Helical pitch parameter dependency of high beta equilibrium of helical plasmas

Tsuguhiro Watanabe and Hitoshi Hojo[a]

National Institute for Fusion Science,322-6 Oroshi-cho, Toki 509-5292, Japan
[a]Plasma Research Center, University of Tsukuba, Tsukuba, 305-8577, Japan

watanabe.tsuguhiro@toki-fs.jp

It is shown theoretically and computationally that LHD type magnetic configuration produced by continuous helical coil systems can confine MHD stable high beta plasma. Bootstrap current driven by plasma pressure can reduce sufficiently the total magnetic energy necessary for the MHD stability of high beta plasma.

The helical pitch parameter $\gamma \equiv a_c \cdot k$ characterizes the magnetic configuration of helical systems, where a_c and k are the current center radius and the wave number of the helical coils, respectively. To confirm the stable high beta equilibrium based on the MHD first principle, a straight helical system, the size of which is comparable to the LHD is analyzed by introducing the rotating helical coordinate system (X, Y, ζ).

The MHD force balance equation determines the plasma current $\boldsymbol{J}$ as a function of pressure profile $P(\Psi)$. Vector potential $\boldsymbol{A}$ and the flux function Ψ are obtained by the Biot-Savart law as,

$$\boldsymbol{A}(\boldsymbol{r}) = \frac{\mu_0}{4\pi}\int \mathrm{d}^3\boldsymbol{r}' \left\{ \frac{\boldsymbol{J}(\boldsymbol{r}')}{|\boldsymbol{r}' - \boldsymbol{r}|} - \frac{\boldsymbol{J}(\boldsymbol{r}')}{|\boldsymbol{r}'|} \right\} \quad (1)$$

$$\Psi(\boldsymbol{r}) = A_\zeta + k\,(X A_Y - Y A_X) \quad (2)$$

Plasma stability is determined by the variation of the potential energy $\delta W \equiv \delta(W_B + W_T)$ where

$$W_B = \int \mathrm{d}V \frac{\boldsymbol{B}^2}{2\mu_0},\ W_T = \int \mathrm{d}V \frac{3}{2} P(\Psi) \quad (3)$$

The bootstrap current J_ζ cancels, partially, the magnetic field outside the helical coils. The magnetic field energy W_B reduces extensively, compared with the plasma thermal energy W_T. The variation of potential energy become negative ($\delta W < 0$) by plasma sustainment as shown in Fig.1, which show that robuster stability is achieved by smaller γ value. An example of MHD stable high beta equilibrium configuration is shown in Fig.2.

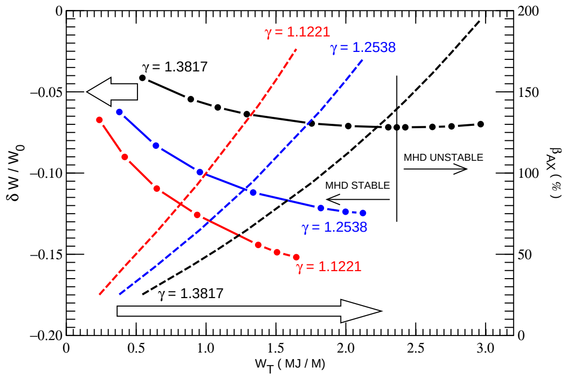

Fig.1. Helical pitch parameter γ dependency of high beta equilibrium of a straight helical system, the size of which is comparable to the LHD. Variations of the potential energy and the beta values at magnetic axis are shown as a function of the stored thermal energy, W_T.

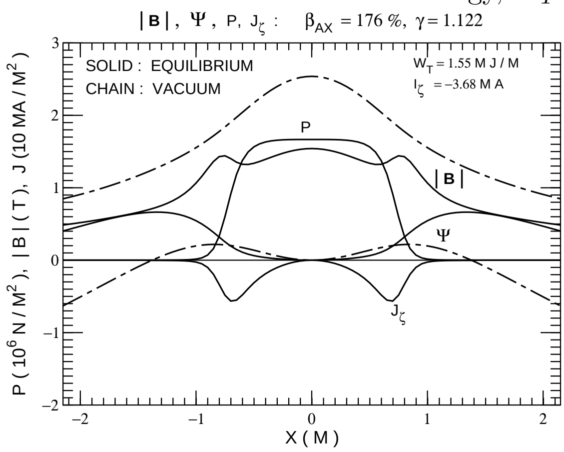

Fig.2. Numerical example of MHD stable high beta equilibrium.