1-3. Theoretical Study

Various theoretical and simulation studies have been done on the Large Helical Device (LHD) plasma through the NIFS collaborative research programs.

Nonlinear magnetohydrodynamic (MHD) simulations are done in order to investigate the mechanisms of pressure collapse phenomena in the core of the LHD plasma by using a three-dimensional finite difference code, MEGA-D. Under a heliotron configuration with higher beta and large pressure gradient, a collapsing scenario of core plasma triggered by resistive ballooning modes appearing in the off-axis region is obtained. The simulation results show a good agreement with the experimental ones of so-called core density collapse (CDC) in LHD with respect to several characteristics such the crash time scale, multiple-step relaxation, convective processes, and the core crash triggered by edge instabilities

The 3-dimensional MHD equilibrium module VMEC, the 1-dimensional diffusive transport module TR, and the linear MHD stability module MSSH are combined for the analysis of the MHD stability beta limit in LHD. For this purpose, the numerical model for the effect of the MHD instabilities is introduced such that the pressure profile is flattened around the rational surface due to the MHD instabilities. The width of the flattening of the pressure gradient is determined from the width of the eigenmode structure of the MHD instabilities. In this simulation study, the effect of the upper poloidal mode number on the MHD stability beta limit is clarified. The quasi-stationary beta profile obtained from the simulation shows a good agreement with the experimental result for the volume-averaged beta value being equal to 4.8%.

An extended version of the numerical neoclassical transport calculation code, FORTEC-3D, is applied to the analysis of Core Electron-Root Confinement (CERC) plasmas in LHD. The CERC plasmas are characterized by the high electron temperature (Te) reaching 20 keV at the plasma core, the steep Te gradient of the electron internal transport barrier (eITB), and the large positive (electron-root) radial electric field (Er). The neoclassical particle transport plays a key role in determining Er in helical devices. The FORTEC-3D can evaluate neoclassical transport fluxes from global solutions of the drift kinetic equation over the whole toroidal region. Effects of the finite orbit width on the neoclassical electron transport and on the Er profile in the CERC plasma are illuminated by the FORTEC-3D simulation for the first time.

Linear analyses of ion temperature gradient (ITG) modes and zonal flows in the high ion temperature (Ti) LHD plasmas are done by using the gyrokinetic Vlasov simulation code, GKV-X. The GKV-X code can accurately treat complex magnetic geometry of 3-dimensional plasma equilibria obtained in the LHD experiments. Linear zonal-flow behaviors such as geodesic acoustic mode (GAM) oscillations and residual zonal-flow levels are examined. The residual levels are enhanced by increasing the radial wave number and are also influenced by the helical Fourier components which depend on the radial position and the Ti profile. The linear frequency and the growth rate of the ITG mode are calculated as functions of the poloidal wave number and the radial position. From the simulation results, the fluctuations observed in the experiment are considered to be driven by the ITG modes. Nonlinear GKV-X simulations of the ITG turbulent transport and zonal flows in the high-Ti LHD are now in progress.

The 3-dimensional configuration usually introduces stochasticity of magnetic field structure in the edge region, where one expects substantial difference in the transport properties compared to those in the axisymmetric tokamak scrape-off layer. The 3-dimensional edge transport code simulations are done to investigate effects of the different magnetic field geometries on the edge impurity transport by comparing the stochastic layer of LHD and the scrape-off layer (SOL) of HL-2A. The ratio of the impurity density at LCFS to that near the divertor plate is obtained as a function of collisionality for both devices.

Furthermore, numerical studies on the optimization of the LHD configuration by the vertical field and on the radiation processes in the LHD-type fusion reactor are done. (Sugama, H.)