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ヘリカル装置における電極バイアスによる閉じ込め改善モード遷移に対する磁場リップル構造依存性

Configuration Dependence of Improved Mode Transition using a Biased Electrode in Helical Devices

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In neoclassical theories the nonlinearity of the ion viscosity plays the important role in the bifurcation phenomena of the L-H transition, which observed in tokamaks and stellarators. The effects of the ion viscosity maxima on the transition to an improved confinement mode were experimentally investigated by the externally controlled $\boldsymbol{J} \times \boldsymbol{B}$ driving force for a poloidal rotation using the hot cathode biasing in Tohoku University Heliac (TU-Heliac) [1, 2]. Here, $\boldsymbol{J}$ and $\boldsymbol{B}$ are a biasing electrode current and a magnetic field. In steady state the $\boldsymbol{J} \times \boldsymbol{B}$ driving force balances with the ion viscous damping force and the friction to neutral particles. Then the ion viscosity opposing to the poloidal rotation can be estimated experimentally by subtracting the friction term from the driving force. We observed the transition to an improved confinement mode from an electrode characteristics, and the local maximum in ion viscosity (viscosity maxima $\Pi_{\mathrm{p,n\_LM}}$) can be evaluated experimentally from the external driving force at the transition (critical driving force F_c), where the jump of the poloidal flow velocity (poloidal Mach number M_p) appeared and the significant increase of the stored energy and the suppression of the fluctuations in probe signals were observed. The predictions from neoclassical theories [3] can explain the estimated local viscosity maxima in different magnetic configurations.

The importance of the biasing experiment in stellarators exists in the ability to understand universally the relation between the transition behavior and the viscosity by taking high order magnetic Fourier components into viscosity evaluation. The achievement of an improved mode transition by the electrode biasing and clarification of the transition mechanism imply the contribution to the progress of understanding H-mode physics. The optimization of helical ripples allows the reduction of viscosity, which is expected to bring good accessibilities to the improved confinement modes. The transition conditions will be decided by the magnetic ripple structure and normalized collision frequency and will not depend on the device size or confinement system. By the survey of comparison for a transition condition with many devices, which have a different magnetic ripple structure, we can demonstrate the important role of neoclassical ion viscosity on the transition of confinement mode if we can observe the consistency of experimental results with theories. Further we can expect the estimation of threshold condition for another device from database surveyed in many devices. Therefore it is important to verify whether the transition phenomena observed in TU-Heliac can appear in the wide plasma parameter range and in the confine systems that have different magnetic configuration.

We have continued the biasing experiment in a high-performance plasma, namely, low collisional plasma in Large Helical Device (LHD). We successfully observed the transition and compared the external driving force $\boldsymbol{J} \times \boldsymbol{B}$ required for the improved mode transition in 3 configurations (R_{ax} = 3.53, 3.60 and 3.75) in LHD. Figure 1(a) shows the configuration dependence of the critical driving forces F_c, which were evaluated at the forward and backward transition point. Figure 1(a) also shows the viscosity maximum Π_{p,n_LM}. The viscosity maximum increases according to the increase in R_{ax}. The critical driving force F_c and the viscosity maximum Π_{p,n_LM} have the same tendency. Critical driving forces F_c at the backward transition were smaller than that at the forward transition, which means the improved mode can be sustained by the smaller driving force in the backward transition phase and is consistent with transition scenario caused by the local maximum in the ion viscosity. We also compared the configuration dependence of radial resistivity in L-mode with the theory. In Fig. 1(b) $dM_p/d\Pi_{p,n}$ was calculated from the viscosity in the low Mach number M_p region. This value is proportional to $dV_E/(dI_E/n_e)$ evaluated from the electrode characteristics. Here, V_E and I_E are an electrode voltage and an electrode current. And these two values represent the radial resistivity. From Fig. 1(b) it is clear that two parameters in L-mode decrease with R_{ax} going outward.

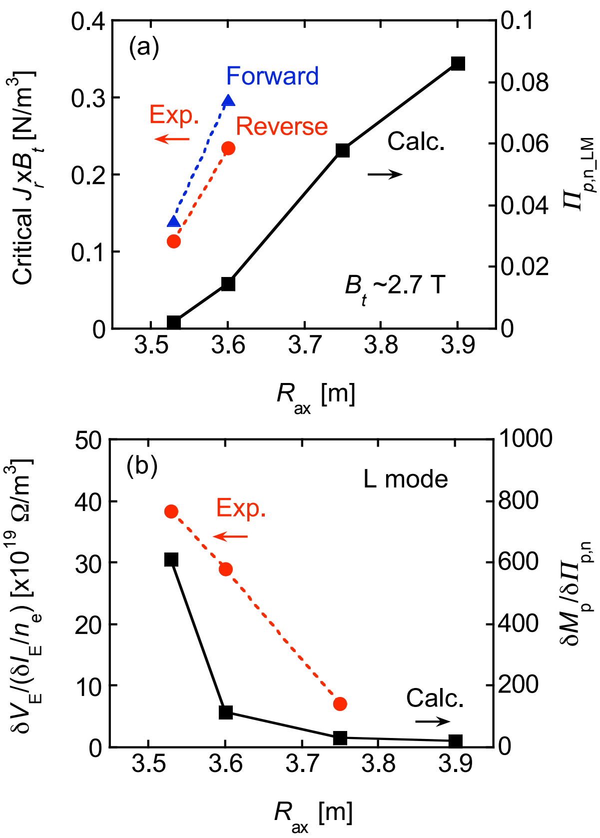

Fig. 1 Relation between (a) the critical driving force and the magnetic axis position, (b) the radial resistivity and the magnetic axis position

Further biasing experiments were tried in CHS and Heliotron-J. Figure 2 shows the operating range for the effective helical ripple ε_{eff} and local maxima in a neoclassical poloidal ion viscosity Π_{p,n_LM} (viscosity maxima) and critical driving force F_c in TU-Heliac, CHS, Heliotron-J and LHD predicted by the neoclassical theory [3], and critical driving forces F_c. estimated from biasing experiments. The biasing experiments in many devices, which have a different magnetic ripple structure, enable us to compare the transition condition and to demonstrate the important role of neoclassical ion viscosity on the transition in the wide ε_{eff} operating range.

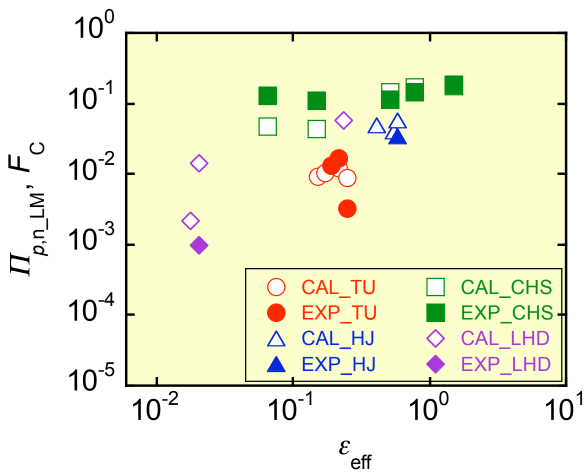

Fig. 2 Operating range for the effective helical ripple ε_{eff} and ion viscosity maxima Π_{p,n_LM} and critical driving force F_c in TU-Heliac, CHS, Heliotron-J and LHD

In this talk we report (1) experimental results of the biasing experiment in TU-Heliac, CHS, Heliotron-J and LHD and observations of the clear transition phenomena from the electrode characteristics in different magnetic configurations in each device, (2) estimation of critical driving forces F_c required for the transition and a radial resistivity in each device, (3) the dependency on magnetic configuration and comparison with theoretical predictions, (4) measurement of the radial electric field profile under the biasing in LHD and (5) evaluation of the radial electric field and the viscosity by the neoclassical transport code FORTEC-3D [4] for a non-axisymmetric system, and discussion of the electrode voltage required for the transition from simulation results.

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