stellarator news

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Wendelstein 7-X News

U.S. trim coils

On 26 June, a key milestone was reached when the first "trim coil" for Wendelstein 7-X (W7-X) was delivered to Greifswald (Fig. 1). The 3 year, $7.5 million project to design and manufacture a set of 5 trim coils for W7-X was launched in 2011 in cooperation with Princeton Plasma Physics Laboratory (PPPL), Oak Ridge National Laboratory (ORNL), and Los Alamos National Laboratory (LANL). The participating U.S. institutions will become partners in the research program at the Max-Planck-Institut für Plasmaphysik (IPP).

Scientists and engineers from PPPL started the design of the coils in January 2011. The construction order was placed with Everson Tesla, Inc. (ETI), of Nazareth, PA, in October. ETI is one of the larger U.S. magnet manufacturers and has collaborated with PPPL for more than 20 years on different projects. Holding to schedule in spite of the large distance and 6 hour time difference separating the partners is a noteworthy achievement. Constructive cooperation between PPPL, ETI, and IPP was facilitated by numerous video conferences and also site visits.

Experiments that will engage U.S. researchers are planned to answer a key question about the suitability of a stellarator for operation as a power plant: Is it possible to generate a stable and at the same time spatially precise magnetic field in such a way that particles and energy can be removed from the plasma while maintaining acceptable loads on the divertor? The key to answering this question lies in the symmetry of the main magnetic field, its accuracy, and the ability to influence the particle and energy fluxes with the help of smaller correction fields. Beside these practical considerations, the trim coils provide an additional experimental tool for investigating the complex interaction of plasmas and fields, studying for instance the influence of particle drifts and shielding effects.

Photo: Everson Tesla, Tom Stenulis

Photo: IPP, Anja Richter Ullmann

Fig. 1. Staff members standing at the first trim coil at Everson Tesla (top) and at IPP Greifswald.

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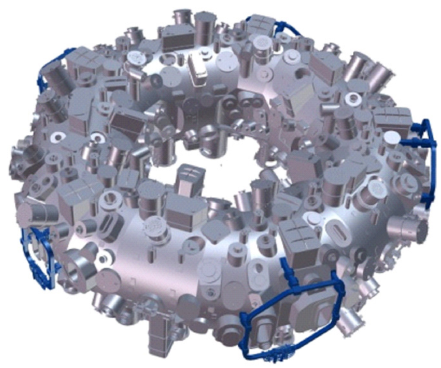

Fig. 2. The trim coils (blue) are shown at their locations on W7-X.

One trim coil will be installed on each of the five Wendelstein 7-X modules (Fig. 2). In contrast to the superconducting main coils, the trim coils are normal conducting copper coils with integrated cooling channels. This is acceptable because the trim coils generate only a small correction field. Four of the five coils are identical in size and shape. Due to limited space on the outer vessel, the fifth trim coil is smaller. Each trim coil will be fed by an independent power supply unit designed for continuous operation. The power supplies provide each coil with almost 2000 A.

The first coil with its overall dimensions of 3.5 × 3.3 m will be prepared for assembly during the next weeks. First the coil will be measured precisely. Next points must be marked where the supports have to be fixed to attach the coil to the outer vessel. With a budget of $4.3 million this largest contribution of the German-American cooperation project will be finished with the delivery of the last coil in 2013.

Other contributions of the U.S. partners have also made good progress. With ORNL in charge, a design is being developed for a special divertor target element that can absorb high heat fluxes from the plasma and thus protect more sensitive structures from overload.

Status of W7-X construction

The five modules are in their final position on the machine's foundation. Three modules are already joined: the central rings have been screwed together and the plasma and outer vessel module planes have been welded. This process was again verified by laser measurements. The port assembly for the last module is near completion, while the assembly of the in-vessel components has just started. In every module about 1200 bolts and supports for fixing the in-vessel components to the plasma vessel will have to be welded in place with the help of a positioning robot (Fig. 3).

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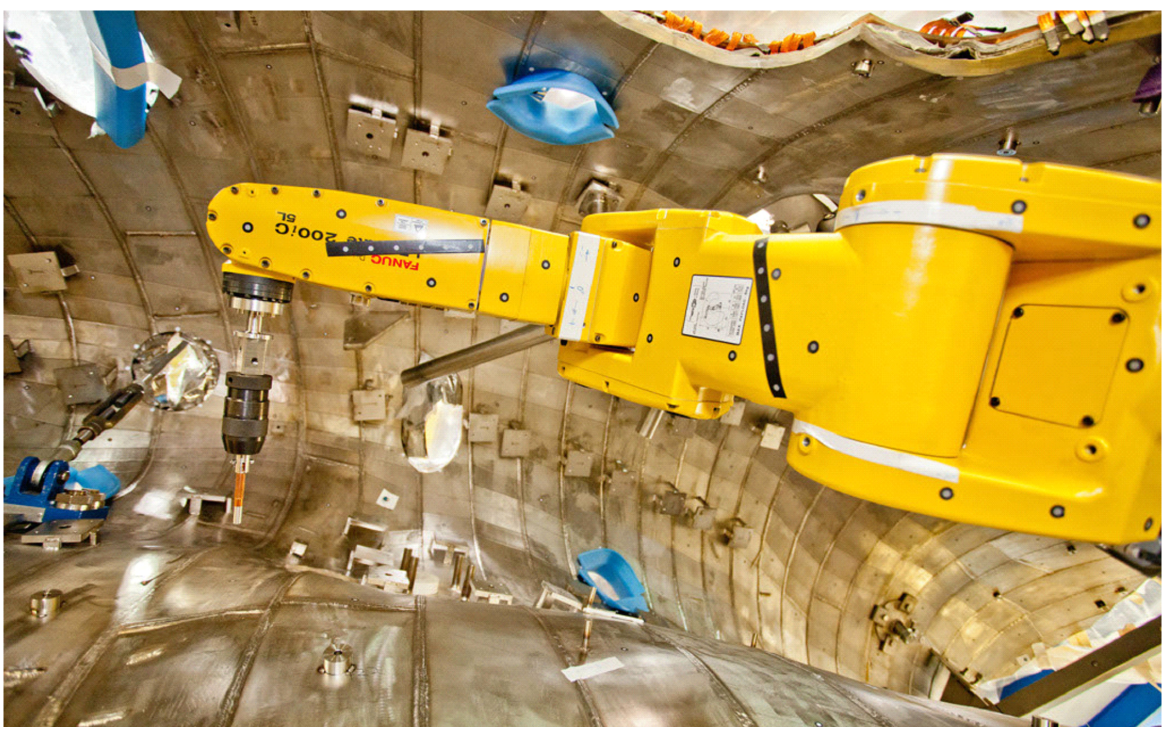

Photo: FANUC Robotics Europe S.A.

Fig. 3. Positioning robot inside the vacuum vessel.

Coordinated Working Group Meeting (CWGM10) for Stellarator-Heliotron Research

The 10th Coordinated Working Group Meeting (CWGM10) was held 6–8 June 2012 at the Max-Planck-Institut für Plasmaphysik in Greifswald, Germany. More than 50 experts (in person and via video conference) participated.

More detailed materials presented at the 10th CWGM are available at http://ishcdb.nifs.ac.jp/cwgm10.html. This paper is an overall summary of the meeting.

At this 10th meeting of the CWGM, H. Yamada (NIFS) reflected on the original intent of the working group, "sharing goals, and acceleration of the output-outcome wheel," referring to material from an informal meeting in 2003 (Greifswald) on the Stellarator-Heliotron Database and the IEA Stellarator Executive Committee meeting in 2004 (Villamoura). Since then, the CWGM activity has embodied these ideas by promoting a comprehensive and exact understanding of complex physics through the Stellarator Database, joint experiments, benchmarking, and joint papers. It was also pointed out that the CWGM become a gateway to global/domestic programs such as the International Tokamak Physics Activity [(ITPA) http://www.iter.org/org/team/fst/itpa] and power plant design activities.

Emerging from CWGM activities, many contributions to the three-dimensional (3D) physics aspects of ITPA have already been made by the stellarator-heliotron (S-H) community. In addition, a reactor session was set up at this 10th CWGM to promote joint efforts in this direction. To further promote joint experiments among S-H devices, the status of the devices LHD, TJ-II, and Heliotron J (H-J) was reviewed. New resources that will soon become available include higher electron (ECH) and ion (ICH) heating power and closed divertor (cryo-pumping at 1 section and baffle/dome installation at 8 of 10 sections) in LHD; the pellet injector and second heavy-ion beam probe (HIBP) (in collaboration with ORNL and Kharkov/Kurchatov Institute, respectively) in TJ-II; and plasma profile measurement by means of several diagnostics in H-J. Increases in device capability should extend the range of joint research. One specific request to TJ-II and H-J was to perform deuterium (D) experiments to increase the database (in addition to previous D experiments in W7-AS) to resolve isotope effects, which should be a critical issue in burning S-H plasmas.

The topics discussed at the meeting were the following: resonant magnetic perturbation (RMP), wall conditioning, 3D equilibrium, flow and viscosity, transport validation (energy transport: ongoing, and particle transport: kick-off), Alfvén eigenmode and energetic particles, database issues, and reactor design and system code. Among these sessions, joint papers have been accepted on Alfvén eigenmode (oral, EX/5-2) and transport validation (poster, EX/P3-14) issues for the 24th IAEA Fusion Energy Conference (IAEA-FEC) at San Diego in October 2012, and on database issues (singularization of data subgroups) for the next EPS conference (Stockholm, July 2012). One more joint paper that originated from CWGM activities will be presented at the EPS meeting on magnetic island dynamics, although the session was not set up at CWGM10.

Summary of each session

RMP

A study on transport modification due to RMP in LHD has been jointly conducted with the tokamak community. It has been formulated as task TC-24 (along with 3D effects on macro- and microstructures) in the transport and confinement topical group of the ITPA. A further joint experiment is being planned for the coming 16th experimental campaign of LHD. It will investigate how the amplitude of perturbations affects the level of turbulent transport.

Wall conditioning

TJ-II reported on recycling and isotope exchange of H, D, and He plasmas resulting from Li-wall conditioning research. Development of a wall conditioning strategy for W7-X has been relying upon the experiences of other devices, such as WEGA, LHD, and Tore Supra. Since ECRH will be the main heating source for the first operational phase of W7-X, an ECRH wall conditioning strategy needs to be developed. For this purpose, a joint experiment is proposed in LHD by utilizing its ECRH capability.

3D equilibrium

Recent progress on 3D equilibrium studies in LHD high-beta plasmas was reviewed, focusing on how to identify the 3D magnetic field structure. One approach uses the positions of the radial electric field null ($E_r = 0$) or the maximum gradient of E_r, originated by the positive E_r generation due to opening magnetic field lines. This has also been observed in DIII-D. Identification of stochasticization in the plasma edge has also been tried using the heat pulse propagation technique. Necessity of rigorous numerical treatment outside the last closed flux surface (LCFS) was pointed out in order to relate measurements at different scrapeoff layer (SOL) positions and for performing simulations on edge physics such as EMC3. An open question raised is how to validate the numerical modeling. As a follow-up discussion, divertor heat flux measurements in LHD were introduced, with a statement that the positions of measured heat flux peaks fit to those predicted from HINT2 numerical results. Such a validation study, including the identification of the LCFS, was discussed as a topic for joint experiments.

Flow and Viscosity

A wide range of research on plasma flow and viscosity issues has been conducted in S-H devices. Based on individual discussions made at the 18th International Stellarator-Heliotron Workshop (Australia, 2012), it was agreed to launch a flow and viscosity session in CWGM. Possible joint actions discussed so far between NIFS and CIEMAT were introduced, such as the numerical code verification/validation and joint experiments on plasma biasing. The HSX team also joined discussions with its Reynolds stress and E_r measurement, and comparisons to PENTA code calculations. Joint action plans have been discussed between NIFS and CIEMAT. Any such proposals will be sent to HSX group so that they can decide to join/update these proposals. The topics-oriented joint actions in such areas as the trigger and dynamics of the L-H transition, 3D effects on zonal flow, and the impact of self-regulation mechanisms in transport and stability were also proposed in connection with the 3D physics session in ITPA.

Transport validation (energy transport)

Transport in S-H plasmas consists of neoclassical and turbulent contributions. To perform studies of transport model validation, the impact of neoclassical transport has been investigated in ion-root plasmas (medium to high density with comparable electron and ion temperature under sufficient ion heating power) of W7-AS (previous documentation), LHD, and TJ-II (new joint experiment). This is a natural extension of joint efforts on CERC (core electron-root confinement) plasmas and successfully documented international benchmarking activities of neoclassical transport codes. Towards a joint paper at the coming IAEA-FEC, progress in energy balance analysis was shared and the formats of materials were discussed along with "homework" assignments. It was also followed up by showing examples from the non-local neoclassical transport code, FORTEC-3D, to provide (in some cases) a quantitatively different prediction of the neoclassical ambipolar E_r. Certainly, it would be valuable to examine discharges of joint experiments using several other codes for validation from different points of view. The XICS (X-ray Imaging Crystal Spectrometer, under collaboration between PPPL and NIFS) measurement of ion and electron temperatures was also reported, to provide profile information for the energy transport analysis. The request to perform particle transport study also was raised, and this became a natural introduction to the following session.

Particle transport

Density control is one of the key issues that must be comprehensively understood for optimal operation in large S-H plasmas and in reactors. The summary of observations on particle transport in LHD is as follows: the density profile becomes more hollow in the outwardly shifted configuration with decreasing collisionality. The density profile is determined not by particle fueling (NBI fueling and wall source) but by transport—the neoclassical contribution is larger (smaller) for convection (diffusion). Gyrokinetic quasilinear analysis shows qualitative agreement of the zero flux condition, indicating that an anomalous feature plays a role in transport. It was pointed out that locating the separation of core and peripheral regions by investigating the penetration depth of neutral particles would be one approach to be considered for particle transport. A joint experiment in LHD was proposed to further investigate particle transport by decoupling heating and particle sources such as ECRH and/or pellet injection.

A summary of methods and results for particle transport studies in TJ-II contributed to this new topic. A poor particle confinement regime identified in low-density plasmas appears to be considerably affected by kinetic effects from ECRH. This identification must be discerned in order to plan a joint contribution. NBI plasma studies are ongoing, but the analysis done so far points to a linear dependence of particle confinement time with density. There seems to be, however, a strong degradation with heating power. Particle confinement improves when the L-H transition occurs, but no steady-state H-mode is available to make a quantitative description.

Alfvén eigenmodes, energetic particles

This is the third session on this topic, after the launch at the 8th CWGM (NIFS, March 2011). Joint experiments have successfully evolved between H-J (low rotational transform ι) and TJ-II (high ι) to understand Alfvén eigenmodes in low-shear S-H plasmas in both devices; this will be reported in a joint paper at the next IAEA-FEC. The comparative study will be expanded to LHD. So far, an independent database in each device has been utilized for numerical code validation, along with ongoing code verification among several codes. It was pointed out that the accuracy of equilibrium, especially the ι-profile, should be carefully considered such as for ι-scan experiments and those interpretations by numerical codes. The Bernstein-wave heated plasmas in the WEGA stellarator were also reported to show the existence of suprathermal electrons in the keV range, and also to show direct momentum transfer with the addition of 2.45 GHz ECRH.

Database issues

ISS04 has been established based on the International Stellarator-Heliotron Confinement Database (ISH-CDB) using data from existing devices. As the next step, the assessment of energy confinement for future devices has been tried by utilizing dimensionless variables and following the principles of similarity and scale invariance. Clustering of data using several sets of dimensionless variables has been going on, and a lot of effort will be still be required. Extension of CDB with new data was requested to increase the capability for discriminating datasets.

Progress of the Profile Database (ISH-PDB) was also reported. Equilibrium information corresponding to registered discharges, such as *wout* and input files for VMEC2000, has been registered (requiring authentication as joint analysis). Reading routines will be provided to cover possible different versions of VMEC2000 (currently, equilibria from version 6.90 and 8.00 coexist in the database). This "de facto standard" platform should enhance the validation activity of numerical codes/modeling by easing the possible difficulties of their applications to experimental data.

Reactors, system codes

One of long-term goals of the CWGM activity is to define the data basis for S-H reactor studies. Thus, it is meaningful for the CWGM activity to share the current status and future prospects of S-H reactor scenario and system code development to guide the research direction. At CWGM4 (CIEMAT, October 2008), a reactor session was held, focusing on engineering issues. At this CWGM, reactor system code application to reactor design was also emphasized. The European fusion road map was introduced and discussed, identifying required steps (the "step ladder") towards DEMO and a commercial fusion power plant.

The design status of HELIAS 5-B (a 5-period HELIAS reactor) was reported with emphasis on engineering issues. Predictive simulation using 1D transport models (including the neoclassical database and anomalous modeling) has been performed for a "upscaled" W7-X, to particularly find the renormalization factor (in ISS04 scaling), which tends to decrease with size of the plasma. This finding provides impact by taking the confinement scaling law into the system code. The application of the reactor system code HELIOSCOPE and the current status/future prospects of FFHR-d1 (the heliotron reactor in the design study) were also reported. HELIOSCOPE has been utilized to specify a design window with several engineering and physics (basically the scaling law, right now) conditions. Fast and accurate insertion of 3D equilibrium and physics modules into the system code will be pursued to obtain a more robust design. It was concluded that the interaction between system code development/application and CWGM activity in this regard should be enhanced. Optimization of the TJ-II configuration has been conducted utilizing DAB (Distributed and Asynchronous Bees) algorithm on grid computers (http://fusion.bifi.unizar.es/).

Figure 1 shows a slide prepared for the final concluding session, summarizing work plans for 2012/2013 (and beyond). Programmatic joint experiments/activities were formulated based on the meeting discussions. These are open to everybody, of course. Thus, if you/your colleagues are interested in joining, please let us know.

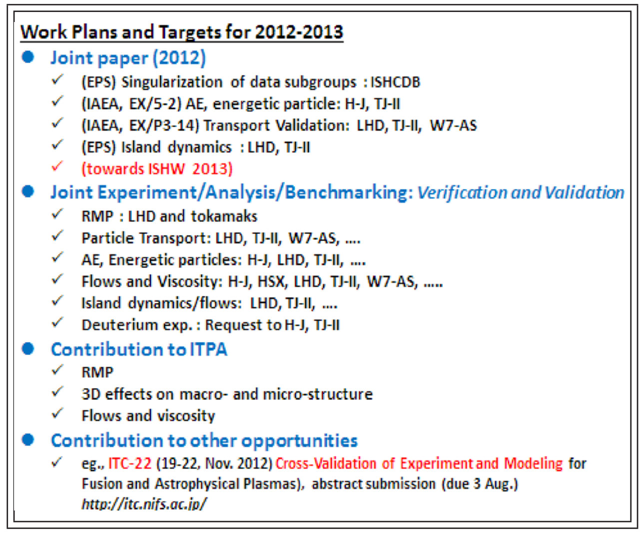

Fig. 1. Slide prepared for the concluding session of CWGM10.

Finally, it was agreed that the next CWGM11will be hosted by CIEMAT. The details will be announced once they become available.

The presented materials in previous CWGMs (except the first one, unfortunately) are reachable through either the IPP or NIFS CWGM website (http://www.ipp.mpg.de/~dinklage/CWGM10/ or http://ishcdb.nifs.ac.jp/). Looking back at the contents of previous CWGMs should be instructive when considering the future directions for this activity.

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