

High-frequency magnetic activity in MST

P. Piovesan¹, J.S. Sarff², A. Almagri², D. Craig^{2,3}, L. Marrelli¹, P. Martin¹

¹ *Consorzio RFX, Euratom-ENEA Association, Padova, Italy*

² *Department of Physics, University of Wisconsin, Madison, WI, USA*

³ *NSF Center for Magnetic Self-Organization in Laboratory and Astrophysical Plasmas*

We present a study on high-frequency magnetic fluctuations in the MST reversed-field pinch. Data have been taken with different extended arrays of external, high-frequency resolved magnetic probes, and with an insertable probe. In RFPs the high-frequency $f > 100kHz$ portion of the magnetic spectrum is not yet completely understood. In particular the origin of intermittency in RFP magnetic turbulence remains to be explained. The aim of this work is to provide a detailed characterization of these fluctuations, their connection with the lower-frequency $f \sim 10kHz$ dynamo modes, and their effects on thermal transport and dynamo.

The diagnostic system used for this study consists of: (i) a toroidal array of 62 and a poloidal array of 16 pick-up coils measuring dB_ϕ/dt with a bandwidth of $300kHz$; (ii) a toroidal array of 32 analog-integrated coils with $f < 100kHz$, which is routinely used in MST to detect the long-wavelength dynamo modes; (iii) a toroidally localized array of 8 coils, 1 – 2cm apart with $f < 3MHz$; and (iv) an insertable probe housing different sets of coils and $f < 3MHz$. Various experimental scenarios have been investigated including standard discharges at different plasma current, 0.2 – 0.6MA, and density, $0.5 - 2 \times 10^{19}m^{-3}$, and enhanced confinement plasmas obtained with pulsed poloidal current drive (PPCD). In the following we will mainly concentrate on high-current discharges without and with the application of PPCD. Future work will regard also low-current plasmas, where also the insertable probe data are available.

The main aim of this work is to study high-frequency perturbations in MST and determine

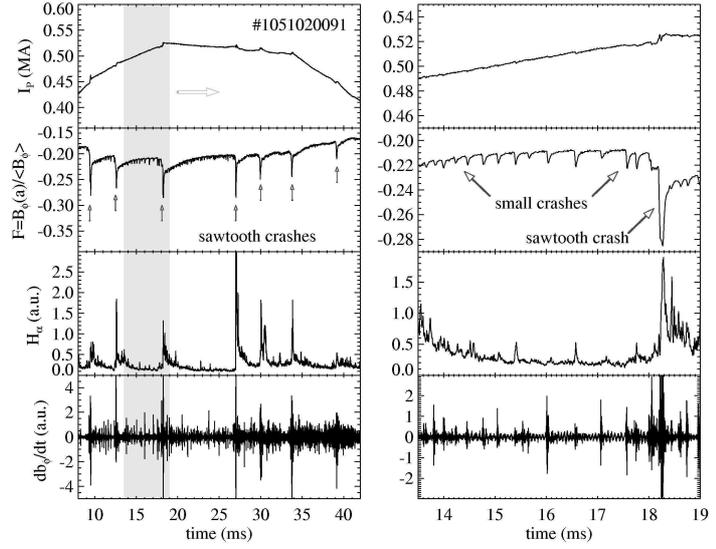


Figure 1: Waveforms for a standard MST discharge showing the main sawtooth crashes and intermittent magnetic activity in between them.

their spatiotemporal structure with high detail. We will consider first of all the standard discharges, and we will focus in particular on the periods between sawtooth crashes. Fig. 1 shows typical waveforms of a standard MST discharge with plasma current $I_p \simeq 0.5MA$, electron density $n_e \simeq 1 \times 10^{19}m^{-3}$, and reversal parameter $F = B_\phi(a) / \langle B_\phi \rangle = -0.2$. We can note in particular the quasi-periodic sawtooth crashes typically present in standard MST discharges. Sawteeth are discrete dynamo events accompanied by a burst of dynamo modes and a fast variation in the magnetic equilibrium, as visible in the F signal.

Time intervals far from sawtooth crashes are usually regarded as relatively quiescent, at least for that regards the low-frequency dynamo mode activity. Nonetheless, as illustrated in Fig. 1, small quasi-periodic bursts of magnetic activity are present during such periods. As also known from previous studies [B.E. Chapman, *et al.*, Phys. Rev. Lett. **80**, 2137 (1998)], these events share some similarities with the usual sawtooth crashes, as evidenced for example by the time behavior of the reversal parameter F , but have also interesting differences.

In fact these smaller-size magnetic bursts are not originated in the plasma core, as usual sawteeth, but in the edge region. We will show in the following that they are characterized by a broad magnetic spectrum mainly composed of edge resonant fluctuations, while the internally resonant $m = 1$ dynamo modes are practically unaffected. Their effect on thermal transport is different from the usual sawtooth activity. During these events soft x-ray tomography shows inward propagating cold pulses that start at the edge, while usual sawteeth are followed by outward heat pulses.

We have characterized these events with the extended arrays of fast pick-up coils described above. Fig. 2 reports a contour of the dB_ϕ/dt signal as a function of time and toroidal angle, as measured by the toroidal array of 62 coils. In particular we zoom here on a time period between two sawtooth crashed, where the interesting events are present. Arrows in the figure indicate the varied magnetic activity present in these plasmas. For that regards the low-frequency dynamo

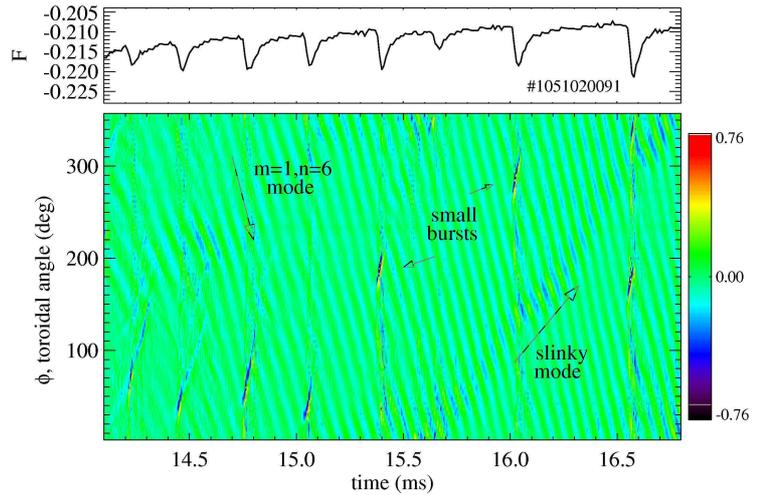


Figure 2: Contour plot of dB_ϕ/dt as a function of the toroidal angle and time for a period between two sawtooth crashes.

activity, we note the rotating $m = 1, n = 6$ mode, which is typically the dominant one in the $m = 1$ dynamo mode spectrum. We then distinguish the so called *slinky* structure, which is due to the interference of all the different $m = 1$ modes and rotates in the opposite direction as these dynamo modes. Let us now consider the high-frequency events associated with the small F crashes. The first interesting feature emerging from this figure is that they are toroidally localized, are born at random toroidal locations, and rotate in the opposite direction as the core modes with a higher toroidal velocity.

To characterize this magnetic activity we combined data from the toroidal and poloidal arrays of fast pick-up coils. Since these events appear to be spatially localized, we can consider the case when they are born at the toroidal location where the poloidal array is placed. This makes possible a simultaneous determination of their toroidal and poloidal wave numbers, n and m , respectively. Fig. 3

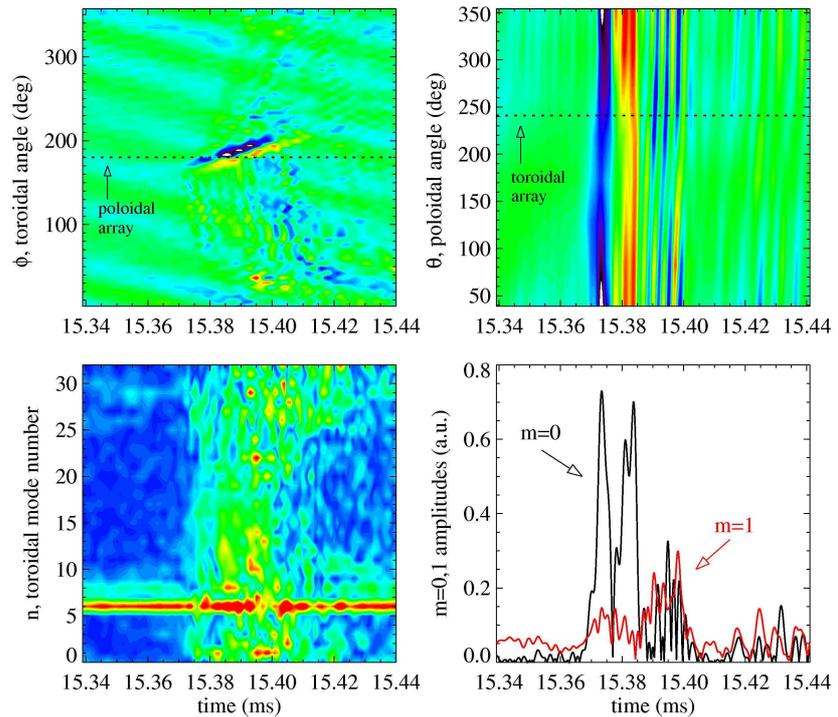


Figure 3: Toroidal and poloidal contour plots showing a small burst and the corresponding toroidal and poloidal mode number spectra. We note that the toroidally localized perturbation has a dipolar structure, and that high-frequency $f \sim 100kHz$ modes with lower amplitude also become visible. When we consider the dB_ϕ/dt signal contour from the poloidal array, we find a similar composite structure: the dipolar localized perturbation has a $m = 0$ shape and initiates the burst; after the $m = 0$ burst come the high-frequency modes, which have a $m = 1$ poloidal dependence.

and poloidal mode number

spectra. We note that the toroidally localized perturbation has a dipolar structure, and that high-frequency $f \sim 100kHz$ modes with lower amplitude also become visible. When we consider the dB_ϕ/dt signal contour from the poloidal array, we find a similar composite structure: the dipolar localized perturbation has a $m = 0$ shape and initiates the burst; after the $m = 0$ burst come the high-frequency modes, which have a $m = 1$ poloidal dependence.

Interestingly these small crashes are composed by edge resonant perturbations, $m = 0$ and $m = 1$ modes with high n . Moreover they seem not to interact strongly with the internal modes, which maintain their structure practically unchanged. As a consequence the strong edge pressure and/or current gradients should be the drive of these modes. These smaller-size events have

indeed a significant effect both on the dynamo generation and the thermal profiles. It becomes clear that the high-frequency portion of the magnetic spectrum could thus play a significant role in the global plasma dynamics and confinement.

An additional piece of information has been found by analyzing PPCD discharges with the same methods. PPCD is applied in the RFP to reduce the dynamo modes, which has the effect to greatly improve the thermal confinement. We have observed that the high-frequency events described above are almost disappeared in these plasmas. PPCD could have a direct effect on these modes, by changing the edge radial profiles in such a way to stabilize them, or it could act indirectly by reducing the long-wavelength modes. In fact it is possible that the high-frequency short-wavelength portion of the spectrum is driven by the large-scale instabilities.

In a recent work [L. Marrelli, *et al.*, Phys. Plasmas **12**, 030701 (2005)] it has been pointed out that the nature of high-frequency magnetic turbulence in MST changes in going from standard to PPCD discharges, and in particular it becomes less intermittent during PPCD. Intermittency in standard plasmas may be associated with the same magnetic bursts studied in the present work. We can thus argue that we have directly imaged the events at the origin of intermittency in these plasma. These are magnetic perturbation with a well defined spatiotemporal structure, are resonant with the edge magnetic field, destabilized by the edge pressure and/or current gradients, and have a significant effect on thermal transport and dynamo in the periods between sawtooth crashes. To prove more robustly the connection between these events and intermittency a statistical analysis is needed, which will be the focus of future work.

The dipolar structures in the dB_ϕ/dt signal could be explained as current sheets aligned with the local magnetic field, which is mainly poloidal at the edge. The intermittent magnetic turbulence observed in standard RFP regimes could thus be thought as a superposition of current sheets localized in time and space. This is a picture suggested also by previous authors, based on numerical work [S. Cappello and D. Biskamp, Nucl. Fusion **36**, 571 (1996)]. Moreover a strong correlation between intermittent events in electrostatic turbulence and magnetic relaxation events was pointed out by previous experimental work in the RFX device [V. Antoni, *et al.*, Europhys. Lett. **54**, 51 (2001)]. We may thus argue that the events studied here are the magnetic counterpart of the intermittent events usually observed in electrostatic turbulence, even though additional data are needed to prove this. Studying together magnetic and electrostatic turbulence will be crucial to obtain a unifying view of turbulence and intermittency in the RFP.

Acknowledgement. This work was supported by the European Communities under the contract of Association between EURATOM/ENEA. The views and opinions expressed herein do not necessarily reflect those of the European Commission.