 7-X experimental campaign successfully completed

The first experimental campaign of Wendelstein 7-X (W7-X), which began on 10 December 2015, was successfully concluded after 10 weeks of intense and dedicated plasma operation on 10 March 2016.

The day after the operational permit was granted by the responsible authority, the "Landesamt für Gesundheit und Soziales" (LAGuS), the first W7-X plasma was achieved. The event was followed by numerous guests from the world-wide science community —most of them by video broadcast—and the national and international press.

During the first week of plasma operation, using helium for the first part of the campaign, electron temperatures of 1 keV were achieved, corresponding to about 10 million °C. The duration of the early plasma discharges was limited to approximately 50 milliseconds by plasma radiation from impurities that cool down the hot plasma core. After the application of short consecutive pulses of electron-cyclotron-resonance heating (ECRH) and, once fully functional, glow discharge cleaning, the conditioning of the plasma vessel significantly improved and the plasma discharge lengths could be extended to about 500 milliseconds.

The first hydrogen plasma (Fig. 1) was produced on 3 February 2016 during an inauguration ceremony in the presence of the German Federal Chancellor Dr. Angela Merkel. About 400 guests from science and politics accepted an invitation and attended the event at IPP Greifswald. Many fusion researchers and the interested public around the world could participate by following the live video stream.

Since these first discharges (see Fig. 2 for helium results), an intense experimental program was conducted until 10 March 10. There was steady progress and finally plasmas lasting up to 6 seconds could

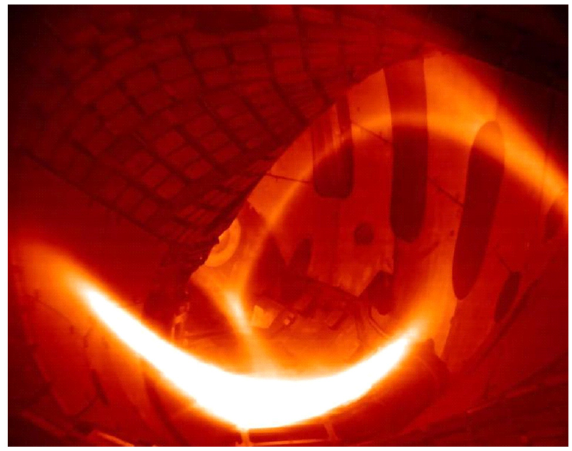

Fig. 1. Video image of the first hydrogen plasma. The image shows a tangential view into the plasma vessel with wall structures and port openings (providing diagnostics access). The visible light emission from the plasma forms a three-dimensional torus, emitting at the edge (the hot plasma core does not emit large amounts of visible light). The interface between the confined plasma and the boundary plasma is visible by the transition from low light levels to the strongly light emitting regions (courtesy of IPP in collaboration with Wigner RCP, Hungary).

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be achieved using 0.5 MW of ECRH power. The initial limit for the energy injected into the plasma was doubled from 2 MJ to 4 MJ, after it became evident that the plasma limiters, which define the plasma boundary, were far from reaching critical temperatures. Plasmas with the highest densities and temperatures were achieved using 4 MW of heating power applied for up to 1 second. At line-averaged electron densities of about 2×10^{19} m^{-3} the central temperatures reached 10 keV (~100 million °C) for the electrons and 1 keV (~10 million °C) for the ions. At slightly higher densities close to 3×10^{19} m^{-3}, electron and ion temperatures of about 7 keV and 2 keV, respectively, were achieved.

The success of the first experimental campaign exceeded our initial expectations. Originally, the aim was to perform an integral commissioning of the W7-X plasma operation, including ECRH and the first set of plasma diagnostics (more than 20). However, swift progress enabled many in-depth physics studies. Not least, this was made possible by the extremely reliable operation and proper interplay between the various technical systems of W7-X, in particular the cryoplant, the superconducting magnet system, the device control, and the microwave tubes of the ECRH system. Overall 940 discharge programs were performed; 92 of them were technical tests, 446 were dedicated to the development of the basic plasma performance (e.g., plasma-vessel conditioning), and 402 were dedicated to physics studies. This allowed for a first assessment of:

- ⇨ the confinement properties of the W7-X magnetic field configuration,
- ⇨ transport at the plasma boundary,
- ⇨ the influence of external error fields (produced by the so-called trim coils) on the heat load distribution on the plasma limiters,
- ⇨ first electron-cyclotron current drive experiments,
- ⇨ and second harmonic O-mode heating, which is important for heating the plasma at high densities.

There was strong participation by our international partners, and more than half of the physics program involved collaborations: In about 40% of the physics experiments, proposals were conducted in the frame of European collaborations and in 24% with partners from the United States. The largest part of the experiments, however, involved all parties, which can be seen as a successful implementation of the one-team approach.

After the completion of the first experimental phase, the focus is now on careful analysis of the data. The measured data have to be validated, which often means that diagnostic calibrations have to be repeated. Numerical codes not only support the evaluation of the experimental results but also allow for a first comparison with theoretical predictions.

Preparations for the next experimental campaign have already started. The plasma vessel has been vented and many peripheral systems have been removed to gain access to the plasma vessel. During the next 14 months, the so-called test divertor unit (TDU) will be installed. It is an inertially cooled island divertor with exactly the shape of the water-cooled steady-state high heat flux divertor, which is currently manufactured and is scheduled to be installed after the next experimental campaign. With the inertially cooled TDU and the full coverage of heat shields

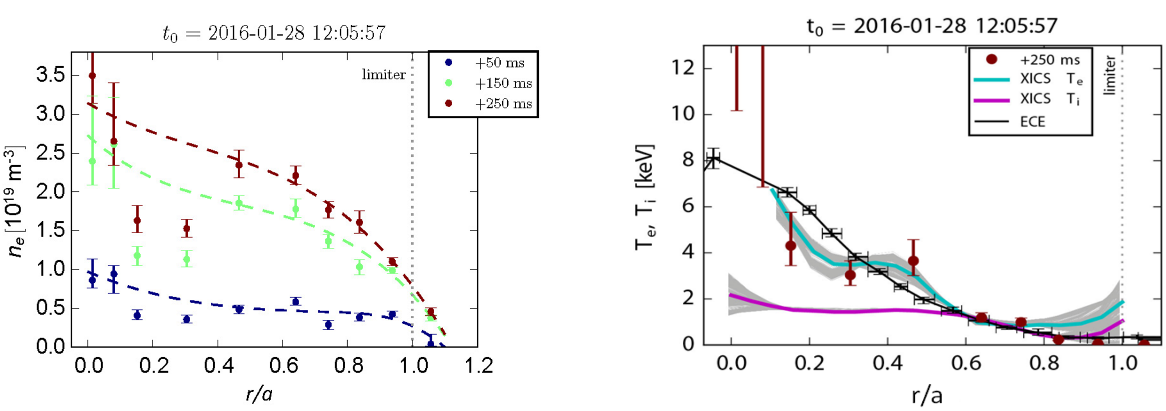

Fig. 2. Radial profiles of electron densities (left) and plasma temperatures (right) of a helium plasma heated by 4 MW of ECRH. The electron temperature and density can be obtained from scattering of laser light on the plasma electrons (Thomson scattering). Electron cyclotron emission (ECE) measures the electron temperature. From imaging X-ray spectroscopy (XICS), profiles of electron and ion temperatures can be inferred (courtesy of S. Bozhenkov, G. Fuchert, M. Hirsch, A. Langenberg, N. Pablant and E. Pasch).

and baffles with carbon tiles, Wendelstein 7-X will be ready for high-power plasmas (8 MW) lasting up to 10 seconds. This campaign is scheduled to start in the first half of 2017.

The Wendelstein 7-X Team
IPP Greifswald, Greifswald Germany

US STELLCON Community Workshop

A workshop was held at the Massachusetts Institute of Technology (MIT) on February 16–17 to discuss and define stellarator design, physics, and research needs for the US program. Approximately 35 researchers from the US fusion and plasma physics community attended and contributed to the presentations and discussions. The meeting was co-led by David Anderson (U. Wisconsin) and David Gates (PPPL), and the local organization was led by Abhay Ram (MIT). The agenda and presentations are available online at

http://www-internal.psfc.mit.edu/STELLCON/Presentations/Agenda_v6.html

Discussions on first day covered a range of scientific and technical issues, organized by the following topics:

- Magnetic configurations (A. Boozer)
- Turbulence and transport optimization (H. Mynick)
- 3D divertors (J. Lore)
- Plasma-material interface in 3D systems (D. Andruczyk)
- Fast particle confinement (D. Spong)
- MHD/high β (C. Hegna)
- Impurity confinement and accumulation (M. Landreman)
- Reactor issues (L. El-Guebaly)
- Design improvements and coil simplification (D. Gates)

For each topic, a designated discussion leader (indicated above) started by summarizing the key issues, their criticality to overall progress, possible solutions, available tools, and a 'straw-man' approach. The summaries incorporated pre-meeting input from the research community. Each initial summary was followed by an open discussion of all aspects of the topic.

The second day started with a summary of the key issues and ideas from the first-day discussions. This was followed by discussions of the research approaches, tools, and facilities needed to address the scientific issues from the first day, organized in the following areas:

- Needs and priorities in analytic theory (J. Friedberg)
- Needs and priorities in code development and computation (J. Canik)
- Needs and priorities in technology (J. Minervini)
- Issues best addressed experimentally on international facilities (H. Neilson)
- Needs and priorities in the domestic experimental program (S. Knowlton)

This was followed by a discussion led by D. Gates and D. Anderson, of action items and plans for further work . In general, the attendees reached substantial concensus in the discussions of the research needs and new developments. This was summarized to include the following conclusions:

- A computational tool is needed to evaluate and optimize 3D divertor configurations
- Advances and opportunities in turbulence optimization are exciting, and experimental validation is important
- New coil simplification approaches offer exciting opportunities
- Detailed comparisons between experiments and extended MHD are important and should be very fruitful.

In addition, participants agreed to launch a comparative study of optimized configurations with either quasi-helical symmetry or quasi-axial symmetry. Several volunteers agreed to take part and contribute to the study.

Finally, it was agreed that the topics, issues, and opportunities discussed at the workshop will be summarized in a community report, using the research-needs report format. Contributing authors were identified and charged to draft sections of the report, which will be circulated to the attendees for discussion and completion. An additional meeting may be held, if needed, to complete the report and finalize the identified research needs and opportunities for stellarators and 3D magnetic configurations in the US program.

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D. Anderson, University of Wisconsin, Madison
D. Gates, PPPL

In memoriam: Julian Dunlap

Julian Dunlap, who led the Experimental Plasma Physics section of the ORNL Fusion Energy Division during the operation of the ATF stellarator in the 1980s–early 1990s, died unexpectedly on April 9 at age 84. Julian came to ORNL in 1959 after completing his PhD at Vanderbilt University, and worked on several mirror plasma confinement experiments before switching to tokamak research with the ORMAK machine. He led MHD stability studies on the ORMAK and ISX-B tokamaks before becoming section head during the ATF era. After ATF shut down in 1991, he worked on stability experiments on the PBX-M tokamak at Princeton Plasma Physics Laboratory before retiring in 1994. He was a Fellow of the American Physical Society.