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Stochastic acceleration of plasma

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Toroidal current plays an important role in the tokamak that it enables a tokamak fusion operator to operate continuously. Toroidal current can generate the poloidal magnetic field that can stabilize the particle motion and improve the confinement of the tokamak.

Radio frequency wave current drive is applied successfully in many existing tokamak operators. Electron cyclotron wave, fast wave and low-hybrid wave systems are under consideration for ITER. [1] These systems have individual characters and can be employed in tokamaks in parallel. However, there are still some problems for current drive systems such as low current efficiency. According to Fisch and Boozer's theory [2], current efficiency is positive associated with the resonant velocity. In contrast, to get more resonant particles, it requires low resonant velocity.

The key point is the strict resonant condition. If the travelling wave is reflected many times in the cave, the wave is stochastic. The spectrum of the wave become broader. The motion equation of the charged particle in the wave packet can be described as L-mapping process. [3]

$$\begin{cases} W_{n+1} = W_n + eEL\cos\theta \\ \theta_{n+1} = \theta_n + kLsign(W_{n+1}) - \omega L\sqrt{\dfrac{m}{2|W_{n+1}|}} \end{cases}$$

Where $W = \frac{1}{2}mv|v|$, θ is the phase angle. The motion of the charged particle is stochastic between a critical threshold $\mathrm{v}_{max} = \left(\frac{eEL^2\omega}{m}\right)^{1/3}$, as shown in figure 1.

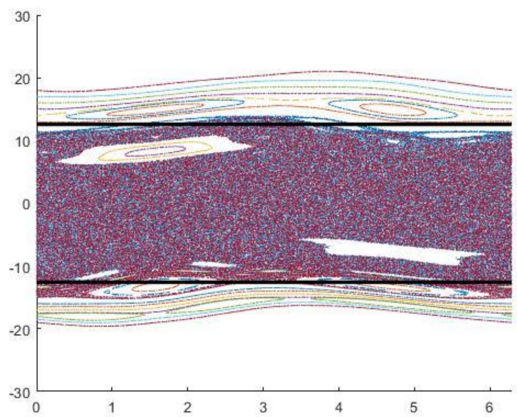

Figure 1. Trajectory of different particles in phase space. The black solid line is the corresponding critical threshold. The trajectory of particle in phase space between the threshold is stochastic.

The process can be described by a normalized one-dimensional Fokker-Planck equation.

$$\frac{\partial f}{\partial t} = \frac{\partial}{\partial v_\parallel} D(v_\parallel) \frac{\partial}{\partial v_\parallel} f + \left(\frac{\partial f}{\partial t}\right)_c$$

$$D(v_\parallel) = \begin{cases} \dfrac{1}{v}, v_{min} < v_\parallel < v_{max} \\ 0, \quad elsewere \end{cases}$$

Where $\left(\frac{\partial f}{\partial t}\right)_c = \frac{\partial}{\partial v_\parallel}\left[\frac{1}{v_\parallel^2} f + \frac{1}{v_\parallel^3}\frac{\partial f}{\partial v_\parallel}\right]$ is the one-dimensional collision operator. Normalizing velocities to $\mathrm{v}_{Te} = \left(\frac{T_e}{m_e}\right)^{\frac{1}{2}}$, time to v_0^{-1}, where $\mathrm{v}_0 = \log\Lambda\, \omega_{pe}^4/2\pi \mathrm{n}_0 v_{Te}^3$. Corresponding steady state distribution function is plotted in figure 2.

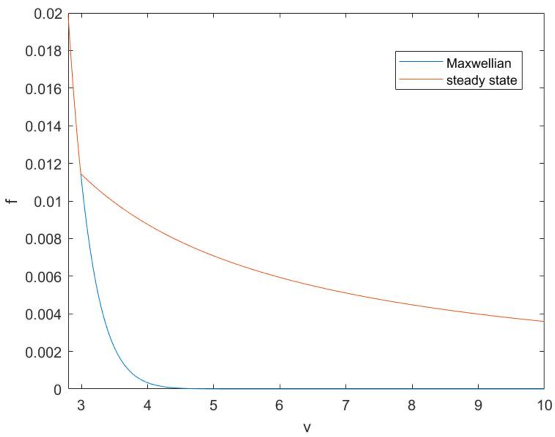

Figure 2. Steady state distribution function for the Fokker-Planck equation

The current $\mathrm{J} = \frac{\exp\left(-\frac{v_{min}^2}{2}\right)}{\sqrt{2\pi}}\left(\sqrt{1+v_{max}^2} - \sqrt{1+v_{min}^2}\right)$ and the current efficiency $\frac{\mathrm{J}}{P} = \sqrt{1+v_{max}^2}\sqrt{1+v_{min}^2}$. J is expressed in units of $en_0 v_{Te}$, and P is expressed in units of $\nu_0 n_0 T_e$. Compare with the results that calculated by Karney, [4] the current efficiency is comparable but the current is much greater.

References

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