§ 4. Inductance of rf-Wave-Heated Plasmas

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Using radio-frequency waves for the generation and sustainment of plasma current in tokamaks has been of considerable interest, both in theory and in experiment. Radio-frequency waves have proved capable of driving the current necessary for the stability of tokamak plasmas, without any contribution from the dc electric fields [1]. The noninductive current drive effect is due to the asymmetric decrease of the electron collision rate caused by resonant absorption of rf power. The same decrease also implies an enhancement of the electrical conductivity [2] that is measured in some experiments [3,4]. This induced conductivity shows a nonlinear behavior in large electric fields and can represent the plasma as an active element [5]. On the other hand, the rate of change of the current drive can be significant, not only because of runaway acceleration by the electric field, but also because of deceleration by collisions. This causes an additional plasma inductance which can be important in studying plasma heating by radio-frequency waves. This is an induced inductance caused by radio-frequency heating of plasma and it is deeply different from a change of internal inductance due to a change of radial current profile in radio-frequency heating regimes that is observed in experiments [6].

The inductance of rf-wave-heated plasmas is derived [7]. To estimate this inductance, a two-dimensional Fokker-Planck equation has been used. Presently, we will find an analytical solution using a perturbation technique. This solution will provide a useful approximation for small electric fields. These small electric fields may accelerate or decelerate the electrons according to their direction relative to electron direction in the current drive. Since the electric field is small in our model, the electrons finally will be decelerated to the thermal energy due to collisions. Consider a uniform electron-ion plasma, initially at equilibrium. Since in rf current drive regimes the distribution function of the bulk electrons remains Maxwellian, the collision operator in the Boltzmann equation can be linearized. This is because most plateau electrons collide with bulk electrons rather than with each other, since there are so many bulk electrons.

Most applied problems do not require knowledge of the distribution function, since their only requirement is the knowledge of several moments. According to Ref. [8], in the direction of applying the adjoint method we introduce the influence function for the current density. The equation which describes time evolution of the influence function j is

$$\frac{\partial j}{\partial t} + f_m \frac{eE}{m} \frac{\partial j}{\partial v_{\|}} + C^*(f_m j) = 0, \qquad (1)$$

where C^* is the adjoint collision operator.

In Ref. [2], Eq. (1) has been simulated as a familiar Ohm's law relation for small electric fields. However, according to Eq. (1) the rate of change of current drive can be significant and must be considered. Here we simulate Eq. (1) as a simple *RL* circuit equation,

$$(a^2/2R_0)L\frac{\partial L}{\partial t} + \frac{J}{\sigma} = E, \qquad (2)$$

where L is the inductance, σ is the conductivity. Integration of Eq. (2) gives the inductance as a function of $\chi(v)$ which represents the resultant displacement of a charge having an initial velocity v. The equation which gives $\chi(v)$ is obtained from time integration of Eq. (1).

The inductance is calculated for small electric fields and for the surface in the velocity space corresponding to the phase velocity of the rf-wave. This inductance represents the inductance of fast electrons located in a plateau during their acceleration due to electric field or deceleration due to collisions and electric field.

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