Improved Beam-Forming Mirror System for a Multi-Frequency Gyrotron at FZK

X.Yang [1], A.Arnold [1,2], G.Dammertz [1], K.Koppenburg [1], B.Piosczyk [1], D.Wagner [3], M.Thumm [1,2]

[1] Forschungszentrum Karlsruhe, IHM, D-76021 Karlsruhe, Germany
[2] also Universitaet Karlsruhe, IHE, D-76128 Karlsruhe, Germany
[3] Max-Planck-Institut fuer Plasmaphysik, D-85748 Garching, Germany
*e-mail: **xiaokang.yang@ihm.fzk.de**; Tel: 49-7247-822455; Fax: 49-7247-824874*

A short-pulse prototype of a stepwise tunable multi-frequency gyrotron (105-140 GHz) for stabilization of nuclear fusion plasmas is under development [1,2] at Forschungszentrum Karlsruhe (FZK). Due to the large Brewster angle of 67.2^o, the maximum effective window diameter for currently available CVD-diamond disks (140 mm diameter) is about 50 mm, and the length of the waveguide to house the disk is 149 mm [3]. This window configuration adds a strict requirement for the gyrotron output beams with different frequencies.

At the IVEC-2005 conference [4] we reported about how to design two adapted phase-correcting mirrors on the basis of plane mirror surfaces to match the requirement of the small effective diameter (50 mm) at the Brewster window. From theoretical point of view, this design is reasonable; a very good fundamental Gaussian output beam has been predicted. However, the adapted phase-correcting mirrors require accurate fabrication and alignment. But in practice, diffraction losses may be introduced due to the procedure of mirror fabrication by a numerically controlled milling machine because of the tolerances of the very strong perturbations on the mirror surfaces. Preliminary cold measurements have shown strong sensitivity of the output beams on the alignment of the mirror system, and relatively high diffraction losses. In order to reduce the perturbations on the adapted phase-correcting mirrors it is necessary to re-design them on the basis of smooth curved mirrors with elliptical surfaces.

We keep the existing dimpled-wall launcher and the first quasi-elliptical mirror unchanged while improving the last two mirrors. The design technique requires knowledge of both the amplitude and the phase distribution of the input beam and the desired output beam. The design procedure for the basis system with two smooth curved mirrors is: (1) back propagate the desired beam onto the last mirror; (2) generate the resulting amplitude distribution with the first and second mirrors; (3) generate the resulting phase distribution with the last mirror. This design procedure incorporates a fast scalar diffraction code for nonparallel apertures, which allows a rapid synthesis of the mirror profiles.

Extensive calculations have been done to optimize the two elliptical mirrors. Results show that the optimized mirror surface contours depend strongly on frequency, beam radius at the window, distance between window and the last mirror, angle of incidence and quality of the RF beam from the launcher and the first quasi-elliptical mirror. Fig. 1 (a), (b) show the surface contours of the two optimized elliptical mirrors.

The second mirror adjusts the beam patterns on the third (last) mirror while the third mirror adjusts the beam patterns to the gyrotron output window. On the basis of the two smooth surface elliptical mirrors shown in Fig.1 (a), (b), we can calculate the field and power distributions of the output beams. Fig.2 (upper row) shows some examples of power distributions at the middle position of the CVD-diamond Brewster window for the modes $TE_{17,6}$ at 105 GHz, $TE_{20,7}$ at 124.1 GHz and $TE_{22,8}$ at 140 GHz respectively. The beams shift by $\pm$5 mm in horizontal direction around the center of the window plane. Unfortunately, the beam-forming mirror system with two smooth elliptical mirrors has no broadband characteristics; the output beams have poor beam quality and thus low Gaussian content. It cannot match the requirement of small effective window diameter for all nine operating modes.

On the basis of the mirror system with two smooth elliptical mirrors described above, we can further optimize this system employing a numerical procedure such as the extended Katsenelenbaum-Semenov algorithm to obtain adapted phase-correcting mirrors, which have broadband characteristics. The optimization process is nearly in the same way as what we used before [4], the only difference is that we set conventional elliptical mirrors as the initial mirror surfaces for the optimization rather than plane mirror surfaces.

Fig.1 (c) (d) show the surface contours of the two optimized adapted phase-correcting mirrors. Compared with Fig.1 (a) (b), it is clear that there are only small perturbations on the smooth mirror surfaces. This may reduce the diffraction losses introduced by tolerances in mirror fabrication, and also reduce the sensitivity of mirror alignment.

Fig. 2 (lower row) shows the power distributions at the middle position of the CVD-diamond Brewster window. In comparison to the beam patterns in Fig.2 upper row which is in the case of two elliptical mirrors, it is obvious that adapted phase-correcting mirrors can be used for gyrotron broadband operation and give much better fundamental Gaussian pattern than the smooth elliptical mirrors do.

In conclusion, two adapted phase-correcting mirrors have been redesigned on the basis of two elliptical mirrors with smooth surfaces. There are only small perturbations on the mirror surfaces, and near fundamental Gaussian distribution for all nine operating gyrotron modes is predicted by the simulations. This design may reduce the diffraction losses introduced by fabrication tolerance and make the alignment of the mirror system less sensitive.

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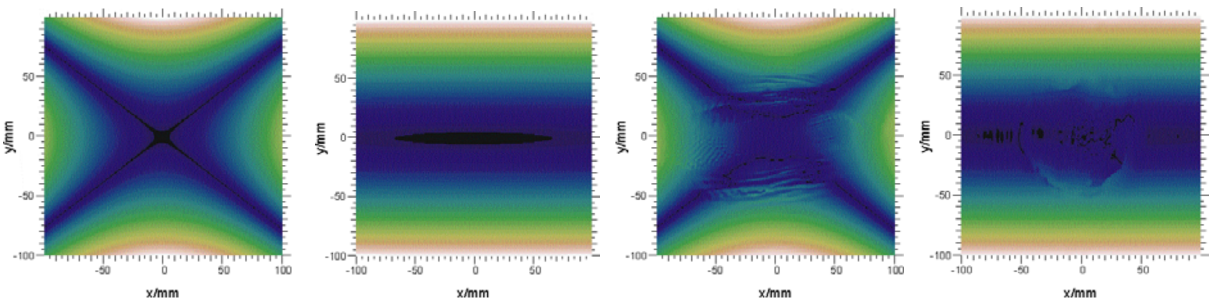
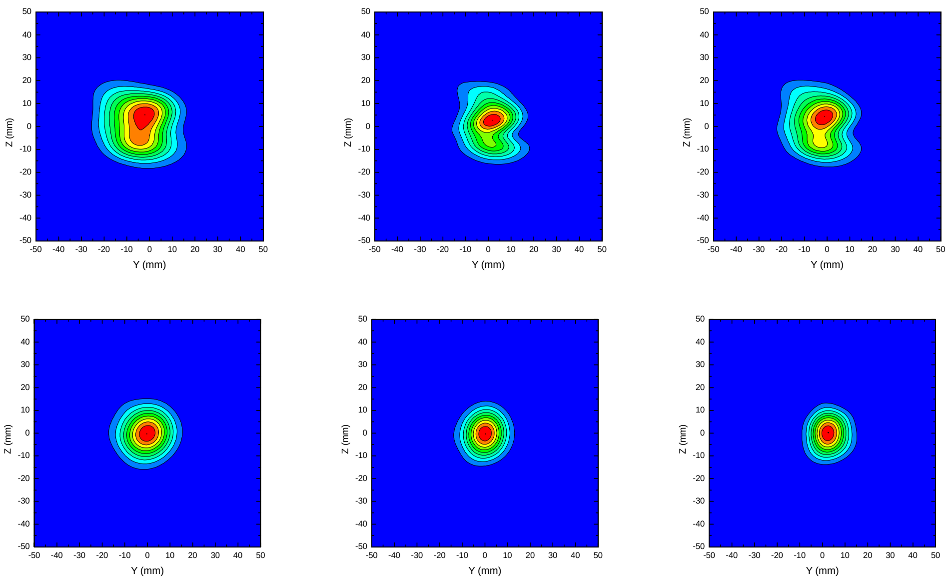


(a) (b) (c) (d)

Fig.1 Calculated contour surfaces of: (a) (b) elliptical mirrors; (c) (d) adapted phase-correcting mirrors.



(a) $TE_{17,6}$ (104.9 GHz) (b) $TE_{20.7}$ (124.1 GHz) (c) $TE_{22,8}$ (140.0 GHz)

Fig. 2. Calculated power distributions at the middle position of the Brewster output window of the gyrotron. Normalized power contours are shown in linear scale with 0.1 relative decrements. Upper row: with two simple elliptical mirrors. Lower row: with two adapted phase-correcting mirrors with non-quadratic surface function.