Kinetic damping in the admittance and impedance spectra of the spherical impedance probe

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Active plasma resonance spectroscopy is a widely used diagnostic method, which utilizes the natural ability of plasmas to resonate near the electron plasma frequency. A radio frequent signal is coupled into the plasma via a probe, the spectral response is recorded, and a mathematical model is used to determine plasma parameter like electron density or temperature. By means of functional analytic methods the response function of a probe with arbitrary geometry can be derived in terms of a kinetic description. Based on this general response function the response of a specific probe design can be determined with an expansion in orthogonal basis functions, which will be presented for the spherical impedance probe. The approximated spectra of the admittance and impedance show a broadening, which can only be explained by kinetic effects.

1. Introduction

Active plasma resonance spectroscopy is a plasma diagnostic method which employs the natural ability of plasmas to resonate close to the plasma frequency. Essential for this method is an appropriate model to determine the relation between the resonance frequencies and demanded plasma parameters. Measurements with these probes in plasmas of a few Pa typically show a broadening of the spectrum that cannot be predicted by a fluid model. Thus, a kinetic model is necessary.

2. General Model

A general kinetic model of electrostatic resonance probes valid for all pressures has been presented [1]. This model is used to analyze the dynamic behavior of such probes by means of functional analytic methods. One of the main results is, that the system response function is given in terms of the matrix elements of the resolvent of the dynamic operator evaluated for values on the imaginary axis. The spectrum of this operator is continuous which implies a new phenomenon related to anomalous or non-collisional dissipation. Based on the scalar product, which is motivated by the kinetic free energy, the non-collisional damping can be interpreted: In a periodic state, the probe constantly emits plasma waves which propagate to “infinity”. The free energy simply leaves the “observation range” of the probe which is recorded as damping.

3. Spectra of the spherical Impedance Probe

Based on the general response function the response of a probe in a specific geometry can be derived by means of an expansion in orthogonal basis functions. Truncating this expansion leads to approximated spectra, which show a broadening of the resonances due to kinetic effects.

To demonstrate this broadening in the spectra of an existing probe design, the spherical impedance probe (sIP) is chosen. Based on the approximated response function, the normalized admittance Y and impedance Z of the sIP are computed and compared to the first kinetically determined spectra of Buckley [2]. Their real parts for an elastic collision frequency of 0.15, which is normalized to the plasma frequency, are depicted in Fig. 1 and they are in good agreement with Buckley’s. The half width of the resonance peaks in the admittance and impedance spectrum are about 0.47 and 0.32, respectively. They show clearly a kinetic damping part compared to the collisional damping of 0.15. Differences compared to Buckley’s spectra are probably due to a different collision term in the presented results [1].

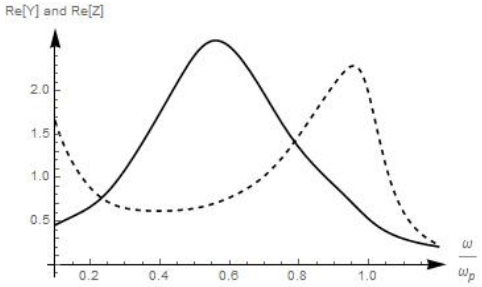

Fig. 1: Real part of the normalized admittance Y (bold) and impedance Z (dashed) of the sIP depended on the normalized frequency.

4. References

[1] J. Oberrath and R.P. Brinkmann, Plasma Sources Sci. Technol. **23**, 045006 (2014).

[2] R. Buckley, J. Plasma. Phys. **1**, 171 (1967).