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MHD Dynamics in Heliotron Fusion Plasmas

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A heliotron concept is one of the most effective concept to confine the fusion plasma in the magnetically confined fusion. Therefore, experiments using the devices of the heliotron concept have been extensively carried out. Here, we show numerical simulation results of the MHD behavior of the plasmas confined in a heliotron device.
In the fusion plasmas, a state without perturbations is favorable. Hence, in the theoretical MHD research procedure, we consider a static equilibrium first, and examine the linear stability of the equilibrium next, and then we follow the nonlinear dynamics of the perturbation if it is linearly unstable. Following the linear MHD stability theory, the linear instabilities are classified into current driven modes and pressure driven modes. In the heliotron magnetic, a large current is not necessary for achievement of the MHD equilibrium. It is followed that the plasma is mostly stable against the current driven modes. Instead, the plasma can be unstable against the pressure driven modes.
The biggest heliotron type machine is the Large Helical Device in National Institute for Fusion Science. The coil system is composed of a pair of helical coils and three pairs of poloidal field coils. By controlling the currents flowing in these coils, various magnetic configurations can be generated. One of figures of merit of confined plasmas, we often use a beta value, which is defined as the ratio of the plasma pressure against the magnetic pressure. Recently, volume average beta value of 5% was achieved in the high beta experiments in one of the magnetic configuration of the LHD. This value is high enough to be accepted economically in a future fusion plant. However, the MHD equilibrium was predicted to be linearly unstable against an interchanged mode, which is one of the pressure driven modes. Therefore, it has been a mystery why such high beta plasma was obtained stably in the linearly unstable configuration. To solve this problem, we have developed a nonlinear MHD dynamics simulation code, NORM, based on the reduced MHD equations.
In the LHD plasmas, as the beta value increases, the equilibrium quantities are change, and, the linear stability property also changes. Hence, to understand the stability consistently, it is necessary to incorporate a beta increasing effect in the analysis of the plasma behavior. To do so, we have to consider the beta increasing effects in both the equilibrium quantities and the perturbations. However, there exists a big difference in the order of 100000 times in the time scales between the development of the equilibrium and the perturbed quantities. Thus, to treat this multi-scale problem, we have also developed a numerical calculation scheme. The basic idea of the multi-scale scheme is that we update the equilibrium every certain time interval of the nonlinear dynamics calculation. In the equilibrium calculation, we develop the pressure by incorporating the deformation effect due to the dynamics and adding a small increment corresponding to the beta increase. Recently, we improved the scheme so that the effects of a diffusion and s continuous supply of the back ground pressure can be included.
We apply this scheme to the plasma in the LHD high beta experiments. As the beta increases from a very low value, unstable modes excite at low beta. However, they saturate immediately because the driving force of the modes is weak. The saturation generates local flat regions in the pressure profile. In these regions, the driving force of the modes is reduced by the decrease of the pressure gradient. The reduction of the driving force is kept even at higher beta. In the beta increasing

process, several flat regions are generated in the pressure profile, which suppress a disruptive phenomenon of the whole plasma. That is, the pressure profile is self-organized and generates a stable path to a high beta regime, which is considered to be the stabilizing mechanism in the LHD plasma.

Keywords: Fusion Plasma, MHD, Heliotron, Numerical Simulation, Pressure Driven Mode