Abstract:
The central beta of the super-dense-core (SDC) plasma in the Large Helical Device (LHD) is limited by a large scale MHD event called “core density collapse” (CDC). The detailed measurement reveals that a new type of ballooning mode, quite localized in space and destabilized from the 3D nature of Heliotron devices, is the cause of the CDC. Avoidance of the excitation of this mode, reduction of the edge pressure gradient, is the key to expand the operational limit of the LHD.

Two operation scenarios for high-beta plasma

There are two high-beta scenarios in the Large Helical Device. One is the standard scenario and the other is the high-density, peaked profile scenario (SDC/IDB) which is realized by the sequentially injected pellets. In the outward shifted configurations, the central electron density greater than $10^{19} \text{m}^{-3}$ can be made. However, the increase of the beta is limited by a collapse event so-called cored density collapse (CDC). The central beta is reduced by 60% at the maximum. This MHD events are the largest observed in LHD.

IDB/SDC discharge with core density collapse (CDC)

A peaked profile is formed in the recovery phase after sequentially injected hydrogen pellets. In this recovery phase, the pressure profile becomes peaked; IDB/SDC plasma is formed. Increase of the $\beta_c$ is disturbed by so-called core density collapse(CDC) events. CDC is an abrupt event where the core density is collapsed within 1 ms. (much faster than other MHD relaxation events in the LHD).

CDC is the first phenomenon that MHD activities are so large that operation space is restricted by them.

Caracteristics of the collapse events

The scale of the CDC collapse becomes larger with increase of the central electron temperature. The time scale of the CDC becomes also shorter. It might be explained by that the stability of the CDC is improved in the high temperature region (resistive mode?) and the collapse becomes larger since the pressure gradient at the excitation is larger.

After the collapse, bad curvature region is expelled

Localization of the heat flux towards the wall has not been clarified. However, there are oscillations after collapse in many diagnostics. With 2D measurements, the blob-like filaments are observed and they may carry the heat flux. The damage of the first wall might not be small where the filaments hits the wall.

Stability of the ballooning mode

$\delta W = \frac{1}{2} \int \left( \frac{1}{2} \nabla \cdot \nabla (r \cdot \xi) - 2 \frac{1}{2} \nabla \times \nabla (k_L \cdot k_L 
abla \cdot \nabla (r \cdot \xi)) \right) \cdot \Delta \xi \cdot \Delta \xi \cdot \nabla \cdot \nabla (r \cdot \xi) \cdot \nabla \cdot \nabla (r \cdot \xi)$

Since $\xi$ is negative, local shear can be zero. Local shear can be reduced in the outward region. High-$n$ ballooning mode can be destabilized in the bad curvature region where the local shear is zero.

Summary

Increase of the central beta is limited by the CDC events. By CDC, core plasma is collapsed within 1ms. Maximum decrease in the central beta is about 60% The characteristics of the activities before CDC is consistent with that of H-Ballooning mode, destabilized by the 3D nature of the plasma.

Pre-cursor activities in density fluctuations is localized in the outboard side. The structure might be localized in the perpendicular (to the magnetic field) direction as well, since there are two peaks in the pre-cursor oscillations at the vertically elongated section.

If pressure gradient in the edge region is reduced, achieved central beta increases significantly from the stabilization of the ballooning modes.

Characteristics and control scheme of transient large-scale MHD activities which will restrict operation regime of helical reactors

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