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 147 April 2015
E-Mail: jamesrome@gmail.com Phone (865) 482-5643
On the Web at *http://www.ornl.gov/sci/fed/stelnews*

Recent milestones in commissioning Wendelstein 7-X

As briefly described in Stellarator News 145, the commissioning of Wendelstein 7-X (W7-X) in Greifswald, Germany, started in the summer of 2014 with the cryostat vacuum system.

A major milestone in July was the first evacuation of the cryostat vessel. In the following weeks, 29 leaks were detected and repaired. Simultaneously, mechanical loads and stresses on the shell structure, resulting in deformations of the vessels and ports, and relative movement between the cryostat and the plasma vacuum vessel were measured during pumpdown at predefined values of 700, 300, and 50 mbar. Of special interest were the port bellows, specifically those bellows at large oval and rectangular ports where significant deformation is expected due to the vacuum load. The measured stresses and deformations were in rather good agreement with the results of the finite element (FE) modeling and confirmed the structural stability of the cryostat.

In fall 2014 the local commissioning of the cryo supply was started with the recommissioning of the cryoplant, the cleaning of all helium circuits, and the commissioning of the machine- and cryo-instrumentation. In parallel to this, the trim coils were commissioned (November/December 2014), the neutron counter system was calibrated (January 2015), and various water cooling circuits were commissioned (October 2014–March 2015). In December 2014 a Paschen test of the complete superconducting (SC) coil system confirmed the quality of the insulation of the magnet system.

In mid-March 2015, the cooldown of the magnet system (50 non-planar and 20 planar SC coils with the bus bar system and the central support ring) was started (Fig. 1).

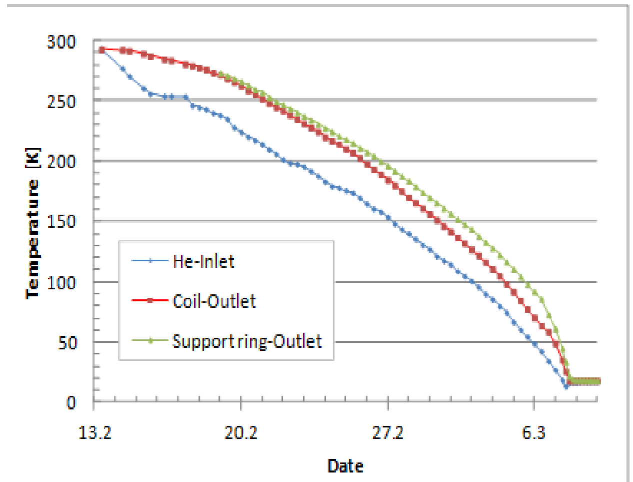

Fig. 1. Cool-own progress of the complete superconducting system.

In this issue . . .

All opinions expressed herein are those of the authors and should not be reproduced, quoted in publications, or used as a reference without the author's consent.
Oak Ridge National Laboratory is managed by UT-Battelle, LLC, for the U.S. Department of Energy.

The cooldown of the coils and support structure to 18 K succeeded in just 3 weeks without showing any leaks (let alone cold leaks). In the following week we continued to 4 K to test for thermoacoustic oscillations. In fact, no oscillations were found. Presently, the system runs at a component temperature of about 10 K, in the so-called short-standby mode (SSM), which will be used during weekends and overnight. In this mode the required operation tests are conducted, e.g., improving the settings of the control system, adjusting all cooling circuits, and performing energy balances. After that, the standard mode (SM) at about 4 K, which will be used for magnet operation, will be commissioned.

Recently, evacuation of the plasma vessel started and the leak search is ongoing.

Dr. Hans-Stephan Bosch
Leiter Wendelstein 7-X Betrieb
Max-Planck-Institut für Plasmaphysik
Wendelsteinstr. 1
17491 Greifswald, Germany
Tel. (03834) 88 - 2212/2000, Fax: -2709, Handy 0173 89 79 128
E-mail bosch@ipp.mpg.de

International Workshop on the Strategy for Stellarator/Heliotron Research

This workshop was held 4–6 March, 2015, in Nagoya. It was organized by O. Kaneko, head of the Research Enhancement Strategy Office, National Institute for Fusion Science. The purpose of the workshop was to discuss plans for stellarator/heliotron research toward a DEMO device. This workshop may have been the first such meeting, and emphasis was placed on free discussion based on the present status of theoretical and experimental research and reactor-relevant design studies, rather than on gaining consensus among participants. Consensus will be gradually formed in continuing workshops. Most of the workshop participants are identified in Fig. 1. (Those who did not attend the last day of the workshop are not in the photograph.) The framework of the workshop was composed of the following seven discussion points.

1. *To review the fusion research program and the roadmap to DEMO in the world, and to know the position of helical research in this roadmap*

Discussion points focused on the critical paths in the roadmap to a tokamak DEMO, the R&D schedule and milestones, and the risks, their mitigation, and the need for alternatives. To address these assignments, roadmaps toward DEMO primarily in Europe, the United States, and Japan were briefly introduced. Presenters were C. Hidalgo, T. S. Pedersen, H. Yamada, M. Zarnstorff, B. Kuteev, B. Blackwell, and V. Moiseenko.

Construction of a tokamak DEMO is expected to start around 2030 in the European Union and in Japan. Successful ITER operation demonstrating $Q = 10$ is the prerequisite for this time schedule. W7-X has an essential place in the future of helical system research in Europe and probably in the United States. In Japan the Committee for Fusion Science & Technology, Council for Science Technology and Innovation, MEXT has organized a Joint-Core Team headed by H. Yamada to establish technological bases required for the development of the tokamak DEMO, maintaining a good balance between the tokamak, and the helical system and laser fusion activities. The stellarator/heliotron is widely considered to be an alternative to the tokamak because of its long pulse capability and freedom from major disruptions, for example. Research on a pilot hybrid plant (PHP) is conducted primarily in Russia on the basis of tokamak and molten salt technologies. Among numerous issues, divertor geometry for heat and ash exhausts is identified as being of particular importance. Energetic discussion was held throughout the workshop, such as in debating whether an ITER-like helical device for burning plasma physics is necessary for building the helical DEMO. Physics and technology databases from ITER and the tokamak DEMO should be fully utilized for the helical DEMO from the viewpoint of risk mitigation. Lessons learned from ITER construction are important. Perhaps we should ask specialists who have been engaged in the ITER construction to participate in the workshop in the future? The necessity of a fusion neutron source using, for example, compact toroidal devices was noted for testing materials under fluences up to 15–20 dpa. An encouraging experimental result from JET, which showed weak confinement degradation with power at high beta plasmas, was reported.

2. *To review the status and near-term future plan of helical research in the world*

A summary of LHD experimental results was presented by Y. Takeiri. Steady progress is seen in LHD experiments, which have attained simultaneously an ion temperature of 6 keV and electron temperature of 7–8 keV at a density of 1.4×10^{19} m^{-3}. The beta of 4.1% was obtained at 1 T. Long-pulse operation of 48 minutes was sustained with 2 keV temperature and 1.2×10^{19} m^{-3} density. The research plan of the deuterium experiment was described and is expected to clarify the isotope effect in a toroidal plasma.

The Numerical Simulation Reactor Research Project, which was reported by R. Horiuchi, consists of eight task groups that cover a wide range of fusion plasma simulations. Achievements from each task will be integrated around 2020 toward construction of the Numerical Test Reactor. Research results of the Fusion Engineering

Research Project, reported by A. Sagara, were summarized into the design of several options for what was originally called a force-free helical reactor, but now known as just FFHR. The magnetic energy reaches approximately 150 GJ. Five fundamental R&D projects are ongoing: superconducting (SC) magnet, blanket, low-activation materials, plasma-facing materials, and tritium handling.

T. S. Pedersen reported that the first plasma of W7-X is scheduled for this fall using a limiter configuration and 2 MW of electron cyclotron heating (ECH) with a duration of < 1 second. Commissioning has started successfully; the cryostat has been pumped down and initial cooldown was completed. The research plan of W7-X Operation Phase 1.1 (OP1.1) includes correction of error fields down to the range of 10^{-5}, that will be made possible by using flux surface mapping and the trim coil system.

In Heliotron J, strong gas fuelling using supersonic molecular beam injection (SMBI) or short high-intensity gas puff (HIGP) increased the electron density to more than 10^{20} m^{-3} with electron and ion temperatures remaining at 200 eV, resulting in an increase in the stored energy. This was reported by T. Mizuuchi. High-density operation is a unique capability widely observed in helical systems.

C. Hidalgo reported that flux surface asymmetries in TJ-II plasma potential were observed using the dual HIBP system, and the role of ion mass on zonal flow-like structures was investigated.

Fusion plasma research on stellarators in the United State is regarded as part of the three-dimensional (3D) plasma physics program, which includes tokamaks. Regarding collaboration with W7-X, the trim coil system was made by the United States, and scraper elements were designed so as to mitigate the risk to steady-state water-cooled target structures when island structures are shifted from the nominal configuration. These were reported by H. Neilson.

In L-2M experiments, which were reported by B. Kuteev, heating power density up to 3 MW/m^3 was attained and heat loading exceeding 0.5 MW/m^2 was expected near separatrix corners. A DEMO-FNS (fusion neutron source) is being designed using compact tori at the Kurchatov Institute.

Effects of H-mode transition on divertor flow characteristics were investigated in U-3M RF plasmas. A conceptual design study on a fusion-fission reactor based on a stellarator-mirror device is being carried out at the Kharkov Institute, as reported by V. Moiseenko.

B. Blackwell reported that Australian activities were conducted following the mission of detailed understanding of the basic physics of magnetically confined hot plasma in the H-1 Heliac.

These ongoing activities continue and near-future plans are being made while being conscious of issues which ITER will face. It was reported that financial support for helical system research may not be adequate for execution of the planned research, unfortunately.

3. *To review design studies on helical reactors*

Ongoing reactor design studies were reported from NIFS, MPI, and PPPL, by A. Sagara, D. Hartmann, and M. Zarnstorff, respectively. Two comments were made: from the viewpoints of the utility grid, initial tritium loading and other issues by K. Okano, and of aspect ratio by S. Okamura.

Advantages and disadvantages of the helical system compared with the tokamak are rather well known. Advantages are as follows: steady-state operation, high-density operation, no major disruption, low recirculating power. Disadvantages are a complicated 3D structure and usually a larger size.

The FFHR design is based on the LHD magnetic field configuration, a coil major radius of 15.6 m, and a plasma minor radius of 2.54 m. The plasma performance of the FFHR is deduced through direct profile extrapolation from LHD experimental data. The design showed the following attractive features: divertors are placed behind the blankets, neutron wall loading can be reduced by making the device size large, and we can obtain a large open space inside the torus. It was pointed out that the construction cost does not depend so much on the device size because the total weight of the coil support scales as $R^{0.4}$ due to the decrease in the magnetic field necessary to keep the confinement time constant. Design window analysis shows that reductions in stored magnetic energy (160 GJ) and neutron wall load (1.5 MW/m^2) are achieved by reducing the blanket space (approximately 0.8 m) on the inboard side. To make the SC helical coils, in addition to continuous winding using cable-in-conduit conductor (LTS), winding of segmented helical coils using gas helium cooled conductor (HTS) has been investigated and an experimental result of 100 kA for a reasonable cross-section has been obtained. By using Flibe+Be/ferritic steel for the blanket it is possible to get the tritium breeding ratio (TBR) larger than unity and also radiation shielding for the SC magnet. Removal of the decay heat in the blanket when it was under maintenance was discussed. Large port openings are needed for divertor pumping and remote handling. Reduction in toroidal non-uniformity of divertor heat flux is important because the heat flux is found to be at a tolerable level if the toroidal distribution is uniform. Discussion on the maintenance method and the construction process for FFHR has been started.

The magnetic configuration of the HeliAS power plant is based on W7-X, in which the configuration is optimized on plasma performance from various physical viewpoints. Basic parameters of HeliAS 5-B are as follows: major radius of 22 m, minor radius of 1.8 m, magnetic field on coils of 10.5 T, and fusion power of 3 GW. Modular coils of HeliAS 5-B are of the same size and of performance as those of ITER, thus ITER coil technology is applicable to HeliAS. A double-hull structure is employed for the plasma vessel, similar to the ITER vacuum vessel. Blanket structure and remote maintenance are the key factors to determine the size of HeliAS 5-B. The thickness of the blanket is 80 cm while the space between coil and plasma is 1.3 m. As an intermediate step, an ITER-like HeliAS is supposed to reduce uncertainties in extrapolation to the DEMO reactor. System studies are very sensitive to confinement enhancement/degradation. For the near future, IPP activities will be focused mainly on scientific exploitation and on confirmation of design criteria rather than on power plant studies.

As for the compact stellarator strategy, ARIES-CS based on NCSX was primarily discussed, but there are also ARIES-ACT activities in the United States. The average major radius is 7.75 m, and the average minor radius is 1.72 m. Compactness has been pursued by stressing the low aspect ratio, which is in contrast to FFHR or HeliAS. The low aspect ratio gives minimization of surface area normalized by volume and higher ion temperature under ion temperature gradient (ITG) mechanism for ion transport. A tapered blanket structure similar to that of FFHR is adopted to minimize coil-plasma stand-off. Because the most important issue for the stellarator is complexity, a simplified modular coil system is being pursued. It was shown that not only neoclassical aspects but also anomalous transport can be optimized by small adjustments in plasma shape. Complete stabilization of ITG/ETG is found in some configurations. A pilot plant with a major radius of 4.75 m as a step to power plant has been designed to integrate power plant science and technology and to generate net electricity, $Q_{\mathrm{ENG}} > 1$. It is noted that producing electricity is found to be easier in a stellarator compared with pilot plants based on an advanced tokamak or spherical torus. If NSCX-scale experiments start soon, a decision on the pilot-plant can be made around 2030.

Electricity produced by a fusion plant should match the demand within the error bar of +/- zero percent. In other words, strict stability is required or the system must have an energy reservoir. Strict stability means that even a minor disruption is unacceptable. Unscheduled outage is at most 0.5 events or less in a year. Also, the system should have load-following capability. We must recognize these points when talking about a fusion power plant.

Comments on the aspect ratio were made from the viewpoint of the initial cost. The initial investment cost should be large when the aspect ratio becomes large, although it was pointed out that the total weight of coil support is proportional approximately to $R^{0.4}$. To reduce the initial cost we need to take account of compactness more intensively.

4. *To discuss the strategy of helical system research in the ITER era*

Free discussion, chaired by O. Kaneko, took place on the following subjects:

- What are the common issues for tokamaks and helical systems?
- How can helical system research contribute to ITER?
- What we should learn from ITER?

First of all, we are indebted to stakeholders, i.e., government, for the fusion budget. This means outreach activities are important, in which almost all institutes engage. Japanese researchers are fortunate because budgets for helical research are separated from those for tokamaks, and the budget situation is rather stable. In Europe, the budget situation for W7-X also seems to be stable although re-evaluation is scheduled in 2015. It is expected that W7-X will receive substantial support for next 10 years. In the United States the priority of research is placed on basic science rather than on DEMO-like projects. Stellarators are regarded as a backup to tokamaks, but if arguments for stellarators are pushed too hard, counter-arguments will occur, because stellarators are thought to be behind tokamaks by 1 or 2 generations.

Collaboration with tokamak researchers is important; as an example, through ITPA the helical community is participating in discussion with the tokamak community. The mission of NIFS as an Inter-University Research Institute includes not only helical system research but also fusion science as a whole. The contribution to ITER from helical research might simply be said to be 3D physics; however, we should look at all aspects of engineering for improving ITER, because common issues in tokamaks and helical systems might constitute most of engineering issues, with the exception of SC coils. One example of contributions to ITER from MPI and NIFS is an RF-based negative ion beam source in collaboration with the Padua group.

The following points were also discussed:

- Are burning physics results from the ITER experiment sufficient or not?
- How can we manage engineering or manufacturing development for SC, divertor, and blanket?
- How should we manufacture a big machine in general.

Fig. 1. Meeting participants. First row (from the left): A.Sagara, V.Moiseenko, B.Kuteev, B.Blackwell, O.Kaneko, M.Osakabe, T.Mizuuchi, Y.Takeiri, M.Zarnstorff, T.Mito. Second row (from the left): K.Nagasaki, K.Matsuoka, R.Horiuchi, K.Okano, H.Yamada, T.Goto, S.Imagawa, S.Okamura, C. Hidalgo, T.Muroga. Third row (from the left): S.Masuzaki, H.Sugama, M.Yokoyama, D.Hartmann, J.Miyazawa, N.Yanagi, H.Neilson, T.Pedersen, S.Ishiguro.

5. *To discuss the way to helical DEMO*

Free discussion was chaired by K. Matsuoka on the following subjects: how should we appeal to the stakeholders in order to survive, what and how can we contribute to ITER, and what lessons could we learn from ITER?

Consensus was obtained about the definition of a helical DEMO, which meets the following requirements: gross fusion output larger than several hundreds of megawatts, viable as a pathway to commercialization, and tritium breeding ratio more than unity. This definition is the same as that for a tokamak DEMO.

Regarding FFHR, it was pointed out that the LHD experiment should be promoted toward satisfying DEMO physics requirements. Among the goals of the LHD experiment steady-state operation at 3 megawatts for 1 hour duration should be pursued more intensively because steady-state operation is the best sales point for superiority over a tokamak. We would be happy if a discharge lasting for hours, days, and weeks is realized. An encouraging result of 4.1% β at 1 T was obtained. In LHD the Shafranov shift is not small at that time, so some method for reducing the shift might be required. The deuterium experiment in LHD takes a step toward an integrated research of science and engineering. The effect of isotopes on confinement improvement is expected to be clarified.

W7-X has been optimized for core plasma physics. We are looking forward to the start of experiments. Concern would be focused on divertor operation because the divertor area might be smaller than that of LHD. Island divertors are inherent to modular stellarators. This is due to an anti-helical winding component that does not allow a helical divertor structure along helical windings such as those of LHD.

Energetic discussions were held on the need for of a helical ITER-level device. The majority of participants agreed it is a] necessity. Burning physics in a helical system might be different from that in a tokamak and the gap from present-day experiments to the helical DEMO is too large.

In any case, the community is looking forward to experimental results from LHD and W7-X. Plan for the future should be drawn up on the basis of experimental results.

6. *To discuss possible international collaborations that assist domestic helical system research activities in each country*

The status of international collaboration was reported by all participating institutes. The reporters were B. Blackwell, K. Nagasaki, V. Moiseenko, T. S. Pedersen, C. Hidalgo, S. Masuzaki, B. Kuteev, and H. Neilson. International collaboration is taking place in almost all areas of fusion research including tokamaks.

H. Neilson announced that a stellarator session would be held at the 26th Symposium on Fusion Energy (SOFE), 31 May–4 June 2015, in Austin, Texas, in the United States. In session SO-22: Design and Analysis Tools for Stellarator DEMO Devices, several invited talks on HeliAS, FFHR, and other topics will be given. Another piece of useful information was the Announcement of Third IAEA DEMO Programme Workshop to be held at Hefei, China, 11–16 May 2016. International programme committee members and a tentative program were introduced. T. Muroga is the chairperson of the international programme committee, and H. Neilson is a member of the committee.

In the report by M. Yokoyama on the IEA Implementing Agreement for Cooperation in Development of the Stellarator-Heliotron Concept it was announced that the chairmanship will change to R. Wolf from A. Komori at the next executive committee meeting in October 2015. The 20th International Stellarator-Heliotron Workshop will be held at Greifswald 5–9 October 2015. The next Coordinated Working Group Meeting (CWGM) will be held in Warsaw 17–19 June 2015.

7. *Summary*

A summary was presented by O. Kaneko. He made the following points: Why don't we make our research more DEMO-oriented? We don't have much time left to make a helical system roadmap to the first candidate of a helical DEMO that is competitive with a tokamak. In order to accelerate the research, we should pick specific critical issues for DEMO, and various groups should proceed to research the subjects and discuss the results, as is done by the ITPA for ITER. This may be possible for scientific issues. How about for engineering issues? This was the original function of the CWGM, and why don't we restart the engine? We hope to discuss this subject at the next CWGM (June) or Stellarator/Heliotron Workshop (October).

Dr. Keisuke Matsuoka
National Institute for Fusion Science
The Research Enhancement Strategy Office
Toki 509-5292 JAPAN
TEL: +81-572-58-2344
FAX: +81-572-58-2309
E-mail: matsuoka@nifs.ac.jp

Announcement: 14th Coordinated Working Group Meeting

We cordially invite you to the 14th Coordinated Working Group Meeting (CWGM) of the International Stellarator-Heliotron research community. This year it will take place in Warsaw, Poland 17–19 June 2015. The objective of the CWGM is to gather numerous experts in the field of magnetic confinement fusion and to debate the hottest results and the future of stellarator-heliotron research.

The conference announcement is appended. For further information please consult the CWGM website http://cwgm2015.ipplm.pl, which will be regularly updated with information about the venue, program, and hotel and travel tips. You may also send your questions directly to cwgm2015@ipplm.pl; we will be happy to help you.

We are looking forward to seeing you in Warsaw!

Krzysztof Gałązka, on behalf of the Local Organizing Committee
Institute of Plasma Physics and Laser Microfusion, Warsaw

THE COORDINATED WORKING GROUP MEETING

of the International Stellarator-Heliotron research

Warsaw, 17-19 June, 2015

Dear Colleagues,

The Institute of Plasma Physics and Laser Microfusion have the honor to invite to:

14th COORDINATED WORKING GROUP MEETING ' 2015

which will be held in Warsaw, June 17-19, 2015.

It is worth to mention that the Coordinated Working Group Meeting (CWGM) implements and coordinates international collaborations in [S]tellarator-[H]elietron research. The work is intended to contribute to the International Stellarator-Heliotron Confinement and Profile Database (ISH-C(P)DB).

The annual Meeting allows to gather numerous experts in the magnetic confinement fusion field. The main objective of the Meeting is to discuss the recent results and the way laying ahead of plasma research.

The general character of the programme provides attendees with sessions coordinated by a topic leader. Session leaders will be announced in due course.

The possible list of topics is as follows:

- **SH Confinement and Profile Database**
- **Highlights in experiment, invitation to joint experiment**
- **Framework for collaborations**
- **Diagnostics collaborations**
- **3D Transport in divertors**
- **Impurity transport**
- **Flows and Viscosity, Transport**
- **Energetic particles, Alfven modes**
- **3D Equilibrium**
- **Reactor/Systems code**
- **Plasma Startup**

With this announcement you are invited to propose a talk in the frame of topics listed above. The deadline for abstract submission is the 26th April, 2015.

More information can be found on the website: http://cwgm2015.ipplm.pl/

Correspondence or questions should be sent to: cwgm2015_ipplm@ipplm.pl

We are looking forward to seeing you in Warsaw!

Local Organizing Committee