Beam Quality Measurements at the ASDEX Upgrade ECRH system

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***Abstract*—An Electron Cyclotron Resonance Heating (ECRH) system employing 8 gyrotrons is in routine operation at the ASDEX Upgrade tokamak. The gyrotrons are of two-frequency type operating at 105 and 140 GHz with a maximum output power of up to 1 MW and 10 s pulse length. The gyrotron output beams are coupled to 8 waveguide transmission lines via quasi-optical Matching Optics Units (MOUs). The oversized corrugated HE_{11} waveguides with a diameter of 87 mm are operated at atmospheric pressure with overall lengths between 65 and 102 meters. The number of quasi-optical miter bends per line is between 6 and 8. High mode purity in the transmission lines is critical with respect to both, losses and atmospheric breakdowns. Beam measurements at low power have been performed along the transmission lines and are compared to high power measurements.**

I. INTRODUCTION

The ASDEX Upgrade tokamak is equipped with an 8 MW, 105/140 GHz ECRH system employing 8 non-evacuated transmission lines, mainly consisting of corrugated HE_{11} waveguides [1]. The total lengths of the transmission lines are between 65 and 102 meters and the number of miter bends per line is between 6 and 8. The large inner diameter of 87 mm of the corrugated waveguides was chosen in order to avoid atmospheric breakdown at power levels up to 1 MW. This is the largest waveguide diameter compared to the wavelength ($40.6{\cdot}\lambda_0$ at 140 GHz) of any existing high-power ECRH transmission line [2]. Each GYCOM gyrotron is connected to the Corrugated Waveguide Transmission Line (CWTL) via a quasi-optical MOU (Fig.1). The MOUs contain a set of 2 phase correcting mirrors for each gyrotron frequency [3] followed by a pair of broadband polarizers [4]. A focusing mirror couples the beam to the waveguide. While mode conversion in miter bends due to diffraction strongly decreases with increasing D/λ_0 [5], a main concern that led to limitation of waveguide diameters in other systems was coupling to lower order asymmetrical modes, like the linearly polarized LP_{11}, due to bending of the waveguides caused by sagging or movements of the waveguide supports or misalignment of the input beam. Low-power measurements at the AUG transmission lines have been performed in search for critical sections w.r.t. mode conversion.

II. LOW-POWER MEASUREMENTS

High power beam measurements at the end of the AUG transmission lines hint at higher order mode contents in the beam (Fig.2). Coupling of a Gaussian beam to a corrugated waveguide with a beam waist at the waveguide entrance of $w_0 = 0.6435{\cdot}a$ (a is the waveguide radius) excites about 2 % of spurious modes [6]. These spurious modes are hybrid modes with higher radial indices and all of them have

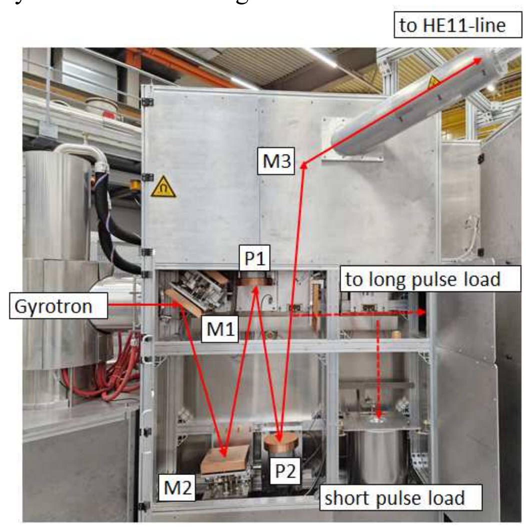

Fig. 1. Matching Optics Unit (MOU) with phase correcting mirrors M1 and M2, followed by the polarizers P1 and P2 and a focusing mirror M3 (not visible in this picture).

azimuthally symmetric patterns. Therefore, the asymmetric content on the measured beam pattern can either be caused by imperfections of the CWTL (i.e. sagging, tilts or offsets), or by imperfect coupling of the free space beam to the waveguide entrance (tilt or offset), or by higher order Gaussian mode content in the free-space beam itself. To separate the influence of the input beam coupling, low power tests were performed at the CWTL. A lens horn connected to the input waveguide flange of the transmission line provided perfectly alignment of the input beam (Fig.3). The wave beam along the transmission line was measured at several locations using a millimeter wave scanner. A cavity stabilized IMPATT oscillator as source and as receiver a mixer with narrow IF bandwidth (ELVA-1) allowed for measurements with a sensitivity of -60 dBm with no connection between source and receiver.

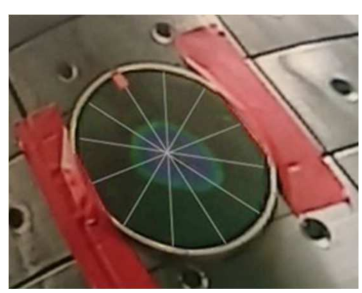

Fig. 2. Hot test with ~1 ms gyrotron pulse at inner torus wall onto a liquid crystal foil target.

Fig. 3. Lens horn mounted at the input of a ASDEX Upgrade waveguide transmission line.

Measurements of the mm-wave beam at arbitrary locations along the transmission line were done by opening of the waveguide line and inserting a miter bend to extract the beam under a 90° angle (Fig.4). Fig.5 shows a comparison between the beam pattern scans of the output of the lens horn and the beam pattern measured after 50 m of waveguide transmission line including 5 miter bends. The scalar Gaussian content of the beam extracted from the waveguide is 98 % compared to 99.7% of the input beam from the lens horn and no asymmetrical beam content was found. Beam patterns were also measured at the end of the transmission line by placing the scanner in the AUG torus (Fig.6). Fig.7 shows the measured output mm-wave beam patterns of transmission lines 3 and 4. There, the beams are radiated from an open-ended waveguide with D = 130 mm (following a corrugated taper from D = 87 mm to D = 130 mm with a length of 1.35 m) via a quasi-optical launcher consisting of a focusing and a flat mirror. The total length of the beam path in free space inside the torus is about 1 m. Both output beams have a scalar Gaussian content of 98 %, which is in good agreement with the theoretical predictions. Again, no asymmetrical spurious mode content was found, proving a good alignment of the waveguide transmission line. A comparison with high-power beam measurements (Fig.1) indicated that the coupling of the free-space beam from the MOU to the corrugated HE11-mode waveguide transmission line is critical for spurious mode excitation.

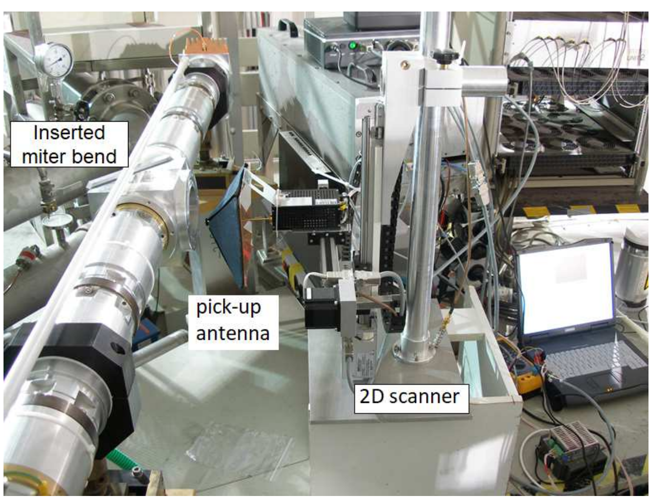

Fig. 4. Scanning of the mm-wave beam along the corrugated waveguide transmission line at the open end of an inserted miter bend.

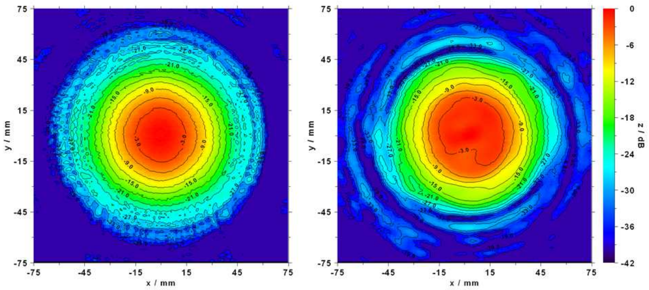

Fig. 5. Measured intensity pattern of the output mm-wave beam of the lens horn (left) and of the extracted beam after 50 m corrugated waveguides including 5 miter bends.

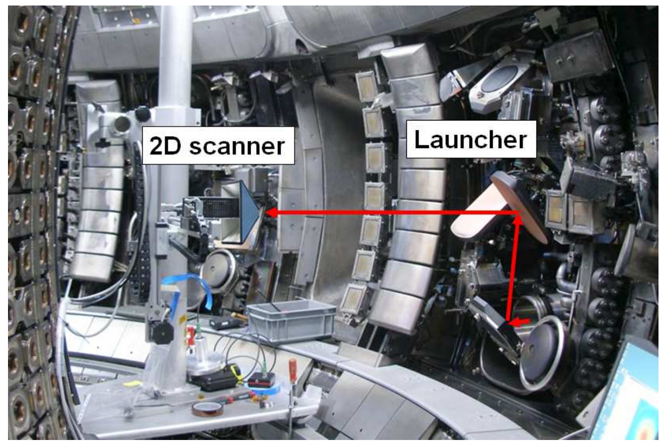

Fig. 6. Millimeter-wave scanner mounted in the tokamak vacuum vessel.

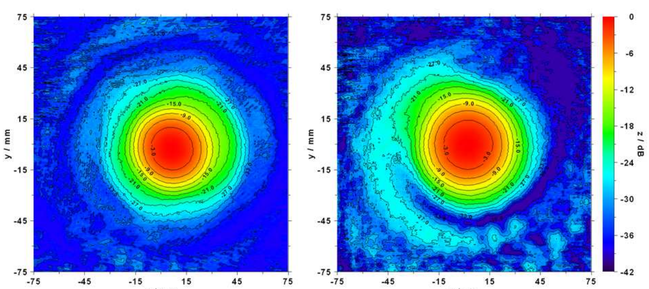

Fig. 7. Beam pattern measured at the end of AUG transmission lines 3 (left) and 4 (right).

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