Session 13. Fusion gyrotrons

April 30 (Tuesday) / 13:30 ~ 15:10 / Room 1

Session Chair: John Jelonnek (Karlsruhe Institute of Technology, Germany)

13:30 ~ 13:50

13.1 / [Keynote] Development of Megawatt Gyrotrons in IAP/GYCOM

G. Denisov (Institute of Applied Physics Russian Academy of Sciences, Russia), A. Litvak (Institute of Applied Physics Russian Academy of Sciences, Russia), E. Sokolov (GYCOM Ltd, Russia), A. Chirkov (Institute of Applied Physics Russian Academy of Sciences, Russia), A. Eremeev (Institute of Applied Physics Russian Academy of Sciences, Russia), E. Tai (GYCOM Ltd, Russia), E. Soluyanova (GYCOM Ltd, Russia), V. Myasnikov (GYCOM Ltd, Russia), L. Popov (GYCOM Ltd, Russia)

A brief summary of current developments in Russia of megawatt power gyrotrons is presented. The gyrotron developed are applied in experiments at several modern tokamaks. New demands to gyrotron parameters and possible ways to reach them are discussed.

13:50 ~ 14:10

13.2 / From W7-X Towards ITER and Beyond: 2019 Status on EU Fusion Gyrotron Developments

John Jelonnek (IHM / IHE, Gremany), Gaetano Aiello (IAM-AWP, Germany), Ferran Albajar (Fusion for Energy, Spain), Stefano Alberti (Swiss Plasma Center, EPFL, Switzerland), Konstantinos A. Avramidis (IHM, Gremany), Andrea Bertinetti (Politecnico Di Torino, Italy), Philippe T. Brücker (IHM, Gremany), Alex Bruschi (National Research Council of Italy, Italy), Ioannis Chelis (National and Kapodistrian University of Athens, Greece), Jérémie Dubray (Swiss Plasma Center, EPFL, Switzerland), Francesco Fanale (National Research Council of Italy, Italy), Damien Fasel (Politecnico Di Torino, Italy), Thomas Franke (EUROfusion Consortium, Germany), Gerd Gantenbein (IHM, Gremany), Saul Garavaglia (National Research Council of Italy, Italy), Jérémy Genoud (Swiss Plasma Center, EPFL, Switzerland), Gustavo Granucci (National Research Council of Italy, Italy), Jean-Philippe Hogge (Swiss Plasma Center, EPFL, Switzerland), Stefan Illy (IHM, Gremany), Zisis C. Ioannidis (IHM, Gremany), Jianbo Jin (IHM, Gremany), Heinrich Laqua (Max-Planck-Institut für Plasmaphysik, Germany), George P. Latsas (National and Kapodistrian University of Athens, Greece), Alberto Leggieri (Microwave & Imaging Solution, THALES, France), Francois Legrand (Microwave & Imaging Solution, THALES, France), Rodolphe Marchesin (Microwave & Imaging Solution, THALES, France), Alexander Marek (IHM, Gremany), Blaise Marlétaz (Swiss Plasma Center, EPFL, Switzerland), Martin Obermaier (IHM, Gremany), Ioannis Gr. Pagonakis (IHM, Gremany), Dimitrios V. Peponis (National and Kapodistrian University of Athens, Greece), Sebastian Ruess (IHM / IHE, Gremany), Tobias Ruess (IHM, Gremany), Tomasz Rzesnicki (IHM, Gremany), Paco Sanchez (Fusion for Energy, Spain), Laura Savoldi (Politecnico Di Torino, Italy), T. Scherer (IAM-AWP, Germany), D. Strauss (IAM-AWP, Germany), Philippe

Thouvenin (Microwave & Imaging Solution, THALES, France), Manfred Thumm (IHM / IHE, Gremany), Ioannis Tigelis (National and Kapodistrian University of Athens, Greece), Minh-Quang Tran (Swiss Plasma Center, EPFL, Switzerland), Fabian Wilde (Max-Planck-Institut für Plasmaphysik, Germany), Chuanren Wu (IHM, Germany), Anastasios Zisis (National and Kapodistrian University of Athens, Greece)

In Europe, the research and development with main focus on achieving robust industrial designs of series gyrotrons for electron cyclotron heating and current drive of today' nuclear fusion experiments and towards a future DEMOnstration fusion power plant is constantly progressing. The R&D is following two different paths. Both are complementing each other: Firstly, it is the adaption of the physical design and basic mechanical construction of the reliably operating 140 GHz, 1 MW CW (spec.: 920 kW, 1800 s) gyrotron of the stellarator Wendelstein 7-X (W7-X), Greifswald, Germany. With regards to time and costs it is the target to perform reliable developments of fusion gyrotrons with advanced specifications for today' plasma fusion experiments. Main focus is on the development of the first EU 170 GHz, 1 MW CW (3600 s) gyrotron for the installation in ITER, Cadarache, France. Another adaption is the dualfrequency 126/84 GHz 1 MW (2 s) gyrotron upgrade for the medium size TCV tokamak, Lausanne, Switzerland. Finally, it is the upgrade of the W7-X gyrotron design towards an RF output power per unit of up to 1.5 MW and possible dualfrequency operation by keeping the basic mechanical construction. Additional to the proven design it allows to fit the new 1.5 MW gyrotron into the already existing infrastructure and to reuse existing W7-X gyrotron auxiliaries, e. g. the highpower voltage supply (HV PS) and the superconducting (SC) magnet. The second R&D path is defined by the complementary approach with regards to development risks towards a future gyrotron which shall fulfil the significant more advanced specifications of a future EU DEMO. The starting point is the 2 MW EU/KIT coaxial-cavity gyrotron design. Main requirements are an RF output power of 2 MW CW at above 200 GHz, multiple operating frequencies, frequency step-tunability and a total efficiency above 60 %.

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13.3 / Study of 140GHz and 170GHz gyrotrons for fusion plasma ECRH

Bentian Liu (Beijing Vacuum Electronics Research Institute, China), Jinjun Feng (Beijing Vacuum Electronics Research Institute, China), Yichi Zhang (Beijing Vacuum Electronics Research Institute, China), Yang Zhang (Beijing Vacuum Electronics Research Institute, China), Bo Chen (Beijing Vacuum Electronics Research Institute, China)

The development of 140GHz and 170GHz MW gyrotron research in BVERI are given in this paper. There are three versions of the 140GHz MW gyrotrons which have been designed and fabricated in BVERI. All of the 140GHz gyrotron have been tested and the experimental results have been enhanced to output power of 500KW with Gaussian beam. Using the techniques achieved in the study on the 140GHz gyrotorns, the 170GHz gyrotron has been designed with the sing-depressed collector and quasi-optical mode converter.

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13.4 / Manufacturing and Test of the 1 MW Long-Pulse 84/126 GHz Dual-Frequency Gyrotron for TCV

Rodolphe Marchesin (Microwave Imaging Solution, THALES, France), Stefano Alberti (Swiss Plasma Center, EPFL, Switzerland), Konstantinos A. Avramidis (Karlsruhe Institute of Technology, Germany), Andrea Bertinetti (Politecnico Di Torino, Italy), Jérémie Dubray (Swiss Plasma Center, EPFL, Switzerland), Damien Fasel (Swiss Plasma Center, EPFL, Switzerland), Gerd Gantenbein (Karlsruhe Institute of Technology, Germany), Jérémy Genoud (Swiss Plasma Center, EPFL, Switzerland), Jean-Philippe Hogge (Swiss Plasma Center, EPFL, Switzerland), John Jelonnek (Karlsruhe Institute of Technology, Germany), Jianbo Jin (Karlsruhe Institute of Technology, Germany), Stefan Illy (Karlsruhe Institute of Technology, Germany), Francois Legrand (Microwave Imaging Solution, THALES, France), Blaise Marlétaz (Swiss Plasma Center, EPFL, Switzerland), Alberto Leggieri (Microwave Imaging Solution, THALES, France), Laura Savoldi (Politecnico Di Torino, Italy), Philippe Thouvenin (Microwave Imaging Solution, THALES, France), Ioannis Gr. Pagonakis (Karlsruhe Institute of Technology, Germany), Minh-Quang Tran (Swiss Plasma Center, EPFL, Switzerland), Manfred Thumm (Karlsruhe Institute of Technology, Germany)

An 1 MW long-pulse (2s), 84/126 GHz dual-frequency gyrotron has been produced by THALES MSI, France responding to the needs for upgrading the ECH system of the TCV tokamak. The initial tests of the prototype carried out at EPFL, Switzerland, have verified a stable operation at both frequencies in short-pulse operation (TRF≤10ms) with measured output powers in excess of 0.9 MW at 84GHz and 1.0 MW at 126 GHz.

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13.5 / Megawatt Power-Level G-band Planar Gyrotrons with Transverse Energy Extraction

Naum Ginzburg (Institute of Applied Physics RAS / Nizhny Novgorod State University, Russia), Vladislav Zaslavsky (Institute of Applied Physics RAS / Nizhny Novgorod State University, Russia), Alexander Sergeev (Institute of Applied Physics RAS, Russia), Irina Zotova (Institute of Applied Physics RAS, Russia)

Modern controlled-fusion facilities are equipped with electron-cyclotron plasma fusion systems based on gyrotron complexes, in which the maximum continuous-wave radiation power has been achieved at a megawatt power level in the millimeter wavelength range. At the same time, a higher frequency of microwave sources is required for novel compact fusion reactors with strong magnetic fields. For example, the DEMO reactor project, which is intensely discussed at present, requires development of shorter-wave megawatt continuouswave sources having a frequency of 220-60 GHz. As such sources, we suggest gyrotrons of planar geometry of interaction space with a sheet electron beam and transverse energy extraction. An advantage of this scheme in comparison with conventional cylindrical geometry is the possibility to ensure effective mode selection over the open transverse coordinate in combination with radiation outcoupling that leads to a substantial reduction of Ohmic losses. In this paper we perform theoretical analysis and numerical simulation of two G-band planar gyrotrons operating at the

first harmonic of the cyclotron frequency. First, 140 GHz planar gyrotron driven by a sheet helical electron beam with an energy of 50 keV and beam current of 30 A is studied. The project of this oscillator is under development at Institute of Applied Physics RAS currently. Finally, simulations of 260 GHz megawatt power planar gyrotron for DEMO project are considered.