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Tolerance analysis of a quasi-optical mode converter for the upgrade of W7-X gyrotrons

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In collaboration with IPP Greifswald, an industrial gyrotron operating at 140 GHz with 1.5 MW RF power for the upgrade of the ECRH system of the W7-X stellarator is under development at KIT. A quasi-optical (q.o.) mode converter has been designed for this 1.5 MW gyrotron, operating in the TE28,10 mode. The q.o. mode converter consists of a mirror-line conical launcher [1] and three mirrors with quasi-quadratic surface contour functions [2]. Launcher and mirrors are optimized using the in-house code TWLDO to provide an RF beam with a high fundamental Gaussian mode content of 99 % at the RF output window and low stray radiation of 1.65 % in the tube. Even though the surface contour of the numerically optimized launcher look quite complex, the wall surface is quite smooth. The perturbations on the wall are in the interval -0.077 mm $< \Delta R < 0.147$ mm. The minimum curvature radii of the perturbed wall surface are 23.2 mm in azimuthal direction (average launcher radius: 24.5+0.004z mm, 0 mm $< z <$ 207 mm) and 159.7 mm in the axial direction, respectively. Generally, the smoother the wall surface the smaller the probability of manufacturing errors.
A copper launcher and a mirror system were fabricated and a low power test facility was built to check the performance of the q.o. mode converter system [3]. The wall surfaces of the fabricated launcher have been measured through the entire length of the launcher at discrete azimuthal angles ($2\pi \cdot n/8$, $n = 0,\ldots,7$). Comparing the measurement data of the fabricated wall surface to the theoretical values, there is a systematic deviation of the average radius of up to approximately 0.025 mm. The relative contour uncertainty is ±0.01 mm. Nevertheless, the low power measurement results show that the fundamental Gaussian mode content of the RF beam is still as high as 97 % at the position of the output window. In order to check the effect of manufacturing errors, a new launcher wall surface has been reconstructed by interpolating the measurements data of the wall surface at the eight measured azimuthal angles. A model q.o. mode converter containing the reconstructed launcher and three designed mirrors has been analysed. The simulation results show that the fundamental Gaussian mode content and the stray radiation are estimated to be 98.9 % and 1.75 %, respectively. The differences between the simulation and the experimental results might be caused by the mode purity of the low power test facility. It is definitely lower than 100 %. Additionally, the reconstructed launcher wall is somewhat different from the real wall surface, and the fabrication errors of the mirror surfaces are not included in the simulation.

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