# §14. Exploration of Optimal High-beta Operation Regime by Magnetic Axis Swing

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In Large Helical Device (LHD), the volome averaged beta value $<\beta_{dia}>$ as high as 5.1 % was achieved in FY2007-2008 experiments. High beta operation regime was explorated by the programmed control of magnetic axis position, which characterizes MHD equilibrium, stability and transport. This control became enable by increasing capability of poloidal coil power supply. The experiments made clear the effect of magnetic hill on MHD activities in high-beta plasmas with more than 4 %. Also it enabled to access the ideal stability boundary with keeping high-beta state.

High beta plasma production is a common subject in magnetic confinement systems for a realization of an efficient fusion reactor, and an understanding of MHD characteristics concerning beta-limit is the most important issue. The magnetic axis position, $R_{ax}$, characterizing MHD stability as well as transport is one of key parameters for high-beta plasma production in stellarators/heliotrons. In the "standard" high-beta experiments, high aspect ratio configuration has been selected for suppression of Shafranov shift because the outward shift decreases heating efficiency of neutral beam and increases helical ripple loss of particle. The achieved beta value has increased year by year, by increasing heating power of neutral beams in the optimized aspect-ratio configuration [1].

In order to optimize $R_{ax}$ further for high-beta plasma production, real time movement of $R_{ax}$ has been performed in FY2008, by increasing the capability of the power supply of poloidal coils for fast change of vertical magnetic flux. Another advantage of $R_{ax}$ swing operation is to enable us to access the stability boundary with keeping high-beta state, which contributes to clarify the available operation regime and to extend accessible stability boundary. The changes of the $<\beta_{dia}>$ as a function of the preset of $R_{ax}$ in several discharges are shown in Fig.1. The plasmas were produced under the conditions with the constant input power of neutral beams and toroidal field in order to find the optimal $R_{ax}$ for high-beta plasma production. The closed and open circles correspond to discharges with and without $R_{ax}$ swing, respectively. The solid star (★) indicates the maximum $<\beta_{dia}>$ obtained by the density increase at the optimal $R_{ax}$. The preset value of $R_{ax}$ was selected in the range of 3.5-365 m. For example, $R_{ax}$ can be changed from 3.6 to 3.5 m during 1.4 s in the case of toroidal field $B_t$ of 0.425 T. The achieved $<\beta_{dia}>$ gradually increased with $R_{ax}$ and approached the maximum around 3.59 m. The $<\beta_{dia}>$ decreases when the $R_{ax}$ exceeds 3.59 m. This tendency is predicted to be due to a reduction of heating efficiency and/or enhancement of particle and thermal transport. When the multiple pellet injections were applied to the $R_{ax}$ = 3.59 m case, the $<\beta_{dia}>$ reached to as high as 5.1 % without the significant MHD activity. The transport seems to play a role to limit the present beta value and it suggests that the higher beta value will be expected by the increase of heating power.

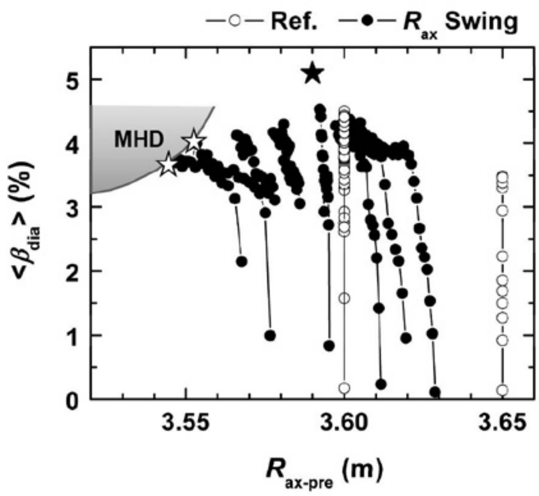


Fig.1 Change of the volume averaged beta value as a function of preset magnetic axis position.

The $<\beta_{dia}>$ was decreased when the $R_{ax}$ was shifted from 3.59 m to 3.55 m. The previous experiments suggest that peripheral MHD activities such as $m/n$ = 2/3, 1/1 and so on are enhanced with the increment of $<\beta_{dia}>$ and the reduction of magnetic Reynolds number [1]. Therefore, it had been anticipated that the inward shift of $R_{ax}$ destabilized the mode further because of the increase in magnetic hill. However, actual experiments showed that low-order MHD activities in the periphery were suppressed with the inward shift of $R_{ax}$ even in the plasmas with the constant magnetic Reynolds number, and the peripheral MHD activities have a little effect on the reduction of $<\beta_{dia}>$ with the inward shift of $R_{ax}$. Thus the main reason for reduction of $<\beta_{dia}>$ with the inward shift of $R_{ax}$, is not due to low-order MHD activities, and $R_{ax}$ dependences of the finite-$\beta$ equilibrium, transport and so on have been investigated to clarify the reason.

In the $R_{ax}$ range of less than 3.55 m, MHD activity excited in core region was enhanced and led to minor collapse (☆) as shown in Fig.1. The $R_{ax}$ swing discharge has been done for identification of the ideal stability boundary with keeping high-beta state with steep pressure gradient compared to the "standard" operation with low pressure gradient, which is valid for clarifying significance of magnetic configuration to MHD activity.

1) Sakakibara S. *et al.*: Plasma Phys. Control. Fusion **50** (2008) 124014.