Study of Runaway Electrons in GOLEM Tokamak

Pravesh Dhyani[1], Vojtěch Svoboda[1], Jan Mlynář[1,2], Jaroslav Čeřovský[1,2], Ondřej Ficker[2], Vladimír Linhart[3], Jan Stöckel[1,2]

[1]Department of Physics, Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University, Prague, Czech Republic
[2]Institute of Plasma Physics, Czech Academy of Sciences, Prague, Czech Republic
[3]Department of Dosimetry and Application of Ionizing Radiation, Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University, Prague, Czech Republic

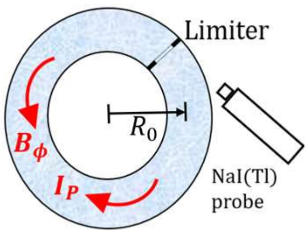
Abstract: High loop voltage and low-density discharges at GOLEM tokamak present favorable conditions for the study of runaway electrons (RE). In this paper, we discuss the interplay between magnetic hydrodynamic (MHD) fluctuations and runaway electrons. In quasi-periodic events, HXR generated due to the RE during the destabilization of the tearing modes. Tearing modes become stable at the time when HXRs are suppressed. During the HXR emission, high amplitude poloidal magnetic fluctuations and toroidal electric field were measured outside the tokamak. Analysis suggests that parallel electric field induced by magnetic reconnections due to the tearing modes excitation triggers the RE generation.

Experimental Setup and Conditions

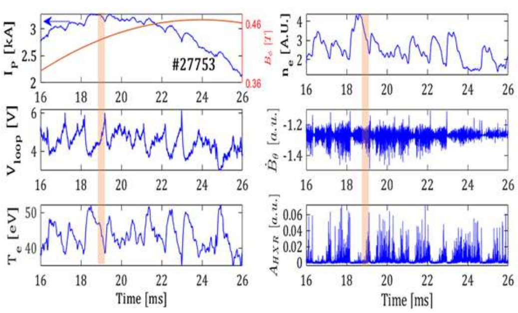
GOLEM and Plasma Parameters (Shot No. #27753)

Major radius (R_0) =0.40m; Minor radius (a) =0.085m
Plasma current (I_P)~ 3.3kA; clockwise as viewed from top
Toroidal magnetic field (B_ϕ)~ (0.4-0.45)T; anticlockwise as viewed from top
Edge safety factor q_a~10-11
Plasma density < $1.0\times10^{19}m^{-3}$
Electron temperature ~ (40-60)eV

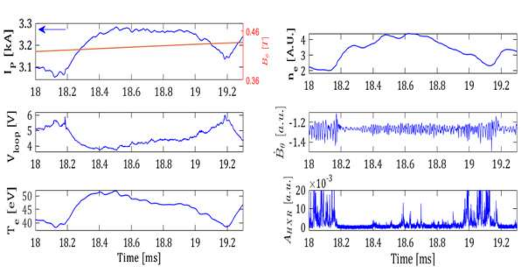
Schematic lay-out of the experiment at GOLEM tokamak (#27753)



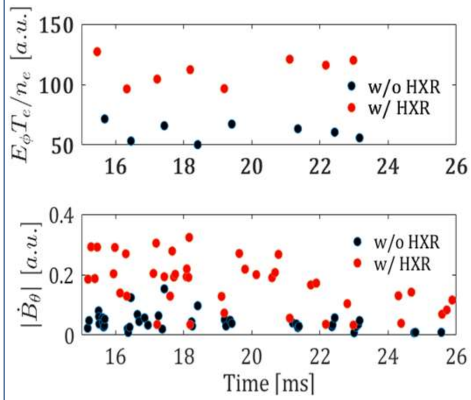
GOLEM tokamak discharge #27753 showing quasi-periodic oscillations during the emission and suppression of HXRs



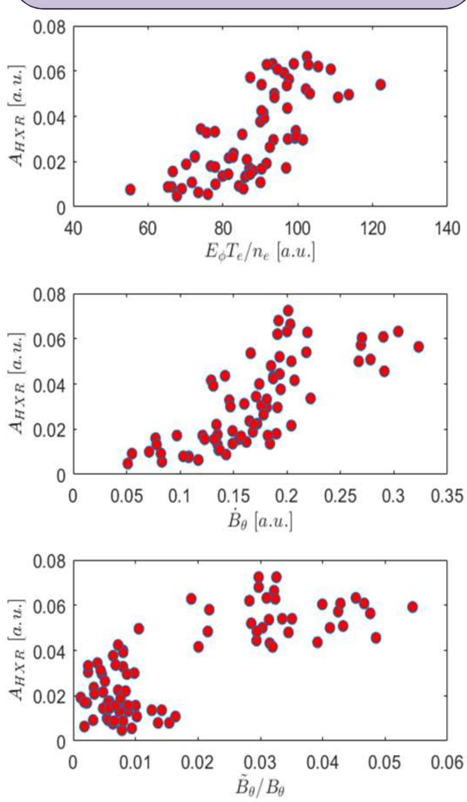
Magnetic fluctuations start growing soon after the rise of plasma current



Temporal profile of toroidal electric field (E_ϕ) normalized with Dreicer field ($n_e T_e^{-1}$) and $\dot{B}_\theta$ oscillations amplitude for the HXR and non-HXR cases (#27753).

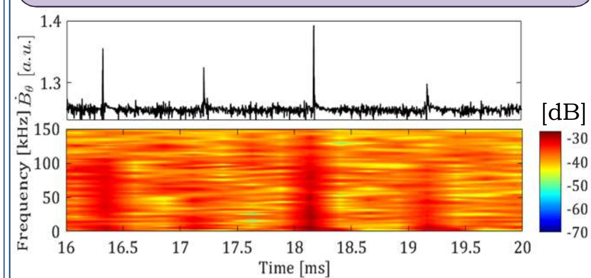


HXR signal amplitude (A_{HXR}) shows linear dependence on normalized electric field ($E_\phi T_e/n_e$), magnetic fluctuations ($\dot{B}_\theta$) amplitude and $\tilde{B}_\theta/B_\theta$ (#27753)

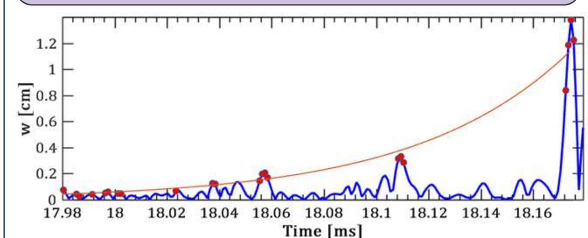


Threshold for RE loss: $\tilde{B}_\theta/B_\theta \sim (1-3)\times10^{-3}$
High HXR signals: $\tilde{B}_\theta/B_\theta \sim (2-5)\times10^{-2}$

Excitation of multiple harmonics of tearing modes up to ~$100kHz$ recorded in $\dot{B}_\theta$ signals at the time of HXR emission



Island growth and parallel electric field generation due to the magnetic reconnection of tearing modes



Magnetic islands grow as $dw/dt \sim (80-90)m/s$

Island width $w = 2\frac{r_s}{m}\left(\frac{r_c}{r_s}\right)^m\left(\frac{\tilde{B}_\theta}{B_\theta}\right)^{1/2} \sim (1.5-2.0)cm$

Parallel electric field $E_{||} = \left(\frac{sB_\phi}{16r_s}\right) w \left(\frac{dw}{dt}\right)$ ~ (0.7-0.8)V/m

Summary and discussion

1. RE generation is triggered by the parallel electric field induced by magnetic reconnections due to the tearing modes excitation.

2. Reason of quasi-periodic excitation – suppression of tearing modes is not yet fully understood. Particularly, the key component causing fast suppression of the tearing modes.

3. Loss of current causes local peaking of magnetic shear and excites tearing modes. Excitation of the tearing modes due to peaking of magnetic shear can be explained by the linear tearing mode growth rate relation : $\gamma \propto (q'/q)^{2/5}$

Acknowledgements: The work has been supported by the Operational programs RDE CZ.02.1.01/0.0/0.0/16_019/0000778: Centre of Advanced Applied Sciences, and CZ.02.2.69/0.0/0.0/16_027/0008465: International Mobility of Researchers CTU.