Progress report on the project

IAEA CRP F1.30.14.17116/R0: **"Use of a Small Tokamak GOLEM as a test bed for application of High Temperature Superconductors in Fusion Devices"**

Performed in the frame of the IAEA Coordinated Research Project (CRP) *"Utilisation of a Network of Small Magnetic Confinement Fusion Devices for Mainstream Fusion Research".*

Responsible investigator: *Vojtech Svoboda, Czech Technical University in Prague, Brehova 7, Prague, CZ 115 19 Czech Republic*

The following tasks have been executed in the year November 2014- November 2015

Remote operation of the vertical plasma stabilization @ the GOLEM tokamak for the plasma physics education.

The GOLEM tokamak at the Czech Technical University has been established as an educational tokamak device for domestic and foreign students. Remote participation in the scope of several laboratory practices, plasma physics schools and workshops has been successfully performed from abroad. A new enhancement allowing understandable remote control of vertical plasma position in two modes (i) predefined and (ii) feedback control is presented. It allows to drive the current in the stabilization coils in any time-dependent scenario, which can include as a parameter the actual plasma position measured by magnetic diagnostics. Arbitrary movement of the plasma column in a vertical direction, stabilization of the plasma column in the center of the tokamak vessel as well as prolongation/shortening of plasma life according to the remotely defined request are demonstrated.

Presented at the 28th Symposium of Fusion Technology, San Sebastian. 2014

For more details, see: V. Svoboda, J. Kocman, O. Grover, J. Krbec, J. Stöckel. Remote operation of the vertical plasma stabilization @ the GOLEM tokamak for the plasma physics education. 28th Symposium of Fusion Technology, San Sebastian. 2014. Fusion Engineering and Design. Volumes 96–97, October 2015, Pages 974–979.
http://www.sciencedirect.com/science/article/pii/S0920379615300740

Contribution to fusion research from IAEA coordinated research projects and joint experiments

* The importance of investigation of capabilities and properties of HTS for application in magnets of the future Fusion devices is well defined in the EuroFusion roadmap. The first application of HTS in PF magnets has been demonstrated on a tokamak GOLEM as a contribution to the CRP activity work plan.

* Studies of the electron cyclotron resonance (ECR) preionization system have been performed during 6th JE on GOLEM using 2.45 GHz 1 kW magnetron from a standard

microwave oven. The use of commercial magnetrons allowed the pre-ionization system to be very cheap and so affordable for small tokamaks.

For more details, see: Mikhail Gryaznevich et al. Contribution to fusion research from IAEA coordinated research projects and joint experiments. Nuclear Fusion, Volume 55, Number 10. http://iopscience.iop.org/article/10.1088/0029-5515/55/10/104019/meta;jsessionid=27F698905E96538A4CA7E0C4E663F9AA.c1

Development of 3D ferromagnetic model of tokamak core with strong toroidal asymmetry

Fully 3D model of strongly asymmetric tokamak core, based on boundary integral method approach (i.e. characterization of ferromagnet by its surface) is presented. The model is benchmarked on measurements on tokamak GOLEM, as well as compared to 2D axisymmetric core equivalent for this tokamak, presented in previous work. Linearized model well describes quantitative characteristics of BR field, generated by poloidal field coils located close to core central column, and distorted by ferromagnet. A discrepancy is seen between linearized form of model for BR field generated by coils under the transformer limbs and the measurements. Future work will thus include implementation of the non-linearity effects in order to further investigate this issue.

Presented at the 28th Symposium of Fusion Technology, San Sebastian. 2014

For mode details, see: Tomas Markovic, Mikhail Gryaznevich, Ivan Duran, Vojtech Svoboda. Development of 3D ferromagnetic model of tokamak core with strong toroidal asymmetry. 28th Symposium of Fusion Technology, San Sebastian. 2014. Fusion Engineering and Design. Volumes 96–97, October 2015, Pages 302–305. http://www.sciencedirect.com/science/article/pii/S0920379615002100

Remote operation of the GOLEM tokamak for Fusion Education

Practically oriented education in the field of thermonuclear fusion is highly requested. However, the high complexity of appropriate experiments makes it difficult to develop and maintain laboratories where students can take part in hands-on experiments in this field of study. One possible solution is to establish centers with specific high temperature experiments where students can visit such a laboratory and perform their experiments in-situ. With the advancements of IT technologies it naturally follows to make a step forward and connect these with necessary plasma physics technologies and thus allow to access even sophisticated experiments remotely. Tokamak GOLEM is a small, modest device with its infrastructure linked to web technologies allowing students to set-up necessary discharge parameters, submit them into a queue and within minutes obtain the results in the form of a discharge

Presented at the 10th IAEA Technical Meeting on Control, Data Acquisition and Remote Participation for Fusion Research, April 2015, Ahmedabad, India.

For more details, see: V. Svoboda et.al.: Remote operation of the GOLEM tokamak for Fusion Education. Submitted to the Fusion Engineering and Design.

Probe measurements on the Tokamak GOLEM

Measurements on the radial profiles of plasma parameters with the linear array of probes (the rake probe). Thanks to unique reproducibility of the GOLEM discharges, the IV characteristics are measured by changing the probe voltage on a shot-to shot basis. Consequently, the temporal resolution about 10 μs is achieved. Measurements are performed during a tokamak discharge, as well as during the pre-ionization phase of a discharge.

Presented at the 22nd IAEA Technical Meeting (TM) on Research Using Small Fusion Devices. October 2015, Prague. Preparing for publication.

Education and training of students

Experiments related to CRP project triggered bachelor and master thesis at the CTU:

Lukas Matena – Master thesis “Interferometry measurement on the tokamak GOLEM.”

Jindrich Kocman – Master thesis “Plasma position control on the tokamak GOLEM.”

Training of students has also been performed remotely, exploiting a unique feature of the GOLEM tokamak, which can be operated via Internet. Several on-site as well as remote courses were organized in the period 2014 – 2015, among these, major events were:

* SUMTRAIC – Summer training course, Prague, Czech Republic

* EMTRAIC – Erasmus Mundus training course, Prague, Czech Republic

* SCIWEEK – Science week for high school students from Czech Republic

* Remote practice for Budapest University, Hungary

Tokamak GOLEM for fusion education

Students of the Czech Technical University in Prague participate on the development of the tokamak operation and its diagnostics base and are involved in the simple projects contributing to the main stream of the tokamak plasma physics and technology. i) A plasma interferometer undergoes reparation, upgrade and re-installation. First density measurements have been conducted to test its function. ii) A real-time plasma positioning system in the vertical direction have been implemented operating in two modes: pre-programmed control of horizontal magnetic field scenario and LabVIEW based real-time system, which controls

the horizontal magnetic field in response to the currently measured vertical position of plasma. iii) The investigation of the runaway electrons behavior in the GOLEM tokamak has continued. The utilization of timepix detector for direct in-vessel measurements of runaway electron properties has begun and first measurements have been conducted. Furthermore, comparison isotopic studies of RE production in helium and hydrogen plasmas were performed. iv) VA characteristics of the Langmuir probe measured on the shot-to-shot basis have been conducted in the various regimes and types of plasma in the tokamak GOLEM demonstrating the basic plasma physics phenomena with the unique temporal resolution.

Presented at the 42nd EPS Conference on Plasma Physics, Lisbon, Portugal.

For more details, see O.Ficker, O.Grover, J.Kocman, J.Krbec, L.Matena, J.Stockel, V.Svoboda, G.Vondrasek. Tokamak GOLEM for fusion education - chapter 6. Poster presentation at the 42nd EPS Conference on Plasma Physics, Lisbon, Portugal. Vol. 39E ISBN 2-914771-98-3:P2.164,2015. http://ocs.ciemat.es/EPS2015PAP/pdf/P2.164.pdf