Industrial Qualification of the THALES TH1509U European 170 GHz 1 MW CW Gyrotron

Alberto Leggieri[1], Ferran Albajar[2], Stefano Alberti[3], Konstantinos A. Avramidis[4], Ruggero Bertazzoni[2], William Bin[5], Daniele Bonetti[6], Falk H. Braunmueller[3], Alex Bruschi[5], Antonio Cammi[7], Ioannis Chelis[4], Davide Dall'Acqua[2], Rosa Difonzo[8], Lukas Feuerstein[9], Eleonora Gajetti[8], Gerd Gantenbein[9], Saul Garavaglia[5, 11], Jérémy Genoud[3], Jérémy Gontard[1], Timothy P. Goodman[3], Gustavo Granucci[5, 11], Jean-Philippe Hogge[3], Stefan Illy[9], Carolina Introini[7], Zisis Ioannidis[4], John Jelonek[9], Jianbo Jin[9], François Legrand[1], Christophe Lievin[1], Rodolphe Marchesin[1], Ijaze M. Oumar[1], Afra Romano[10, 11], Tomasz Rzesnicki[9], Francisco Sanchez[2], Laura Savoldi[8], Sebastian Stanculovic[9], Ioannis Tigelis[4], Etienne Vallée[1] and Manfred Thumm[9].

[1]THALES, Vélizy-Villacoublay, France 78140; [2]Fusion For Energy, Barcelona, Spain 08019
[3]Swiss Plasma Center, Lausanne, Switzerland 1015; [4]National and Kapodistrian University, Athens, Greece 15771
[5]Institute for Plasma Science and Technology (ISTP-CNR), Milan, Italy 20125; [6]EniProgetti, Rome, Italy 00144
[7]Politechnic of Milan, Milan Italy 20133; [8]Politechnic of Turin, Turin Italy 10129
[9]Karlsruhe Institute of Technology, Germany 76131
[10]ENEA, Fusion and Nuclear Safety Department, Frascati, Italy 00044; [11]DTT S.C. a r.l. Frascati, Italy 00044

Abstract: *The progress of the European THALES TH1509U 170 GHz 1 MW CW industrial gyrotron program is presented in this report. The test results on the upgraded TH1509U and the compliance with main technical requirements are discussed.*

Keywords: ECH&CD; Gyrotron; Millimeter Waves; Fast Wave Devices; Magnetic Confinement Nuclear Fusion.

Introduction

For decades, THALES Microwave & Imaging Sub-Systems (MIS) has produced high power gyrotrons. This report summarizes the progress achieved on the industrial gyrotron TH1509U by the end of 2023 that concretizes the European response to the ITER and DTT technical needs for the microwave sources of their respective ECH&CD systems. The physics design has been performed by the European GYrotron Consortium (EGYC), which is composed of the following institutions: The Karlsruhe Institute of Technology (KIT), the Swiss Plasma Center (SPC) Lausanne, the Kapodistrian University of Athens (NKUA) and the National Research Council in Italy (ISTP-CNR). The Polytechnic of Turin (PoliTO) and the Polytechnic of Milan (PoliMI) have been integrated into the R&D program by contributing to the upgrade of cooling circuits and to the development of the cathode temperature control system respectively. The industrial design and manufacturing are performed by THALES.

Technical Details and Design Evolution

The TH1509U gyrotron is based on the THALES diode-type magnetron injection gun (MIG) and single-stage depressed collector configuration, whose strong reliability has been proven during several years [1]. The unit relies on an interaction cavity operating in the $TE_{32,9}$ mode with an axial magnetic field of $B_c = 6.77$ T to provide 1 MW output power in continuous wave in the form of a Gaussian TEM_{00} beam, that is generated by a quasi-optical system including a launcher antenna, phase correcting mirrors and a CVD diamond window [2]. The industrial gyrotron design has been optimized during several years through a step-by-step approach by integrating and validating last generation subassemblies, including the cathode structure, the high-voltage feedthroughs with the strengthening of body insulation as well as the beam tunnel and the interaction cavity with particular care to maximize the power output while suppressing the excitation of parasitic modes. The cooling circuits have been consequently upgraded to manage the higher power load attainable and a dedicated filament control system has been introduced in order to improve the power output stability of the gyrotron. Other improvements were dedicated to the manufacturing files of the gyrotron assembly and to the means of production. All these operations have allowed THALES and EGYC to finalize the European industrial gyrotron dedicated to the ITER and DTT 170 GHz ECRH systems.

Design Validation at KIT

The TH1509U design has been validated in a dedicated experimental campaign performed on the short-pulse (SP) modular pre-prototype at KIT. Extensive measurements have been performed for pulse durations up to 5 μs with different magnetic field profiles. By varying the electron beam radius at the cavity between 9.35 mm and 9.65 mm and the angle of the magnetic field at the emitter from -3° to +2°, in order to investigate different electron beam parameters, providing velocity pitch (transverse over axial velocity) factors ranging from 1 to 1.6 [3].

The tube has been operated up to a beam voltage of ~80.5 kV and it has provided 1.6 MW (350 kW more than the previous design version tested in SP) of output power at the window with total absence of parasitic modes up to 66 A beam current. An RF efficiency of 33% (5 percentage points more) without collector depression and 50% of total efficiency with single stage collector depression have been demonstrated.

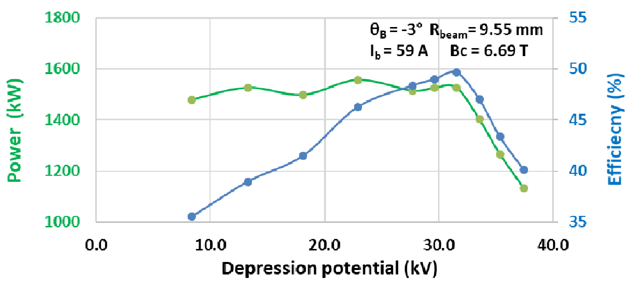

Figure 1. Measured performances of short-pulse modular gyrotron in single-stage collector depression at KIT.

TH1509U Gyrotron Manufacturing and Test

Following this encouraging result, a new TH1509U gyrotron has been manufactured. The preliminary factory test revealed the full compliance to the vacuum level, hydraulic characteristics, heating filament impedance and high voltage standoff requirements. The TH1509U gyrotron has been successfully tested at the SPC Lausanne, showing a power level of 1.03 MW at the gyrotron output window, corresponding to 990 kW at the output of the Matching Optics Unit (MOU) with an RF power stability below 5%. An efficiency exceeding the 40 % has been demonstrated during 100 s pulses (5 consecutive), for a beam voltage of 79.75 kV (including 24.75 kV body voltage depression) and 47.5 A beam current, in total absence of parasitic modes. The compliance of the TH1509U gyrotron tube with DTT requirements has been verified during this campaign, even if the working point and tube alignment were not fully optimized yet. The operating parameters are being optimized to investigate the maximum performance of the tube, mostly by increasing the body voltage in order to further improve the efficiency.

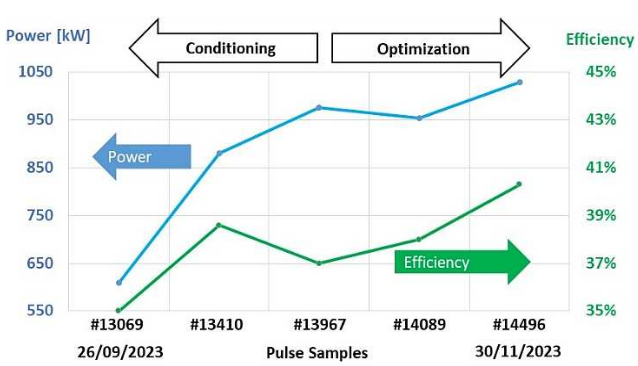

Figure 2. Evolution of measured power and efficiency of the TH1509U CW unit in long pulse operation at SPC.

In the next campaign, the compliance with all the ITER requirements will be assessed. ITER & DTT technical specifications are articulated in a large set of requirements concerning not only performance and reliability but also usability, maintainability, manufacturability and the respect of international standards and regulations. The compliance of the TH1509U to all these requirements creates a solid customer's added value.

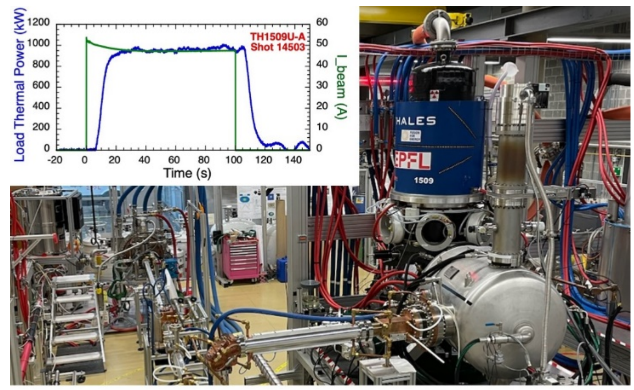

Figure 3. TH1509U under test at SPC and output plot.

Conclusions

In the frame of a solid European collaboration, continuous improvements are being provided to the state-of-the-art of gyrotrons for nuclear fusion applications. The industrial means for reliable prototyping processes, increased series production and deep test campaigns are available at THALES, KIT and SPC. The robustness of actual programs and new gyrotron developments provide a large confidence in the progress of gyrotron design and manufacturing, including possible future collaborations in new projects that are emerging all over the world. The test of the TH1509U gyrotron are in progress to optimize the gyrotron performance and complete results will be presented during the IVEC 2024 conference.

Acknowledgements

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