Quasi-continuous low frequency edge fluctuations in the W7-X stellarator

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Introduction: We have observed quasi-continuous low frequency (150-400 Hz) edge oscillations via multiple diagnostics in Wendelstein 7-X, which appear to be similar to ELM-like events observed in W7-AS [1-2]. These oscillations exist in “high iota” discharges, with a 5/4 magnetic island at the plasma edge. These events originate inside the last closed flux surface, losing energy outwards through the island towards the wall, while a weak cold wave (seen by ECE temperature measurements) propagates towards the core. They are characterized by easily observable decreases in plasma kinetic energy (via diamagnetic loops) and simultaneous large ($\Delta I/I = 300\%$) transient plasma current bursts, albeit on a small net plasma current (<1kA). Segmented Rogowski loops show a poloidally varying fluctuating edge toroidal plasma current. Using fiber filterscopes at multiple toroidal locations, no toroidal phase delay of the edge response (H-alpha, Carbon-III emission) is seen. Langmuir probes in the divertor show an edge density increase with each burst, coincident with the current bursts. The fluctuation magnitude is larger with higher input power. Sawtooth-like energy losses, integrated over one energy confinement time, account for ~20% of the total energy loss balance.

Setup: During the most recent operating campaign, we ran a high-iota magnetic configuration, with iota nearly unity on axis, rising to iota = 5/4 at the plasma edge, as shown in Figure 1. This results in a 5/4 magnetic island at the plasma boundary. Uniquely (in experiments to date), this configuration excites a large amplitude fluctuation of the (small) toroidal plasma current in the plasma edge, easily detected on both the continuous Rogowski loop, and on eight segmented ones in the triangular cross section of W7-X.

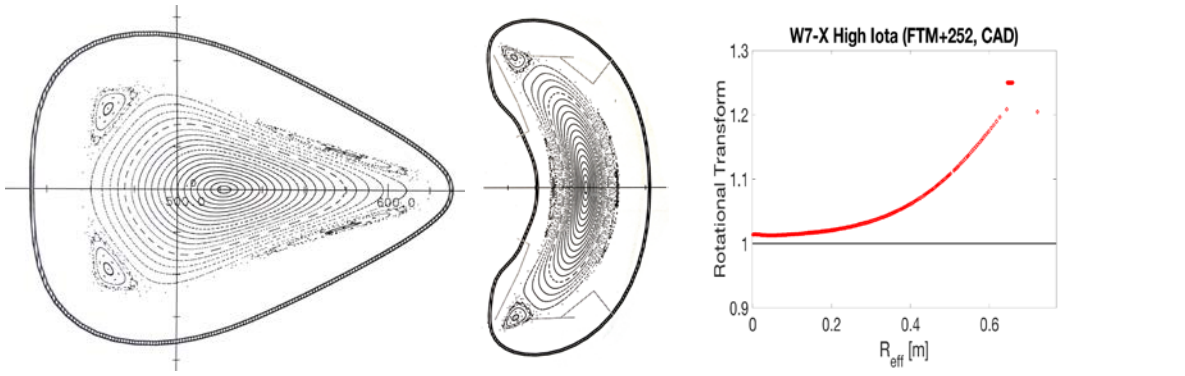

Figure 1: High iota configuration with a linked 5/4 magnetic island in the plasma edge. Calculated vacuum configuration island positions in the triangular and bean shaped cross sections are depicted, along with an iota radial profile. Iota is nearly one in the plasmas core. Figures from T. Andreeva, “Vacuum Magnetic Configurations of W7-X” IPP Report III/270 May 2002

Experimental Data: We first identified this fluctuation in W7-X on the plasma current trace. A large (ΔI/I = 300%) fluctuation (not noise) is noticeable as a prominent fuzz even on long duration plots, shown in Figure 2, as the bootstrap current slowly rises during pulse 2017025.040.

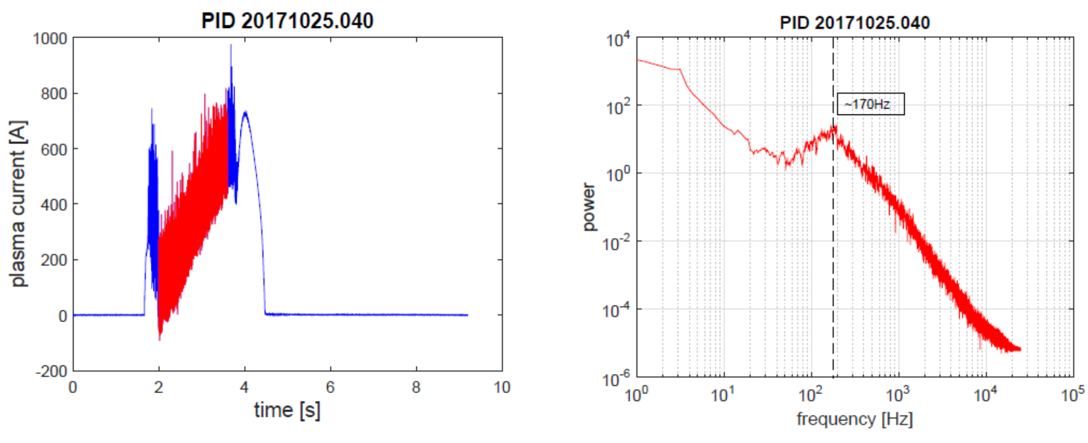

Figure 2: Plasma current from the continuous Rogowski coil in Module 1, showing the quasi-continuous fluctuation. The Fourier spectrum (from the time marked in red) shows a broad peak at 170 Hz.

The Fourier power spectrum of the plasma current in Figure 2 has a dominant, well-defined feature at ~170 Hz, as do virtually all diagnostic signals with sufficient time resolution (in particular, all plasma light signals from the plasma edge, or Langmuir probes).

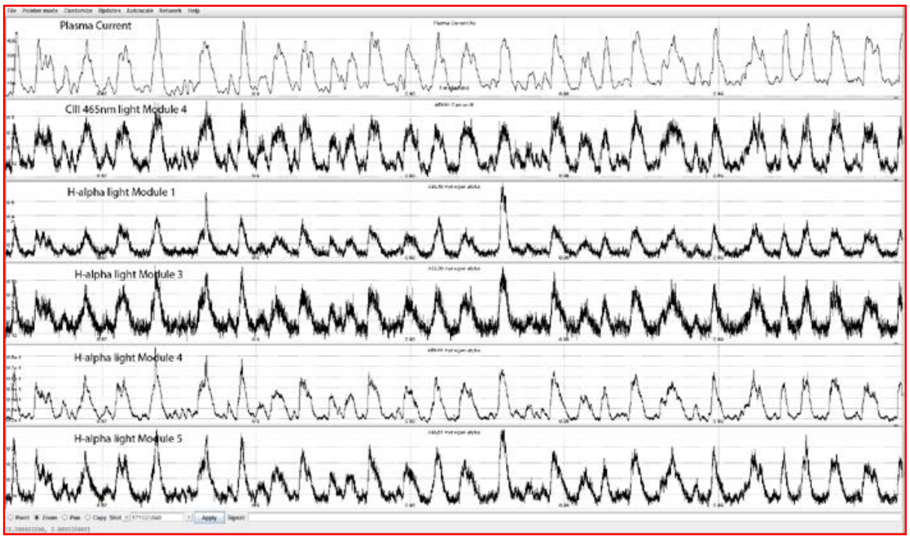

Figure 3: Filterscope light traces versus time for H-alpha or CIII, from four different toroidal locations, compared to the plasma current.

Remarkably, the light signals from different toroidal locations have the same fluctuation behavior (with no phase shift), as the plasma current, as shown above in Figure 2. This indicates the n = 0 nature of the fluctuation. On the other hand, the poloidal behavior is more complex. Looking at segmented Rogowskis in Module 2 (triangular section); each one clearly picks up the signal, but two of the eight are 180° out of phase. Rogowskis with an island located directly in front of them show the same phasing as the toroidal current fluctuation.

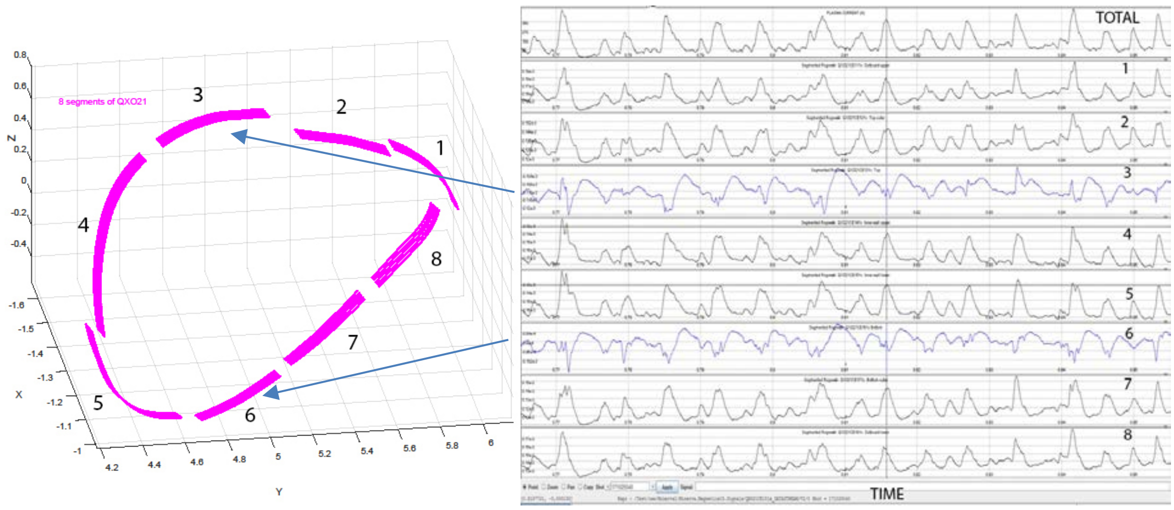

Figure 4: Segmented Rogowski coil time traces from Module 2 show out of phase variation, poloidally, from just two of the eight traces (marked in blue).

Discussion: We have identified a quasi-continuous low frequency edge fluctuation in W7-X, which seems to initiate just inside the last closed flux surface (LCFS). This mode is very sensitive to the magnetic geometry, seen best in the high iota configuration, which has a 5/4 edge magnetic island, and iota near one in the plasma center. It is seen both on low-field and high field side ECE channels (electron temperature), but the resulting cold wave does not propagate all the way to the plasma center. It causes a burst of toroidal plasma current in the plasma edge, positive to the wall near the 5/4 island locations, negative at other poloidal angles. Photomultipliers (filterscopes) monitoring plasma light from different toroidal locations show the same time response as the total plasma current. The HEXOS XUV spectrometer shows that all the ionized charge states of carbon (CII-CVI) have the same fluctuating time dependence, but the lower charge states of oxygen (OIII-OVI) (seen on the same sight line) have a small time delay (~2.5 msec). There is an associated burst of edge density and floating potential, measured by Langmuir probes both on the plasma midplane, and in the divertor. Reflectometry also sees a density/electric field perturbation just inside the LCFS. Individually, each event causes a drop of 0.5-6% in the plasma-stored energy, and when added up over time, results in a loss rate of 20% of the input power. There is a clear correlation between the magnitude of the light fluctuations and the size of the associated discrete plasma-stored energy loss events, with a similar loss fraction (20%) over a range of 2*x* in ECRH input power.

These “ELM-like” events may be similar to ones previously identified in the smaller W7-AS machine, 20 years ago, but on slower transport times and larger spatial scales, commensurate with the increased size of W7-X. We will be looking for fast magnetic precursors, and detailed profile analysis using more diagnostics (in particular the soft x-ray arrays, sodium beam, and TS profiles) in the coming campaign (OP1.2b).

Acknowledgements: Supported by the US-DOE/IPP collaboration under DOE LANS Contract DE-AC52-06NA25396. This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

References

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