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Studies of ELM toroidal asymmetry using ICRF antennas at JET and ASDEX Upgrade

Vl.V. Bobkov[1], M. Becoulet[2], T. Blackman[3], J. Brzozowski[4], C. Challis[3], S. Gerasimov[3], P.U. Lamalle[5], M. Maraschek[1], M.-L. Mayoral[3], I. Monakhov[3], J.-M. Noterdaeme[1 6], G. Saibene[7], A. Walden[3], P. Wouters[5], ASDEX Upgrade Team and JET-EFDA contributors

[1]-*Max-Planck-Institut für Plasmaphysik, EURATOM-Association, Boltzmannstr. 2, D-85748 Garching, Germany*
[2]-*Association Euratom-CEA, CEA Cadarache, F-13108 St. Paul-lez-Durance, France*
[3]-*EURATOM/UKAEA Fusion Association, Culham Science Centre, Abingdon, OX14 3DB, UK*
[4]-*Association EURATOM-VR, Stockholm, Sweden*
[5]-*LPP-ERM/KMS, Association EURATOM-Belgian State, TEC, Royal Military Academy, B-1000 Brussels, Belgium*
[6]-*Gent University, EESA Department, B-9000 Gent, Belgium*
[7]-*EFDA Close Support Unit, Boltzmannstr. 2, D-85748 Garching, Germany*

Introduction

Edge Localized Modes (ELMs) are known to affect dramatically the coupling of the Ion Cyclotron Range of Frequencies (ICRF) antennas [1, 2]. In order to investigate the influence of transient effects on the operation of the ICRF systems, data acquisition systems with high time resolution are used on JET and ASDEX Upgrade. It was found on both machines, that the response of the four toroidally distributed antennas to ELMs is not simultaneous. The observations indicate constraints for design of an efficiently working ELM-resilient ICRF system [3, 4]. The observed asymmetry can also provide additional information on ELM physics [2, 5, 6, 7]. This paper presents studies of the delays in appearance of the perturbation on RF signals due to type I ELMs for different ICRF antennas on JET and ASDEX Upgrade.

Experiment and measurements

Two transmission lines (out of 4) for each A2 antenna [8] on JET have fast measurements of reflected voltages with 10 μs time resolution. All transmission lines of the antenna straps on ASDEX Upgrade [9] were equipped with measurements of RF current with time resolution of 1 μs. This provided 8 measurement points distributed toroidally both for JET (see Fig. 1) and ASDEX Upgrade.

The ICRF antennas respond sensitively to changes of the plasma density in front of the antennas. The RF signals change rapidly at the rising edge of ELMs. However, the antennas do not provide poloidal and radial resolution of the change in density distribution during ELMs. A semi-automatic software has been used to deduce the times between responses on ELMs for the antennas (straps) based on the following approach, which assigns a time of reaction of an antenna to the maximum of the 1^{st} derivative of the RF signal (the most dynamical point):

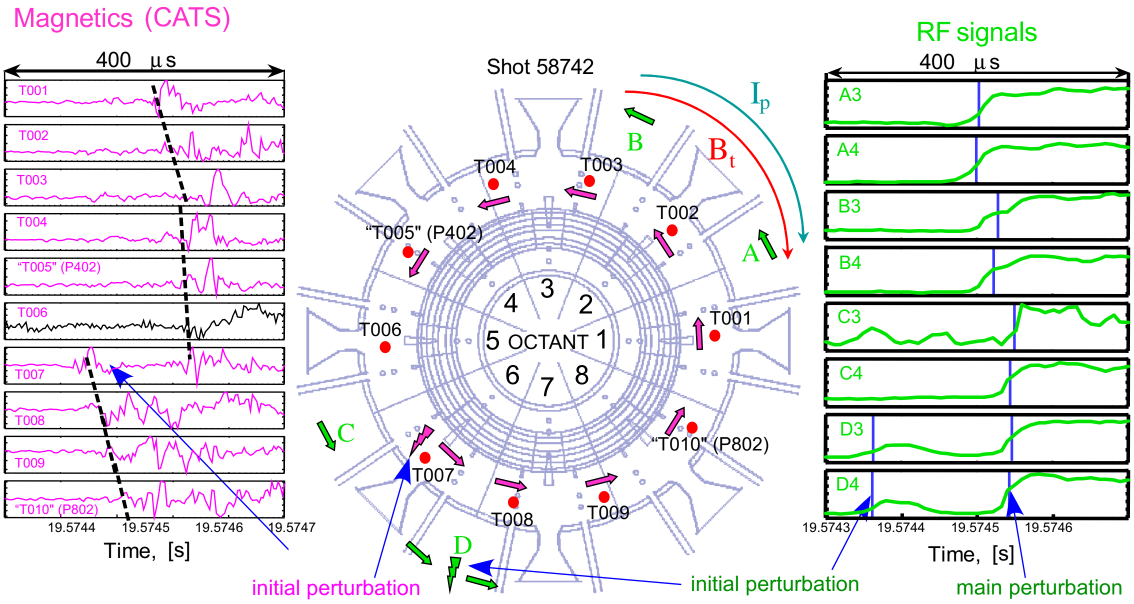

Figure 1: *Example of the toroidal propagation of an ELM perturbation seen on magnetic coils and reflected voltages on the antenna transmission lines in JET. Vertical lines on the RF measurements indicate the software evaluated times of reaction. Straps D3 and D4 measure the "initial perturbation" in this case.*

1) ELM is detected using D_α signal;
2) RF signals are smoothed, the 1^{st} derivative is taken and smoothed and the 2^{nd} derivative is taken;
3) two time points of zero 2^{nd} derivative are taken, with the values of the 1^{st} derivative at least 20% of the absolute value of the maximal 1^{st} derivative;
4) if two points are taken at step (3), the first zero of the 2^{nd} time-derivative is taken as the "initial perturbation" and the second zero is taken as the "main perturbation" (see Fig. 1, antenna D); if one point is taken at step (3), it is the "main perturbation";
5) the response time of the single antenna to an ELM is determined by averaging the "main perturbation" times of two adjacent antenna straps;
6) velocity of propagation of the ELM perturbation is calculated by averaging the velocities of the propagation between antennas (5), the plasma radius at which ELMs propagate is assumed R_p =3.7 m for JET and R_p =2.15 m for ASDEX Upgrade.

Results

On both machines, the ICRF antennas response to the majority of type I ELMs indicates a toroidal propagation of ELM perturbation in the counter-current direction. The direction of the propagation is the same as for the electron diamagnetic drift.

Fig. 1 shows an example of the fast signals collected on the JET toroidal array of magnetic coils and on 8 transmission lines of the four A2 antennas, at the rising edge of a type I ELM in JET. Both magnetic and RF measurements indicate an initial perturbation starting in octant 6 (magnetic coil T007 and antenna D) and propagating counter-clockwise, until the ELM perturbation has spread over the whole torus. The starting location of the propagation differs from ELM to ELM and typically has no preferred point. The time delays between the antennas are typically larger for the an-

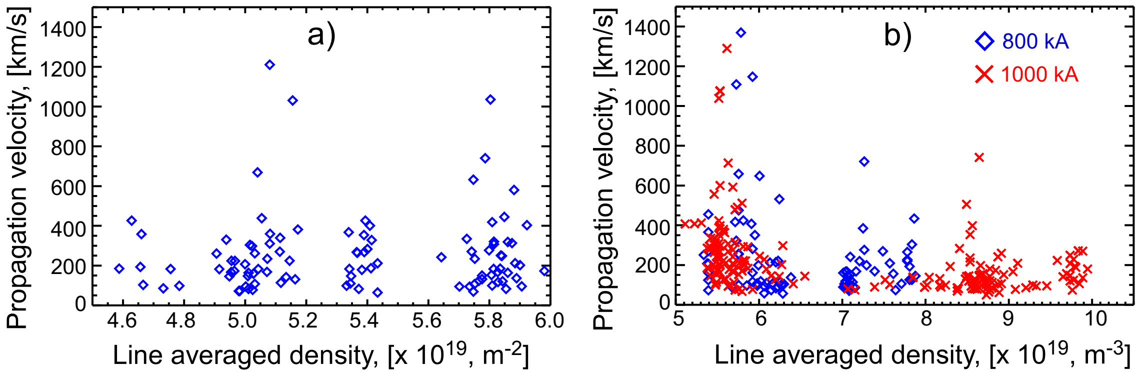

Figure 2: *Velocities of propagation of the ELM perturbation as measured by ICRF antennas, depending on central line averaged densities for JET (a) and ASDEX Upgrade (b).*

tennas which the "main perturbation" passes at first. This indicates, that the toroidal velocity of the ELM perturbation increases with the development of the perturbation.

The shape of the RF time traces at the rising edge of ELMs is very similar for adjacent straps, but is not always similar for different antennas. In the following analysis, only cases with similar RF signals shape have been taken into account.

A first attempt to find a correlation between evaluated velocities of propagation of the ELM perturbation from the antenna delays and basic plasma parameters has been made. The velocities are plotted in Fig.2 vs. the central line-of-sight density measured by interferometry. Fig.2a includes ELMs from 3 JET discharges ($B_t = 2.45$ T, $I_{plasma} = 2$ MA, $f_{ICRH} = 42$ MHz), Fig.2b includes ELMs from 29 ASDEX Upgrade discharges ($B_t = 2.0$ T, $f_{ICRH} = 30$ MHz). ASDEX Upgrade discharges with 800 kA and 1 MA are treated separately. One observes the highest velocities of propagation of the ELM perturbation at lower densities, however no monotonic dependence on the density is observed.

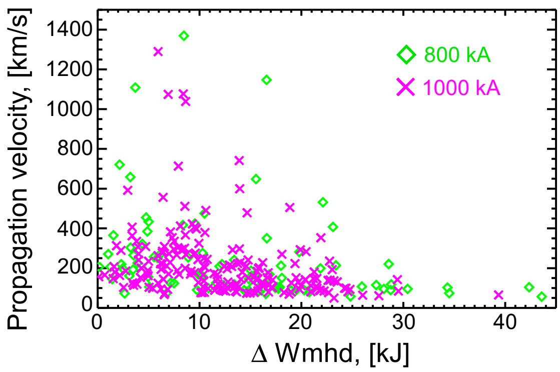

Figure 3: *Velocity of propagation of the ELM perturbation vs. change of diamagnetic energy for ASDEX Upgrade.*

The average velocity of propagation of the ELM perturbation for JET is about 200 km/s which corresponds to $\approx 120\ \mu s$ time for a full toroidal turn. The average velocity in ASDEX Upgrade 220 km/s corresponds to a toroidal turn time of 60 μs. Such delays for one toroidal turn have marginal effect on the operation of ELM-resilient ICRF systems on JET and ASDEX Upgrade, if the straps from one toroidal octant are connected to the compensation network.

For ASDEX Upgrade data, a qualitative dependence of the propagation velocities on absolute losses of diamagnetic energy of the plasma ΔW_{mhd} during ELMs has been found. The smaller propagation velocities (both maximal and minimal values) are correlated with the larger losses of the plasma diamagnetic energy. To estimate ΔW_{mhd}, a difference between energy 1 ms before ELM (detected as described above) and the minimal value between the detected ELM and the subsequently detected ELM is calculated. The dependence of the velocities on the relative losses of the diamagnetic energy $\Delta W_{mhd}/W_{mhd}$ has no good correlation.

For the described set of data for ASDEX Upgrade, the dependence of ΔW_{mhd} (estimated as above) on the density has a non-monotonic character, as ΔW_{mhd} increases when density is increased in low density range and decreases with the density in high density range.

Conclusions

Both on JET and ASDEX Upgrade, the perturbations associated with type I ELM rise are observed on ICRF antennas. The perturbations move in electron diamagnetic drift direction. Experiments on JET have shown that RF data is in agreement with magnetic measurements which also see the ELM perturbation propagation. Typical velocities of toroidal propagation of 200 km/s (lying in general in 50-1200 km/s range) are observed for JET and 220 km/s (lying in general in 50-1400 km/s range), corresponding to 120 μs and 60 μs toroidal turn times for JET and ASDEX Upgrade respectively. The highest measured velocities belong to low density cases. Therefore for most of the observed ELMs, the delays between the antenna straps situated in the same toroidal octant have marginal, or no effect on the operation of the compensation networks for the ELM-resilient ICRF systems.

Measurements on ASDEX Upgrade show a decrease of the propagation velocities when the absolute losses of the plasma diamagnetic energy are increased. However the nature of the toroidal rotation of the ELM perturbation is still not understood. As a next step, comparative analysis of the toroidal propagation velocities delivered from the RF signals and electron diamagnetic velocity from the pedestal parameters [10] is underway.

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