§57 Z_{eff} Dependence of Neutral Beam Current Drive in LHD

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Neutral beam injection (NBI) is powerful tool for plasma heating and non-inductive current drive in magnetically confined fusion plasmas, and has been installed to many devices. In helical device, no toroidal plasma current is need for production of magnetic configuration, however, boot-strap current is spontaneously driven in high beta plasmas. Thus the control of plasma current is also important in helical devices from viewpoint of the control of rotational transform. So far, the efficiency of neutral beam current drive (NBCD) has been experimentally obtained in LHD, and is comparable to that in DIII-D. In 7th campaign of LHD, the Z_{eff} dependence of NBCD has been experimentally investigated.

Three negative-ion-based neutral beam injectors have been tangentially installed in LHD, and 13MW of total port-through power and beyond 180keV of beam energy have been achieved in 7th campaign. NBCD experiments have been performed in NBI plasma with neon or hydrogen gas puff in LHD, and the neutral beam driven currents in different Zeff conditions have been compared. In general, neutral beam driven current is given by

$$I_{NBCD} = \frac{I_b \upsilon_b}{2\pi R} \tau_s \left(1 - \frac{1}{Z_{eff}} G\right) \quad (1)$$

Where I_b, v_b, τ_s, Z_{eff}, and G are beam current, beam velocity, slowing down time, effective Z value, and geometric factor, respectively. The beam slowing down time is almost determined by collision to the electron because the condition $v_i << v_b << v_e$ is satisfied in LHD, so $\tau_s = \alpha T_e^{3/2}/n_e$, where α, T_e and n_e are proportional constant, electron temperature and electron density, respectively. In order to estimate the G, which indicates the Z_{eff} dependence of NBCD, eq.(1) is divided into two part, one depends only Z_{eff} and the other does other parameters which can be obtained experimentally,

$$I_{NBCD} = A(Z_{eff}) \cdot X(I_b, \upsilon_b, T_e, n_e) \quad (2)$$

where

$$A = \frac{\alpha}{2\pi R}\left(1 - \frac{1}{Z_{eff}} G\right)$$
$$X = \frac{T_e^{3/2} \sum I_b \upsilon_b}{n_e} \quad (3)$$

The toroidal current obtained by experiments includes both neutral beam driven current and bootstrap current. In this analysis, the neutral beam driven current is assumed that $I_{NBCD} = I_p - \beta W_{dia}$, where β is proportional constant. The values A and β are iterated until the experimental data converge to eq.(2), which is shown in Fig.1. The values of $A(Z_{eff})$ obtained by this method are 0.163 in hydrogen and 0.20 in neon plasma. The ratio of Z_{eff}^* ($=Z_{eff}(Ne)/Z_{eff}(H)$) is estimated to be 1.47 by a shine-through measurement of neutral beam. The results are compared with the eq.(3), which is shown in Fig.2, and the value of geometric factor G is obtained that $G=(0.4\pm0.1)Z_{eff}(H)$. This value is considered to be slightly higher than that respected by a theory, so the prompt loss of beam ion should be taken account, which is left for future study.

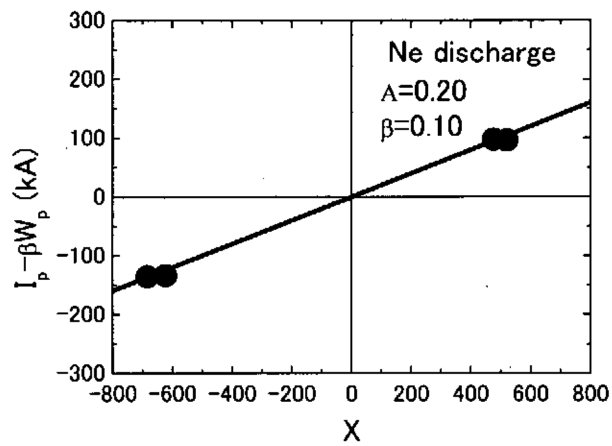

Figure 1. The closed circles show the neutral beam driven currents v.s. X given by eq.(3) in neon discharges, and solid line eq.(2). The values of A $\alpha v \delta$ β are iterated until converge the closed circles to solid line.

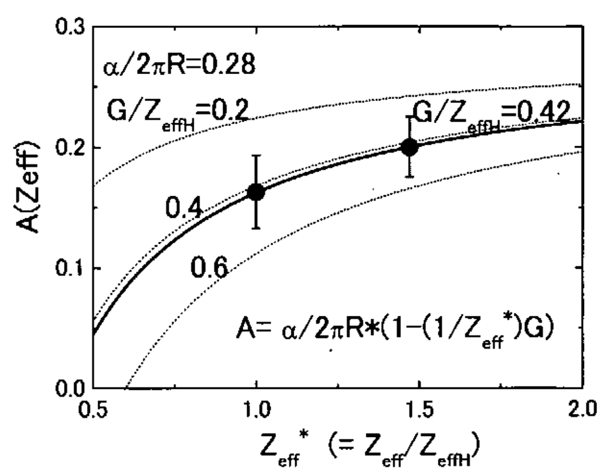

Figure 2. The closed circles show Z_{eff}^* dependence of $A(Z_{eff})$, and solid line shows eq.(3) fitted to experimental results.