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§8. Optimized Plasma Aspect Ratio to Extend High Beta Operational Regime in LHD

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For an economical fusion reactor, achievement and sustainment of high beta plasma with $<\beta>=5\%$ is necessary. In order to predict the behavior of reactor plasma, we have made big effort aimed at achieving $<\beta>=5\%$ by increasing the heating capabilities and optimizing the operational conditions like the configurations, the heating efficiency of NBI and so on. The heating efficiency of the NB and the MHD stability might be the very important key parameters to extend the operational high beta regime. In high beta operations in LHD, the plasma was mainly heated with the tangentially injected neutral beam (NB). Because the tangential radius of the NB is located at ~3.65m, the optimal magnetic axis (R_{ax}) for the heating efficiency is located around 3.65m. As well known, the magnetic axis shifts torus-outwardly as the beta increases. In order to keep the magnetic axis ~3.65m in the high beta regime, the vacuum magnetic (pre-set) configurations with the much torus-inward shifted magnetic axis and/or the high aspect plasma ratio are favorable. On the contrary, the both configurations with the more torus-inward shifted pre-set magnetic axis and the higher aspect plasma ratio are more unfavorable for the property of MHD stability. After optimizing the magnetic axis position and the plasma aspect ratio, we found the R_{ax}=3.6m and A_p=6.6 configuration the most optimum for the high beta operation, and we obtained a $<\beta_{dia}>\sim 5.0\%$ plasma in F.Y.2006 [1]. In this article, we study the reason why A_p=6.6 is optimized value for the achievement of high beta plasma in LHD.

Figure 1 shows the achieved beta value for various plasma aspect configurations with almost same port through NBI power, ~10.5MW. Here the operational magnetic field strength (B_0) is 0.5T, and the pre-set magnetic axis (R_{ax}^V) is 3.6m. As shown in Fig.1, A_p=6.6 is the most optimized value for the extension of the beta value. Here it should be noted that any disruptive discharges are not included in all plasma aspect configurations. Then the reason that A_p=6.6 is optimal might be related with the transport properties. When the global energy confinement properties is assumed to follow the ISS95 experimental scaling [2], the beta is expressed as the followings,

$$\beta \sim f_H \overline{n}^{0.51} P^{0.41} B^{-1.17} a^{0.21} R^{-0.35} \iota^{0.4}$$
$$\sim f_H \left(\overline{n}/n_{Sudo}\right)^{0.51} P^{0.67} \left(a^{-0.3}\iota^{0.4}\right) B^{-0.91} R^{-0.61} .$$

Figure 2 (a), (b), (c) and (d) show the dependence of the improvement factor of the confinement (f_H), a geometrical factor ($a^{-0.3}\iota^{0.4}$), the normalized density by the density limit based on Sudo empirical scaling ($\overline{n}/n_{Sudo}$) [3] and the normalized NB heating efficiency (P_{eff}/P_{port}). From Fig.2, the dependence of f_H and $a^{-0.3}\iota^{0.4}$ on A_p mainly leads to the optimal A_p. According to another analysis [4], the confinement properties in LHD high beta plasmas is governed by g-mode turbulence, whose dependence on A_p is quite consistent with the optimal A_p.

[1] K.Y.Watanabe et al., in Proc. of ITC-17 and ISWS-16, I-13, Toki, 2007.
[2] U.Stroth et al., Nucl. Fusion, 36 (1996) 1063.
[3] S.Sudo et al., Nucl. Fusion, 30 (1990) 11.
[4] H.Funaba et al., Fusion Sci. Technol. 51 (2007) 129.

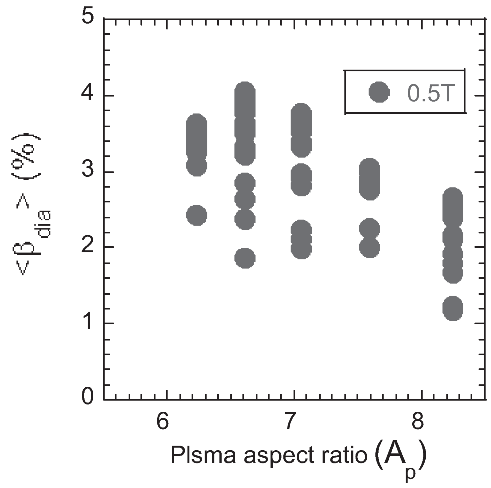

Fig.1 The dependence of the achieved beta value on A_p with R_{ax}^V=3.6m and B_0=0.5T.

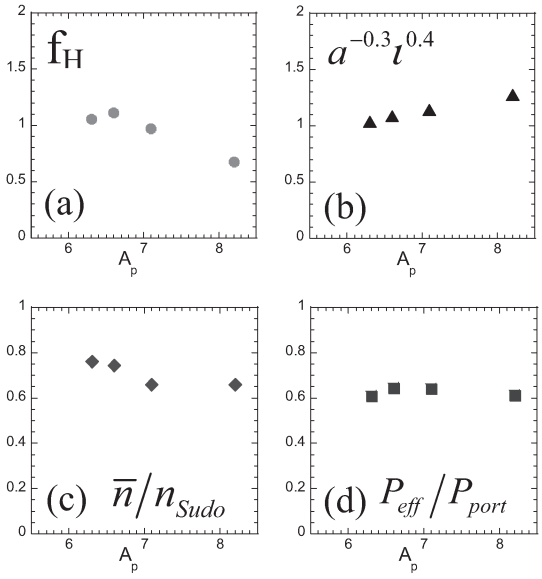

Fig.2 The dependence of the improvement factor, a geometric factor, the operational density and the heating efficiency on A_p around maximum beta value.