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TRANSPORT PROPERTIES OF OPTIMISED SHEAR DISCHARGES WITH ELMy H-MODE IN JET

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1. INTRODUCTION

Analysis of the transport properties of Optimised Shear (OS) discharges in JET has been carried out using the TRANSP and EFIT codes. The transition to ELMy H-mode occurs in a short time (~0.1s) after the start of the main plasma heating in OS discharges with the Gas Box divertor. Internal Transport Barriers (ITBs) occur in the ELMy H-mode phase. Strong dependence of $E \times B$ shearing rate [1] on q at ITB location has been observed. The magnitude of ion χ_i diffusivity in the plasma centre can reach the level of the ion neoclassical diffusivity χ_{neo}. The electron diffusivity χ_e is typicaly above the level of χ_i. ELMs may deteriorate the ITBs. Noble gasses puff was used to control ELMs. Tearing and 'snake'-like modes limit the plasma confinement with ITBs in discharges with the highest performance.

2. ITB FORMATION

ITBs have been observed in the Gas Box divertor configuration at magnetic field 1.8T<B<4T. The total heating power threshold for ITB formation increases with magnetic field. ITB formation is facilitated in discharges with rational q in the vicinity of the forming barrier. There is a strong dependence of $E \times B$ shearing rate [1] on q at ITB location (Fig.1). The $E \times B$ shearing rate is comparable with the linear growth rate of ITG instability [2] at least 0.2s before ITB is formed (Fig.1).

3. ITB EVOLUTION IN HIGH PERFORMANCE OS DISCHARGES (GAS BOX DIVERTOR)

The highest neutron yield has been reached in discharges with narrow T_i, T_e profiles without noble gas puffing. q=2 surface is narrow as deduced from equilibrium reconstruction code EFIT. Evolution of TRANSP calculated electron χ_e and ion χ_i diffusivities are shown in fig.2 together with EFIT calculated q=2 surface location. The min($\chi_{i,e}$) indicates ITBs positions. It is situated close to a steep grad($\chi_{i,e}$). ITBs follow, roughly, the q=2 surface expansion. EFIT and TRANS calculated q-profiles remain monotonic throughout the high performance phase. ITB formation is accompanied by gradual, but transient decrease in ELM activity. Typically discharges of this type disrupt due to global internal ideal modes driven by increasing plasma pressure gradient.

Large diamagnetic energy and neutron yield have been achieved in OS discharges with noble gas puffing (Ar or Kr) [3]. The peripheral radiation increases significantly during

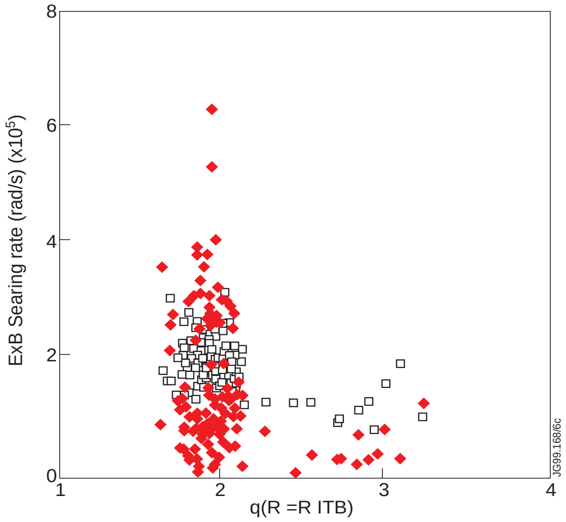

Fig.1. Calculated $E \times B$ shearing rate (solid diamonds) vs. q at ITB radius 0.2s before the barrier formation. Measured thermal particle pressure, toroidal and neoclassical poloidal rotations are included. Majority of discharges with ITB in Gas Box divertor configuration are presented (without noble gas puffing). Linear growth rate of ITG instability [2] with $k\rho_s$=0.3 is shown for comparison (open squares).

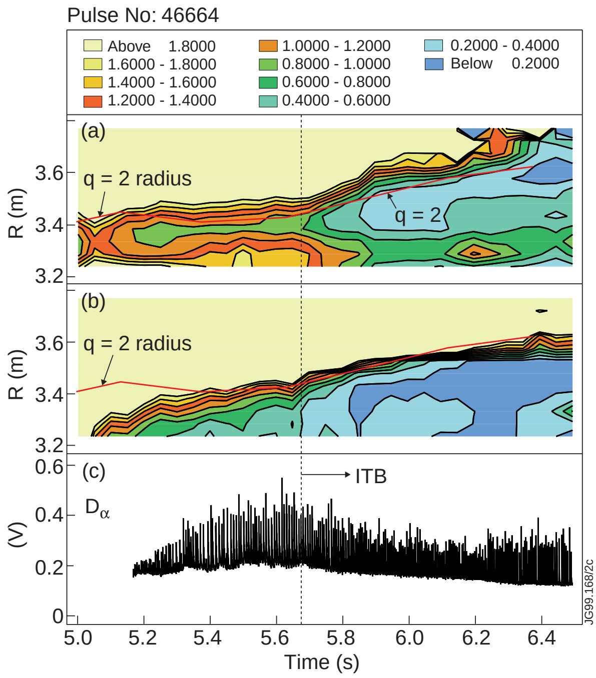

Fig.2. Contour plot of a) χ_e, b) χ_i and c) D_α signal in high performance discharge without noble gas puffing. Pulse 46664. ITBs are formed at 46.7s. Min χ_i and χ_e close to q=2 surface.

and after noble gas puffing with subsequent decrease in the plasma temperature at the edge. ELMs amplitude is noticeably reduced by puffing. ITBs appear in discharges with broad q=2 surface. Broad ITB prevents excessive pressure build-up and reduces the risk of a disruption. Quasi-steady state discharges are produced using noble gas puffing [3].

4. ELECTRON AND ION HEAT TRANSPORT IN OS DISCHARGES WITH AND WITHOUT NOBLE GAS PUFFING

Ion heat diffusivities are comparable in discharges with and without noble gas puffing (Fig.3). χ_I is close to its neoclassical value inside the ion ITB (Fig.3). Electron heat diffusivities are significantly larger than χ_i between ITB and magnetic axis (Fig.3). The overwhelming majority of high performance OS discharges are affected by 'tearing'-like modes with a wide spectrum of toroidal mode numbers n=1~10. Tearing modes may persist throughout the entire high performance phase. These modes have

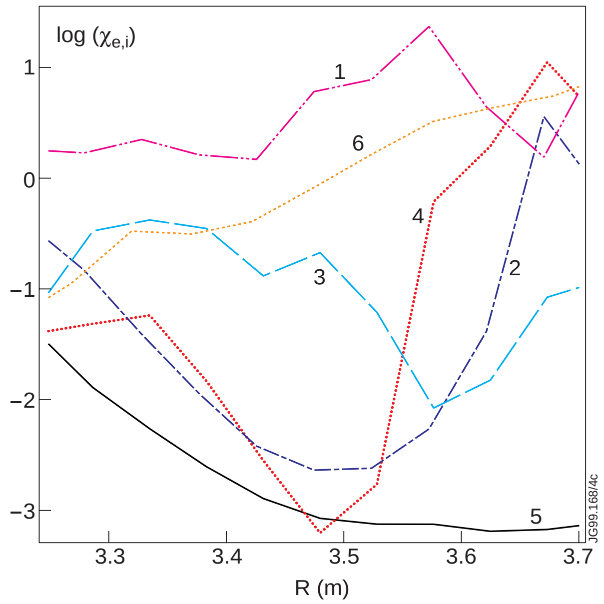

Fig.3. Comparison of electron and ion thermal diffusivities in OS discharges with and without noble gas puffing. 1)log(χ_e), 2) log(χ_i), t=7.5s, pulse #47413 (with Ar), 3)log(χ_e), 4) log(χ_i), t=6.4s, pulse #46664 (no Ar), 5) log(χ_{ineo}), t=6.4s, pulse #46664, 6) log(χ_i), t=16.8s, pulse #47480,standard ELMy H-mode without ITB (no Ar). Time slices are chosen for fully developed ITBs, when diamagnetic energy and neutron yield are approaching their maximum values.

a global structure, i.e. they cause plasma perturbation in the major part of the plasma volume. Maximum perturbation is localised inside ITBs (Fig.4). χ_e is strongly enhanced by 'tearing'-like modes inside ITB in high performance OS discharges with Ar puffing (Fig.3,4). Location of the peak perturbation correlates with χ_e enhancement. The electron ITB may coexist with tearing mode though can be noticeably deteriorated.

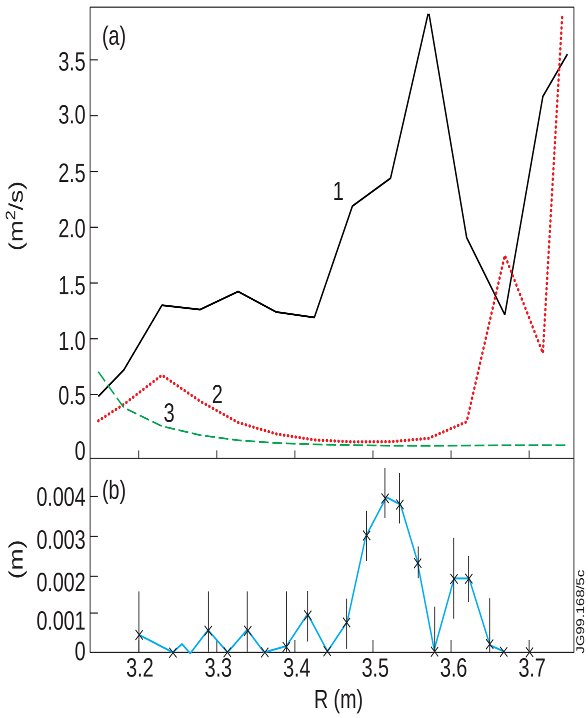

Fig.4. a) Profiles of 1-χ_e, 2-χ_i, 3-χ_{neo}, b) plasma displacement caused by tearing mode with n=5, as deduced from T_e fluctuation measurements. Pulse #47413 (with Ar puffing), t=7.5s.

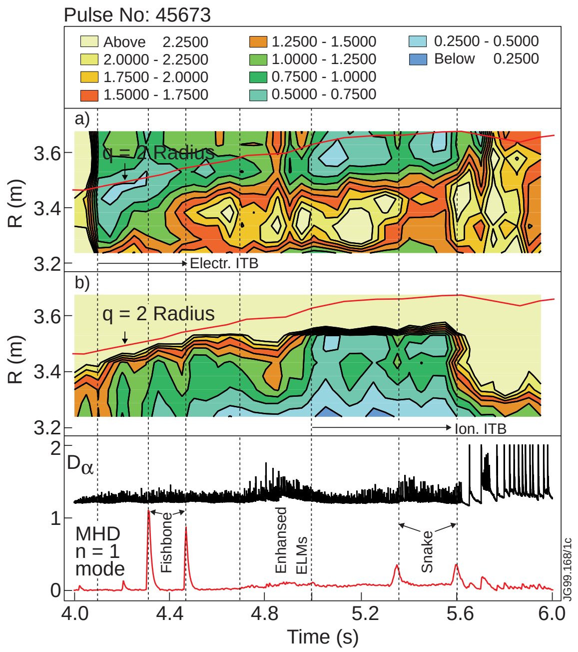

Fig.5. Contour plot of a) $\chi_{e,}$, b) χ_i and c) D_α signal d) Mirnov probe signal for n=1 MHD activity in OS discharge with ITBs (no Ar puffing). Pulse 45673. Electron ITB appears at 4.1s, the ion ITB appears at 5.0s. 'Fishbone'-like mode bursts at 4.32s and 4.47s accompanied by χ_i Increase. Erosion of electron ITB and increase in χ_i is associated with enhanced ELMs between 4.7s and 4.9s. ITBs are slightly eroded and then destroyed by 'snake'-like modes at 5.35s and 5.6s, respectively.

5. EFFECT OF ELMs, 'FISHBONE' AND 'SNAKE'-LIKE MODES ON ELECTRON AND ION HEAT DIFFUSIVTIES

'Chirping' or 'Fishbone'-like mode bursts are observed in majority of OS discharges [4]. They are caused by fast particle population, which is produced by combined RF and NBI heating. These modes are well pronounced in a phase with a moderate plasma density $n_e(0)\leq 3.10^{19}m^{-3}$. The mode intensity decreases with n_e increase. 'Snake'- like modes are, also, quite common for OS discharges [4,5,6]. The most pronounced, as a rule, is the mode with n=1, m=2. It is localised on q=2 magnetic surface in the vicinity of the electron ITB. The nature of these modes is currently under investigation. Figure.5 shows evolution of χ_i and χ_e **,** D_α and magnetic n=1 mode signal in OS discharge with ITBs. χ_i increase can be seen during enhanced ELMs and MHD activity. χ_e is mostly affected by ELMs and 'snake'-like modes. 'Snake'-like modes may cause ITBs deterioration. Their excitation is accompanied, typically, by ELMs enhancement with further ITB destruction (Fig.5).

6. PERFORMANCE LIMITATION BY MHD ACTIVITY IN OS DISCHARGES

MHD activities impose severe limitations on the maximum achievable beta normalised β_N, diamagnetic energy W_{dia} and neutron yield R_{NT} in all high performance OS discharges. The most dangerous are ‘snake’ or ‘tearing’-like modes. ‘Tearing’-like modes affect mostly the electron energy confinement (Fig.3, 4). ‘Snake’-like modes cause ITBs deterioration (fig.5). Their excitation is accompanied, typically, by ELMs enhancement. Figure 6 shows relation between measured W_{dia}/B_{tor} and averaged magnetic shear inside q=2 region at the time, when W_{dia} reaches its maximum during MHD activity.

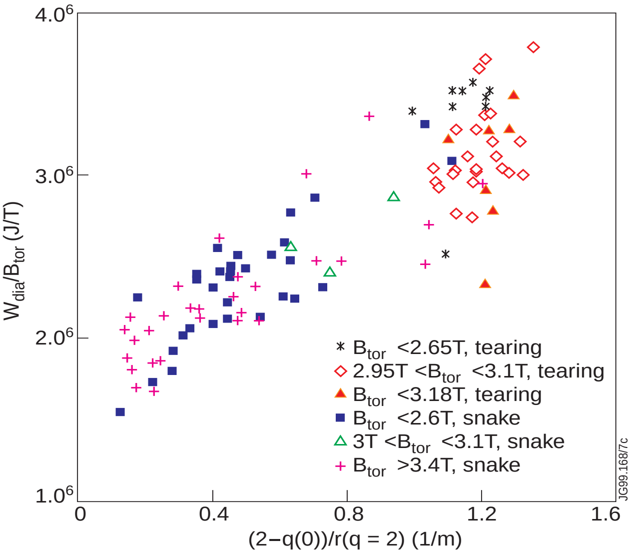

Fig.6. Experimentally observed relation between maximum reached W_{dia}/B_{tor} and ratio $(2-q_o)/r_{(q=2)}$ in OS discharges affected by MHD, where q_o and $r_{(q=2)}$ are safety factor on magnetic axis and radius of q=2 surface, respectively, deduced from EFIT calculations. Discharges in Gas Box divertor configuration only included

7. CONCLUSIONS

Pressure gradient, radial electric field and E×B shearing rate deduced from experimental data are strong function of the safety factor q at ITB location. ITB formation is facilitated in the vicinity of rational q, in particular q=2. Broad ITBs are obtained in OS discharges with noble gas puffing in Gas Box divertor configuration. χ_i inside ITB is quite comparable for the best OS discharges with and without noble gas puffing. χ_i can reach the level of the ion neoclassical diffusivity χ_{neo}. χ_e is well above the level of χ_i in the region between ITB and magnetic axis. χ_e increases considerably in high performance discharges with noble gas puffing due to tearing mode excitation. Tearing or ‘snake’-like modes may limit performance in OS discharges with the highest beta normalised, diamagnetic energy, and neutron yield.

8. ACKNOWLEDGEMENTS

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