Development and Test of a Millimeter-wave MW-power Bolometric Load for CW gyrotrons and High-Power Transmission Lines

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***Abstract*—The development of high-power dummy loads with calorimetric capabilities started in IFP with short pulse loads and continued with the design of a 2MW CW load in the frame of EGYC Consortium activities on the development of the European Gyrotron for ITER, coordinated by F4E. The loads are characterized by a spherical shape, with the cavity internal surface coated by a ceramic absorber. Special care has been devoted to the design of the power distribution on the surface and on the selection of the coating thickness. For the CW version, the cooling channels cover completely the external surface, for a fast heat removal. A prototype load with partial coating of the internal surface has been tested successfully in pulses up to 300 sec. at the 170 GHz JAEA ITER transmission line test bed, proving the capability of a full-coated version at power levels exceeding 1 MW. Load design and test results are discussed.**

I. INTRODUCTION

THE development of high-power millimeter wave sources, typically gyrotrons which emit mm-wave gaussian beams with power now exceeding the MW level, requires dummy loads with reflection of the order of 1%, a precise power measurement, CW capability and often also vacuum compatibility.

The design of dummy loads with the proper characteristics thus proceeded in parallel to the gyrotron development, with two main alternative concepts for loads: the metallic (stainless steel) cavity and the (aluminum or copper) cavity coated with an absorbing layer. In the first case the internal surface has to be increased as much as possible with well-cooled internal surfaces, typically a large number of cooling tubes, while in the second case the input power must be distributed as uniformly as possible on the coated inner surface.

The load concept developed in IFP[1] (Fig.1) is based on the absorption of the power by a suitable ceramic microwave-absorbing layer, deposited on the internal surface of a spherical copper cavity. The low reflection is obtained with the combination of a low reflectivity (given by the coating material and the deposition thickness) with the shape of the spreading mirror designed to avoid the escape of the residual radiation after one reflection[2].

The load has been developed so far for millimeter waves (80-170 GHz) but the concept could be easily extended to higher and moderately lower frequencies.

II. LOAD DESIGN

The load has been designed for use with the most powerful sources of millimeter waves, whose transmission is realized in the form of collimated gaussian beams or by means of circular corrugated waveguides, carrying the HE_{11} mode.

The load has been designed for input gaussian beams, but is also compatible with the open-ended waveguides, since the HE_{11} mode is coupled to a gaussian beam at ~98% in power.

In order to realize the most uniform distribution of the input beam power on the absorber, a properly designed fixed mirror is placed opposite the beam entrance. The mirror design procedure takes into account the beam divergence at the mirror location, and, once prescribed the desired azimuthal power distribution on the sphere inner wall, computes the mirror shape realizing it. The prescribed first-pass power distribution takes into account that part of the power is absorbed after multiple reflections on the cavity wall and that the power accumulating at (or escaping from) the entrance has to be minimized for coating protection and low reflection.

The ceramic absorber has been selected among plasma sprayed ceramic coatings used in industry, on the basis of microwave absorption, heat conductivity and resistance to high temperatures[3]. The layer is deposited with a precisely controlled thickness, that guarantee the desired microwave absorption coefficient, that may be also different along the surface, to improve the power load uniformity[4, 5].

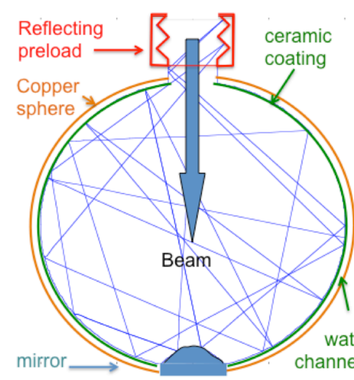

Fig. 1. The load concept: the beam is entering from the top and is diffused by the mirror in front of the entrance to the absorbing coating on the load walls.

The cooling necessary to remove the power and keep the absorber temperature low enough is realized obtaining external channels fully covering the surfaces of the two hemispheres composing the cavity. The channels (16 or 20 in parallel) are realized in spirals by a special technique based on electroforming the channel walls on a thin copper shell and then completing the channel closure. This guarantees a fast heat removal by the cooling medium (water) that can be measured with precise thermal and flow sensors, to provide the deposited power. An overall reflection down to 1% can be obtained adding a back-reflecting preload at the load entrance[6], which, for use in vacuum, can provide also the connections for the vacuum line and the arc detection window.

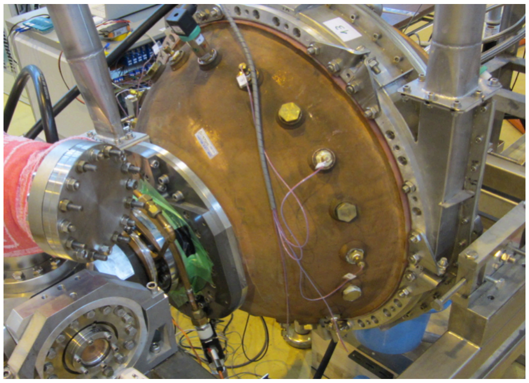

Fig. 2. The prototype hybrid CW load during tests at JAEA, Naka (Japan); temperature probes are installed in the spiral channels of the coated shell.

III. Test Results

In the frame of the development of the 170 GHz, 1 MW European Gyrotron for ITER, performed by TED and EGYC consortium under coordination of F4E[7], a load has been designed[8] for 2 MW CW power. According with this design, a 'hybrid' prototype load was assembled, joining one hemisphere fully coated with absorber with one fully reflecting: the power load on the coated hemisphere has been demonstrated to be equivalent to twice the load in a fully coated sphere at the same input power. This allows testing the load design for 2 MW using a 1 MW power source. First tests were performed at KIT, Karlsruhe, at 140 GHz, in air, up to 3 min. at power > 0.5 MW, limited by breakdown in air at the preload level[4].

In order to test the load concept at 1 MW (or possibly above), 170 GHz and under vacuum (the design conditions), a common test program with the Japan Atomic Energy Research Institute was realized at the JAEA ITER transmission line test bed, exploiting the JAEA 170 GHz, 1 MW prototype gyrotron for ITER as power source[9, 10].

For the tests the load was connected to the end of an evacuated 63.5 mm circular corrugated waveguide and was equipped with diagnostic thermocouples in the cooling channels of the coated shell (Fig.2). The temperature of the external load surface was monitored by IR cameras (Fig.3).

During the first week of tests, after conditioning of the load and adaptations of the evacuation line, a pulse at average power of 500 kW for 84 s was completed. The load was inspected and the coating was found intact. In the second week the pulse length was extended to 300 s at 510 kW.

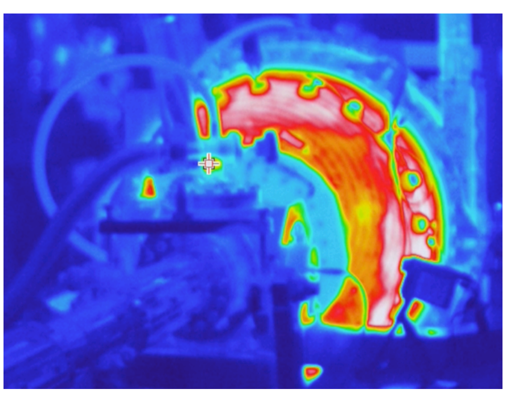

Fig. 3. I.R. image of the load during tests, showing the spiral channels pattern.

This qualifies the complete load design (with two coated hemispheres) for 1 MW. At higher power the pulse reached 180 s, 140 s, 15 s respectively at 700, 800, 915 kW[11].

No major problems were found during the tests: pulse duration was limited only by the overheating of the evacuation line. For its prevention, special microwave-absorbing sections have been prepared for future tests. The overheating of parts of the transmission line and/or the preload seems responsible of a small drift of the temperatures measured on the probes in the load channels: while the mean water temperature rise is constant during pulse, the temperatures on one side of the load keep increasing, while decrease on the other side, maybe due to a misalignment of the beam on the diffusing mirror (Fig.4). Proper cooling of all parts at the load input should prevent it.

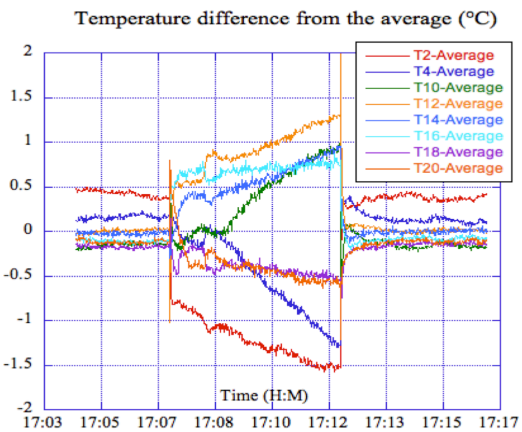

Fig. 4. The temperature difference with respect to the average in the channels: the temperature in channels 10 to 16 is increasing, decreasing in the others.

IV. Summary

The long-pulse tests of a hybrid (half-coated) load at 170 GHz at JAEA validate the design of the CW load for 1 MW, 300 s and 1.6 MW, 140 s. Further tests are programmed to extend pulse length and clarify open issues.

V. Acknowledgment

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