Structure generation of the edge radial current during the L-H transition on JT-60U

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More than 30 years have passed since the theoretical model of the structural bifurcation of the radial electric field E_r for the transition from the Low- to High-confinement modes (so-called, L-H transition) was proposed [1]. According to a theoretical model [2], the non-uniformity of the radial electric field E_r (i.e. its shear and/or curvature effect) at the plasma peripheral region just inside the separatrix, which occurs spontaneously with a fast time-scale (such as a few 10 micro second, typically, or up to 1 ms at the latest), plays an essential role for the turbulence suppression during the formation of Edge Transport Barriers, ETBs, across to the L-H transition.

One of remaining issues in this research area is to identify the origin of E_r in the ETBs. Apart from the H-mode which occurs spontaneously, it was demonstrated that the L-H transition could be externally controlled also by electrode bias [3], exhibiting an essential role of E_r-bifurcation (including Zonal-flow, ZF [4]) for triggering the L-H transition. Probe measurement confirms the effects of complex nonlinear response of E_r, and theoretical model has been verified using HIBP measurement data with high time resolution [5], only recently. However, comparison between model and experiment is very limited, and there is no finding that can be extrapolated to ITER/DEMO other than the scaling rule of threshold power according to the rule of thumb.

In this study, we analyzed the structure generation of the edge radial current, j_r, by means of Poisson's equation with a measured E_r data from CXRS diagnostic in JT-60U NBI heating plasmas [5-9]; $j_r^{Exp.}$=-$\varepsilon_0\varepsilon_\perp\frac{\partial}{\partial t}E_r$ (1). Here, $\varepsilon_\perp$ is the relative dielectric constant of toroidal plasmas. As shown in Fig. 1, a slow L-H transition takes place about 200 ms after the start of NBI heating, which evolves into a fully-developed H-mode spending a few 100ms. During this slow transition process, a smooth decrease in D_α emission, increase in the edge line-averaged electron density and steepening of ion temperature take place. The E_r-well bottom value at ~3 cm inside the LCFS becomes large up to -40 kV/m as a similar time-scale of the change in the density, while the j_r shows a local Max. value of ~0.01-0.02 A/m^2 just after a slow L-H transition and its broader radial structure propagates toward plasma core region in the time-scale of ~100 ms as seen in the pedestal development. On the other hand, we found a more strongly localized radial structure in the j_r ~ $\boldsymbol{O}$(~0.4-0.5 A/m^2) with positive or negative polarities after development of ETBs, which occurred spontaneously with a fast time-scale. This observation suggests a co-existence of the non-linear physical mechanism for the j_r generation in terms of its spatio-temporal variation.

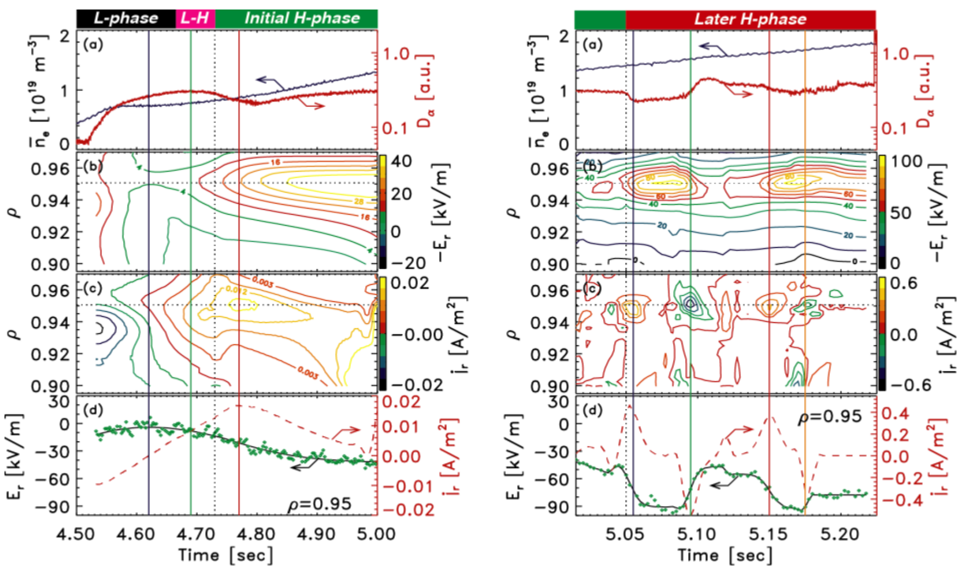

Fig. 1 Waveform for E049219 discharge, showing different time-scales for the bifurcations in E_r-j_r.

As shown in Fig. 2 (Left), we found that the order of the $j_r^{Exp.}$ during the L-H transition phase (e.g. t = 4.690 s) does not contradict to the fast ion loss current $j_r^{Fast.}$, which can be estimate by the OFMC-code [9]. However, a more detailed comparison exhibits that the $j_r^{Fast.}$ solely seems be not enough for the driving force to cause the slow L-H transition, since the $j_r^{Exp.}$ having a local peak structure, at which the T_i profile have their own steepest gradient values, becomes more positive than that for the $j_r^{Fast.}$ across to this phase. Furthermore, the $j_r^{Fast.}$ during the E_r transition at the later H-phase is smaller than the observation by one order of magnitude, suggesting another additional different driving forces (e.g. pressure gradient of bulk ions and/or turbulence) according to each transition type having different time-scales.

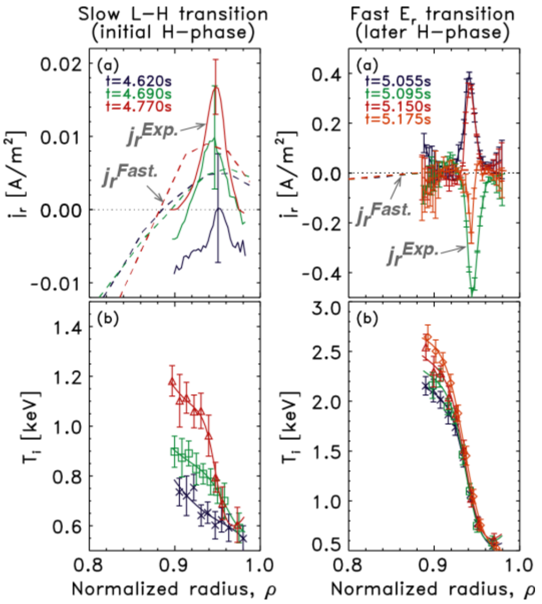

Fig. 2 Radial profiles for (a) j_r and (b) T_i.

There are many processes which are associated with the radial current as follows;

$j_r^{Cal.} = j_i^{lc} + j_i^{bv} + j_i^{v\nabla v} - j_{e-i}^{wave} + j_i^{CX}$ (2). We calculated the $j_r^{Cal.}$ value by taking all five terms in Eq (2) into account using the same definition as Ref. 6-7. As a result, we confirmed that the $j_r^{Cal.}$ value based on the bifurcation model is qualitatively in agreement with experimental result, especially for the later H-phase with fast time-scale, while a more detailed comparison between them is needed. As shown in Fig. 3, the $j_r^{Cal.}$ value makes an abrupt change at the normalized E_r value, X ~ 1 at the forward E_r-transition

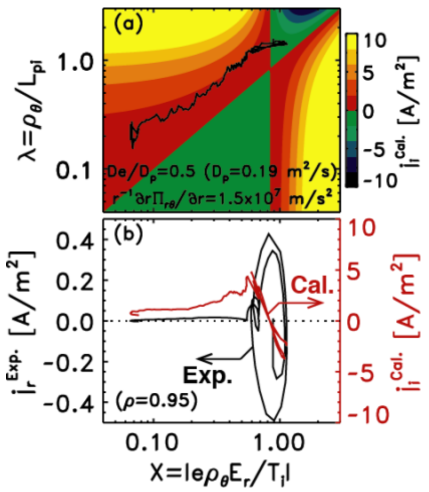

Fig. 3 Relationship between λ, j_r, and X.

at t ~ 5.05 s. During this phase, the bulk-viscosity term in the $j_r^{Cal.}$ value takes a value close to zero as that seen in JFT-2M [5-7]. On the other hand, the $j_r^{Exp.}$ value exhibits a jump toward negative one at the backward E_r-transition at t ~ 5.08 s, and X value returns to the original one as that seen just before the forward E_r-transition, and hence the normaized pressure gradient value, λ, can not exceed critival value of ***O**(1)*. This observation suggests the existence of wave-convection term that could compensate the bulk-viscosity term as suggested in Ref. 5, while it depends on the parameter selection, such as plasma diffusivity. Determination of parameters is the focus of future research.

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