stellarator news

Published by Oak Ridge National Laboratory
Building CR 5600 P.O. Box 2008 Oak Ridge, TN 37831-6169, USA

Editor: James A. Rome
Issue 151 December 2015
E-Mail: jamesrome@gmail.com Phone (865) 482-5643
On the Web at *http://www.ornl.gov/sci/fed/stelnews*

Recent Milestones for Wendelstein 7-X: Commissioning and Operations

After the confirmation of the magnetic flux surfaces in Wendelstein 7-X (see *Stellarator News* No. 149, August 2015), the commissioning continued with the preparation for plasma operations. In August, the plasma vessel and the ports were baked to 150°C with hot water in the cooling circuits. The outsides of ports and flanges were heated electrically to the same temperature. During the 2.5 days of heating, the plasma vessel expansion amounted to about 15 mm. Also, the mechanical stresses were measured and compared to the results of finite element calculations. The mechanical measurements matched the predicted values very closely and once again confirmed the proper manufacturing and assembly of the device.

After 4 days at 150°C, the plasma vessel was cooled down again over 2 days. The water content in the plasma vessel exhaust dropped considerably and the total pressure decreased by more than one order of magnitude.

Following cooldown, measurements of the magnetic flux surfaces continued. Primarily, we attempted to find an equilibrium sensitive to error fields that could be corrected using the trim coils. These experiments are ongoing. Most of the time was used to bring diagnostics into operation and to develop and test the central safety control system (cSS). This was a very tedious process, accompanied by the auditors of the Technical Supervisory Association (TÜV) who were appointed by government authorities to evaluate the set-up of operations, including radiation protection measures, safety systems, and the planned operation processes. In November, the TÜV accepted all measures (after some additions), and the authorities of Mecklenburg-Vorpommern have announced that the operation permit will be granted in the second week of December.

At this writing, final preparations are under way: the commissioning of the valve control, glow discharge cleaning. and central operations management (cOPM), which controls the plasma discharges, the gas inlet, the heating power, and the triggers for diagnostics.

Update: W7-X completed its first discharge (Fig. 1) on December 10:
https://www.euro-fusion.org/2015/12/wendelstein-7-x-begins-fusion-journey/

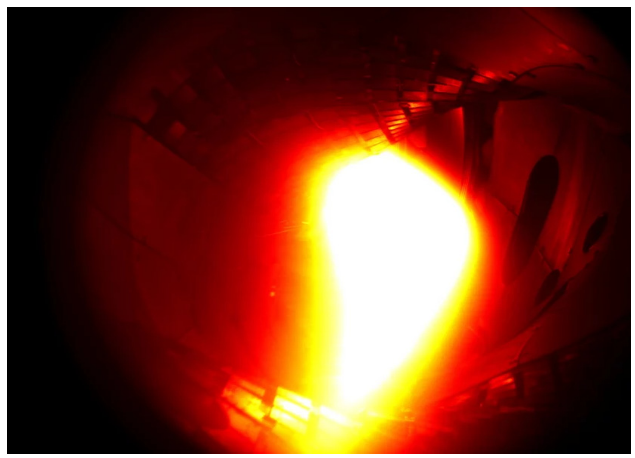
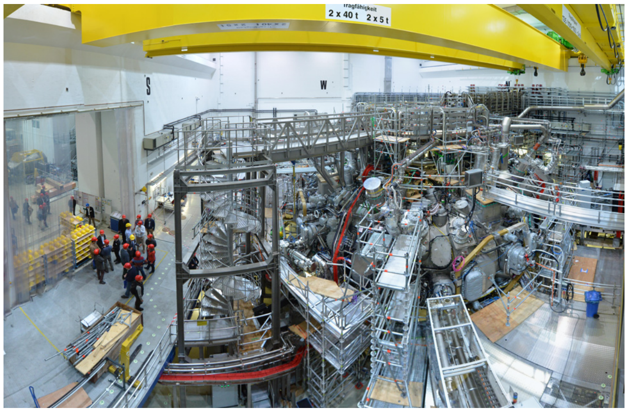


Fig. 1. The first plasma produced by the Wendelstein 7-X stellarator. (Photo: IPP)

In this issue . . .



A recent picture of Wendelstein 7-X taken by Glen Wurden during the ISHW 2015 tour.

Hans-Stephan Bosch
for the W7-X Group

20th International Stellarator-Heliotron Workshop

The 20th International Stellarator-Heliotron Workshop (ISHW) was held 5–9 October 2015, at Greifswald, Germany. The Max Planck Institute for Plasma Physics hosted this workshop, which was planned to take place against the background of initial experiments in Wendelstein 7-X (W7-X). The workshop was held at the Alfried Krupp Wissenschaftskolleg, which is located in the medieval city center of Greifswald, next to the 14th-century cathedral. Head of the International Programme Committee (IPC): Prof. Katsumi Ida, National Institute for Fusion Science, Toki, Japan. Head of the Local Organizing Committee (LOC): Prof. Per Helander, IPP, Greifswald, Germany.

This workshop consists of 1 overview session and 6 topical sessions. The topics of this workshop are listed below and the distribution of presentations is shown graphically in Fig. 1.

1. Overview (4 invited)
2. Impacts of magnetic topology/three-dimensional (3D) effects (6 invited, 8 orals, 56 posters).
3. Edge-core coupling of turbulence and transport (6 invited, 8 orals, 56 posters)).
4. Interactions among energetic particles, MHD, and transport (6 invited, 8 orals, 56 posters).
5. Impurities, neutral sources and sinks, and transport (3 invited, 4 orals, 16 posters).
6. Reactor perspectives (3 invited, 4 orals, 16 posters).
7. Coupling of core optimization to the plasma boundary and plasma-materials interaction (PMI) (3 invited, 4 orals, 16 posters).

Overview session

The following four overview talks were given in the Overview session.

1) Recent Progress of Japanese heliotrons, LHD and Heliotron J by T. Morisaki (National Institute for Fusion Science),

2) Overview of TJ-II, TJ-K, and H-1NF experiments by C. Hidalgo (Laboratorio Nacional de Fusion, CIEMAT),

3) Recent results and program on the HSX device by S. Anderson (Wisconsin Univ.), and

4) 15 years of construction of Wendelstein 7-X by T. Klinger (Max-Planck Institute for Plasma Physics).

Recent research progress on each concept was reviewed by the overview speaker, and key issues for each concept were discussed. This session delineated current understanding and remaining issues for scientists working on other concepts.

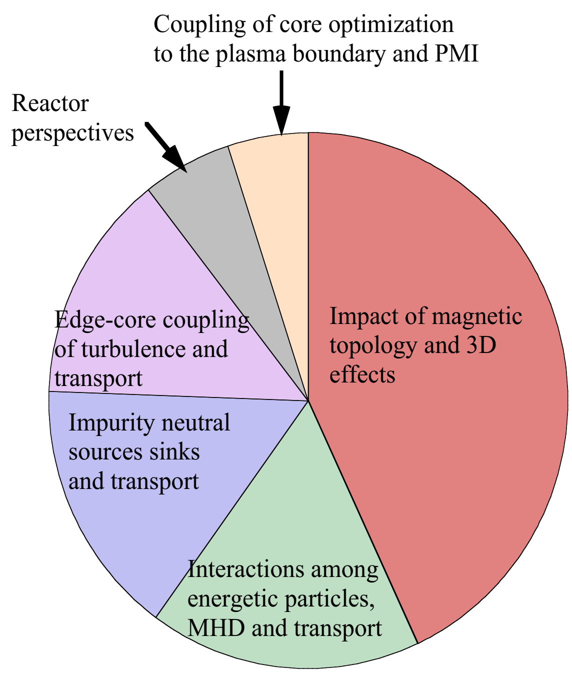


Fig. 1. Distribution of talk topics.

Topical sessions

Impacts of magnetic topology/3D effects

Edge-localized mode (ELM) mitigation by 3D fields is an important issue in both tokamak and helical plasmas. An ELM suppression experiment using a resonant magnetic perturbation (RMP) field in a tokamak was reported by W.

Suttrop. Small magnetic perturbations (0.1% of toroidal field) to the axisymmetric tokamak are used to form a ergodic divertor, compensate error fields, and most importantly, control ELMs and other MHD instabilities. Differences in shielding effects between tokamak and helical plasmas were discussed by K. Y. Watanabe. The collisionality dependence on penetration threshold current is a negative dependence in the Large Helical Device (LHD). The penetration threshold current of RMP decreases as the density and collisionality increase in LHD. This density dependence is opposite to that observed in tokamak.

Another approach to suppress ELMs was presented by Y. Liang. The lower hybrid current drive (LHCD) experiment in EAST has demonstrated that LHCD can be a powerful tool to suppress giant ELMs. The field-aligned helical current filament of the LHCD antenna produces an optimized perturbation spectrum. M. Rack presented calculation results showing that the magnetic perturbation due to LHCD near the plasma edge has an ideal mode number for the ELM suppression.

Many presentations addressed the effects of RMP on particle transport in both experiment and simulation. O. Schmitz presented the experimental results of helium control by RMP in TEXTOR and LHD. RMP fields are a fine-tuning actuator for improvement of divertor functionality. M. W. Jakubowski also presented that the effect of pump-out by RMP is also observed in L-mode and H-mode plasmas in tokamaks. A comparison of helium profiles near the plasma edge obtained from the charge-exchange spectroscopy measurements and an EMC3-EINERE simulation code was presented by K. Ida, A. Bader, and M. Kobayashi. The experimentally observed effect of RMP is reproduced by simulation; however, the slope is opposite.

Close correlation between magnetic topology and turbulence, transport, and plasma potential is observed in the RFX-mod reverse field pinch, H-1NF heliac, and Helically Symmetric Experiment (HSX). M. Spolaore presented an experimental observation in RFX-mod. This observation highlights a tight and dynamical correlation between small-scale electromagnetic filamentary structures and the actively modulated magnetic topology. C. Michael presented experimental results from H-1NF. The change in density/pressure is most closely localized to a zero shear region, and a standing wave structure which is frozen to the magnetic configuration is observed. A. R. Akerson discussed the 3D scrape-off layer (SOL) transport in HSX. Density and space potential are measured with probes and the observations indicate the presence of both SOL and diffusive transport channels at the edge of HSX.

Edge-core coupling of turbulence and transport

An internal electron transport barrier is commonly observed in stellarator, heliotron, and heliac plasmas. Various interesting experimental results were presented for LHD, Heliotron-J, and HSX. S. Anderson presented the internal electron transport barrier observed in HSX. A peaked electron temperature profile is observed when the deposition of the electron cyclotron resonant heating (ECRH) is focused at the magnetic axis. This observation is explained by a lack of stiffness of the electron transport. H. Takahashi presented the internal electron transport barrier in LHD. N. Pablant showed clear evidence of the radial electric field using an imaging X-ray spectrometer. The reduction of turbulence transport associated with the formation of a radial electric field on the electron root was discussed. Similar experimental results in Heliotron-J were presented by T. Minami.

Key aspects of the internal electron transport barrier were discussed. The important issues raised are (1) the relationship between the radial electric field, turbulence suppression, and temperature gradient, (2) the contribution of neoclassical anomalous transport, and (3) the role of rational surfaces. T. Estrada showed the relationship between turbulence and radial electric field shear in the limit cycle oscillation (LCO) observed in TJ-II. Turbulence leads the process and produces an increase in the $\boldsymbol{E}\times\boldsymbol{B}$ flow shear. However, the radial propagation of the $\boldsymbol{E}\times\boldsymbol{B}$ shear location and the foot-point of the electron internal transport barrier does not match in LHD experiments, which is inconsistent with turbulence suppression by $\boldsymbol{E}\times\boldsymbol{B}$ shear.

Edge-core coupling of turbulence and transport was discussed by H. Takahashi. Simultaneous increase and decrease of temperature gradients are observed during ramp up/down of ECRH power. With an increase in ECRH power, the spatiotemporal coherence is decreased due to the change of the correlation length and the turbulence lifetime. F. Fernández-Marina presented radial correlation length studies performed in the TJ-II stellarator using both Doppler reflectometry experiments and simulations.

Isotopic effects on turbulence are important in toroidal (tokamak and stellarator) plasmas. C. Hidalgo presented an isotope effect on experimental turbulence in TJ-II, while S. Ohshima presented experimental results in Heliotron-J. The long-range correlation increases as the hydrogen ratio increases in TJ-II, however it decreases as the ratio increases in Heliotron-J. The discrepancy of the experiments in TJ-II and Heliotron-J is due to the complex excitation and damping mechanism of zonal flow. The isotopic effect on the long-range coherence of turbulence may depend on the radial electric field and damping rate which are sensitive to magnetic field configuration.

Isotopic effects on turbulence have also been studied in simulations. M. Nakata showed the impact of isotope species and collisionality on the ion temperature gradient (ITG) mode and the trapped electron mode (TEM) instabilities in helical plasmas. The zonal flow energy in deuterium plasmas is larger than that in hydrogen plasmas. Similar results are also obtained by the transport model presented by S. Murakami.

Interactions among energetic particles, MHD, and transport

Interactions among energetic particles, MHD, and transport were also discussed. T. Estrada discussed the experimental study of Alfvén eigenmodes (AE) in focusing on nonlinear coupling in TJ-II. An MHD mode with frequency 20 kHz due to nonlinear coupling with the high-frequency AE modes was reported. These observations suggest the existence of an interplay between the oscillating $\boldsymbol{E}\times\boldsymbol{B}$ flow and the MHD mode as a precursor for the LCO onset. F. Castejon presented the well-depth dependence of turbulence and the frequency of Alfvén modes. Increasing the magnetic well depth decreases the turbulence level, and the frequency of the Alfvén mode increases. It is open to question whether this correlation is coincident or the result of causal relation.

The simulation of AE instabilities driven by fast ions was discussed. Improved understanding of these modes is motivated by observations that they can lead to enhanced fast ion transport and lowered heating efficiencies. D. A. Spong described recent development and testing of a global gyrokinetic PIC (particle-in-cell) simulation model, based on the GTC code, for analyzing Alfvén instabilities in 3D configurations. Results were presented for both linear and nonlinear stability analyses of these instabilities in the LHD and W7-X stellarators. The AE amplitudes showed couplings in toroidal mode number over field period intervals, which is an expected characteristic of macroscopic modes in stellarators. G. W. Bowden reported simulation results for AE instabilities in H1-NF and C. R. Cook and C. C. Hegna discussed the island-induced AE predicted with the SIESTA code. The eigenfunction of AE instability was found to be localized close to island core.

Impurities, neutral sources and sinks, and transport

This session centered on the poloidal asymmetry in the impurity density.

A. Alonso reported the observation of poloidal asymmetry of impurity density measured with a bolometer in TJ-II and compared it to simulation results. M. Landreman presented calculations of poloidal and toroidal variations of potential as candidate mechanisms for this poloidal asymmetry.

Impurity transport studies using tracer encapsulated solid pellets (TESPEL) was reported by N. Tamura. In LHD experiments, ECH suppresses the emission intensities from a highly ionized V tracer impurity, providing clear evidence of impurity exhaust due to ECH.

Neutral density also has a strong impact on transport. M. Goto reported the measurement of neutral density in the core of LHD. The reduction of neutral density makes it easier to achieve high ion temperature plasmas. U. Wenzel discussed neutrals in the divertor region of W7-X. The neutral density is expected to have a maximum value at the transition from attached to detached plasma.

Verification, validation, and prediction of simulation codes for transport and ray tracing were discussed. S. Satake and S. Matsuoka reported the comparison of the radial heat flux in LHD experiments to that predicted by neoclassical transport codes. T. Tsujimura presented the the ray tracing calculation for ECH (LHD-Gauss) in the LHD experiment. ECH injection in LHD is optimized using these ray tracing results. W. Kernbichler reported the prediction of electron cyclotron current drive (ECCD) efficiency in W-7X using the NEO-2 code. J. H. E. Proll presented calculations of heat flux driven by trapped electron modes (TEMs) for W7-X, HSX, and DIII-D. The radial heat flux increases with the increase of the electron density gradient as normalized by (n/a), where a is the minor radius.

Reactor perspectives

Research toward a helical reactor was reported in this session.

R. C. Wolf reported on the prospects of a HELIAS fusion power plant, and F. Warmer reported on the European roadmap for stellarator research. For the heliotron concept, T. Goto used an integrated 1D code to examine plasma operation and control scenarios in the LHD-like FFHR-d1 helical reactor. A. H. Boozer reported on the concept of nonresonant divertors in which the sharp edges act as X-points and divert field lines to the walls; its advantage is that it is insensitive to plasma currents.

Coupling of core optimization to the plasma boundary and PMI

Two important issues in the coupling of core optimization to the plasma boundary and PMI ares wall retention and the effects of magnetic islands. H. Kasahara reported the change in recycling after a long pulse of 2000 s in LHD. This was because the wall retention was affected by a mixed-material layer during the long discharge.

Numerical study of W7-X magnetic island divertor performance was discussed. Y. Suzuki presented the effects of beta and current density, which significantly change the edge magnetic topology in the W7-X magnetic island divertor. Y. Feng studied the effect of magnetic islands on the carbon concentration using the EMC3-EIRENE code, which predicts the minimum carbon concentration at a medium island size.

Summary

A summary was given by K. Ida (NIFS) at the end of the workshop. He highlighted the following achievements of the last two years:

⇨ Completion of W7-X construction.
⇨ Simultaneous achievement of electron internal transport barrier (e-ITB) and ion-ITB in LHD.
⇨ High beta (~4%) with low collisionality.
d) Steady-state operation up to 48 min with 1.2 MW of heating in LHD.

Then he summarized the physics issue on each topic:

1. Impact of magnetic topology and 3D effects
   - ELM suppression
     LHCD is found to be as good as (or better than?) RMP as a technique to suppress ELMs.
     The role of 3D fields on ELM suppression should be investigated by various approaches.

   ⇨ Interplay between turbulence and magnetic topology. Turbulence localization due to magnetic topology was observed. (An interesting research area?)
2. Edge-core coupling of turbulence and transport
   - Mechanism of e-ITB
     The mechanism of the formation of e-ITB is open to question.
     The reduction of transport by E_r due to the transition to electron root is insufficient to explain this.
   - Isotope effect
     The isotope effect on long-range correlation has been studied in experiment, and may vary depending on the magnetic topology (the relation of damping and excitation to E_r). Experiments on isotope effects in LHD and W-7X are quite important.
3. Interactions among energetic particles, MHD, and transport.
   - Nonlinear coupling of AE modes and dependence on well depth are observed. Development of a simulation code for AE modes (AE in magnetic island) is needed.
4. Impurities, neutral sources and sinks, and transport.
   - Impurity transport
     ECH contributes to the exhaust of impurities (Mechanisms? E_r and potential asymmetry).
     Coexistence of asymmetry of potential and impu-

20th ISHW attendees.

rity density is observed.
Neoclassical parallel transport with friction, inertia, parallel electric field are important.

- Helium transport
  Magnetic islands can reduce the helium density in the core.
  Some inconsistencies between measurements and simulation (EMC3-EIRENE) of the screening effect in the stochastic region are observed when the helium fraction is high.

International Program Committee:

- Katsumi Ida. chair (NIFS, Japan)
- Boyd Blackwell (ANU, Australia)
- Robert Wolf (IPP, Germany)
- Kieran McCarthy (CIEMAT, Spain)
- Vladimir Voitsenya (Kharkov, Ukraine)
- Oliver Schmitz (University of Wisconsin, USA)

Local Organizing Committee (IPP Greifswald, Germany):

- Per Helander, chair
- Jutta Gauger, conference secretary
- Beate Kemnitz, public relations
- Matthias Borchardt, scientific programme, technical support
- Carolin Nührenberg, scientific programme
- Karin Schier, finances
- Andrea Kleiber, website, registration

Katsumi Ida
National Institute for Fusion Science
Tel +81-572-58-2182
Fax+81-572-58-2624
E-mail ida@nifs.ac.jp