§79. Physics Study for Modular Heliotron (MH)

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1. MHD equilibrium and stability analysis

The MHD properties of the MH are analyzed by using VMEC code. Here we adopted a fixed boundary assumption.

Figure 1 shows the equilibrium central beta limit versus the outside-plus/inside-minus pitch modulation parameter for three cases with gap angle $\Delta_{gap}=0°$, 4° and 8°. Here equilibrium beta limits are determined by the criteria for the convergence of the VMEC calculation or large outward magnetic axis shift from the outermost magnetic surface center (beyond 0.7 of notarized plasma minor radius). Optimum modulation for MHD equilibrium is $\alpha_{in}=-\alpha_{out}=-0.15$ at $\Delta_{gap}=4°$ and $\alpha_{in}=-\alpha_{out}=-0.3$ at $\Delta_{gap}=8°$, which are similar to the magnetic surface analysis. The MH devices with the optimum modulation parameter have almost equal equilibrium performance to conventional heliotron(CH). In the case of lower pitch modulation, the magnetic shear is not strong, the central rotational transform is small and the magnetic surface becomes horizontally elongated. Then shafranov shift is extremely large. On the contrary, in higher modulation case than optimum value, the degradation of calculation convergence determines beta limit.

As concerns stability analysis, we apply the mercier analysis. For $\beta_0 \geq 6\%$ in CH, $D_I > 0.2$, which corresponds to existence of unstable global ideal interchange mode[4]. In the modified MH device with the optimum modulation parameter with $\Delta_{gap}=8°$, $D_I<0.2$ for $\beta_0<4\%$. The stability property is compatible to that of CH.

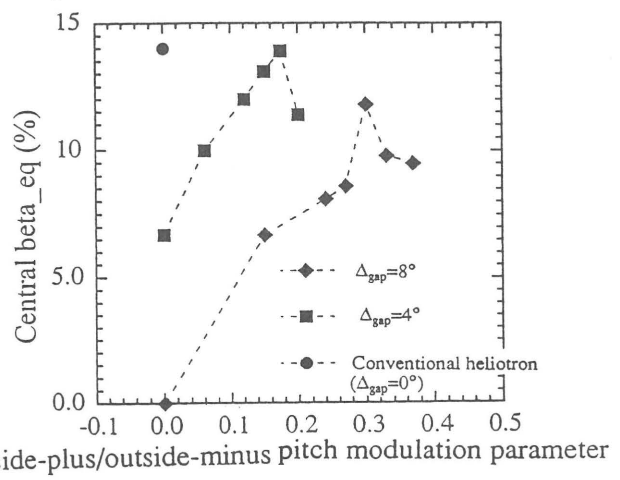

Fig.1 Dependence of equilibrium beta limit on the plus/minus pitch modulation parameters with $\Delta_{gap}=4°$ and $\Delta_{gap}=8°$.

2. Neoclassical ripple transport and particle orbit confinement

Figure 2 shows the geometric factor of helical ripple loss for three systems estimated by means of multi-helicity model of ripple transport. The level and radial profile in helical ripple and toroidal ripple are almost same in all systems. The reference MH system has extremely bad confinement property because it has strongly deformed plasma surface with horizontally elongated shape and large inward magnetic axis shift. In CH, the effective helical ripple amplitude at the plasma edge is 0.08. On the other hand, for MH system with outside-plus/inside-minus modulated windings, the effective helical ripple amplitude at the plasma edge is 0.14, which is larger than CH. For the reactor we need the 2 times confinement improvement of the anomalous loss, and we should also reduce the ripple loss by about 1/5 for MH system with outside-plus/inside-minus modulated windings. The reduction of the neoclassical ripple transport by means of changing outside-plus/inside-minus modulation parameters independently is future subjects.

Particle orbit property is estimated from the minimum B contours. For $\Delta_{gap} \leq 4°$, in MH system with outside-plus/inside-minus modulated windings, the outer magnetic surface nearly agrees with the outer contour of minimum B. However, unlike the CH, the central minimum B contour is deformed owing to the bumpy component of magnetic field (m=0/n=10). As Δ_{gap} becomes large, this effect becomes large. The outer magnetic surfaces do not coincide with the minimum B contour even if the magnetic axis coincides the center of minimum B contour.

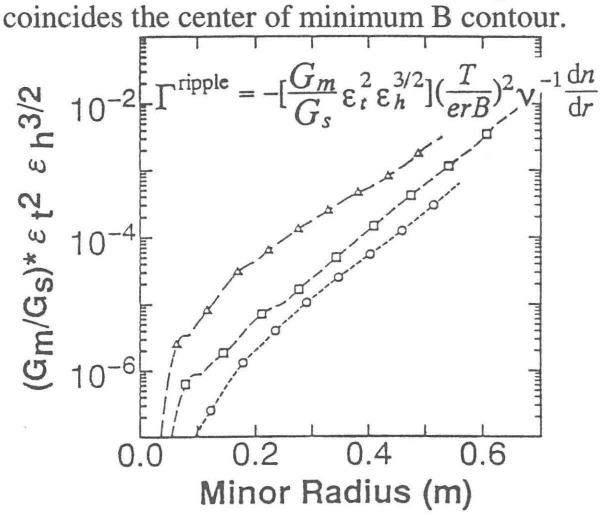

Fig.2 Geometric factor of helical ripple transport. (○; CH □; improved MH, △; reference MH with $\alpha_{in}=-\alpha_{out}=0$).