Upgrade Of The TH1506B 118 GHz Gyrotron Using Modelling Tools

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Abstract. The first TH1506B prototype showing problems of overheating and spurious oscillations, a new modified gyrotron was built. During the tests, the extwo peaks, which was never predicted by simulations. Various low level tests were performed on the mode converter with different shapes for the launcher but without real improvement. Besides measurements, the use of a new software Surf3D[1] showed that the problem mainly comes from the 3rd mirror whose curvature is too high and not well taken into account by the calculation. This analysis software is based on integral equations and the complete 3D modelling allowed to determine a new profile for the 3rd mirror. An aluminium model of a new mirror was manufactured and thorough low level tests made at FZK showed that there was no double peak.The next step would consist in building a gyrotron based on this new design, to confirm the simulation and to validate it for long pulses.

Keywords: Gyrotron, simulation, twin peaks.
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INTRODUCTION

In accordance with the long pulse objectives of the Tore Supra Tokamak program, an ECRH system planned to inject 2.4 MW for a pulse length up to 600 s at the frequency of 118 GHz was under construction at CEA Cadarache. The generator should have been made of 6 gyrotrons developed through a collaboration between TED, Association Euratom - Confédération Suisse and Association Euratom – CEA, with technical support from Association Euratom – FZK. All the auxiliary equipment – Power Supplies, Control and Protection systems, Cryogenic and Vacuum Systems - for the complete plan and two tubes are already installed : the prototype and the 1st series gyrotron are connected to the Tokamak and have been used for plasma operation for several experimental campaigns from 2001 to 2006. Due to problems of overheating and spurious oscillations observed on both gyrotrons, modifications have been made for the 2nd series tube, including the integration of a conical launcher (instead of the previous cylindrical one) together with a new set of three mirrors. But, a major problem has been detected during these factory acceptance tests through a mode purity analysis. The power distribution in the beam emitted from the gyrotron is measured at various distances from the window with an infrared camera, the RF waves propagating in air. Using a phase reconstruction program, the mode purity relative to a pure gaussian beam could be determined. Instead of a gaussian power distribution, the output beam is seen to contain two peaks, diverging at a constant angle of 1 or 2 degrees. The simulation used to calculate the output pattern, using the FZK code based on the diffraction integral, employing the thin-lenses model for the second and third mirrors never predicted such a behavior [1].

1. DESCRIPTION

The new quasi-optical output system of the TH1506B transforms the rotating $TE_{22,6}$ cavity mode into a gaussian beam and is composed of a dimpled wall conical launcher (the conical angle is 0.1°) and a set of three mirrors [2]. The first one has a quasi-elliptical shape, the second one is plane and the third one is parabolic with smooth surface (see figure 1).

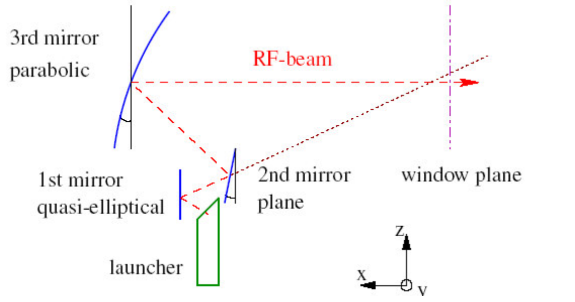

FIGURE 1. Quasi-optical output system of the TH1506B

The cold and hot measurements performed on this system showed a twin peak structure, on the contrary of the simulation which can be seen on figures 2 and 3:

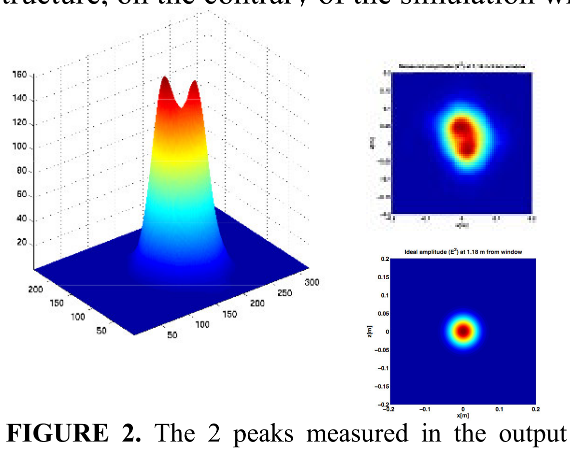

FIGURE 2. The 2 peaks measured in the output beam in 2D and 3D compared to a gaussian distribution.

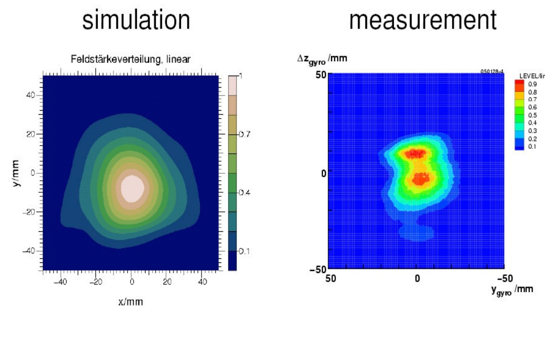

FIGURE 3. Comparison between simulation and cold measurement in the window plane.

Many investigations were done to understand the origin of the problem on the manufacturing point of view, but after care examination of the characteristics of the launcher and the mirrors (dimensions, positions), any production error could be excluded. The whole analysis was then focused on the design.

2. ANALYSIS OF THE DESIGN

The main difference between the first 118 GHz gyrotron and the new one being the launcher, the analysis began with the calculation of new launchers with improvement on the level of wall currents. As no simulation could predict the two peaks, various models of launchers have been produced (modifications on the cut angle of the existing one and manufacturing of completely new launchers) but the cold measurements always showed the double peak, even if the patterns look different.

The use of a new software, solving the electrical field integral equations, gave new ideas on the origin of the problem. It has the possibility to simulate the full mode converter, but as the wavelength is rather small compared to the dimensions of the launcher and the mirrors, the computational time required for the 3D simulation is not negligible !

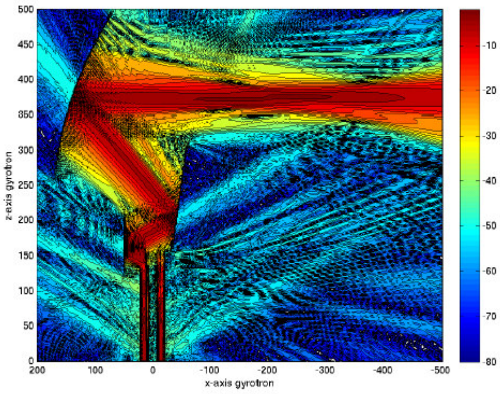

FIGURE 4. Simulation of the propagated beam inside the gyrotron

For the first time, the comparison between the calculation and the measurements showed a good agreement, especially inside the gyrotron, and the propagated beam showed in figure 4 clearly shows that the focusing is too tight, the waist being located inside the tube instead of at the window plane.

Due to the characteristics of the two first mirrors, the origin of the twin peaks might be the third mirror. This idea was checked with following low level measurements: the outer sides of the third mirror in the y-direction have been covered with absorbers, causing the vanishing of the double peak structure, as showed in figure 5.

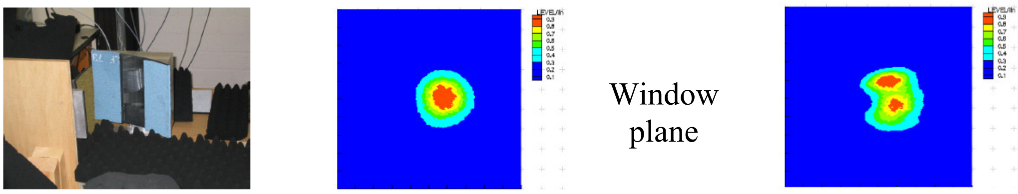

FIGURE 5. Measurements in the window plane with absorbers on the left, reducing the aperture to 100 mm in the z direction, compared to the right figure where there is no absorber.

3. MODIFICATION OF THE STRUCTURE – SIMULATION AND MEASUREMENTS

A new third mirror has been calculated, in order to reduce its curvature and the new whole quasi-optical output system has been simulated. The figures 6 and 7 show the absence of the twin peak in various planes (inside and outside the tube) and that the waist is now located outside the tube.

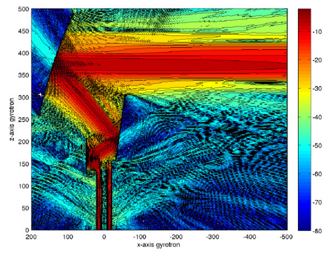

FIGURE 6. Wave propagating outside the gyrotron with the new 3rd mirror.

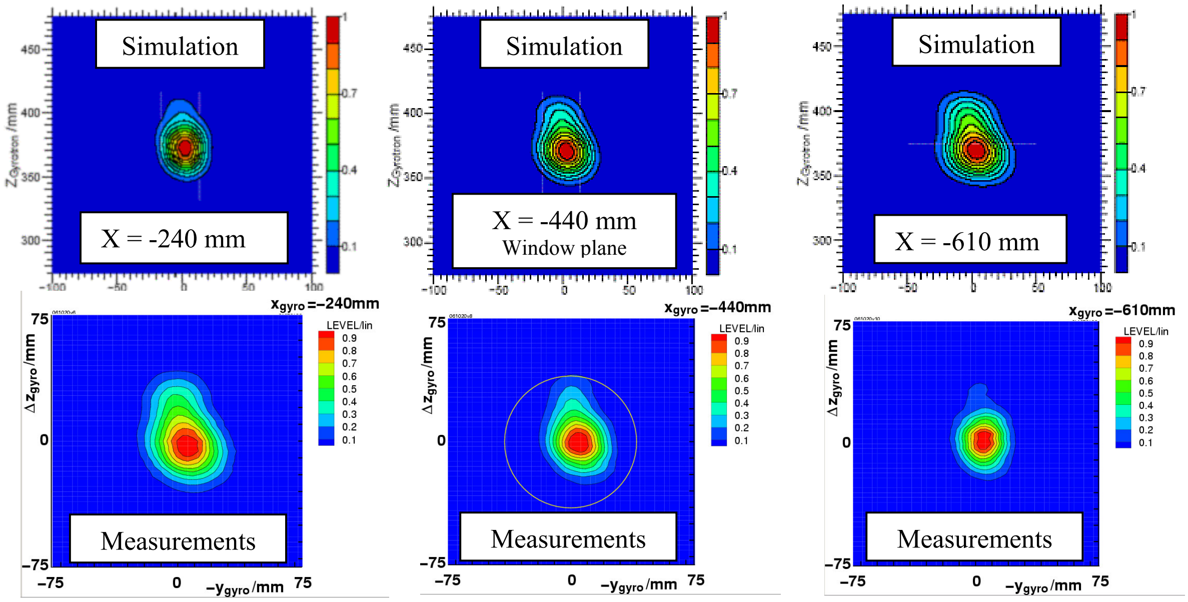

FIGURE 7. Evolution of the simulation of the beam compared to the measurements made on the aluminum model in linear scale, inside and outside the gyrotron.

The low level measurements are quite comparable to the simulation and point out the disappearing of the double peak structure.

The precise measure made in the window plane show that a part of the beam is not going through the window (about 7%) and then a part of these 7% is intercepted by the window in a first time, but after some reflections in the mirror tank, calculation shows that only 4 % of the power will be dissipated inside the mirror tank, which means an additional loss of 15 kW to 20 kW. As many improvements have been made on this prototype, especially on the cooling system of the mirror tank, based on a double-wall structure with water flowing between the two walls, this additional loss should be evacuated with a reasonable surface temperature.

CONCLUSION

The problem of the twin peaks output pattern seems to be clearly identified: first the simulation, then the cold measurements showed that the decrease of the curvature of the third mirror led to suppress the double peak structure. Moreover, the results of the simulation performed with the new software are quite similar to the low level measurements and give confidence to next calculation for future gyrotrons.

The next step consists in applying the modifications on a real gyrotron, in order to verify the results and to try to extend the pulse duration for plasma experiments, which was the purpose of the new prototype of the TH1506B developed 3 years ago.

REFERENCES

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