§22. Tail Effects on D-3He/FRC Startup

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An intense neutral beam injected into a plasma creates a tail (i.e. non-Maxwellian component) in distribution function of the same species as the one injected with enhancing (or reducing) fusion reactivities from the values for Maxwellian plasmas[1,2].

An optimal D-3He plasma startup scenario, to bring the injected with enhancing (or reducing) fusion injection heating is simulated by simultaneously solving the values for Maxwellian plasmas[1,2], in field reversed configuration (FRC)[4], in consideration of tail creation in fuel-ion distribution functions.

A D-3He/FRC startup due to deuterium beam injection heating is simulated by simultaneously solving the plasma power, density, pressure and trapped field balance equations, together with the Fokker-Planck equations.

A typical magnetic field profile \( B(r) \) in FRC equilibrium can be expressed, for example, by using the following equation:

\[
B(r) = -\text{sign}(1 - \frac{2r^2}{r_s^2})B_e[1 - \frac{2r^2}{r_s^2}]^\nu,
\]

and then trapped magnetic flux \( \phi \) is written as:

\[
\phi = \pi r_s^2 B_e \frac{1}{(\nu + 1)},
\]

where \( \nu = (2 - x_s^2)/2x_s^2 \), plasma radius \( r_s \) is normalized to coil radius \( r_c \), i.e. \( x_s = r_s/r_c \). \( B_e \) represents external magnetic field. From the plasma pressure and trapped field balances we can derive the following equations to calculate temporal behaviors of plasma length \( l_s \) and normalized radius \( x_s \):

\[
\frac{\dot{x}_s}{x_s} = \frac{2 + x_s^2}{2(4 + x_s^2)} \left[ \frac{\phi}{\phi_B} - \frac{\dot{B}_e}{B_e} \right],
\]

where \( W = \frac{3}{2} \sum_j n_j T \),

\[
\dot{W} = P_{\text{NBI}} + P_t - P_{\text{syn}} - P_{\text{blem}} - \frac{W}{\tau_E}.
\]

Here \( P_{\text{NBI}} \), \( P_t \), \( P_{\text{syn}} \) and \( P_{\text{blem}} \) are, respectively, the NBI input power, the rates of energy deposition by fusion produced ions, synchrotron radiation power loss, and bremsstrahlung power loss.

The velocity distribution functions for deuterons and tritons are determined by solving the Fokker-Planck equations[5].

Throughout the calculations, the classical confinement scaling is assumed. The beam injection energy \( E_{\text{NBI}} \) is determined so that its penetration length becomes less than plasma radius.

Owing to the deuterium beam injection, initial plasma (\( T=3\text{keV} \)) is heated to ignition (\( T=83.5\text{keV} \)) in 50 sec. Figure 1 illustrates the optimal startup scenario for both Maxwellian and tail-created plasma in \( n-T \) diagram. When Maxwellian plasma is assumed, a startup keeping the plasma density lower during initial heating phase has more advantages to reduce the NBI heating power. This is because we can get higher values of both confinement time and reactivities, as a result of rapid rise of plasma temperature. On the other hand, when the tail effect is considered, plasma density during initial phase should be kept higher. Although plasma temperature takes lower values during initial phase, higher reactivity can be expected as a result of tail effect. Furthermore, high-density startup causes higher reaction rate (fusion power) to heat the plasma.

In Maxwellian plasma, at least 110 MW of \( P_{\text{NBI}} \) is required to stably bring the plasma up to the operating temperature. As a result of tail formation, the required \( P_{\text{NBI}} \) is reduced to 40 MW; a reduction of 64 % from the Maxwellian value.

References