Progress with the New Multi-Frequency ECRH System for ASDEX Upgrade

D. Wagner[a], T. Franke[a], F. Leuterer[a], F. Monaco[a], M. Münich[a], H. Schütz[a], J. Stober[a], F. Volpe[a],H. Zohm[a], M. Thumm[b], G. Gantenbein[b], J. Flamm[b], R. Heidinger[c], A. Meier[c], W. Kasparek[d], C. Lechte[d], A.G. Litvak[e], G.G. Denisov[c], A. Cirkov[e], E.M. Tai[f], L.G. Popov[f], V.O. Nichiporenko[f], V.E. Myasnikov[f], E.A. Solyanova[f], S.A. Malygin[f]

[a]Max-Planck-Insitut für Plasmaphysik, EURATOM-IPP, Boltzmannstr.2, 85748, Garching, Germany
Forschungszentrum Karlsruhe, EURATOM-FZK, [b]Institut für Hochleistungsimpuls- und Mikrowellentechnik, [c]Institut für Materialforschung, PO Box 3640, 76021 Karlsruhe, Germany
[d]Institut für Plasmaforschung, Universität Stuttgart, Pfaffenwaldring 31, 70569 Stuttgart, Germany
[e]Institute of Applied Physics, RAS, 46 Ulyanov St., Nizhny Novgorod, 603950, Russia
[f]GYCOM Ltd., 46 Ulyanov St., Nizhny Novgorod, 603155 Russia

Abstract— **Currently, a new multi-frequency ECRH system is under construction at the ASDEX Upgrade Tokamak experiment. This system employs, for the first time in a fusion device, multi-frequency gyrotrons, step-tunable in the range 105-140 GHz. The system includes fast steerable launchers at the front end that will allow for very localized feedback controlled power deposition in the plasma.**

I. INTRODUCTION

A multi-frequency ECRH system is currently under construction at the ASDEX Upgrade tokamak experiment[1]. The system employs depressed collector gyrotrons, step-tunable in the range 105-140 GHz, with a maximum output power of 1 MW and a pulse length of 10 s. One two-frequency GYCOM gyrotron is in routine operation at ASDEX Upgrade since 2006. A further extension of the system with 3 more gyrotrons is underway. They will be step-tunable and operate at two additional intermediate frequencies between 105 and 140 GHz. The multi-frequency gyrotrons will be equipped with broadband CVD diamond Brewster vacuum windows. Since the transmission of the power from the gyrotron to the tokamak is in normal air, a second broadband vacuum window is required at the tokamak vacuum barrier. It must be broadband also for elliptically polarized beams. Therefore tunable double disc CVD diamond windows will be used at the torus. One of the main applications of the new ECRH system will be the suppression of neoclassical tearing modes (NTM). For this reason fast-steerable mirrors have been installed. This capability will allow feedback control of the deposition on the time scale of NTM growth, providing the possibility to validate this scheme for ITER in ASDEX Upgrade [2]. A fast modulation capability of the gyrotrons is required for this application and was successfully tested.

II. GYROTRONS

The two-frequency GYCOM gyrotron Odissey-2 is in regular operation at the ASDEX Upgrade tokamak. It is equipped with a single-stage depressed collector. Therefore the cathode voltage can be limited to 60 kV, the maximum beam current is 40 A. The maximum output power is 640 kW and 880 kW at 105 GHz and 140 GHz respectively at a pulse length of 10 s. The time required to change the current in the superconducting magnet is about 20 min. This allows a change of the frequency between two consecutive ASDEX Upgrade pulses. The tuning requires an adjustment of the cryomagnetic field, the gun and collector magnetic fields and the operating voltages. Fast modulation up to 25 kHz was achieved by modulating only the cathode voltage while keeping the body voltage constant.

The gyrotron Elisey-1 will be the first multi-frequency high-power gyrotron in operation at ASDEX Upgrade. It will be operated at 4 frequencies, namely 105, 117, 127 and 140 GHz. Since the single disc CVD diamond window is only resonant at 105 and 140 GHz for perpendicular incidence of the gyrotron output beam at the window, a different mirror arrangement in the gyrotron is required to transmit the linearly polarized output beam under the Brewster angle (67.2° for diamond) [3], for which the window is transparent.

III. MATCHING OPTICS UNIT AND TRANSMISSION LINE

The Matching Optics Unit (MOU) contains individual pairs of phase correcting mirrors (M1, M2) for each frequency. The first two mirrors also align the beam, which leaves the gyrotron at slightly different azimuthal angles at different frequencies, to the optical axis of the waveguide transmission line input. The mirrors are mounted on rotating discs which are set automatically according to the operating frequency (Fig.1).

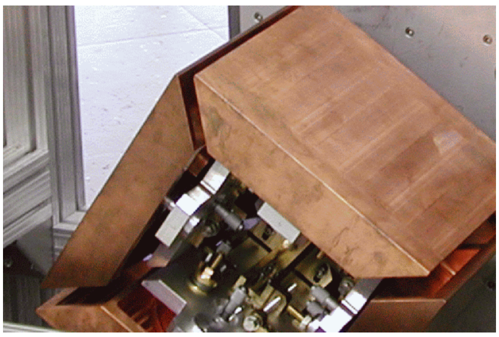

Fig.1 Four phase correcting mirrors mounted on a turn-table for application with a multi-frequency gyrotron

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The second mirror M2 contains a coupling-hole array for pulse monitoring and power measurement. The phase correcting mirrors are followed by a set of broadband polarizers (P1, P2) with groove depths of λ/4 and λ/8 scaled to the center frequency of 122.5 GHz [4]. Additional mirrors can be switched into the beam path to direct the beam to a spherical load with 1s pulse length capability which is part of each MOU, or to one long pulse load, which is connected to the MOU via a quasi-optical beam tunnel. A new long-pulse all stainless steel dummy load, capable of 1 MW, 10 s and operation in normal air has been operated very reliably. Using the 1 s loads, all four gyrotrons can be started up simultaneously every day. The 1 s spherical load can be exchanged with a 0.1 short-pulse calorimetric load for power measurements. The transmission to the torus is in normal air, through corrugated aluminum HE_{11} waveguides with I.D.= 87 mm over a total length of about 70 m. All four transmission lines are mounted. A second calorimetric load (0.1 s) is permanently installed at the end of the transmission line at the torus. This load is used to test the transmission line prior to plasma shots as well as for calorimetric measurements of the transmission efficiency. The measured transmission loss is below 10% at both frequencies and therefore in reasonable agreement with the theoretical predictions of 8%. Main contributions to the losses are diffraction losses in the quasi-optical miter bends and atmospheric absorption.

Since the polarization is set by the two polarizer mirrors in the MOU, the torus vacuum window has to be transparent also for elliptical polarization. A tunable double-disc CVD diamond window with a remote controlled adjustment of the distance between the discs was installed at the torus. The two diamond discs have a thickness of 1.8 mm and are resonant at 105 and 140 GHz (3λ/2 and 4λ/2 respectively). For intermediate frequencies the double-disc window can be tuned to a reflection minimum by changing the distance between the two discs. A critical value is the width of the Fabry-Pèrot resonances at intermediate frequencies between the single-disc resonances. Only a maximum distance of 10 mm between the discs can be allowed for a possible frequency drift of 140 MHz during the gyrotron pulse to keep the reflection below the critical value of 1 %. For safety reasons this distance could be reduced to the range around 5 mm. The volume between the two discs will be evacuated in order to increase the power handling capability. First cold test results were in good agreement with theory. In order to test an in-situ measurement of the installed window, a Gaussian beam was launched into a short transmission line section (straight waveguide + miter bend) and the reflection of the double disc window was measured using a quasi-optical directional coupler (Fig.2). The measurements were in good agreement with theory, both after remounting the window on the test set and also following bake-out tests (Fig.3). The difference between calculation and measurement is due to the bending of the discs by the atmospheric pressure with an evacuated interspace.

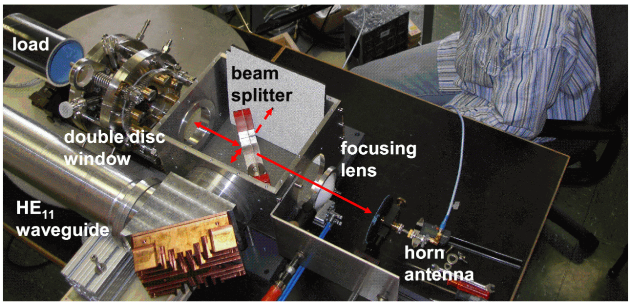

Fig.2 Setup for the in-situ test measurement of the CVD diamond double disc window.

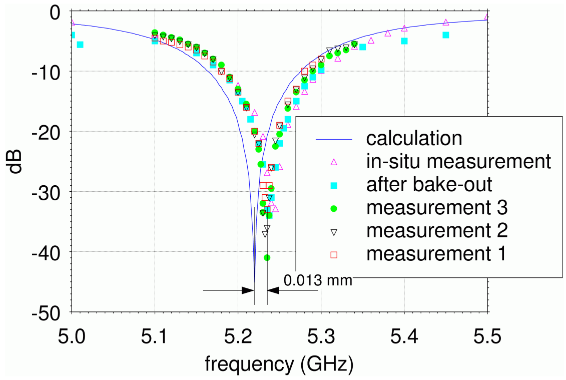

Fig.3 Calculated and measured reflection of the double disc CVD diamond torus window at f = 117.6 GHz.

IV. Remotely Controlled Beam Steering

The new launchers allow for fast poloidal steering of the beam during ASDEX Upgrade discharges. The toroidal injection angel can be changed between discharges. A fast spindle drive with a push rod mechanism controls the poloidal angle during a discharge. The maximum value for poloidal steering is 10° / 100 msec. The poloidal steering capability during the plasma discharge is also very useful for many other applications like the Collective Thomson Scattering diagnostic, where a 105 GHz beam is launched into the plasma and a second launcher and transmission line is used for receiving the signal scattered by the fast ions [5]. For launcher movements with moderate speed it is also possible to rotate the polarizer mirrors simultaneously during the shot. This allows for different scenarious within one plasma discharge and therefore increases further the flexibility of the system for plasma heating and current drive.

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