Multi-Frequency Gyrotrons for Plasma Fusion Installations

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Abstract— **During last years several new gyrotrons were designed and tested at IAP/GYCOM. Main development efforts were spent for development 170GHz/1MW/50%/CW gyrotron for ITER and multi-frequency gyrotrons. The paper presents new results in development of gyrotrons capable to operate at several frequencies.**

I. Introduction And Background

Gyrotrons with step-frequency tuning are very attractive for plasma experiments. The use of step-tunable gyrotrons can greatly enhance flexibility and performance of ECRH/ECCD systems due to larger accessible radial range, possible replacement of steerable antennas, higher CD efficiency for NTM stabilization. Even two-frequency gyrotrons can bring real improvements of the system. Russian team with collaboration with German partners develops a dual- and multi-frequency gyrotrons for 105-140 GHz frequency range. There are also other requests for multi-frequency gyrotrons.

Gyrotrons operate with high-order modes of high-Q (~1000) resonators. So the possibilities of the frequency change means either small frequency tuning comparable with width of the resonant curve or change of a resonant mode. In both cases the frequency tuning implies operating voltage and magnetic field adjustment (see also Table 1). Lower line of the table shows possible application of frequency tunable gyrotrons.

Table 1. Frequency tuning in gyrotrons

One operating mode Magnetic field or voltage tuning	**Azimuth index change** Magnetic field and voltage optimization	**Series of azimuth indices at each radial index** Magnetic field and voltage optimization
Typical frequency tuning ~ 0.1%	Typical frequency step 2-3%, 3-4 steps	About 10 steps in 30% frequency range
FADIS	Multi-purpose ECW systems	

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II. Results

The list of developed and tested multi-frequency mock-ups and gyrotrons for different customers is shown by Table 2.

Table 2. Two- and multi-f gyrotrons tested in 2005-2008

Frequency, GHz	Power, MW	Pulse, sec	Note
105 / 140	0.7 - 0.9	10	2 tubes for to ASDEX-Up
147 / 170	0.9	0.1	CW design, 50% eff
100-150	1.2-1.5	10-4	Short –pulse mock-up, 6 frequencies, high-eff. converter
100-150	0.7-0.8	0.1	Short-pulse mock-up, 11 frequencies, BN Brewster window
105 -140	0.8 – 1.0	0.1 (10)	2 tubes, CW design, 4 frequencies High-eff. mode converter
71.5/74.8/78.1	0.8	0.1	3 frequencies, 56% eff. BN Brewster window

The main problems in development of multi-frequency gyrotrons are to provide:

– efficient gyrotron operation at different modes,
– efficient conversion of different modes into a Gaussian beam,
– reliable operation of a broadband or tunable window.

It was proven in several experiments that optimization of an electron gun and a proper choice of operation parameters results in a possibility of efficient interaction of many modes (~10) with electron beam in a frequency band 20-30%. Besides the main magnetic field change the operating mode change usually requires some adjustment of electric field in the gun (voltage) and electron beam radius in the cavity (gun coil current).

A new internal mode converter consisting of a synthesized dimpled-wall waveguide launcher and four shaped mirrors recently was been developed for the gyrotron and it reduces the power fraction carried away by stray radiation (due to diffraction losses on the mirror apertures) to about 3% for all operating modes.

The key component of the mode converter – launcher was synthesized by a special method generating a waveguide wall deformation (Fig.1) which provide efficient conversion of all operating modes into a paraxial beam which propagated towards the gyrotron window and through it (Fig.2). Calculated diffraction losses inside a tube are less then 3 % for all modes.

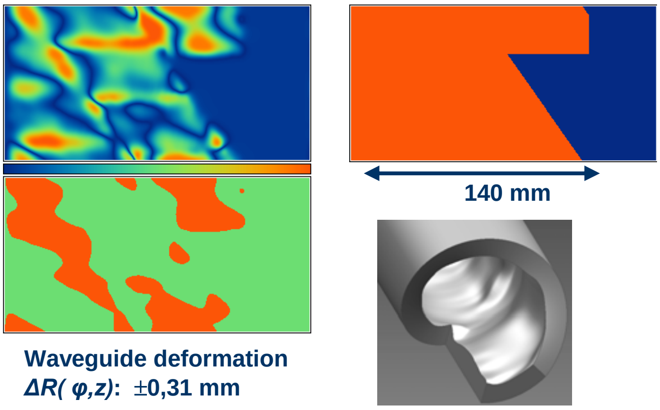

Fig.1. Unrolled surface of the waveguide (launcher) converting high-order modes into a paraxial wave beam. Right-bottom picture shows ten times exaggerated deformation of the waveguide.

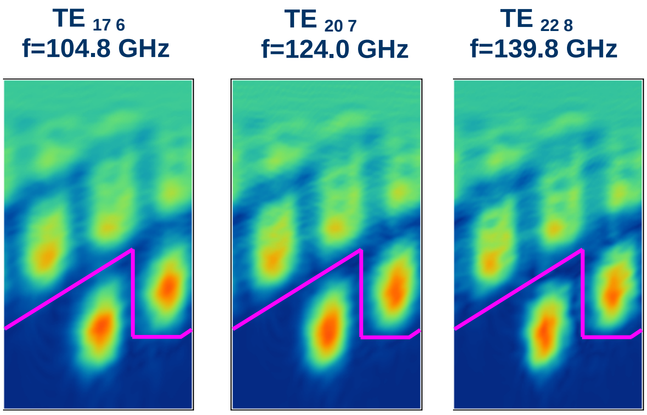

Fig. 2. Field amplitude on the launcher surface for three modes of the multi-frequency gyrotron. Spots below broken line correspond to launcher output wave beams.

Two window concepts are in consideration: Brewster window and two-disc adjustable window. Both concepts imply for long-pulse tubes the use of CVD diamond discs. The Brewster window is very attractive because of very wide instant frequency band, however the quasi-optical converter design in this case is more complicated (see, for example, Fig.3). The disc brazing for the Brewster window is also specific: it requires radially extended cuffs (Fig.4). A Brewster-angle type window with a CVD diamond disc was fabricated and mounted to several gyrotrons.

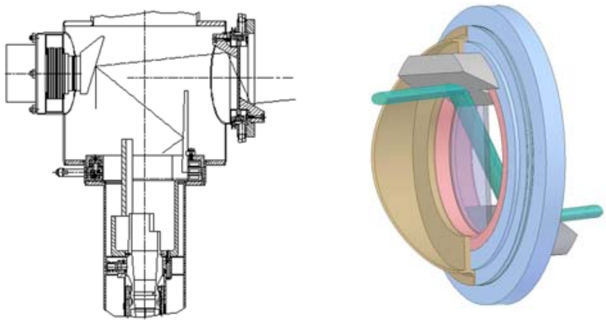

Fig. 3. Schematic of a multi-frequency gyrotron with circular-disc Brewster window.

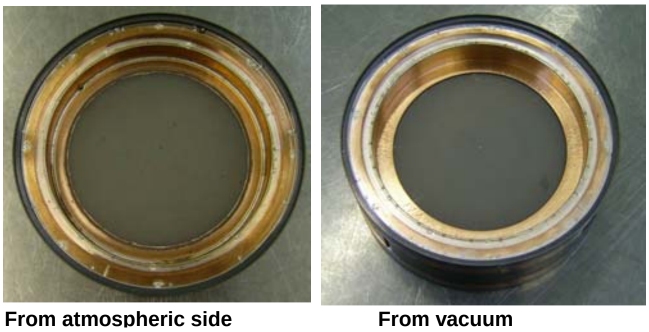

Fig. 4. View of the diamond disc brazed for a Brewster-type gyrotron output window.

Test with long-pulse multi-frequency 105-140 GHz gyrotrons are in progress now and new results are expected by the Conference.

SUMMARY

Last years a significant progress was demonstrated in development of multi-frequency gyrotrons for plasma fusion installations. The key development problems have been solved:

- Efficient operation of the gyrotron at several modes/frequencies demonstrated;
- Efficient quasi-optical converters of a set of operating modes into Gaussian wave beam developed;
- Broad-band Brewster window based on high-temperature brazed ceramics or CVD diamond disc;

Several two- and multi-frequency gyrotrons have been developed and tested at MW power level in the ranges of 70-80 GHz, 100-150 GHz, 140-170 GHz with pulses 0.1-10 seconds.