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Possible ways to suppress anomalous absorption at ECRH

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Possible approaches which allow reducing of anomalous absorption rate associated with the low-power-threshold two-UH-plasmon parametric decay instability, which is excited by the extraordinary pump wave in the X2 ECRH experiments in the vicinity of the plasma density maxima, are considered. Due to a rather low threshold of this instability the total suppression of it in the MW power level ECRH experiments is hardly possible. However, it is demonstrated that both the growth of the pump beam radius and the growth of the single beam microwave power allow reducing the related anomalous absorption rate.

The electron cyclotron resonance heating (ECRH) is a popular method to produce fusion relevant plasma in magnetic confinement devices. There are plans to utilize it for heating and the neoclassical tearing mode control in ITER as well. Its concept is based on the prediction of the localized microwave energy deposition and on the absence of any nonlinear phenomena, including the parametric decay instabilities (PDI), which can accompany the microwave propagation and damping [1]. However, during the last decade various anomalous phenomena (anomalous microwave scattering producing strong spurious radiation interfering with ECE and CTS diagnostics [2], ion acceleration [3, 4], evident broadening of the ECRH power deposition profile [5, 6] and gyrotron frequency sub-harmonics emission [7]) were discovered in the ECRH experiments at different toroidal devices. They can be interpreted as a consequence of various low-power-threshold absolute PDIs which can be excited in the presence of a non-monotonic (hollow) density profile [8] often encountered at ECRH. The most dangerous scenario discovered recently is a pump wave parametric decay leading to the excitation of at least one daughter upper hybrid (UH) wave trapped along the direction of the plasma inhomogeneity and localized on a magnetic surface due to the finite-width pump [9]. The developed theoretical model and its predictions (the power-threshold of the primary instability, the spectrum of secondary waves and the saturation level) were confirmed by comparison [10] to anomalous backscattering observations performed at TEXTOR [2]. According to the theory predictions [10 - 12] this instability could result in a substantial (10% - 80% depending on the number of secondary decays in the saturation cascade) anomalous absorption of the pump power. The possibility of a strong anomalous absorption of the extraordinary mode pump in X2 ECRH experiments predicted theoretically [10 - 12] was confirmed in the model experiment utilizing plasma filament produced by the RF discharge [13]. Thus the low-power-threshold parametric decay instabilities leading to excitation of trapped UH waves discovered experimentally and investigated theoretically possess a potential for a deterioration of the efficiency of the ECRH auxiliary heating. Therefore investigation of the possible ways which allow avoiding or reducing these parasitic effects is of great importance.

In this paper we consider the possible ways which allow reducing the fraction of the pump power gained by decay daughter waves. As it will be demonstrated below, the variation of the pump beam's width and power impacts on the efficiency of the nonlinear phenomenon. To illustrate this we are using the plasma parameters typical of the off-axis X2-mode ECRH experiments at TEXTOR, for which the abundant experimental database exists. The density profile measured in a magnetic island (m=2/n=1) in these experiments was non-monotonic with its local maximum corresponding to the O-point of the magnetic structure [14]. We focus on the case when the strongest anomalous effects were observed in these experiments [2] which corresponds to the local UH frequency in a magnetic island being slightly bigger than half the pump wave frequency. Under these circumstances the low-power-threshold PDI leading to the excitation of two UH ways trapped in the vicinity of the plasma density maximum was shown in [8] to be possible.

The power threshold of this PDI is determined by a balance of the power coming from the pump to UH waves and its diffractive losses with UH waves leaving the region eliminated by the pump. According to analytical theory predictions and numerical computations it is invers proportional to the pump beam radius squared. However the growth-rate of the primary decay, when the pump power exceeds much its threshold value as well increases invers proportionally to the beam radius. Therefore the beam radius decreasing in order to increase the instability threshold which is usually rather low (Pth=88 kW at w=1 cm in the particular case of TEXTOR) could be not the best solution for suppression of the anomalous absorption. Taking into account that the latter is determined by the instability saturation level we turn to investigation of the pump beam radius influence on it.

The PDI saturation in the theoretical model [10, 12] is achieved via a cascade of consequent decays leading to excitation of trapped UH waves. In the case of odd number of the cascade steps the saturation level is determined by a balance of the primary instability pumping and nonlinear losses introduced by the secondary instability. The anomalous absorption rate in this case, according to theoretical estimations, is invers proportional to the pump beam radius and to the square root of its power. Well above the PDI threshold the numerical solution of the nonlinear UH wave equations system confirms this prediction. In the case of even-step PDI saturation cascade the tendency of the anomalous absorption rate reduction with increasing pump beam radius and power persists, however its value appears to be higher.

Thus due to a rather low threshold of the two-UH-plasmon PDI excited in the X2 ECRH experiments in the vicinity of the plasma density maxima, the total suppression of it in the MW power level ECRH experiments is hardly possible. However, it is demonstrated that both the growth of the pump beam radius and the growth of the single beam microwave power allow reducing the related anomalous absorption rate.

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