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Transmission Measurement with high Power ECRH at the W7-AS Stellarator

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High power, intensive ECRH is used in many fusion Experiments. The power density and the power flux density of today ECRH-systems have already reached more than 2 MW/m^3 and 400 MW/m^2 respectively. At this power level the linear theory of EC-absorption may fail, and quasi-linear as well as non-linear effects have to be taken into account. In case of quasi-linear effects the absorption is changed due to a deviation of the electron distribution function from the Maxwellian. While in case of non-linear effects the absorption is reduced by the saturation of the energy transfer from the wave to the single electrons passing through the beam spot as illustrated in Fig.1. More details can be found in [2]. Usually the heating efficiency is calculated from the increase of plasma energy or from the power balance. Both methods are rather uncertain and the results often indicate, that some power is missing. The transmission diagnostics is a direct and precise measurement of the single pass absorption. The flexibility of the W7-AS ECRH-system allowed to distinguish between linear, quasi-linear and non-linear effects.

In the experiment for non-linear effects, the power flux density was modulated between 10 and 400 MW/m^2, while the total heating power remained constant on the flux surface. This was performed with the use of two 140 GHz ECRH-beams with 400 kW power each, which were modulated with a triangularly shaped function, but with a phase shift of 180° between each other. The amplitude of the two ECRH beams was set such that the total power was constant at a level of 400 kW during the modulation. Therefore all plasma parameters remained constant, while the power flux at the beam spots was varied only. In a first step the polarisation of the beam was set to exactly second harmonic X-mode, by minimising the transmitted signal at the opposite side of the beam. Here a pick-up horn array was installed to measure the transmitted power and to detect the beam position. The horn was also sensitive for O-mode polarisation. Therefore any second harmonic O-wave, which has a low single pass absorption, had to be avoided. Further on, as illustrated in Fig. 1 the EC-absorption layer was shifted towards the high field side by a reduction of the magnetic field until the a transmitted signal appears. For a linear absorption process a linear increase of the signal is expected. While in our case the transmission showed a non-linear deviation, starting at a power level of above 200 MW/m^2 as shown in Fig. 2. At twice that density the deviation vanishes as expected.

An other reason for the deviation of the cyclotron absorption from the linear theory is a non-Maxwellian electron distribution function. If the power density on a flux surface is large enough, that the distribution function is flattened at the cyclotron resonance, the absorption can be reduced.

In another type of experiments the ECRH the electron distribution function of the target plasma was changed to show quasi-linear effects. Two ECRH beams were launched at the same toroidal position, but slightly off-axis to avoid an overlap at the EC-resonance. Inside the stellarator torus opposite to the first beam, which has a complete X2-Mode polarisation, the transmitted power was measured. The other beam was launched either with X-mode polarisation or with O2-polarisation from the low field side. In the first case it is nearly completely absorbed at the same flux surface as the first beam. In the second case the plasma was optically thin for the radiation, the beam reached special high field side reflectors, which rotated the polarisation by 90° into the X2-polarisation as reported in [3]. By high field side launch the ECRH interaction first took place at a higher magnetic field and a supra-thermal electron population was generated at the high field side of the EC-Layer. With this experimental set-up two magnetic configurations were investigated. In the first, the so-called standard configuration, there was a local minimum, while in the second. the so-called maximum B configuration, there was a maximum at the toroidal ECRH launch position. The outcome of this is, that in the standard configuration mainly trapped electrons were heated by ECRH and that this trapped electron population remained at that toroidal position, while in the maximum B configuration passing particles were heated and were distributed on the flux-surface around the torus. The toroidal distribution of trapped particles is a Stellarator specific feature and is in contrast to an axial-symmetric magnetic configuration like a Tokamak. First the transmission was measured in the standard configuration. The two beams were launched into a plasma, while the density was continuisly increased. Here the supra-thermal thermal population, which was generated by the second beam, strongly reduces the transmitted power of the first beam at a density below 2 10^{19} m^{-3} as shown in Fig.3. In the same experiment but with the maximum B configuration there was no difference between the low field and high field launch.

A possible explanation for the reduced EC-transmission in the standard configuration can be the existence of additional EC-absorption due to supra-thermal electrons at the high field side of the EC-resonance. This is confirmed by the fact, that with the maximum-B configuration , where the electrons were diluted toroidally, no influence on the EC-absorption was found with the high field launch.

Summary and conclusion

The measurement of the transmitted ECRH-power a precise test of the ECRH-theory. Even small deviation from the linear prediction can be extracted by a proper experimental set-up. The limit of the quasi-linear approximation [1] due to non-linear effects was demonstrated by a wide range variation of the power flux density. A limit of the linear theory is the deviation from the Maxwellian electron distribution function. Here the ECRH absorption could be increased by additional supra-thermal electrons in the target plasma.

References

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Figures

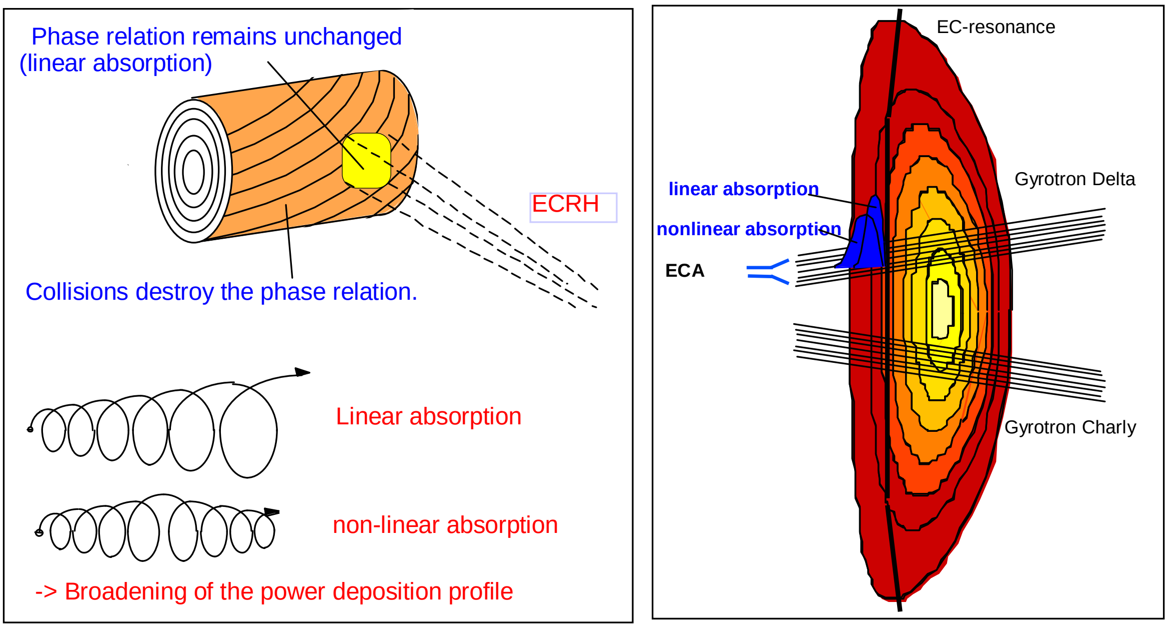

Fig.1 Left: Scheme of ECRH interaction. Right: Schematic view of the transmission measurement. By non-linear effects the absorption profile is broadened. If the EC-layer is

shifted towards the high field side a significant increase of the transmitted signal should be detected.

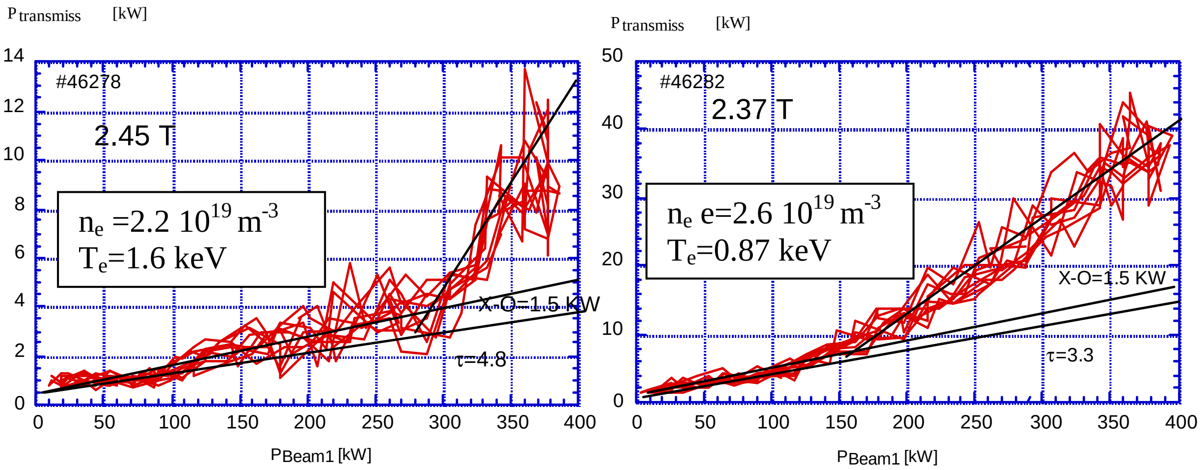

Fig. 2 Transmitted ECRH power as a function of the beam power for two position of the EC-layer in the plasma. In addition the optical depth calculated by a ray-tracing code is shown by the lower solid line. The second line show the part of mode conversion into the O2-mode.

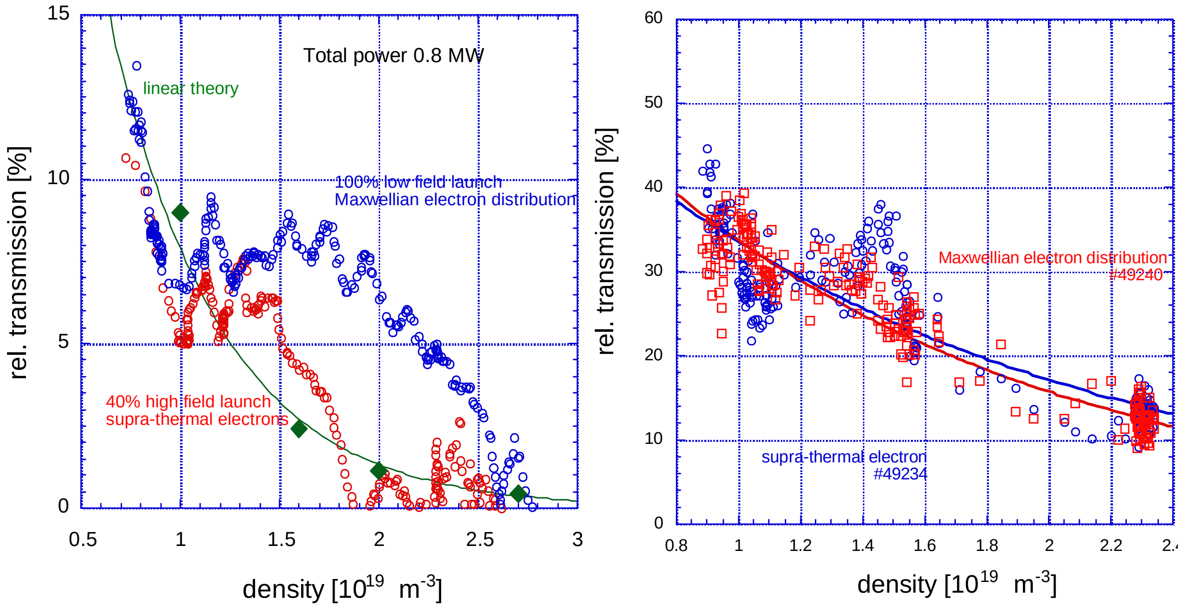

Fig. 3 Relative ECRH-transmission as a function of the electron density for a magnetic configuration with (left) and without trapped particles (right) at the ECRH-launch position. The different colours mark the different launch scenarios. Low field launch stays for a Maxwellian electron distribution and high field launch generates supra thermal electrons.