Low power measurements on the output beam of a 140 GHz $TE_{28,8}$ Gyrotron

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Abstract

For the ECRH system of the plasma fusion experiment W7-X in Greifswald, Germany, ten 140 GHz gyrotrons each delivering 1 MW continuous output power are foreseen. They are equipped with a quasi-optical mode transformer system to convert the field distribution of the resonator mode ($TE_{28,8}$) to a Gaussian like output beam [1]. An exact copy of this system consisting of an advanced launcher and three beam forming mirrors was set up for low power (also known as cold) measurements. This system is used for cold test verification of the design calculations and studies on installation tolerances and their effect on the output beam. This simplifies the development process as design errors or mechanical errors are difficult to be corrected as soon as the system is installed in the gyrotron.

To gain easy access to all of its parts, the test system has been set up outside the vacuum vessel. For measurement purposes it needs to be fed with the gyrotron's resonator mode, but at a lower power level. Building such a mode generator becomes more difficult as the order of the mode increases.

The mode in the gyrotron is fully rotating. But the mode generator has always a portion of the counter rotation of the mode because of the geometrically asymmetric power injection. Measurements which have been performed in the past, have shown negative effects of even small parts of the counter rotating power on the measurement. To prevent this influence a new mode generator was constructed which made the reduction of a mode's counter rotating power of less than 1% possible.

This paper shows the most recent measurements on the $TE_{28,8}$ transformer system in conjunction with the calculations of the output beam.

1 Introduction to the measurement setup

The measurement setup consists of four main parts which are shortly introduced here for an overview.

Network-Analyzer: The measurements have been performed at 140.015 GHz. This frequency, where the mode generator works with best performance, is generated using a phased lock loop backward wave oscillator tube. The output power is about 10 mW. The received signal is down-converted by a harmonic mixer to 640 MHz and in a second step to 10 MHz. The analyzer can be tuned in the whole D-waveguide band and has a dynamic range up to 100 dB. More information about this analyzer can be found in [2].

Mode Generator: For low power excitation of high order modes a quasi-optical design is used. This mode generator simulates the high power generating process inside a gyrotron where an electron beam interacts with a resonator mode of high order.

Launcher: The Launcher is a cylindrical waveguide with a helical cut at the end, forming an aperture antenna to feed the mirror system.

Mirror System: The mirror system consists of three mirrors in total. The first mirror is quasi elliptical for collecting and focusing all of the launcher's radiated power. The second and third mirrors are toroidally formed each in two planes.

2 The Quasi Optical Mode Generator

Very good performance of high-order mode generators has been found by using a quasi-optical design [3]. A wave with Gaussian amplitude distribution and nearly plane phase front propagating in free space is injected via a caustic mirror into a perforated gyrotron-like resonator. The caustic mirror is shaped in a way, so that all waves are tangent to the so-called caustic of the mode. An inner rod is used to improve the mode selection (coaxial resonator). A detailed description of the theoretical performance is given in [4].

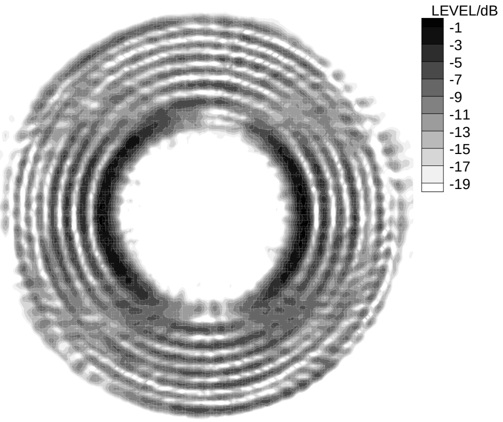

Figure 1: E-field distribution of the $TE_{28,8}$ mode.

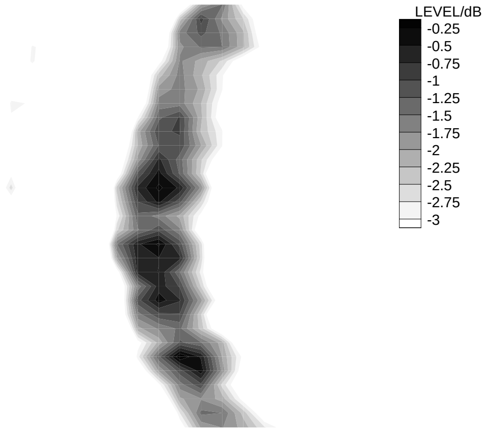

Figure 2: Zoomed inner ring.

In difference to formerly used mode generators at FZK, three construction-conditioned improvements have been established:

1. The construction has been built more stiffly and closer toleranced.
2. The plane phase front is achieved using a $TE_{1,1}$ horn antenna and Teflon lenses, which are fixed on a two dimensional moving table.
3. The coupling holes of the resonator are located on its whole circumference in spite of only one sector. As this structure is fully symmetric it suppresses the stimulation of the counter rotation of the mode.

With these modifications it was possible to tune the mode generator to a counter rotating fraction of power down to 0.25%. In contrast, older measurements used mode generators with counter rotating fractions of power between 5% and 10% [5][6].

This improvement is shown in two figures. **Figure 1** shows the $TE_{28,8}$ mode's E-field distribution measured at the output flange of the mode generator. **Figure 2** shows a zoom of the inner ring with a more detailed power scaling.

The standing wave ratio of the E-field distribution has been detected to determine the counter rotating power of the output mode. Microwave measurement equipment usually measures power in logarithmic scaling. Δ is the difference of maximum power to minimum power in φ-direction of the power distribution in dB. Using equations (1) and (2) with s as the standing wave ratio, P_- can be determined from a field pattern measurement. **Figure 3** shows a plot of equations (1) and (2).

$$s = 10^{\left(\frac{\Delta}{20}\right)} \quad ; \quad P_{\oslash} = \frac{P_-}{P_+} = \frac{(s-1)^2}{(s+1)^2} \tag{1}$$

$$\text{with} \quad P_- + P_+ = 1 \rightarrow P_- = \frac{P_{\oslash}}{1+P_{\oslash}} \tag{2}$$

3 Measurements on the launcher

A photograph showing the helical slot of the launcher antenna is printed in **figure 4**. This slot forms an aperture over which all the transported power is radiated to the mirror systems. The inner waveguide wall is deformed in a way which minimizes diffraction losses.

Figure 5 shows a comparison of the calculation and measurement of the E-field output distribution of the launcher antenna. The measurement plane is situated in a distance of 100 mm from the launcher's axis, in a plane parallel to the first mirror.

For the measurement the launcher was directly connected to the mode generator.

The calculated plot in figure 5 looks much smoother than the measured one. This can be explained by edge diffraction and reflection on posts or metallic plates which cannot be completely reduced even with large amounts of absorbing material and which are not considered in the calculation model.

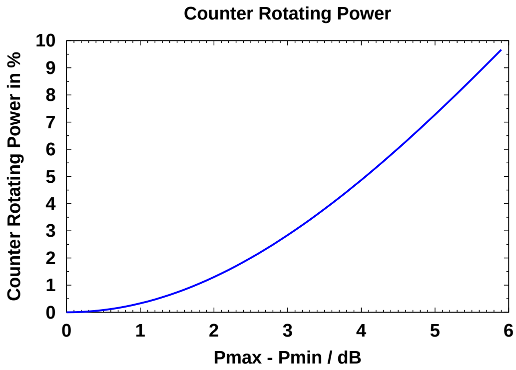

Figure 3: Fraction of counter rotating power.

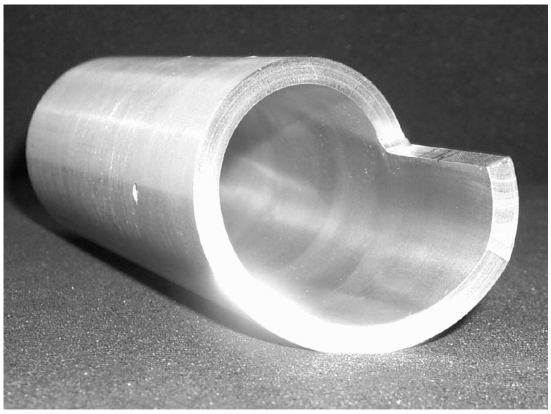

Figure 4: Photograph of the launcher.

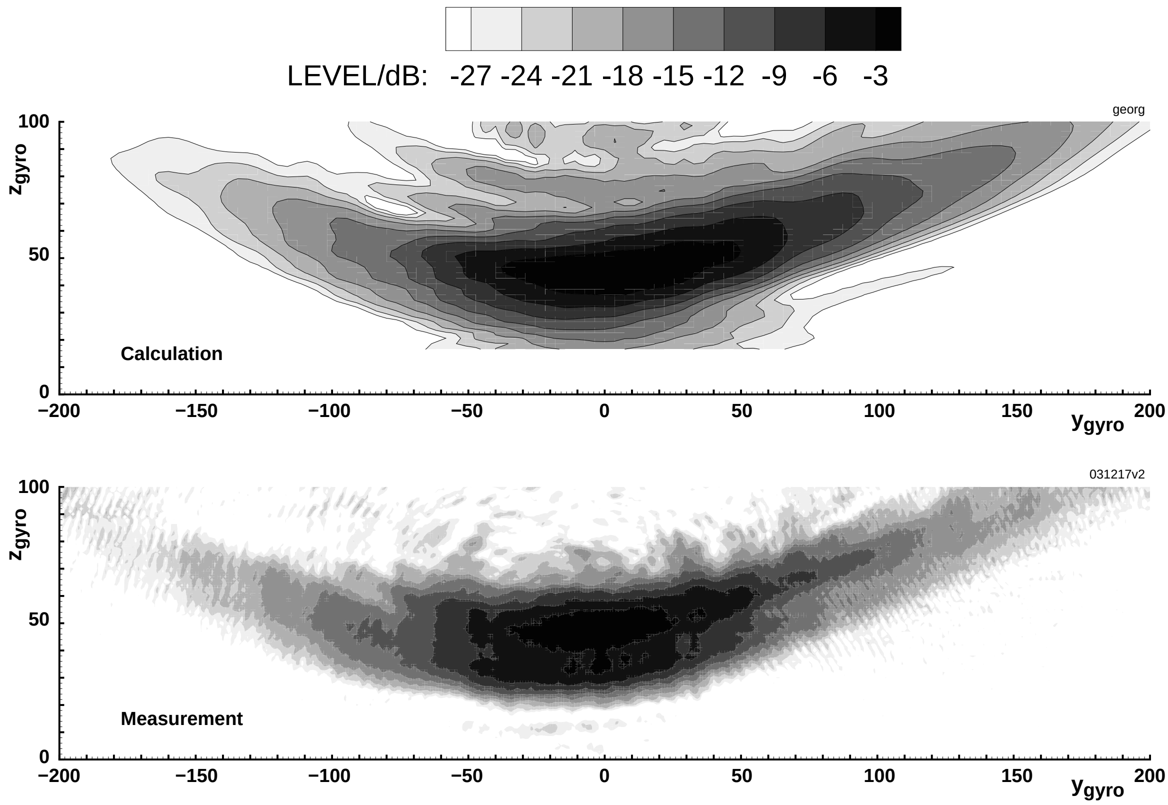

Figure 5: Field distribution of the launcher's output, at a distance of 100 mm. Comparison to the calculation.

4 Measurement of the transformer's output beam

The whole transformer system consists of the launcher and the mirrors. They were all installed on a base plate and connected to the mode generator.

The E-field distribution was taken in different planes parallel to the gyrotron's output window. Three of the measurements are shown here together with the calculation.

Figure 6 represents the field distribution in the plane of the window, **figure 7** at 250 mm and **figure 8** at 775 mm outside of the gyrotron.

The plots are centered on the calculated beam axis of the mirror system. For each of the figures the left hand plot shows the measurement and the right hand plot the calculation. Additionally the aperture of the window (88 mm in diameter) is drawn in figure 6.

As a result the beam leaves the gyrotron tube parallel to the axis as predicted in the calculations. Further investigations on the beam geometry parameters like size, beam waist and Gaussian mode content are in progress at this moment.

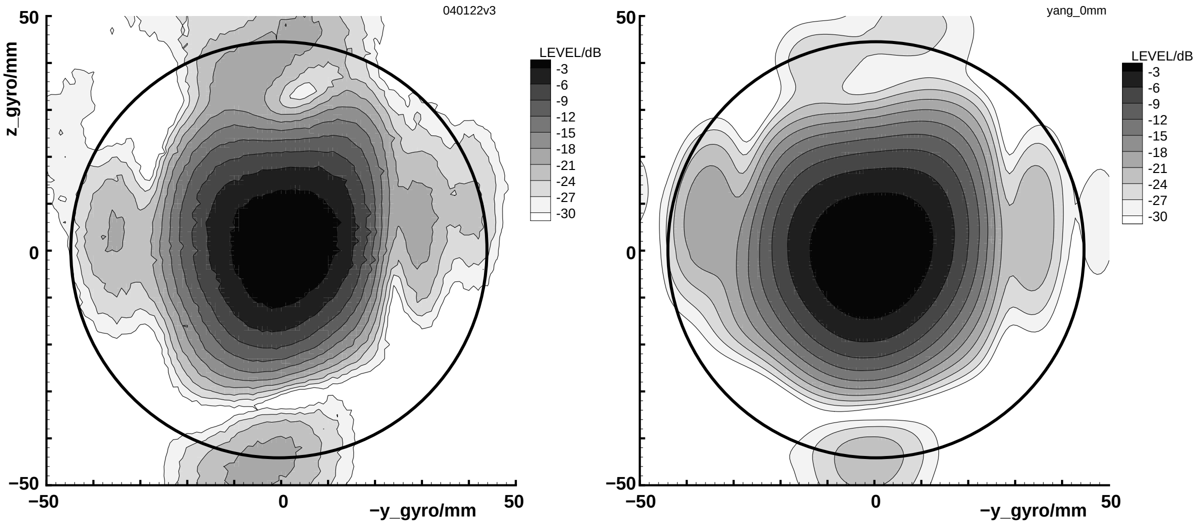

Figure 6: Output beam in the window plane. Left: measurement, right: calculation.

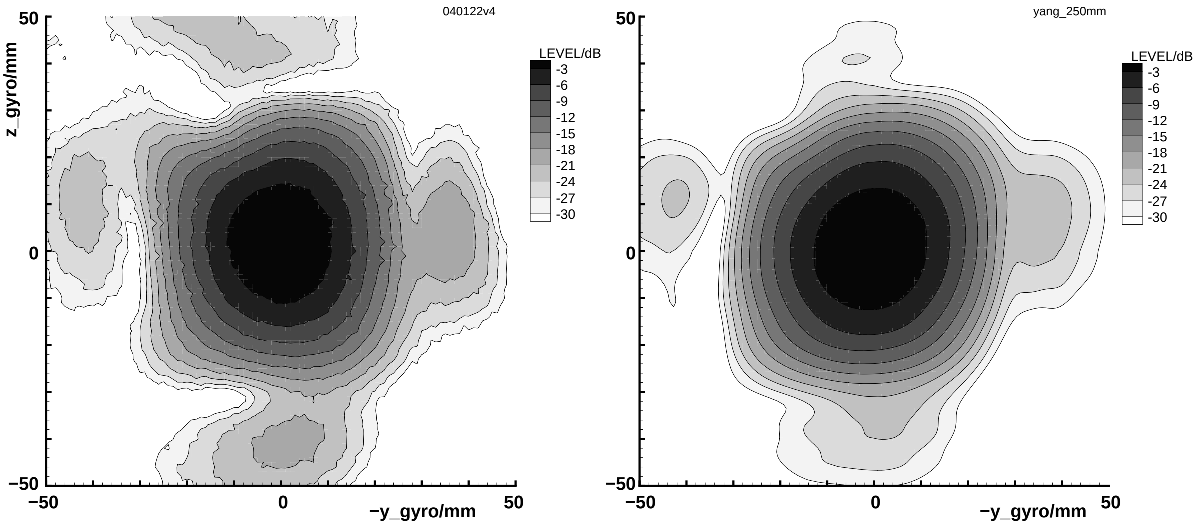

Figure 7: Output beam 250 mm outside the gyrotron. Left: measurement, right: calculation.

5 Parallel beam offset

While setting up and performing the measurement it came apparent that small offsets of the first mirror in y-direction of the gyrotron coordinate system lead to huge offsets of the output beam also in y-direction. The first measurement on the system showed an offset of 18 mm. Carefully checking every item resulted in the post of the first mirror was 0.4 mm too short and the post for launcher was 0.45 mm too tall. This is within the tolerance for each item itself but summed up to 0.85 mm in total.

The beam offset was measured for different offsets for the first mirror. The result was drawn in **figure 9** and is also given in the table. The black dots are the beam centers at a distance of 894 mm away from the window. The power scaling was inverted

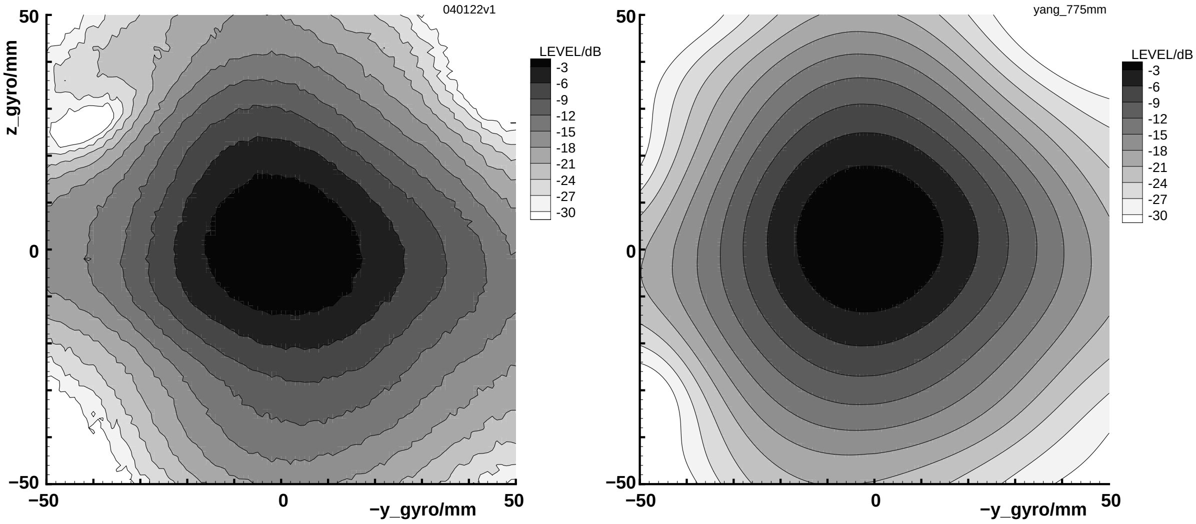

Figure 8: Output beam 775 mm outside the gyrotron. Left: measurement, right: calculation.

contrary to the other figures.

1st mirror offset y/mm	beam offset y/mm	beam offset z/mm
-0.85	-18	0
-0.35	-5	0
0.0	0	0
0.15	2	0.5
0.65	17	1.5

Within the resolution of the measurement (about 1 mm) the beam centers follow the black line.

Regardless of the offset, the beam leaves the mirror system nearly parallel to the axis, which is an interesting result.

The sensitivity for misalignment was not considered to be such important because the mirrors have huge curvatures. These cold measurements have shown one direction where small inaccuracies lead to offsets multiplied by a factor of more than 10. Of course this will be an important topic for further investigation.

A photo of the mirror system is printed in **figure 10** to have an impression of the dimensions. The drawn ray is 190 mm above the base plate.

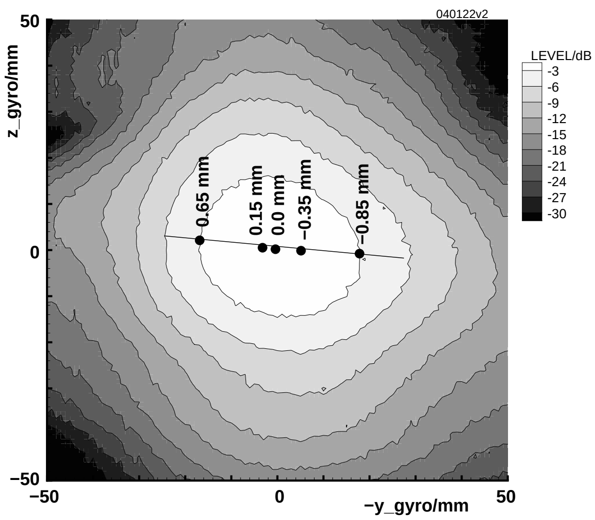

Figure 9: Beam offset at 894 mm.

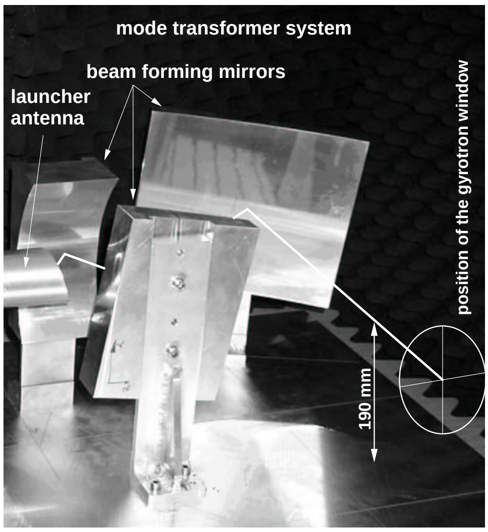

Figure 10: Photo of the mirror test setup.

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