DEVELOPMENT OF A 2 MW, CW, 170 GHZ COAXIAL CAVITY GYROTRON FOR ITER

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A 170 GHz coaxial cavity gyrotron with an RF output power of 2 MW in continuous wave (CW) operation, as can be used in the electron cyclotron heating (ECH) system of ITER, is under development within the frame of a collaboration between European research centers and Thalès Electron Devices (TED), under the auspices of the European Fusion Development Agreement (EFDA). Based on recent achievements (P_{RF} = 2.2MW) on a short pulse (up to 20 ms) 165 GHz coaxial cavity gyrotron at Forschungszentrum Karlsruhe (FZK) [1], the conceptual design of such a tube compatible with CW operation has been completed and the manufacturing process of a first prototype has been launched.

In parallel, the Centre de Recherches en Physique des Plasmas (CRPP) is presently setting up a test facility especially designed to host

2MW/CW gyrotrons and to perform experimental investigations up to full performances.

In this paper, we present the design of the coaxial cavity gyrotron and of the test facility. Milestones on the road aiming to a 2MW/CW tube are also given.

Introduction

The main advantages of increasing the unit power of the gyrotrons for the electron cyclotron wave (ECW) system at ITER reside in a more flexible upper port launcher design and in an overall reduction of the installation costs. Coaxial gyrotrons are serious candidates to reach such power levels since the inner conductor cumulates the positive effects of mode selectivity and a minimization of beam voltage depression [2]. This matches the choice of a very high order operating mode, and a larger cavity radius in order to maintain the cavity peak ohmic load at a reasonable level (≤2kW/cm^2).

Tube design

With the perspective of achieving 2MW in CW at 170GHz, the conceptual design of such a tube has been completed. The gyrotron is schematized in Fig.1, and the main characteristics are presented in Table 1.

Frequency	170 GHz	Magnetic field	6.86 T
Operating mode	$TE_{34,19}$	Cavity Peak losses	2kW/cm^2
Cathode Voltage	-55 kV	Cavity total losses	54kW
Body Voltage	+35 kV	Insert peak losses	.2kW/cm^2
Beam Current	75 A	Insert total losses	2kW
RF output power	2 MW	Stray radiation losses	~100kW
Power modulation	0.6 - 2MW	Window	CVD
Efficiency	45%	Window diameter	96 mm
Beam Radius	10.0 mm	Window losses	880W
Pitch Ratio	1.3	Collector loading (CW)	2.4MW
Modulation frequency	≤5kHz	Collector Loading (modulated operation)	3.1 MW

Table 1: 170GHz, 2MW, CW coaxial gyrotron design characteristics

A particular care was brought to the handling of stray radiation inside the tube which is identified as the main issue towards the achievement of CW operation . The mode $TE_{34,19}$ is not ideal for conversion to a gaussian beam and the edge diffraction losses of the conical rippled-wall mode converter and quasi-optical mirror system were initially estimated to 10% of the RF output power.

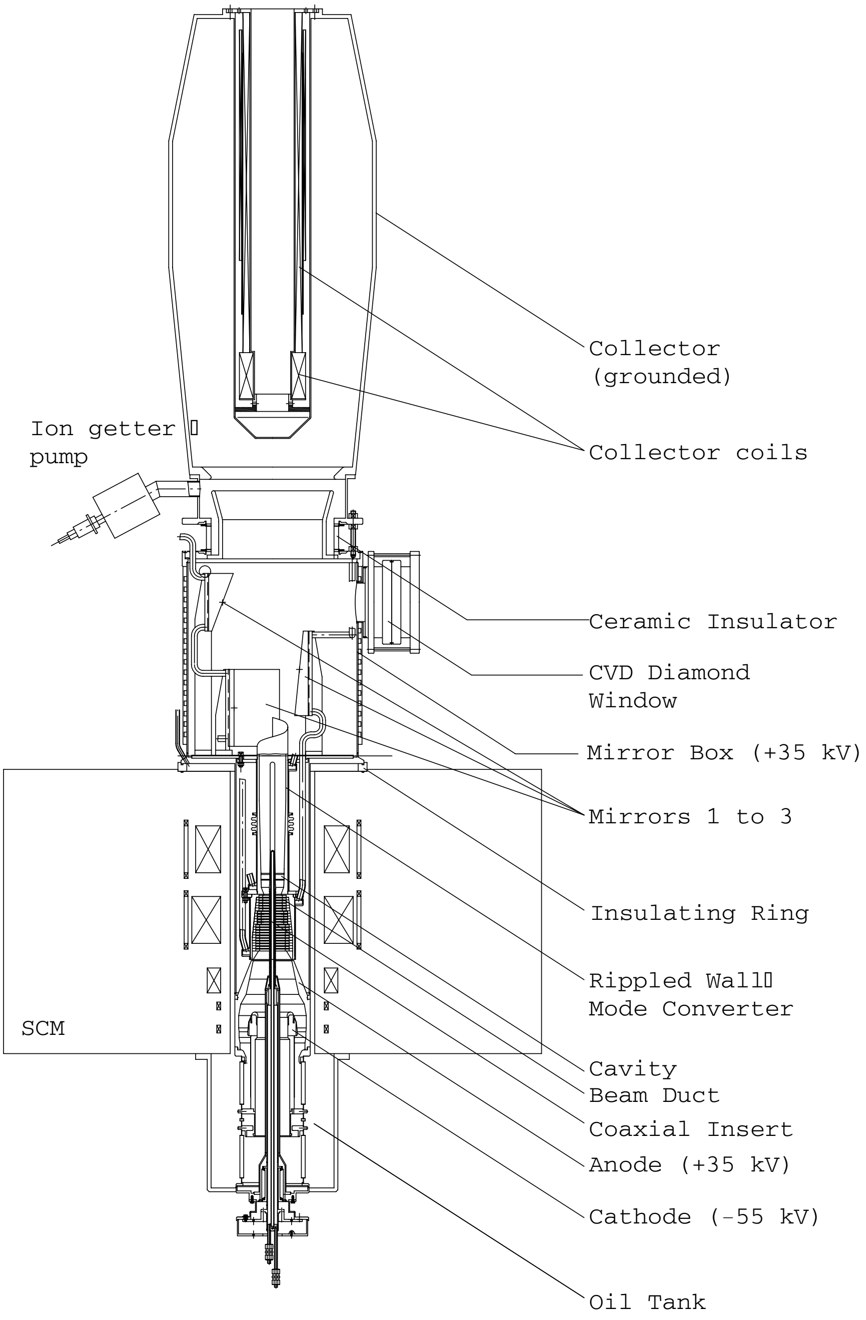


Figure 1: Schematic of the 170GHz, 2MW, CW coaxial Gyrotron

This value could be decreased to 5% by using a set of optimized non quadratic phase correcting mirrors, at the cost of conversion efficiency [3].

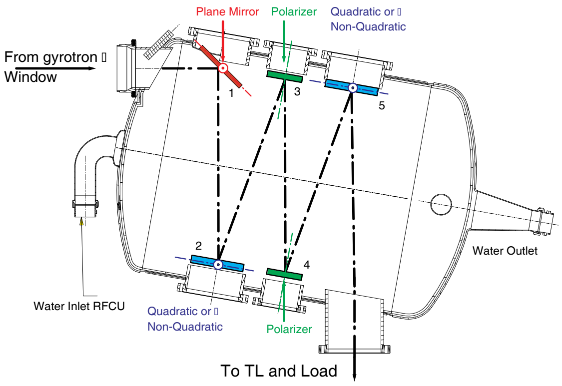
Internal water loads consisting in a water cooled ceramic tube will be placed inside the tube to efficiently evacuate trapped radiations. Initial estimations show that 40% of the stray radiation could be absorbed in this way. The mirror box itself has a double-wall structure and computations have shown that it can evacuate 100kW safely.

The inner conductor alignment will be performed at reduced parameters by using a set of dipole coils. The required accuracy in the concentricity of the inner conductor to the cavity is 0.05mm. The cooling will be performed by means of a coaxial water flow.

Among issues which are clearly identified so far, three of them appear challenging:

1. The collector loading is a step above the present day achievements. It is not yet clear whether the sweeping of the spent electron beam will be realized through internal or external coils.
2. The stability of the inner conductor is important. Cooling-induced vibrations might affect the tube performances.
3. The cooling of certain components such as the cavity is critical. Table tests are foreseen to have a further insight of the achievable heat exchange coefficient in realistic conditions.

Although the design is CW compatible, three prototypes are foreseen with the goal of achieving pulse lengths of 1s, 60s and 3600s respectively. The first prototype will mainly be dedicated to the validation of the RF set-up. The typical thermomechanical time constant of the main elements is of the order of a few seconds, which justifies the second step. In the state-of-the-art gyrotron tubes, the pulse length is limited by the outgassing of internal elements which occurs on a typical time scale of 60s [4,5]



RF coupling Unit (RFCU)

Figure 2: RFCU

The design of the RFCU was dictated by the need of flexibility. It consists in 5 mirrors located on an horizontal plane (see Fig. 2). The first one (1) is planar and will be used to compensate for any misalignment of the gyrotron output beam. Two quadratic mirrors (2 and 5) will be used to match the beam to the HE_{11} mode of the transmission line while minimizing the peak power density on the universal polarizer made of two gratings (3 and 4). The alignment of such an in-plane arrangment is easy: mirrors 1,2 and 5 must be rotated around 2 axes, whereas the polarizer have only to be rotated around an axis normal to their surface.

In case the output beam profile at the window would lead to unacceptable edge diffraction losses and/or to a poor coupling to the HE_{11} mode, it is envisaged to to use a quadratic first mirror and synthetized mirrors 2 and 5.

The RFCU cooling has been dimensioned to evacuate as much as 80kW.

Power Supplies

It is foreseen to test the gyrotron tubes at the CRPP. A Test Stand, able to provide the electrical power will be built and will be available for the beginning of the tests. A design study of the power supplies has been performed by different Associations within the EFDA Technology Workprogramme. The electrical supply scheme is depicted in Fig. 3.

The Main High Voltage Power Supply (MHVPS) fixes the cathode potential with respect to ground (55kV nominal, 60kV max.) and delivers the electron beam current (75A). A PSM like (pulse step modulator) electrical structure has been retained.

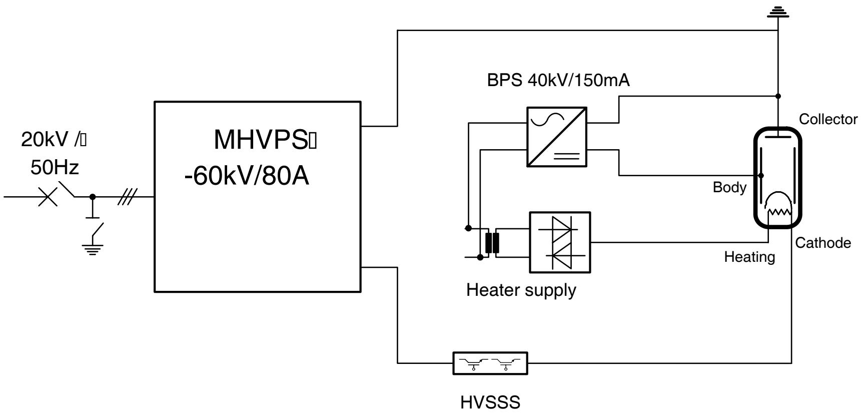


Figure 3: Electrical supply scheme

The Body Power Supply (BPS, 40kV, 150mA static, <5A transient) is connected between the body and the grounded collector. Its main functionality is to regulate the beam voltage (cathode to body potential) with an accuracy of ±0.5%. It will also provide the modulation capability (25kV peak-to-peak) at frequencies up to 5kHz and a shutdown time <10µs. The minimal modulation frequency is fixed by the maximal thermal loading that the collector can stand. The construction of the BPS will be PSM based as well.

In order to limit the fault energy in the gyrotron to a value <10J in case of failure or arc, a High Voltage Solid State Switch (HVSSS), equipped with IGBT's (Isolated Gated Bipolar Transistor) will be used. Beyond the protective usage of this device, it can also be used to make on-off modulation of the electron beam (with the advantage that there is no collector loading during the off phase) at frequencies up to 5kHz.

Present Status

A contract has been placed by the European Commission with TED for the production of the first prototype tube. The delivery is scheduled for end of 2005. The superconducting magnet is the object of another contract. Negociations with the manufacturer are underway and the manufacture should start by autumn 2004. The power supplies contract is at a similar stage, and the contract could be awarded this year too.

The Test Stand infrastructure itself is at an early stage of development, but no major issue is foreseen and it is expected to be operative when the first prototype is delivered, i.e. end of 2005.

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