Observation of Edge Reynolds Stress Increase Preceding an L-H Transition in Compact Helical System

Yoshihiko NAGASHIMA, Kenichi NAGAOKA[1)], Kimitaka ITOH[1)], Akihide FUJISAWA[2)], Mitsutaka ISOBE[1)], Tsuyoshi AKIYAMA[1)], Chihiro SUZUKI[1)], Shin NISHIMURA[1)], Yasuo YOSHIMURA[1)], Keisuke MATSUOKA[1)], Shoichi OKAMURA[1)], Yuichi TAKASE, Akira EJIRI, Sanae -I. ITOH[2)], Masatoshi YAGI[2)] and CHS Group[1)]

Graduate School of Frontier Sciences, The University of Tokyo, Kashiwa 509-5292, Japan
[1)]National Institute for Fusion Science, Toki 509-5292, Japan
[2)]Research Institute for Applied Mechanics, Kyushu University, Kasuga 816-8580, Japan

(Received 28 February 2010 / Accepted 6 April 2010)

An increase in turbulent Reynolds stress preceding an L-H transition in the Compact Helical System (CHS) was observed. A positive increase in the Reynolds stress is associated with a negative jump in the floating potential. The relationship of signs is consistent with the momentum balance equation. Therefore, this observation supports the hypothesis that the Reynolds stress plays an important role in triggering the L-H transition in CHS plasmas.

Keywords: L-H transition, Reynolds stress

DOI: 10.1585/pfr.5.022

Understanding of the mechanism that triggers the transition to high-confinement plasmas [1] is important for realizing fusion plasmas. In some tokamak operations, H-mode transitions are triggered by a sawtooth crash. However, such events have not been observed in H-mode transitions in helical plasmas. In this rapid communication, we present a direct observation of turbulent Reynolds stress (RS) preceding an L-H transition in Compact Helical System (CHS) [2]. Compression of RS could be a source of shear flows and is a candidate mechanism for the formation of a radial electric field, leading to H-mode plasmas [3].

The CHS is a low-aspect ratio middle size stellarator with a major radius $R_0 = 1$ m, minor radius $a = 0.2$ m, number of helical windings $l = 2$, and toroidal period number $N_t = 8$. In these experiments, the magnetic axis is located at $R = 92.1$ cm (R_{axis}), and the toroidal magnetic field $B_t = 0.9$ T. Two neutral beam injection (NBI) units were used to make reproducible H-mode plasmas. Edge fluctuations were measured with the hybrid probe (HP) [4]. The HP has six electrodes by which the floating potential signals were measured. The RS is calculated from the floating potential measured with two pairs of electrodes separated radially and poloidally, respectively. The HP is movable in the poloidal plane, and the two-dimensional RS structure was obtained, neglecting temperature fluctuations.

Figure 1 (a) shows the time evolution of two-dimensional maps of the RS. Positive RS indicates radially outward transport of velocity in the electron diamagnetic drift direction. The maps are reconstituted from shot-by-shot scan data from the HP. Timings of the H_α drop are used as the standard to synchronize different shot data in the same time series in two-dimensional maps. The RS starts to increase at 78 ms, indicated by red square (1) in Fig. 1 (a), has a maximum at 86 ms (2), and vanishes at 94 ms (3). We have discovered an increase in the RS preceding the H_α drop (the L-H transition). At the beginning of the increase, the RS is localized near the outermost surface of the plasma at $Z = 0$ m. However, around the period when the RS has a maximum (84 ms), a large RS is distributed along the plasma surface, and the radial gradient of the RS is strong. The RS can transfer poloidal momentum in the radial direction and/or radial momentum in the poloidal direction. The RS gradient is a source/sink for momentum. Therefore, the finite radial gradient observed here can drive poloidal shear flow.

The momentum balance equation determines the correspondence of negative electrostatic potential to positive RS in the coordinate used. We compare the waveforms of H_α, the floating potential, and the RS in detail in Fig. 2 to investigate the relationship between the potential and the RS. The waveforms were sampled simultaneously in a discharge. A positive spike in the RS, preceding the end of the H_α drop, is correlated with a negative jump in the floating potential. If the magnitude of the RS is significant, the driving RS term balances the damping term of the potential in the momentum balance equation [6]. The RS term is on the order of several $10^5\ \mathrm{m}^2/\mathrm{s}^2$, similar to or larger than the potential damping term $\mu_{ii}\nabla^2\Phi/B = \nu_{ii}\rho_i^2/\lambda_\Phi^2\Phi/B$. Here, ν_{ii} is ion-ion collision frequency (several kHz), ρ_{ii}

author's e-mail: nagashima@k.u-tokyo.ac.jp

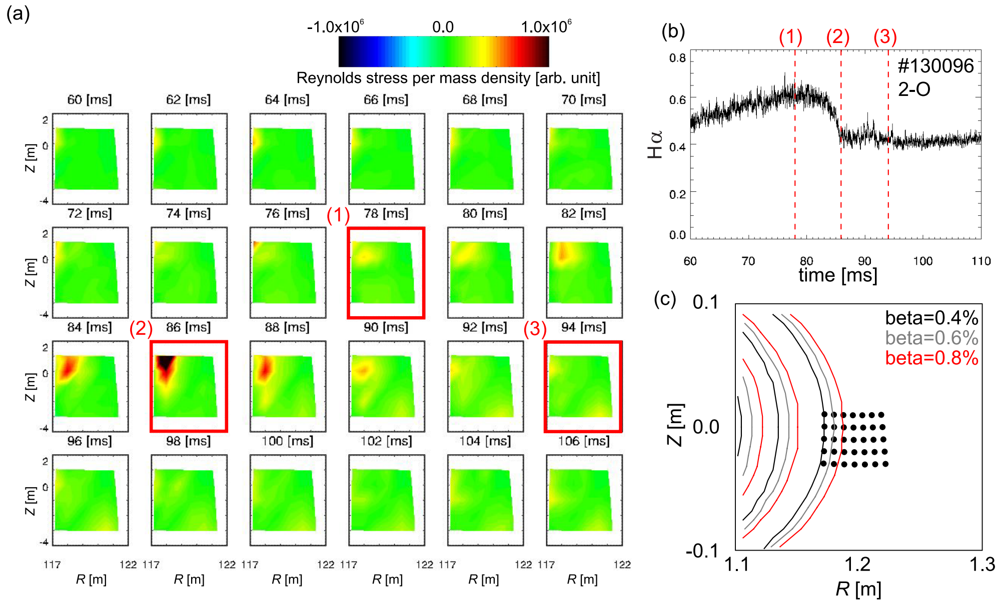

Fig. 1 (a) Time evolutions of two-dimensional Reynolds stress profile around L-H transition. (b) Waveform of H_α emissivity. Red vertical lines with numbers correspond to times in (a). (c) Observation locations with poloidal fluxes at different βs calculated by VMEC code [5]. The $\beta \sim 0.4\%$ before the H_α drop (86 ms), and gradually increases up to 0.7% after the L-H transition.

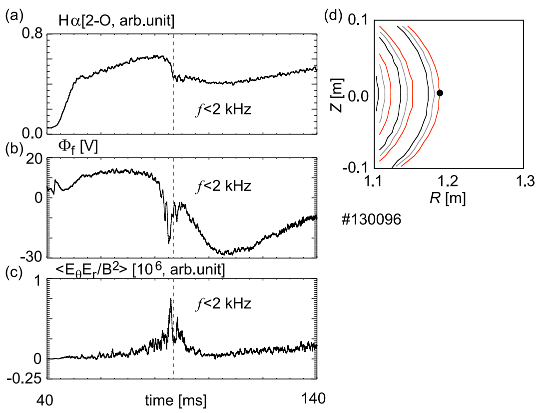

Fig. 2 Time evolutions of (a) emissivity of H_α, (b) floating potential, and (c) turbulent Reynolds stress. (d) Observation locations. In (a)–(c), vertical red lines mark the end of the H_α drop.

(~2 mm) is the ion gyro-radius, and λ_Φ is the potential gradient scale length (mm order), using an electron temperature $T_e = 30$ eV and electron density $n_e = 2 \times 10^{18}\ \mathrm{m}^{-3}$. The inertia term $\partial(\Phi/B)/\partial t$ is on the order of $10^5\ \mathrm{m}^2/\mathrm{s}^2$ or less (assuming $\Delta\Phi \sim 50$ V, B_t at the observation location $\simeq 0.53$ T, and $\Delta t \simeq$ 1-2 ms were used), thus the RS can accelerate solitary potential structure.

Here, we discuss about the RS profile after the L-H transition. In Ref. [3], the RS maintains poloidal flows after the transition. However, in CHS, the radial gradient of the RS is poor after the transition. This observation suggests that the RS does not play significant roles on sustaining plasma rotation [7] after the transition. Further studies are necessary to clarify the existence of the radial electric field and edge structure of H-mode plasmas in CHS.

In summary, the detailed time evolution of two-dimensional maps of the turbulent Reynolds stress was reconstituted during the L-H transition on CHS. The RS starts to increase before the transition, reaches a maximum, and has a finite radial gradient just before the H_α drop is complete. After the transition, significant RS vanishes. The increase in RS coincides in time, with a negative jump in the floating potential, and its sign is consistent with the momentum balance equation. In the future magnitude of the force due to RS will be analyzed in detail and compared to the rate of change in floating potential to determine if they are of similar order. In previous work, significant toroidal and/or poloidal asymmetry in electrostatic fluctuations were observed around the L-H transition in CHS [8]. The asymmetry may affect evaluation of flux surface averaged RS. We evaluated the RS at one toroidal location in this experiment. Simultaneous measurement of the RS at a number of toroidal/poloidal locations is necessary to evaluate the existence of zonal flows by which plasma confinement may be improved. This work was partially supported by the collaboration research of NIFS (NIFS09KZPB001), Grant-in-Aid for Specially Promoted Research (16002005) of MEXT, Grants-in-Aid for Scientific Research (21224014, 21226021, 21246137) of JSPS, by a Grant for Japan-related Research Projects of the Sumitomo Foundation (No 030943), and by the collaborations between RIAM, Kyushu University and the University of Tokyo.

[1] F. Wagner *et al.*, Phys. Rev. Lett. **49**, 1408 (1982).
[2] S. Okamura *et al.*, Nucl. Fusion **45**, 863 (2005).
[3] Y.H. Xu *et al.*, Phys. Rev. Lett. **84**, 3867 (2000).
[4] K. Nagaoka *et al.*, Phys. Rev. Lett. **100**, 065005 (2008).
[5] S.P. Hirshman *et al.*, Comput. Phys. Commun. **43**, 143 (1986).
[6] Y. Nagashima *et al.*, Phys. Plasmas **16**, 020706 (2009).
[7] S. Nishimura *et al.*, Plasma Fusion Res. **2**, 037 (2007).
[8] M. Takeuchi *et al.*, Nucl. Fusion **48**, 024015 (2008).