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140 GHz, 1 MW, CW Gyrotron for Fusion Plasma Heating

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1. Introduction

Gyrotrons at high frequency with high output power are mainly developed for microwave heating and current drive in plasmas for thermonuclear fusion. For the stellarator Wendelstein 7-X now under construction at IPP Greifswald, Germany, a 10 MW ECRH system is foreseen. A European collaboration has been established between Forschungszentrum Karlsruhe, CRPP Lausanne, IPF Stuttgart, CEA Cadarache and TED Vélizy, to develop and build the 10 gyrotrons each with an output power of 1 MW for continuous wave operation (30 min).

2. Design

Cavity mode	$TE_{28.8}$
Frequency	140 GHz
Output power	1 MW
Accelerating voltage	80 kV
Beam current	40 A
Average velocity ratio	1.3
Cathode half angle	21.8°
Beam radius at cavity	10.1 mm
Cavity radius	20.48 mm
Cavity length	15 mm

Tabelle 1: Design Parameters

The design parameters of the gyrotron are summarized in Table 1. A temperature limited magnetron injection gun without intermediate anode (diode type) is used.
The cylindrical cavity is designed for operating in the $TE_{28,8}$-mode. It is a standard tapered cavity with linear input downtaper of 2.5° and a non-linear uptaper with the initial angle of 3°. The length of the cylindrical part is 15 mm, its diameter 40.96 mm. The transitions between tapers and straight section are smoothly round-ed over a length of 4-6 mm to avoid mode conversion.
The $TE_{28,8}$-cavity mode is transformed to a Gaussian $TEM_{0,0}$ output mode by a mode converter consisting of a rippled-wall waveguide launcher followed by a three mirror system. The output window vacuum unit uses a single, edge cooled CVD-diamond disk with an outer diameter of 106 mm, a window aperture of 88 mm and a thickness of 1.8 mm corresponding to four half wavelengths.
The collector is at ground potential, and a depression voltage for energy recovery can be applied to the cavity and to the first two mirrors. Additional normal-conducting coils are employed to the

collector in order to produce an axial magnetic field for sweeping the electron beam with a frequency of 7 Hz.

3. Experiment

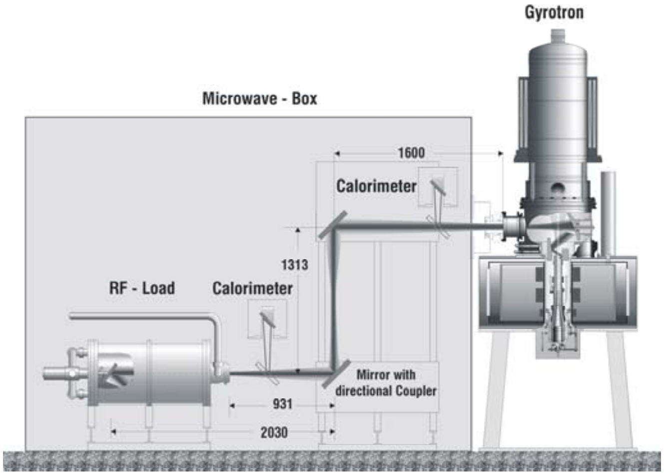

Fig. 1: Schematical view of gyrotron and microwave measurement chamber

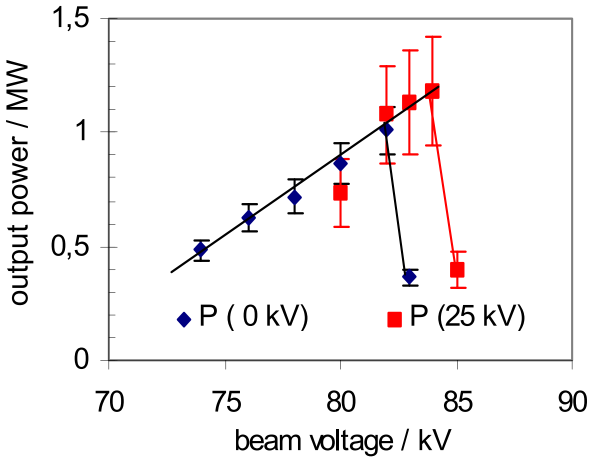

Fig. 2: Output power vs. accelerating voltage: without and with depression

Fig. 1 shows a schematic layout of the gyrotron and the microwave measurement chamber. The RF beam is injected into an RF-tight microwave chamber which is equipped with water-cooled mirrors directing the beam towards the 1 MW water load.

The second mirror inside the microwave chamber contains a directional output coupler formed by a row of holes in the mirror surface. A diode detector is connected to the directional coupler and the forward power can be determined once the signal has been calibrated. This is performed by calorimeters put into the RF-beam in short pulse measurements. The mode purity of the Gaussian beam is measured by a thin dielectric target plate placed at different positions across the RF beam. The measured beam distribution agrees very well with the theoretical predictions.

In short pulse operation at the design current of 40 A, an output power of 1 MW could be achieved for an accelerating voltage of 82 kV without depression voltage, an output power of 1.15 MW at an accelerating voltage of 84 kV with a depression voltage of 25 kV (Fig.2). For these values an efficiency of 49% was obtained. At constant accelerating voltages, the output power did not change up to depression voltages of 33 kV.

Pulse length	Power	efficiency
10 s	1 MW	50 %
45 s	0.9 MW	39 %
100 s	0.74 MW	32 %
140 s	0.64 MW	

Table 2: Output power for long pulse operation

After some problems with the RF-load, long pulse operation was performed: The power measurements were done by the signal of the diode detector placed at the second mirror. The measured output power of the calorimetric RF-load normally show values reduced by about 20%. The results are summarised in Table 2. Output powers of 1 MW could be achieved for 10s, and an energy as high as 90 MJ per pulse has been produced with an output power of 0.64 MW. The pulse lengths were mainly determined by the preset values, and due to lack of experimental time no attempt was made to increase the pulse length. Only for the 100 s pulse, a limitation was found due to a pressure increase beyond about 10^{-7} hPa. The gyrotron was sent back to the manufacturer Thales ED for a visual inspection, and an improved tube will be built and delivered to Forschungszentrum Karlsruhe in February 2002.