STATUS OF DEVELOPMENT OF THE 2MW, 170GHz COAXIAL-CAVITY GYROTRON FOR ITER

S. Alberti[1], F. Albajar[2], K. A. Avramides[3], P. Benin[4], W. Bin[5], T. Bonicelli[2], A. Bruschi[5], S. Cirant[5], E. Droz[1], O. Dumbrajs[6], D. Fasel[1], F. Gandini[5], T. Goodman[1], J.-P. Hogge[1], S. Illy[7], S. Jawla[1], J. Jin[7], S. Kern[7], C. Lievin[4], B. Marlétaz[1], Ph. Marmillod[1], I. Pagonakis[1], A. Perez[1], B. Piosczyk[7], L.Porte[1], T. Rzesnicki[7], U. Siravo[1], M. Thumm[7;8], M.Q. Tran[1]

[1]Centre de Recherche en Physique des Plasmas, Association EURATOM–Confédération Suisse, Ecole Polytechnique Fédérale de Lausanne, CH-1015, Lausanne, Switzerland
[2]The European Joint Undertaking for ITER and the Development of Fusion Energy', C/ Josep Pla 2, 08019 Barcelona
[3]School of Electrical and Computer Engineering, National Technical University of Athens, Association EURATOM-Hellenic Republic, 9 Iroon Polytechniou st. GR-15772 Athens, Greece
[4]Thales Electron Devices, 2 Rue de Latécoère, F-78141 Vélizy-Villacoublay, France
[5]Instituto di Fisica del Plasma Consiglio Nazionale delle Ricerche, Via Cozzi 53, I-20125 Milano, Italy
[6]Helsinki University of Technology, Association EURATOM-TEKES, FIN-02150 Espoo, Finland
[7]Forschungszentrum Karlsruhe, Association EURATOM-FZK, Institut für Hochleistungsimpuls- und Mikrowellentechnik, P.O. Box 3640, D-76021 Karlsruhe, Germany
[8]Universität Karlsruhe, Institut für Höchstfrequenztechnik und Elektronik, Kaiserstr. 12, D-76128 Karlsruhe, Germany

Abstract— **A collaborative effort between European research Associations and Thales Electron Devices (TED) has been launched by the European Fusion Development Agreement (EFDA) in 2003, aiming at the development of an industrial 170GHz/2MW/CW coaxial cavity gyrotron. The first prototype is expected to reach 2MW/1s and is presently being tested in Lausanne at a dedicated test facility. The test facility has been designed to be flexible: allowing the possible commissioning of tubes with different characteristics, as well the tests of a version of the ITER upper launcher antenna at full performances. The test facility has been commissioned during the first test phases on the gyrotron which include: high voltage stand-off, coaxial insert alignment and cathode conditioning without depressed collector power supply at a slightly reduced electron beam power of 85kV/78A/2ms. The short pulse (<5ms) operation of the gyrotron has demonstrated stable single mode operation in the designed $TE_{-34,19}$ mode at RF power levels in excess of 1.4MW, at below nominal electron beam parameters (79kV/75A). Further RF optimization in view of reaching the nominal beam parameters of 90kV/75A is presently underway and the status of the short pulse (< 100ms) experimental results will be reported.**

This work, supported by the European Communities under the contract of Association between EURATOM/Switzerland was carried out within the framework of the European Fusion Development Agreement (Task agreements: TW6-THHE-TFO1 and TW6-THHE-CCGT1).

I. Introduction

It has been shown in the past that coaxial gyrotrons offer a serious alternative to conventional gyrotrons in the perspective of increasing the unit power to multi-megawatt levels, in a frequency range compatible with the ITER requirements [1].
The inner conductor (coaxial insert) combines the advantages of mode selectivity and a reduction of the space-charge beam depression, making it possible to maintain the cavity ohmic losses at a reasonably low level (< 2kW/cm^2) by increasing the cavity diameter and selecting a very high order operating mode.
Based on these considerations, the coaxial option was chosen by the European Fusion Development Agreement (EFDA), which launched a collaboration between European institutions and a commercial partner (Thales Electron Devices, TED) to develop a 2MW/CW/170GHz coaxial gyrotron in three steps: the first prototype tube aims at a performance of 2MW/1s, the second one will target 2MW/60s after a possible redesign phase, and the third prototype is expected to reach CW operation. The prototype tube is being tested in short-pulse operation (< 100ms) at the newly built CRPP test stand and the present status of the experimental results are reported in this paper.
In parallel, the FZK 165GHz short-pulse coaxial tube has been modified to operate as a *pre-prototype* at 170GHz, with internal components very similar to the actual design, giving the possibility to test the different scientific or technical options envisaged in a high power environment, such as the use of internal water loads, the effect of stray radiation on the interaction and the study of low-frequency oscillations [2].

In section II, the key aspects of the gyrotron are briefly summarized, with emphasis on the high power and long pulse operation. The section III gives an account of the experimental results obtained in short-pulse operation, and the conclusions and future prospects are listed in section IV.

II. Design features

The design gyrotron parameters and criteria are presented and discussed in reference [3]. A picture of the prototype gyrotron mounted in the European Gyrotron Test-Stand is shown in Figure 1. The main gyrotron design features are outlined below:

- The tube is designed to be CW compatible. In particular, a set of internal loads consisting in water-cooled ceramic tubes are implemented. Such loads were proved efficient in absorbing stray radiation in the short pulse pre-prototype.

- The present RF output system consists of a launcher with Δm=1, Δm=2 and Δm=3 perturbations. The last mirror with a non-quadratic surface has been optimized to obtain a Gaussian amplitude distribution in the window plane in order to maximize the RF transmission efficiency at the window plane [2]. Since the Gaussian content of the RF output beam is low an improvement of the RF output beam quality is necessary and is under intensive study. An updated RF output system will already be implemented on the first prototype, once refurbished.

- Most of the subassemblies, including the beam duct, the cavity, the RF output system and the mirror box are at the depressed voltage (+35kV). DC-Breaks are used between the output window and the RF Conditioning Unit (RFCU), and between the mirror box and the collector.

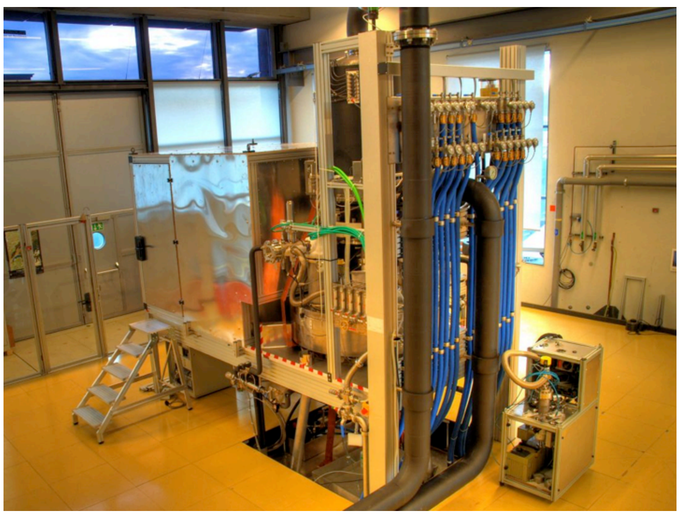

Figure 1: Picture of the European Gyrotron Test-Stand with the first gyrotron prototype gyroton installed.

III. Experimental Results

Immediately after the superconducting magnet acceptance tests the experimental campaign on the first prototype gyrotron has started at the beginning of December 2007. The coaxial insert alignment by means of the transverse dipole coils was successfully carried out at reduced beam parameters and has reached a radial electron beam alignment better than 0.04mm.

In a first phase with the electron beam on but without RF, the collector has been successfully tested at the nominal loading for pulses up to 2s and a longitudinal 7Hz sweeping of the electron beam via AC collector coils.

Using a very short pulse load (VSPL, T_{RF} <1-2ms) with a Brewster-angle window, the RF power optimization was carried out in the designed $TE_{-34,19}$ mode and an RF power in excess of 1.4MW was measured in the load with the following gyrotron parameters: cavity magnetic field, B_0 = 6.8T, beam energy V_b = 82.5keV, beam current, I_b = 72A, pitch angle α = 1 and beam radius r_b = 10.03mm. The experimentally optimized pitch angle value is significantly lower than the design value (α_{design} = 1.3) and was limited by internal arcing events, which are believed to be associated with reflected electrons due to a high perpendicular spread of the electron beam. The high level of perpendicular spread will be discussed later and is also addressed in reference [4].

The transverse mode time evolution was measured with an heterodyne receiver coupled to a spectrometer composed by 16 channels evenly spaced over a 5GHz bandwidth. With the experimentally optimized parameters, stable single mode operation of the $TE_{-34,19}$ mode has been measured with an excitation mode sequence during a beam voltage scan corresponding to the mode sequence predicted from the multimode simulation. The experimentally measured RF power (circles) versus beam voltage is shown in Figure 2. In this same figure the RF power predicted by a multimode self-consistent model is shown for two different levels of perpendicular velocity spread. In order to make a direct comparison the simulated power has been decreased by 15% taking into account various loss mechanisms such as ohmic losses, diffraction losses, etc.

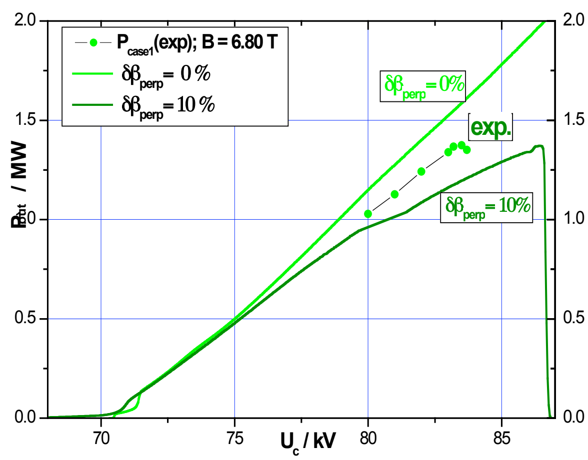

Figure 2: RF power versus beam voltage. Comparison between experimental results (circles) and simulations based on a multimode self-consistent model taking into account two different levels of perpendicular velocity spread. The simulated power is decreased by 15% to make a direct comparison with the power measured in the VSPL.

As previously mentioned, the large spread in perpendicular velocity is believed to be responsible for the moderate value of experimentally obtained α, therefore limiting the maximum reachable RF power. Already at the design level, the gun optimization was found to be significantly more difficult than for high-power conventional-gyrotron electron-guns previously designed and successfully operated (e.g. 140GHz, 118GHz). An important effort, using new tools, has been placed in further optimizing the present gun. By modifying its geometry it should be possible to decrease the beam perpendicular velocity spread by a factor of three. This would open up the potential to operate the electron beam at α's larger

978-1-4244-2120-6/08/$25.00 ©IEEE.

than the presently achieved one. This optimization has been performed using a newly developed versatile gun parameterization technique which is the object of the paper by I. Pagonakis et al. presented at this conference [4].

During the excitation of the nominal $TE_{-34,19}$ operating mode at 170GHz a transient excitation of a low-frequency (170MHz) has been observed. Here, transient excitation means that this low frequency mode systematically disappears 1-2ms after the first excitation of the nominal frequency at 170GHz.

Extensive measurements of the free-space properties of the emitted RF beam have been carried out using reconstruction techniques based on IR measurement of the RF beam profile taken at different distances along the propagation axis [5]. Due to the high dynamic range (> 20 dB) of the IR data, the reconstruction efficiency is as high as 98-99% and, as shown in Figure 3, an excellent agreement is found between the predicted and reconstructed RF beam amplitude and phase profiles.

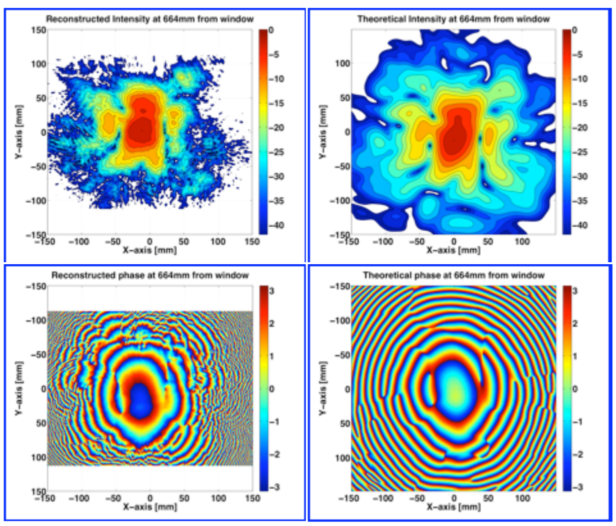

Figure 3: Reconstructed and calculated RF beam properties on a transverse plane placed 664mm after the gyrotron window. Top-left and bottom-left, reconstructed amplitude and phase profiles, respectively. Top-right and bottom-right, calculated amplitude and phase, respectively.

The Gaussian content of the RF beam is not optimal and, as mentioned earlier, its value is related to the launcher that is presently implemented in the gyrotron. A significant effort is ongoing to design a more efficient coupler and a design by Jin et al. [6] including also an improved phase correcting mirror (3^{rd} mirror) predicts a Gaussian content around 95%. Other launcher schemes than the one presented in [6] are also evaluated.

At present the gyrotron has been operated without depressed collector voltage by a using a temporary HV-source which does not allow to reach the nominal electron beam voltage of 90kV at the achieved nominal beam current of 75A. The body power supply for operating the depressed collector is presently being commissioned in the integrated test facility configuration.

IV. CONCLUSIONS

The first short-pulse operation of the 170GHz coaxial-cavity gyrotron for ITER has demonstrated a stable single-mode excitation of the nominal $TE_{-34,19}$ mode. At an experimentally optimized pitch angle of α_{opt} =1, a maximum RF power of 1.4MW has been measured in the VSPL calorimetric load. With this first gyrotron prototype, in a depressed collector operation the RF pulse extension to intermediate pulse length (< 100ms) using a medium pulse length calorimetric load [7] is underway.

The low experimental α-value is probably related to the high perpendicular velocity spread and a newly optimized gun has been designed predicting a reduction of this spread by a factor of 3. This new gun together with an optimized launcher giving a Gaussian mode purity significantly higher than the presently achieved value will be implemented in the second prototype. The refurbished gyrotron (second prototype), after its planned refurbishment at the end of the present experimental campaign, will be tested in the final gyrotron test-stand configuration (including the final main voltage power supply to be installed this fall) starting from June 2009.

REFERENCES

[1] B. Piosczyk et. al., *A 2-MW, 170-GHz, Coaxial Cavity Gyrotron*, IEEE Trans. Plasma Science, **32**, 2004, 413--417.

[2] B. Piosczyk et. al., *Investigations on an Experimental 170GHz Coaxial Cavity Gyrotron*, Joint 32rd Int. Conf. Infrared Millimeter Waves and 15th Int. Conf. THz Electronics, 2007, Cardiff, UK, p.96.
T. Rzesnicki et al. *Recent experimental results on the 170 GHz, 2 MW coaxial cavity pre-prototype gyrotron for ITER*, this conference

[3] J.-P. Hogge et al., *The European 2MW, 170 GHz Coaxial Cavity Gyrotron for ITER,* Joint 32rd Int. Conf. Infrared Millimeter Waves and 15th Int. Conf. THz Electronics, 2007, Cardiff, UK, p.38.

[4] I. Pagonakis et al., *Parametrization technique for the preliminary Gun Design of the EU 170GHz 1MW Conventional Gyrotron for ITER,* this conference.

[5] S.K. Jawla et al., *Beam Profile Measurements of the Output Microwave Beam of 2MW/170 GHz Coaxial-Cavity Gyrotron for ITER,* The 35th IEEE International Conference on Plasma Science, ICOPS 2008, Karlsruhe Germany, p. 249.

[6] J. Jin et al., *Improved quasi optical launcher for coaxial cavity ITER gyrotron* , this conference

[7] A. Bruschi et al., *High-power millimeter-wave calorimetric beam absorbers,* Fusion Sci. Technol. 53, 62-68 (2008).

978-1-4244-2120-6/08/$25.00 ©IEEE.