# Experimental evidence of neoclassical tearing modes on COMPASS tokamak

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## I. Introduction

Magnetohydrodynamic (MHD) instabilities belong to the most important limiting factors in achieving a high plasma performance in present tokamaks. Among them, neoclassical tearing modes as a resistive form of the kink instability developing on rational magnetic surfaces restrict the achievable $\beta$ to values well below the ideal MHD limit and can also result in a disruption, if the mode is locked. Following earlier investigations on the COMPASS-D tokamak [1-3], we introduce an experimental evidence of tearing modes on the COMPASS tokamak, which is newly equipped with neutral beam heating systems and a set of new diagnostics. We show fresh observations of magnetic islands in discharges with and without NBI heating and indicate a connection of MHD activity with edge plasma parameters and fast electron losses.

## II. Experimental setup

The COMPASS tokamak, a device of the ITER-like divertor plasma geometry ($R$=0.56m, $a$<0.23 m, currently $B_T$~1.15 T, $I_p$<230 kA, $T_e$ ~1 keV, discharge duration about 300 ms, linear size ratio to ITER plasma 1:10), has been reinstalled at IPP in Prague [4]. The original microwave auxiliary heating systems have been replaced by two neutral beam injectors of 300 kW each [5] with the aim to increase an ion to electron temperature ratio. In the experiments mentioned in this paper, COMPASS has been operated in an inner limiter regime of circular plasmas with $q_{edge}$ = 2-4 and $\beta_N$ ~ 0.5-1.

The standard set of magnetic diagnostics together with the EFIT code was used for magnetic topology reconstructions. However, COMPASS has also been equipped with a set of significantly upgraded or completely new plasma diagnostics [6]. Arrays of fast AXUV diodes measure a spatial profile of radiated power at microsecond scales. High resolution Thomson scattering diagnostic provides vertical profiles of both electron temperature and density. The edge plasma behaviour is monitored by Langmuir and ball-pen probes mounted on the horizontal reciprocating manipulator at low field side (LFS). Heat flux at high field side (HFS) is measured by the slow infra-red camera. Finally, hard X-rays corresponding to fast electrons interaction with the wall are detected by the scintillator.

## III. Observations of magnetic islands on COMPASS

Since the beginning of the COMPASS tokamak operation, a strong influence of MHD instabilities on discharge performance and plasma configuration stability has been observed. The first experimental proof of the presence of tearing modes was provided by signals of magnetic coils and of spatially resolved AXUV diodes. Spectrograms calculated using Fast Fourier Transform showed the birth, acceleration and deceleration of these periodic structures in the frequency range of 5-20 kHz [7]. Later, poloidal mode number *m* and poloidal rotation speed were added from the cross-correlation analysis. Parity of toroidal mode number was derived from the toroidally separated sets of the coils. In a typical situation angular speed of the island is much higher at LFS than at HFS as a result of Shafranov shift forcing the reduced island width at LFS, see Fig.1 for the case of the island of $m/n$=3/1 and $\omega_{LFS}$=28 $ms^{-1}$ > $\omega_{HFS}$=5 $ms^{-1}$. Growth rate of the magnetic island development can be derived from the envelope of the poloidal magnetic field perturbation, which is calculated using the Hilbert transform. When a magnetic island starts to grow, it quickly saturates in order of milliseconds or its growth is accompanied with decrease of mode frequency continuing by mode locking, often resulting in a disruption. Reduced plasma performance caused by tearing modes is demonstrated on two similar discharges with dominating (#4707) and suppressed (#4706) MHD activity, see Fig.2. Energy confinement time reduction $\Delta\tau_E/\tau_E$ is about -0.3 in this case.

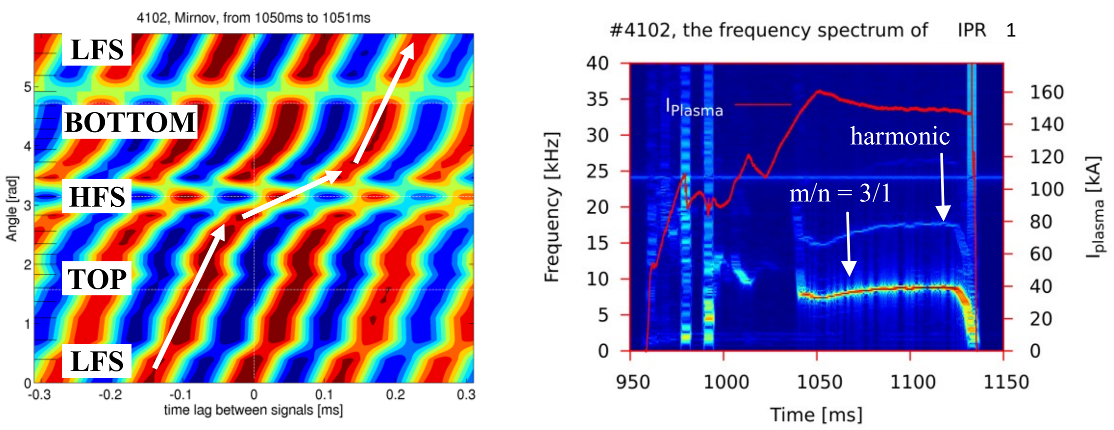



Fig.1 Cross-correlation graph of the set of Mirnov coils at 1050-1 ms showing poloidal rotation and mode number (left) and the corresponding spectrogram of IPR coil no.1 located at LFS (right) in the shot #4102.

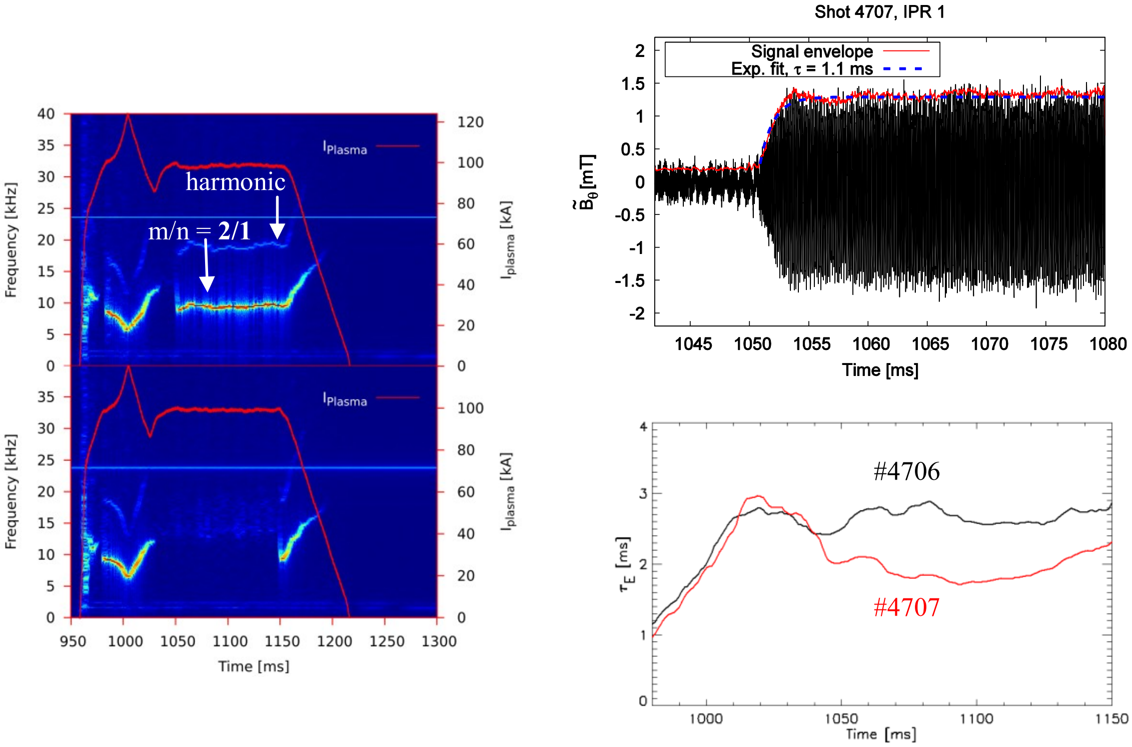



Fig.2 Spectrograms show two similar shots with (#4707, top left) and without (#4706, bottom left) strong MHD activity. Detail of the poloidal magnetic field perturbation (black) and its envelope (red – from Hilbert transform, blue – exponential fit) corresponding to the 2/1 mode growth during the shot #4707 (right top). Energy confinement time (from diamagnetic signal) degradation is demonstrated in the right-bottom graph.

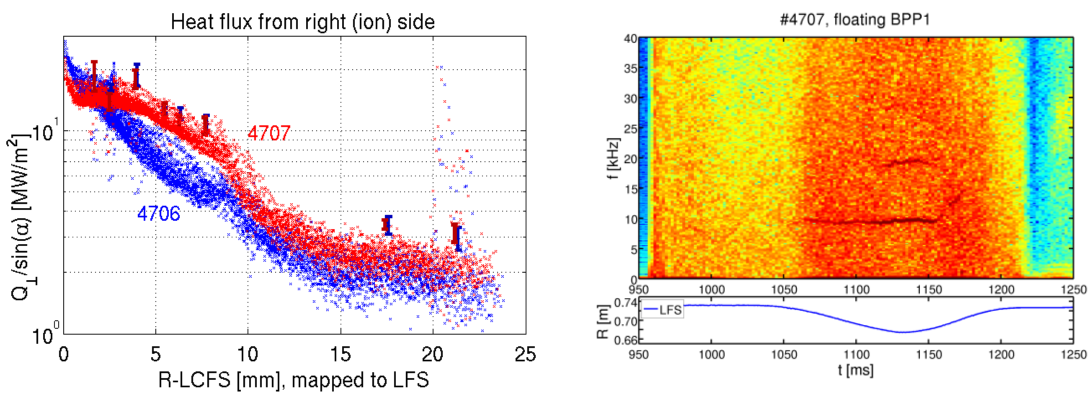
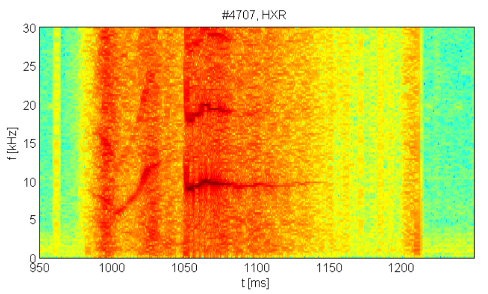



Fig.3 Edge plasma modification by tearing modes in #4707: flattening of the profile of parallel heat flux to the HFS limiters observed IR camera (points) and probes (vertical bars) on the left figure, where unperturbed profile from #4706 is shown for comparison; modulation of the floating potential signal measured by ball-pen probe during the manipulator insertion (top right) and of hard X-ray intensity as a result of freed runaway electrons (bottom right).



We also would like to emphasize a connection of the island rotation with a modification of edge plasma parameters, see Fig.3. The flattening of the profile of parallel heat flux to the HFS limiters caused by presence of tearing modes was observed by IR camera in the shot #4707. At the same time, a modulation (with frequency of island rotation) of floating and plasma potentials and edge electron density signals measured by ball-pen and Langmuir probes inserted from LFS to proximity of separatrix was evident. Whilst the island amplitude is stable in time during plasma current plateau, the observed modulation of the hard X-ray intensity corresponding to freed runaway electrons interacting with the vacuum vessel fades. Note that hard X-rays usually start to be modulated when the island rotation reaches minimum, i.e. island size has maximum, and then modulation slowly decreases.

The reverse process to the island growth, i.e. healing of tearing modes, is observed in discharges with the neutral beam injection or during plasma current ramps, see Fig.4. Characteristic healing time is comparable with growth time. The healing is probably caused by an increased plasma rotation caused by NBI. Tearing mode presence and position were confirmed by HRTS measurements of the flattening of the density and temperature profiles.

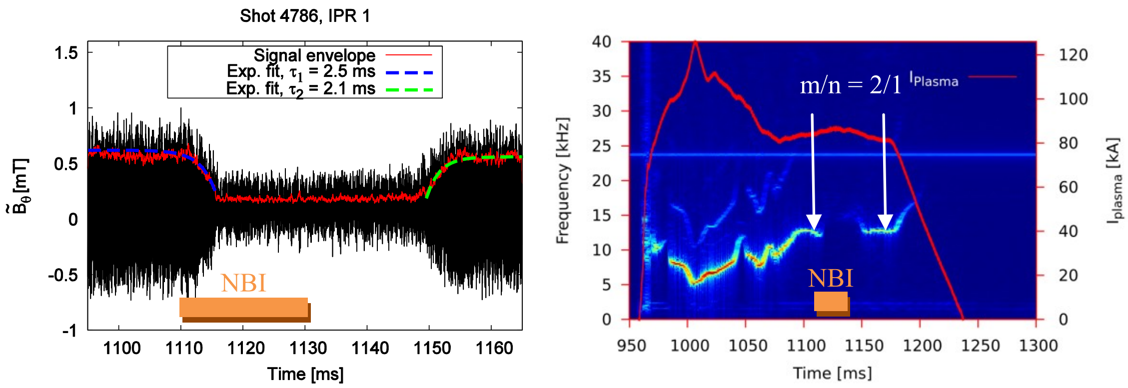



Fig.4 Mode healing by 200 kW of NBI at 1110-1130 ms and consequent mode revival in the shot #4786.

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**References**

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