THALES TH1507U 140 GHz 1.5 MW CW Industrial Gyrotron for W7-X ECRH System Upgrade

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Abstract: *The status of the first 140 GHz 1.5 MW CW (1800s) industrial gyrotron unit (TH1507U) manufactured by THALES for the W7-X Stellarator at Greifswald, Germany, is presented in this paper. The design of the industrial tube and the performance achieved are briefly discussed.*

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

Introduction

The TH1507U gyrotron is a new 140 GHz 1.5 MW CW (1800 s) tube that is manufactured for the ECRH system upgrade of the Wendelstein 7-X (W7-X) Stellarator at IPP Greifswald, Germany. The TH1507U industrial unit is an upgrade of the already existing 140 GHz 1 MW CW TH1507 gyrotron that operates at W7-X successfully [1].
The physical design of the TH1507U gyrotron upgrade was initiated by IPP and KIT, Germany, in frame of the Innovation Pool (IP) project W7-X HiPower of the German National Helmholtz Association. The manufacturing of the TH1507U industrial gyrotron follows the successful test of a modular pre-prototype that was designed and manufactured at KIT in frame of the IPP project [2-3]. As for all European gyrotrons, the development relies on an European collaboration including IPP, KIT, NKUA, SPC and POLITO. The development of the TH1507U is managed by IPP whereas KIT and NKUA are responsible for the physical design, POLITO for thermo-hydrodynamic simulations and THALES for the industrial design and manufacturing.

Technical Details and Reliability of the Design Baseline for the W7-X ECRH Gyrotrons

Today, all major designs of the industrial gyrotrons manufactured by THALES base on the technical layout of the TH1507 gyrotron for W7-X [1]. This portfolio includes the EU 170 GHz 1 MW (3600 s) gyrotron (TH1509) for ITER and DTT, the 126/84 GHz 1 MW (2 s) dual-frequency gyrotron for TCV (TH1510, the only THALES gyrotron based on non-depressed collector & triode Magnetron Injection Gun), and the forthcoming gyrotrons for CEA/WEST (TH1511) and GA/DIII-D (TH1512). The original TH1507 gyrotron is designed for 1 MW RF output power at pulse lengths of up to 1800 s [1].
Today, nine units of TH1507 gyrotron are producing more than 900 kW for plasma heating at the W7-X Stellarator. The excellent robustness of the TH1507 tube has been demonstrated by dismantling the 2nd prototype after 10 years of operation [1]. The TH1507 uses a diode-type magnetron injection gun (MIG) and a single-stage depressed collector that withstand up to 35 kV at the body and up to 85 kV acceleration voltage. The unit relies on the $TE_{28,8}$ cavity mode with an axial magnetic field of approximately $B_c = 5.55$ T. As for all THALES gyrotrons, it is equipped with a beam tunnel originally patented by KIT. A dedicated circuit equipped with Raschig Rings, patented by THALES, cools the cavity. The cavity mode is converted into a Gaussian TEM_{00} beam, provided by a quasi-optical output coupler including a harmonically-deformed-wall launcher, three mirrors and a CVD diamond-disk window.

Motivation and Industrial Design of the TH1507U 1.5 MW 140 GHz CW Gyrotron

The W7-X ECRH system is planned to receive an increased power-to-volume ratio and a higher heating power. These upgrades are required for achieving high plasma beta values where the improved confinement of fast ions, one of the optimization criteria of W7-X, can be examined. The expansion of the ECRH system is planned to be achieved in several consecutive steps by increase the number of gyrotron positions from 10 to 12 and, at the same time, to evolve the gyrotron output power in a development steps from 1 MW to nominal 1.5 MW and, finally, up to 2 MW [2].

The European response to the W7-X ECRH technical improvement is addressed by the direct evolution of the TH1507 gyrotron, the TH1507U, where the term "U" stands for "Upgrade". The new design relies on the $TE_{28,10}$ cavity mode with an axial magnetic field of $B_c = 5.55$ T to generate up to 1.5 MW of RF output power at the window for a maximum pulse length of 1800 s. By addressing, the maximum allowed thermal loading of the cavity walls and by mitigating the design risks the TH1507U gyrotron features a slightly larger cavity radius is used, while keeping the same electron beam radius as the TH1507 tube. As for the TH1507 gyrotron, the diode MIG of the TH1507U tube permits an electron beam current of up to 60 A. Additionally, it includes an improved cavity cooling and a new mirror-line quasi-optical launcher (instead of the harmonically-deformed-wall launcher installed on the TH1507) as well as an adjustable third mirror [3]. An advanced beam tunnel structure and upgraded collector depression scheme based on the EU 170 GHz 1 MW (TH1509U) tube [4] are integrated in the TH1507U.

Manufacturing and Test

The TH1507U prototype has been manufactured in 2022. It is in the qualification phase. The Factory Acceptance Test (FAT) has verified the high voltage standoff up to 35 kV depression, the requirements on pressure drops and water flows on the cooling circuits, the filament functionality and the vacuum level conditions.

Figure 1. TH1507U prototype under test at KIT (Left) and the unit installed at IPP (Right).

The prototype is being tested at IPP, where it confirmed the short-pulse performance obtained on the pre-prototype used to validate the RF design at KIT [5]: Power levels between 1.1 and 1.6 MW demonstrated in short pulses up to 5 µs. Long pulse tests are planned for the first half of 2024.

Evolutive Series Gyrotrons for W7-X Upgrade

A development program is planned on the incoming manufacturing of series TH1507U gyrotrons aimed to integrate new improved subassemblies including a new emitter structure oriented to improve the heat transmission from the filament and an advanced layout of the electron gun for a better control of the electron velocity factor and some other elements being discussed. The units will share the best upgrades used in the last gyrotrons developed, manufactured, tested and validated by THALES.

Conclusions

Continuous improvements are being provided to the ECRH system of the Wendelstein 7-X (W7-X) Stellarator at IPP Greifswald in the frame of a strong European collaboration in gyrotron development. The last released 1.5 MW unit of this family, the TH1507U integrates several improvements on cathode structure, beam tunnel and cavity design as well as on the voltage depression arrangement and cooling circuit configurations. The prototype has demonstrated encouraging results and it is now in the qualification phase. The test results will be presented at the IVEC 2024.

Acknowledgements

This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 - EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of European Union or European Commission. Neither European Union nor the European Commission can be held responsible for them.

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