IN VESSEL MAGNETIC FIELD MEASUREMENTS IN RFX

R. Bartiromo, E. Martines, S. Peruzzo, N. Pomaro and P. Sonato

Consorzio RFX - C.so Stati Uniti, 4 - 35127 Padova - Italy

1. Introduction

RFX is provided with a large number of magnetic transducers dedicated to equilibrium analysis, located outside the vessel on the internal surface of the stabilizing shell [1]. In order to obtain a better characterization of the magnetic field at the plasma edge, in particular in presence of magnetic perturbations induced by MHD mode locking, a prototypical version of a new in-vessel diagnostic system has been recently installed on RFX. The system consists of a graphite tile equipped with five pick-up coils for the measurement of the three components of the magnetic field: two for the toroidal, two for the poloidal and one for the radial component (Fig. 1). A further measurement of the current flowing from the plasma to the vessel through the tile is provided by an equivalent Rogowsky coil, obtained combining the two toroidal and the two poloidal coils.

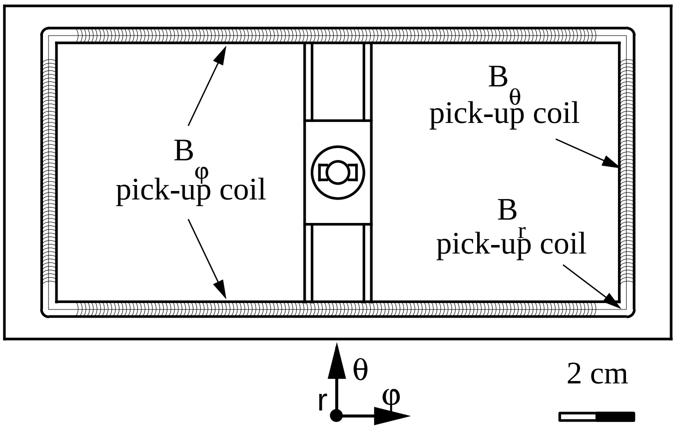


Figure 1. Pick-up coils placed in slots in the back side of the tile

The instrumented tile has been mounted near an equatorial port (φ = 305°, θ = 19°), in order to allow easy assembly and removal. In the experimental campaign in which the instrument has been tested, a large range of plasma current was explored (300 ÷ 700 kA), with plasma horizontal shift ranging from -2 cm to +3 cm and with the stationary magnetic perturbation induced by MHD mode locking located either in the proximity of the tile or far from it.

2. Analysis of the radial component of the magnetic field

A displacement of the plasma column with respect to the vacuum vessel gives rise to a radial component of the magnetic field at the first wall. In RFX a typical axis-symmetric horizontal displacement can lead to a radial field up to 6% of the poloidal component (the main component at the edge of an RFP plasma) in the upper and lower part of the vacuum vessel. In the position of the instrumented tile (19° above the equatorial plane) this ratio decreases to 2%.

In RFX each pulse is affected by a magnetic perturbation induced by MHD mode locking, which causes a displacement of the plasma column along a helical path that typically extends over about 40 toroidal degrees [2]. This deformation induces an enhanced radial component of the magnetic field, as evidenced in Fig. 2, and consequently an increased local plasma-wall interaction [3].

In the unperturbed region the radial field induced by axis-symmetric shift is lower then 2% of the poloidal field, in agreement with the theoretical prediction. Otherwise, in the region affected by mode locking the radial field can reach a maximum value equal to 10% of the poloidal field, as shown in Fig. 3 in which the absolute value of the radial field, averaged out of 10 ms during the plasma current flat-top phase, is plotted as a function of the plasma current.

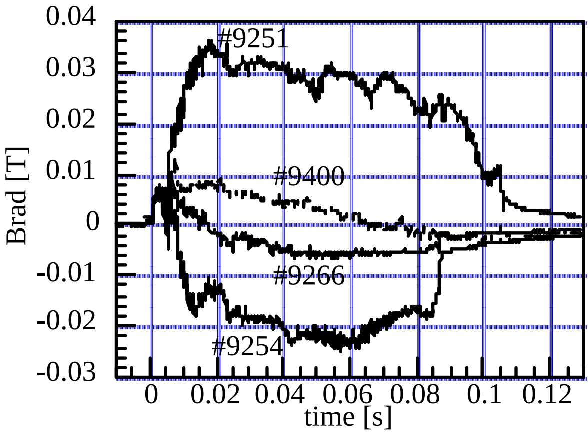


Fig. 2. Radial field neasurements *(Iplasma=700 kA, B_θ=300 mT)*. Shots 9266 and 9400: locking far from the tile; shots 9251 and 9254: locking near the tile.

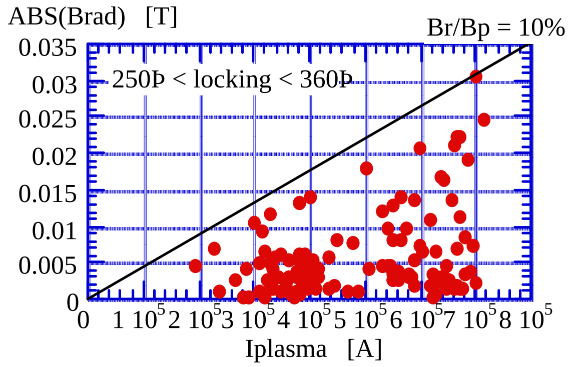


Fig. 3. Absolute value of the radial field, as a function of the plasma current in the locking region.

The absolute value and the sign of the radial field depend on the radial and poloidal displacement of the plasma column that, following an helicoidal path, can assume whatever position. In Fig. 4 a subset (with plasma current ranging from 600 kA to 700 kA) of the pulses represented in Fig. 3 has been considered and correlated with the local position of the plasma column at the tile location, reconstructed by means of external magnetic measurements. The first graph indicates that the maximum values of Brad occur only in correspondence with extreme radial displacements; the second one confirms that an upper position of the column induces an inward radial field (θ>19°, Brad < 0), whereas a

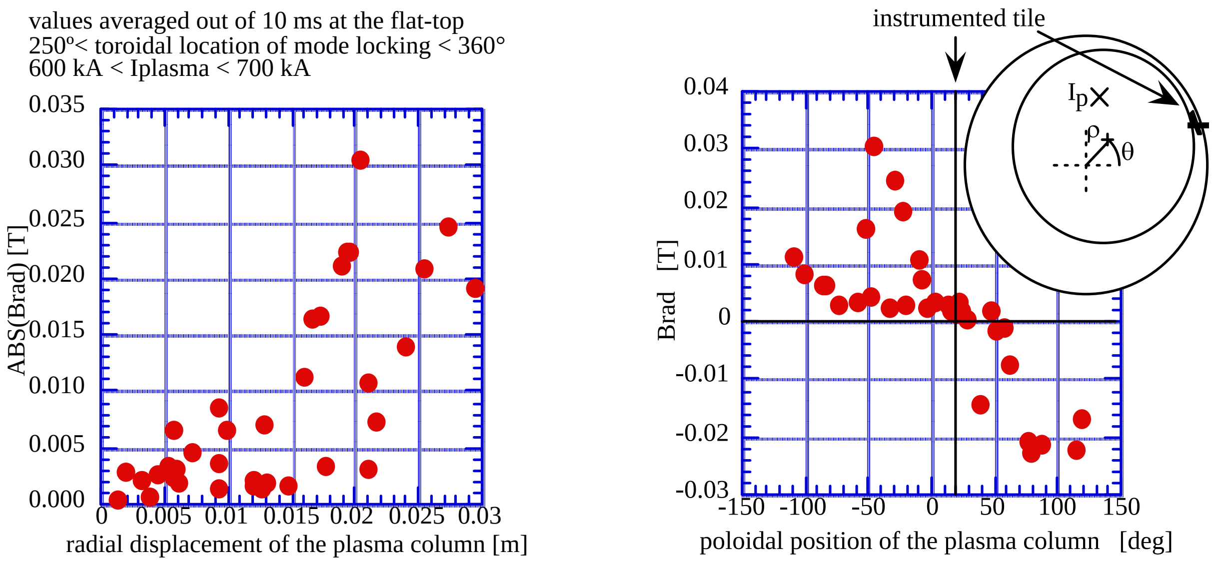


Figure 4. Radial field at the tile position as a function of local plasma displacement

lower position induces an outward radial field (θ<19°, Brad > 0).

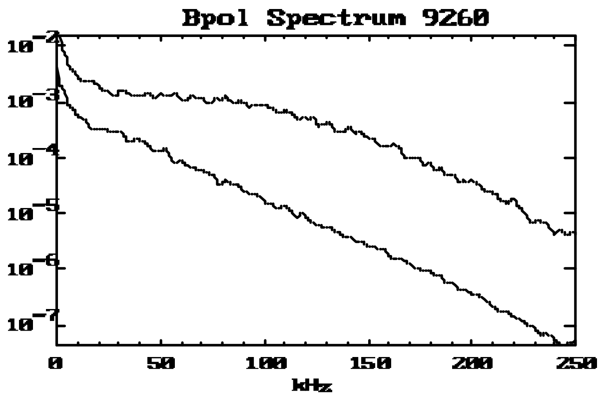
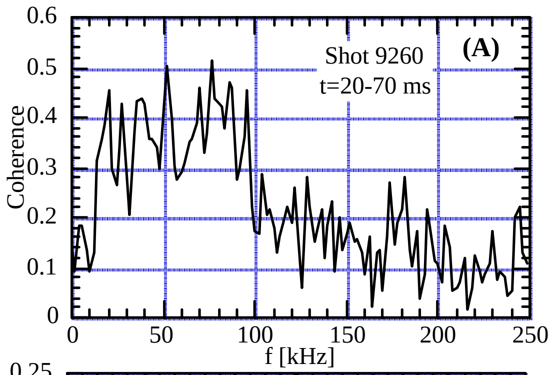


Fig. 5. Power spectrum of poloidal field with mode locking near the probes

3. Analysis of magnetic field fluctuations

An analysis of fluctuations of the poloidal magnetic field has been carried out. Signals of the two available probes, acquired at 500 kHz, show a typical power spectrum decreasing with frequency. Spectrum components concentrate mainly in the 0÷200 kHz band. Amplitudes depend strongly on the presence of mode locking near the probes: without locking, the r.m.s value for f>200 Hz during the plasma current flat-top is 0.1 % of the peak poloidal field, and does not depend on plasma equilibrium position. With locking, an increment of one order of magnitude in fluctuations level is observed, reaching 1 %. Moreover, due to the very localized variations of plasma position, signals from the two probes (16 cm distant) can present a marked asymmetry, as shown in Fig. 5.

Analyses of cross-correlation and coherence between the two signals have been also carried out: coherence (Fig. 6A) is significant, especially in presence of mode locking, and cross-correlation (Fig. 6B) exhibits a peak at τ = 5÷15 μs, corresponding to a phase velocity of 10÷30 km/s in the direction of the toroidal field at the wall. These numbers are in agreement with results from other diagnostics and values of the inward directed radial electric field at the edge [4]. This result is confirmed also by the calculation of the phase delay of the two signals vs. frequency, which yields a transverse wavenumber vs. frequency plot (Fig. 6C). The graph is typically linear up to 100 kHz, in which band spectral components of signals are stronger.



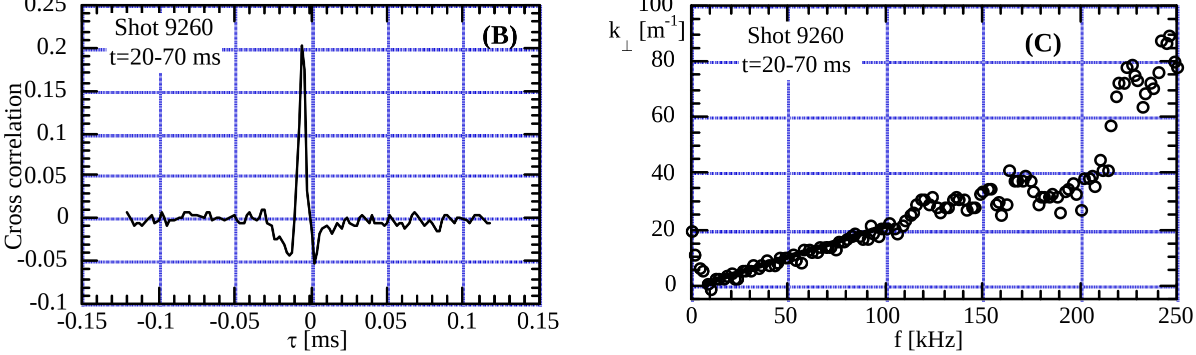


Fig. 6. Fluctuation analysis of poloidal field signals: (A) Coherence (B) Cross-correlation (C) Transverse wavenumber vs. frequency

4. Plasma-vessel current measurement

A current flow through the tiles in the locking region has been evidenced from observation of damage on tiles and external voltage measurements on the vessel [5, 6]. From theoretical estimations [7], a current of electrons that flows from the plasma into the graphite tiles is expected in the locking region close to the contact point.

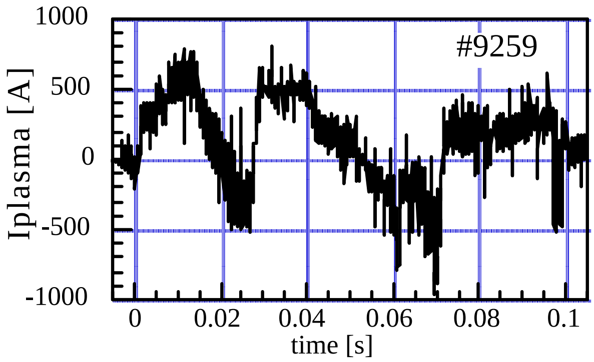


Fig. 7. Example of plasma-vessel current measurement.

Since probes have been optimized for magnetic measurements, the indirect current measurement results to have low sensitivity and precision, so only currents greater than 500 A can be distinguished from noise. Nevertheless, in some shots a signal that can be interpreted as a current, with versus and amplitude in agreement with the theoretical expectation, has been identified. Fig. 7 shows the current flowing into the tile: the negative variation of the signal that appears between 13-28 ms and between 40-70 ms corresponds to the proximity of the plasma contact point to the instrumented tile, inferred by means of external measurements and confirmed by an increase of fluctuation level.

5. Conclusions

The instrumented tile has been successfully tested; after removal, the absence of damage on the probes has demonstrated the reliability of the adopted technology.

First in-vessel measurements of the three components of magnetic field at the plasma edge have been performed. A maximum radial field up to 10% of the poloidal field has been detected in the mode locking region, and preliminary analysis of fluctuations has been carried out for the poloidal component, evidencing r.m.s.values up to 1% of peak poloidal field in a bandwidth of 200 kHz.

In spite of a low sensitivity of the measurement system, an indication of the presence of current flowing from the plasma to the vessel has been found. For better understanding of this phenomenon new detectors with a close Rogowski and shunt are presently in development.

References

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