Technology Collaboration Programme on the Stellarator-Heliotron Concept (SH TCP)

Annual Briefing 2017

1 Preface

1.1 Objective

The SH TCP's objective is to improve the physics base of the Stellarator concept and to enhance the effectiveness and productivity of research by strengthening co-operation among member countries. All collaborative activities of the worldwide stellarator and heliotron research are combined under the umbrella of this programme, which promotes the exchange of information among the partners, the assignment of specialists to facilities and research groups of the contracting parties, joint planning and coordination of experimental programmes in selected areas, joint experiments, workshops, seminars and symposia, joint theoretical and design and system studies, and the exchange of computer codes.

1.2 Organization

The joint-programming and research activities are organized via the Coordinated Working Group Meetings (CWGM). The bi-annual "International Stellarator-Heliotron Workshop" (ISHW) serves as a forum for scientific exchange.

1.3 Major achievements 2017

In 2017 major achievements were the deuterium plasma campaign in the Large Helical Device (LHD) and start of the second experimental campaign of the optimized stellarator Wendelstein 7-X (W7-X). First results of LHD deuterium plasmas were shown at the International Stellarator-Heliotron Workshop (ISHW) in Kyoto including record heating powers, extremely high ion temperatures and intriguing transport properties. The first half of the second experimental campaign was completed with success. With an uncooled divertor the injected energy was extended from 4 MJ to 80 MJ - a major milestone on the way to a steady state plasma.

2 Chair's Report

2.1 Main events

2.1.1 21st International Stellarator-Heliotron Workshop (ISHW)

The 21^{2t} ISHW was hosted by the Institute of Advanced Energy at Kyoto University from Oct. 2 to Oct. 6, 2017 and included a special session on the physics of decoupling transport channels to promote synergies between tokamaks and stellarators. The conference attracted nearly 200 delegates coming from the whole Stellarator-Heliotron community as well as invited speakers from the tokamak community.

2.1.2 16th Coordinated Working Group Meeting (CWGM)

The 16th Coordinated Working Group Meeting (CWGM16) was held Jan. 18-20, 2017 in Madrid, Spain was the largest CWGM participation in recent years, due to the then imminent operational phase OP 1.2a of Wendelstein 7-X (W7-X) and the first deuterium plasma campaign at the Large Helical Device (LHD). Discussion of physics problems that could be addressed by these new experiments had a prominent place in all the sessions.

2.2 Milestones achieved

2.2.1 Deuterium campaign at LHD

In 2017, the 19th experimental campaign of the Large Helical Device (LHD) took place from Feb. 7, 2017 to August 3, 2017. Several thousand individual plasma experiments were carried out with support and interaction from national and international collaborators. After several years of preparation for device upgrades and improved administrative procedures, this new phase was highly anticipated, since it was the first time that the hydrogen isotope deuterium was employed as plasma species in a large non-axisymmetric fusion device. Full deuterium plasma operation started on March, 7 after the complete machine conditioning in hydrogen and the test as well as confirmation of the safety systems. One of the major goals was to investigate the well-known "isotope-effect" from tokamak experiments where it can be observed that the plasma performance and confinement is enhanced with increasing isotope mass.

To date, statistically relevant evidence of an isotope-effect in helical devices was lacking, but recent large-scale gyrokinetic simulations predicted an improved confinement with isotope mass using turbulence reduction. During the course of the campaign it was found that in plasmas generated with Neutral beam injection (NBI) heating as well as in ECRH plasmas, the performance favourably increased with deuterium, therefore giving clues for an isotope-effect in helical devices. The ion temperature could be extended to a new LHD record value of 120 million degrees, marking a milestone for helical systems research by demonstrating its capability to satisfy one of the conditions for fusion. Beyond that, an important discovery has been the expelling of impurities through microwave heating, i.e. a plasma with deliberately injected impurities could be cleaned through an immediate injection of microwaves.

During the last month of the campaign additional experiments were undertaken with hydrogen as working gas in order to establish a reference database to enable a detailed comparison between hydrogen and deuterium plasmas. With the conclusion of this highly successful experimental campaign with many novel results and highlights, the main focus is now set on detailed data evaluation and analysis while simultaneously preparing the next operation cycle, which is to continue in fall 2018.

Research highlights of the first deuterium campaign were presented at the 17th ISHW and will be reviewed at other international events, such as the upcoming 27th IAEA Fusion Energy Conference.

2.2.2 Milestones from TJ-II

Together with experts from Ukraine and Russia experiments for the operation of the dual heavy ion beam probe system to allow the validation of gyrokinetic code calculations were successfully conducted. In collaboration with NIFS, researchers carried out the dual operation of a pellet injector using Tracer-Encapsulated Solid Pellets (TESPEL) and cryogenic pellets.

2.2.3 Wendelstein 7-X Campaign OP 1.2a

The second experimental campaign of Wendelstein 7-X took place from August - December 2017. The experiments were conducted on helium and hydrogen plasmas using ECRH as the only heating system with a maximum power of 7.2 MW, which is the highest ECRH power ever employed in a fusion experiment. The scientific program focused on the demonstration of stationary, high performance discharges and the characterization of the inertially cooled test divertor units in preparation for operation of the high heat-flux divertor in the later campaign.

It was demonstrated that high plasma densities can be reached with a transition of the microwave heating power from X2 to full power O2 polarization. Discharge lengths could be considerably improved from seven seconds in the previous campaign to a maximum of 25 seconds with stationary conditions.

Heat load patterns on the test divertor modules could by symmetrized using the magnetic trim coils. Even for long high-power discharges, divertor temperatures remained well within the specifications. Strongly reduced heat loads on the divertor were observed in high-density hydrogen operation with and without pellet fuelling, suggesting that detachment was achieved. For high-density discharges, a remarkable triple product approaching $6 \cdot 10^{19}\,m^{-3}\,s\,keV$, which is well within the range of medium sized tokamaks, was reached.

2.3 Future Plans

2.3.1 W7-X

The schedule for W7-X foresees two more completion phases (CP 1.2b, CP 2) and one operations phase with 15 weeks of plasma experiments (OP 1.2b), until the machine will have reached steady state capability at the end of the year 2020.

In January 2018, W7-X will be reopened for the installation of two so called “Scraper Elements” which serve as extensions of the Test Divertor Unit (TDU) and are designed to protect the main divertor target edges against possible overheating in certain magnetic configurations. In addition, new diagnostic systems will be integrated and the available heating systems will be extended. Plasma experiments are scheduled to resume in July 2018.

The subsequent completion phase CP 2, which is planned to last from October 2018 until November 2020, will consist of the installation of several major components that are essential for achieving steady state capability, most prominently the actively cooled high-heat-flux (HHF) divertor.

The operations phase OP 2 itself will follow a staged approach, consisting of several energy steps from 1 GJ to 18 GJ. The creation of long-pulse, high performance plasmas with 30 minute pulse length and 10 MW heating power is intended to be achieved in the years 2023/2024.

2.3.2 LHD

LHD is now preparing further deuterium campaigns. The 20th experimental campaign of LHD is foreseen to start in October 2018 and last until February 2019. A LHD deuterium workshop is planned for February 7-8, 2018. Proposals by international collaborators are requested until July 1, 2018.

2.3.3 Participation

A letter of invitation to join the SH TCP was sent to the Ministry of Science, Technology and Telecommunications Costa Rica.

China is extending its fusion activities towards stellarator research. This includes the start of the joint project to construct Chinese First Quasi-axisymmetric Stellarator (CFQS) by the joint project between NIFS and Southwest Jiaotong University, and the move of the Heliac H1 from the Australian National University to the University of South China. In preparation, an international workshop will be held on March 26-28, 2018 in Hangzhou, China.