Investigation of high frequency magnetic fluctuations in the RFX-mod device

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The modified RFX reversed field pinch experiment (RFX-mod) is equipped with a large set of electrostatic and magnetic probes, which constitute the ISIS (Internal System of Integrated Sensors) system, aimed at the investigation of the edge plasma [1]. In this paper we report the results concerning magnetic fluctuation measurements, obtained using a subset of the full ISIS diagnostic. The probes are located behind the graphite tiles, which cover the first wall of the machine, and consist of pick-up coils measuring the time derivative of the toroidal component of the magnetic field. The coils are placed in two toroidal arrays, covering the full toroidal circumference, in two opposite poloidal positions (top-bottom). Each array consists of 48 equally spaced coils. The sampling frequency is 2 MHz, while the estimated bandwidth of the measurement is up to 300-400 kHz.

Various regimes of plasma current density I_Φ, I/N parameter, where N is the section integral density, and reversal parameter F= B_Φ (a)/ $\langle B_\varphi \rangle$ are explored, along with the dependence of the fluctuation levels on the Lundquist number $S=\tau_R/\tau_A$, which is the ratio of the resistive diffusion time $\tau_R=\mu_0 a^2/\eta$, to the Alfvén time, $\tau_A=a/v_A$, where η is the electrical resistivity and v_A the Alfvén velocity. Moreover, an investigation of the effect of feedback stabilization system for the active control of MHD instabilities, the so-called *Virtual Shell* [2], which is operated in RFX-mod, is performed. I_Φ has been scanned between 500 and 900 kA, and a range of I/N from 3 to 8 × 10^{-14} Am has been explored. The reversal parameter F was varied between –0.05 and –0.25. Particular attention has been dedicated to the dynamical behaviour of F, as this is observed in RFX-mod to exhibit large fluctuations, related to relaxations of the magnetic field profile during the discrete Dynamo Relaxation Events (DRE) [3]. The continuous dynamo phase, characterized by an almost constant value of F, has been thus distinguished from the discrete dynamo phase.

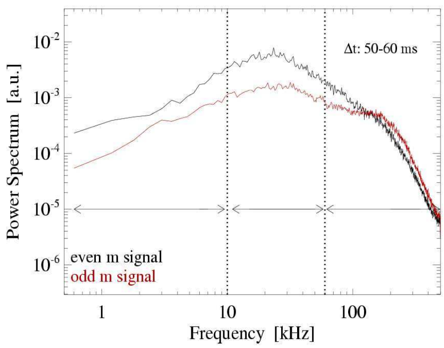

Fig. 1: Power spectrum of a magnetic signal.

A typical power spectrum of the time derivative magnetic signal during the flat-top phase of the discharge is shown in Fig. 1. Sums and differences of couples of probes (top-bottom) located at the same toroidal locations are computed in order to distinguish between even and odd m contributions (m is the poloidal mode number). In the spectrum three main frequency regions has been (somehow arbitrarily) individuated: a low frequency region, below 10 kHz, an intermediate region between 10 and 60 kHz, and a high frequency region, which includes a broad peak around 100 kHz, which is observed, in some experimental conditions, to be present in the odd m component of the magnetic fluctuations. The fluctuation levels corresponding to different time scales have been thus evaluated by computing the root mean square (RMS) of the signals, subjected to a band-pass numerical filter in order to select the three frequency regions, in time intervals lasting 1ms in the flat top phase of the discharge. The investigated plasma parameters, such as I_Φ, I/N, and F have been averaged over 1 ms, and several experimental points are considered in each discharge. The effect of the Virtual Shell operations on the fluctuation levels has been analysed by comparing different discharges in almost the same experimental conditions (I_Φ, I/N and F), with and without the application of the active control system. In Fig. 2 the RMS of the signals as a function of the toroidal position is shown (Φ=0° has been chosen to correspond to the position of the maximum localised distortion of the plasma column, sometimes called slinky mode, which characterizes RFX-mod discharges, due to the phase and wall locking of many m=1 tearing modes).

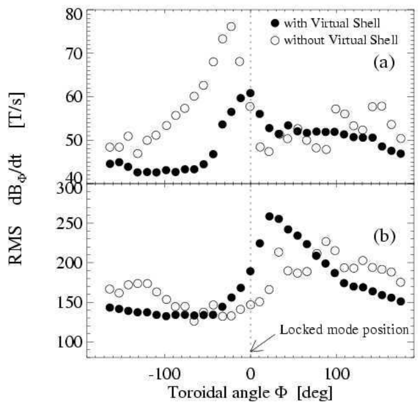

Fig. 2: RMS of the magnetic signals vs Φ

A significant reduction of the fluctuation level is observed to be induced by the MHD control system at the position of the locked mode, and, asymmetrically in the toroidal direction, in a large part of the toroidal circumference. It is important to note that the effect is mostly visible in the low frequency component of the fluctuation, while at frequency above 60 kHz the magnetic signals seems almost unaffected.

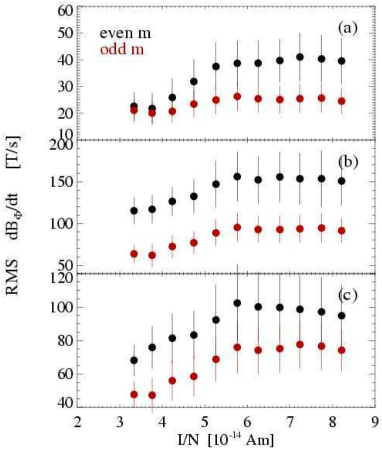

Fig. 3: RMS of the magnetic signals vs I/N: a) f<10, b) 10<f<60, c) f>60 kHZ.

The dependence of the fluctuation level on I/N for the 3 frequency regions is shown in Fig. 3, for odd and even poloidal components. In the figure the experimental values have been averaged over a set of shots characterized by a reversal parameter F spanning from -0.08 to -0.1, and time intervals have been selected to correspond to the continuous dynamo phase of the discharges. An increase of the fluctuations levels for all m components is observed with I/N, with a tendency to a saturation level for I/N> ≥6 × 10^{-14} Am. In Fig. 4 the scaling of the magnetic fluctuations with F, averaged over a set of shots characterized by 6.5<I/N<8 × 10^{-14} Am and I_Φ > 600 kA, is shown. An increase of the magnetic activity with even m is observed for the low frequency part of the spectrum when moving from shallow towards deeper reversal, when the continuous dynamo action is taken into account. During the discrete relaxation events, when deeper F values are dynamically reached, a strong activity with odd m at high frequency is observed. Measured magnetic fluctuations are, moreover, observed to scale with S, which has been evaluated in the plasma core, from measured quantities, following the expression given in [4]: $S = \frac{10 I_\Phi T_e(0)^{3/2}}{(0.4+0.6Z_{eff})\ln\Lambda(m_i n_e)^{1/2}}$, where the plasma current I_Φ is in kA, the line averaged electron density n_e in 10^{19} m^{-3} units, the electron temperature $T_e(0)$ is in eV, m_i is the ion mass in amu, and lnΛ is the Coulomb logarithm. The effective charge Z_{eff} is evaluated from the bremsstrahlung emission measured by interference filters in three

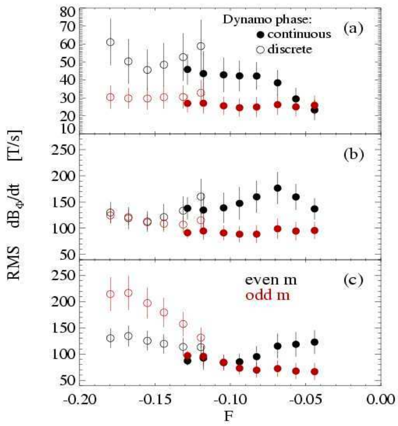

Fig. 4: RMS of the magnetic signals vs F: a) f<10, b) 10<f<60, c) f>60 kHZ.

different line-free spectral regions, while the electron temperature by means of a soft X-ray multi-foil spectrometer [5].

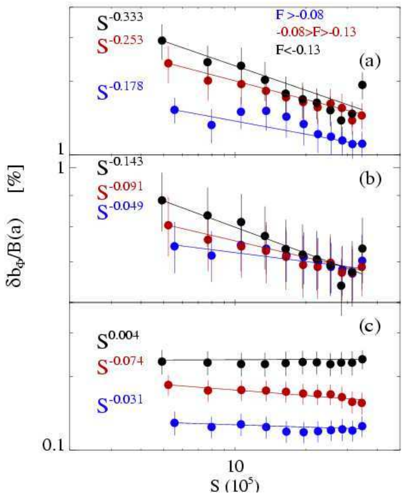

Fig. 5: Normalized RMS of the magnetic signals vs S: a) f<10, b) 10<f<60, c) f>60 kHZ, for 3 F values.

Fig. 5 shows the behaviour of the normalized RMS of the edge toroidal magnetic field fluctuation amplitude, $\delta b_\Phi/B(a)$, obtained by a numerical integration of the dB_Φ/dt signals. Due to a lack in the available data, no distinction between odd and even m numbers has been made in this case. A decrease of the fluctuations is observed, with a scaling law $\delta b_\Phi/B(a) \propto S^\alpha$. The values obtained for α show a strong dependence on the frequency range and on the reversal parameter considered. At frequency below 10 kHz, α is observed to span between –0.33, for shallow reversal discharges, and –0.178 for deeper F values. These values are comparable to the result of numerical simulations [6], where current sheet reconnection is assumed to govern the magnetic dynamic processes. The scaling with S of the fluctuations becomes weaker in the frequency range between 10 and 60 kHz, and $\delta b_\Phi/B(a)$ seems almost independent on S at higher frequencies.

In conclusion an experimental analysis of the magnetic fluctuations levels, measured by the ISIS system in RFX-mod, in different frequency ranges, has been performed in a wide range of experimental conditions. We observed an increase of the magnetic fluctuation with I/N at all the explored time scales, a robust high frequency activity, with odd m number, during magnetic relaxation events, and a scaling with S, comparable with the theoretical prediction only if the low frequency part of the spectrum is taken into account.

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