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THE TEXTOR LINE-OF-SIGHT ECE SYSTEM FOR FEEDBACK CONTROLLED ECRH POWER DEPOSITION

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INTRODUCTION. Active control of plasma instabilities forms a major challenge in the realization of tokamak fusion energy reactors. Sawtooth oscillations in the plasma core on the one hand provide necessary transport of He-ash, while on the other hand they lead to losses of energetic fusion alphas or trigger neoclassical tearing modes (NTMs). NTMs limit the achievable and may cause disruptions. Electron cyclotron current drive (ECCD), has been proven to be an ideal tool to influence the sawtooth period and suppress or prevent NTMs.[1] Control of sawteeth or NTMs by ECCD requires precise localization of the power, which is to be achieved by feedback control of the ECCD launcher. In a feedback control loop, measurements are required to determine mode location, and ECCD power deposition. For this purpose, electron cyclotron emission (ECE) measurements along the sight-line of the ECCD wave beam have been proposed.[2] This allows detection of structures in the plasma using the same optical path along which the ECCD power is launched. Through steering of the ECRH/ECE wave beam, a structure then only needs to be localized in the ECE spectrum at the gyrotron frequency in order to deposit the ECCD power exactly on top of it. On the TEXTOR tokamak a dedicated ECE diagnostic for control of ECCD localization has been implemented based on this "same line-of-sight" principle.[3] This paper describes the design, low- and high-power performance tests, and presents the results of first measurements.

DIAGNOSTIC DESIGN AND PERFORMANCE.[4] The major challenge for a “same-sight-line” ECE diagnostic is separation of ECE power (a few nW) from ECCD power (up to 1 MW). At TEXTOR, transmission from the gyrotron to the tokamak is fully quasi-optical. This led to the choice of a Fabry-Pérot filter in the form of a 25.75 mm thick quartz plate as key, frequency selective element. The plate is made of water free quartz (Infrasil301™) chosen for its low absorptivity of microwaves. At an angle of 22.5^o, the plate is transparent (~ 95%) to the gyrotron radiation and has maxima in reflection (~ 35%) at selected ECE frequencies with a periodicity of 3 GHz. The reflection has a minimum at the gyrotron frequency of about -27 dB. The absorption in the plate is 5%. The reflected gyrotron beam is directed to a high power dump where it is absorbed. The reflected ECE radiation coming from the plasma is projected onto a horn antenna by two flat mirrors and a final focusing mirror which shapes the wave beam into the antenna pattern of the receiving horn. The second of the flat mirrors is a copy of the quartz plate and further reduces gyrotron radiation into the microwave horn. The optics is mounted in a box, whose walls are covered with microwave absorber (Eccosorb™) as a final measure to reduce stray radiation.

The radiometer is protected by a -80 dB, 140 GHz notch filter with a bandwidth of 100 MHz, and a pin-switch to reject spurious modes produced during switch-on and switch-off of the gyrotron. The ECE spectrum is monitored in an RF band from 132 to 148 GHz, which covers typically ~ 1/3 of the plasma cross-section on the high field side. Changing the magnetic field varies the coverage from regions around the q = 2 surface (for tearing mode control) to the q = 1 surface (for sawtooth control). Moving the launcher up or down also moves the coverage outward in minor radius. Six ECE channels are selected in accordance with the maxima in reflection of the quartz plates, i.e. with a spacing of 3 GHz from 132.5 to 147.5 GHz and an IF bandwidth of 500 MHz. Acceptance tests showed a low average noise temperature of 4500 K. At a video bandwidth of 10 kHz the minimum detectable power than is 0.2 pW. This should provide a more than sufficient Signal to Noise ratio to detect the temperature oscillations from magnetic islands down to island sizes of about 1 cm.

Low power tests showed -50 dB reduction of the power transmitted from the plasma to the radiometer horn at 140 GHz, in agreement with expectations from the combination of two quartz plates. Broad maxima in transmission were found at the ECE frequencies. During high power (400 kW) gyrotron operation, the stray radiation at the position of the radiometer horn was measured to remain below 1 mW. The -80 dB notch filter then provides sufficient protection of the radiometer against stray gyrotron radiation. High power (400 kW) long pulse (2 s) operation resulted in a temperature rise in the quartz plate of 43 K, consistent with the predicted 5% absorbed power. Finally, during a 400 kW gyrotron pulse measurements revealed 700 W in the reflected power dump, consistent with an expected 0.2% (-27 dB).

ECE MEASURMENTS DURING HIGH-POWER ECCD. Measurements showing good signal to noise behaviour have been obtained for the full pulse length of TEXTOR discharges including periods with high power (up to 400 kW) long pulse (up to 2 s) ECCD. Sawteeth and rotating magnetic islands are clearly seen. Figure 1 shows measurements during a sawtoothing discharge. The sawtooth inversion between 132.5 and 135.5 GHz, i.e. to the low field side of the gyrotron resonance, shows that in this case ECCD is located outside the q = 1 surface. As expected in this case, the sawteeth are stabilized after the switch-on of 400 kW co-ECCD.

Figure 2 shows results from a discharge with a rotating tearing mode. In this case the vertical launcher angle was scanned from -15^o up to $+15^o$ during the 2 s, 400 kW co-ECCD pulse. Before ECCD, the phase reversal of the oscillations indicates that the island is located between 132.5 and 138.5 GHz. At the start of ECCD, power deposition then is to the outside of the magnetic island, and subsequently the scan in vertical injection angle moves the power deposition inward towards the magnetic island resulting in stabilization of the mode.

Large perturbations of the ECE signals are observed in Fig. 4 at the beginning of the ECCD pulse during the presence of the magnetic island: in particular, the channel at 138.5 GHz becomes saturated, leading to compression of the radiometer response at the other channels. These perturbations are observed to be in phase with the rotating magnetic island. Perturbations are also observed in the absence of rotating tearing modes. In this case however, the perturbations are observed over only a limited range of launching angles, close to perpendicular. Possibly, gyrotron radiation is scattered into the 138.5 GHz ECE band, leading to saturation of this channel and compression of the response in the other ECE channels.

SUMMARY AND CONCLUSIONS. A line-of-sight ECE diagnostic, which views the plasma along the same sight line as the injected ECCD wave beam, has been taken into operation on the TEXTOR tokamak.[4] The low power ECE radiation at selected frequencies is separated from the high power microwaves by a quartz plate acting as a Fabry-Pérot filter. Various tests show that the system operates in accordance with specifications. In particular, stray gyrotron radiation has been successfully suppressed and does not interfere with ECE measurements. Measurements, also during high-power ECCD, demonstrate the possibility of localizing the sawtooth inversion radius or a rotating magnetic island in the ECE spectrum. In the presence of magnetic islands, and for close to perpendicular injection, the measurements are perturbed by scattered high power microwave radiation.

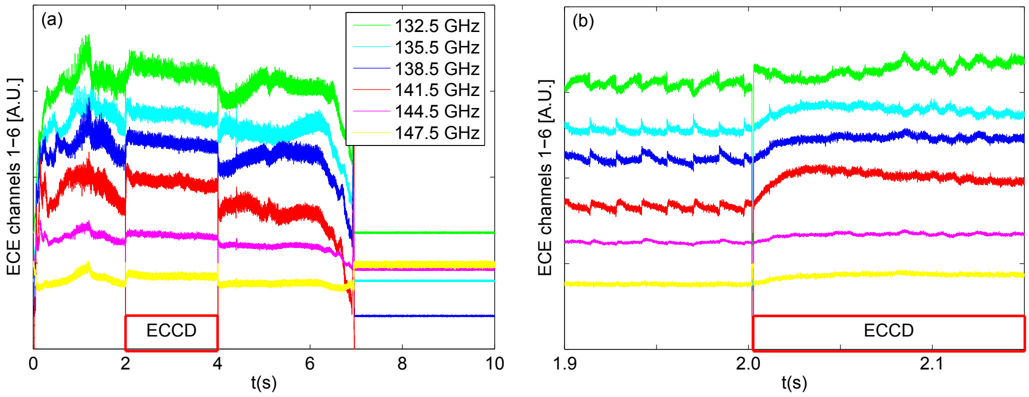

Figure 1. Measurements of the in-transmission line ECE radiometer in case of TEXTOR discharge #106913 (B = 2.3 T and I_p = 300 kA). The figures show (a) an overview over the entire discharge as well as (b) the response of the plasma at the start of co-ECCD. A 400 kW ECCD pulse is applied from 2 to 4 s.

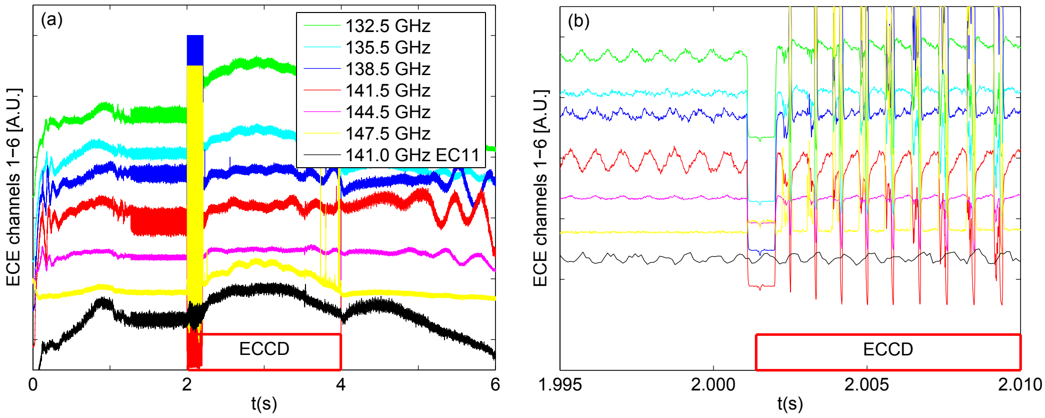

Figure 2. Measurements of the in-transmission line ECE radiometer for discharge #107125 (B = 2.25 T and I_p = 300 kA) with a rotating tearing mode. Figure (a) shows an overview over the entire discharge. The bottom trace shows a channel from the TEXTOR 11 channel ECE radiometer coming from near to the tearing mode. Whereas the in-line ECE signals are strongly perturbed by the mode, the stabilization of the tearing mode is clearly visible on the 11 channel radiometer data. In the period before ECCD, (b) shows the 180^{o} phase reversal indicating the position of the island between 132.5 and 138.5 GHz. Strong perturbations, in phase with the island rotation, are observed as soon as ECCD is applied.

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